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# SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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#### CORRECTIONS

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**CHAPTER C.**

Page 51, column 2, line 16, *Lepidocystis chesterianus* should be *Lepidocystis chesterensis*.  
 Plate 11, figure 15, *Adiantites* sp. should be *Aphlebia* sp.

**CHAPTER E.**

Page 91, column 1, line 11, *Eodoxylon zonatum* should be *Endoxylon zonatum*.

**CHAPTER F.**

Plates 28 and 29. The photographs printed on plate 28 should have been printed on plate 29, and those on plate 29 should have been printed on plate 28. Thus the descriptions printed on plate 28 apply to the figures on plate 29 and vice versa.

**CHAPTER G.**

Page 133, column 1, line 18 from bottom of page, "southeastern Arkansas" should read "southwestern Arkansas."  
 Page 135, figure 7, numbers designate faunal zones as follows:

7. *Diploschiza cretacea minor* zone (=Diploschiza cretacea zone in Alabama).
6. *Ostrea elegantula* zone.
5. *Ostrea travisana* zone.
4. *Ostrea centerensis* zone.
3. *Exogyra tigrina* zone.
2. *Gryphaea wratheri* zone.
1. *Inoceramus undulato-plicatus* zone.

**CHAPTER J.**

Page 170, column 1, line 28, *Paliurus hesperia* should be *Paliurus hesperius*.  
 Page 178, column 1, line 30, *Umbellaria dayana* should be *Umbellularia dayana*.

**CHAPTER K.**

Page 222, column 2, line 4, "Smoky Hill marl" should be "Hays limestone."  
 Plate 64, symbols designate geologic formations as follows:

Kd, Dakota sandstone; Kgr, Graneros shale; Kgn, Greenhorn limestone; Kcl, Carlile shale; Kn, Niobrara formation;  
 Kps, Sharon Springs member of the Pierre shale; Kp, Pierre shale above the Sharon Springs member (black dots marked Kpt indicate location of tepee buttes); Tu, Tertiary deposits; Qal, alluvium (shown only along the Arkansas River).

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# SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1936

## NEW UPPER CRETACEOUS OSTREIDAE FROM THE GULF REGION

By LLOYD WILLIAM STEPHENSON

### ABSTRACT

Four species of Ostreidae from the Upper Cretaceous of the Gulf region are described and figured. Three of the species, *Gryphaea wratheri*, *Ostrea johnsoni*, and *Ostrea travisana*, are new. *Ostrea elegantula* White, originally described from New Mexico, is here first recorded from the Gulf region. All four of the species are narrowly confined in their vertical range and have more or less extended geographic ranges; they are therefore useful as index fossils. The zones that the species characterize lie either in the upper part of the Austin chalk or in beds of upper Austin age (Santonian).

The family Ostreidae is represented in the Upper Cretaceous formations of the Atlantic and Gulf Coastal Plain by the four genera *Ostrea*, *Gryphaea* (in the broad sense), *Gryphaeostrea*, and *Exogyra* and by many species, some of which have not yet been described. Three new species, one of *Gryphaea* and two of *Ostrea*, are placed on record in this paper; they are *Gryphaea wratheri*, *Ostrea travisana*, and *O. johnsoni*. A fourth species, *Ostrea elegantula* White, not previously identified from the Gulf region, is redescribed, and shells from Alabama, more nearly perfect than the type material, are figured; one specimen from New Mexico is figured. These species all occur within a relatively narrow stratigraphic range, which is believed to correspond approximately to the Santonian division of the Senonian of Europe.

In Texas *Gryphaea wratheri* occupies the lowest stratigraphic position of the four species under consideration. It occurs in a zone well above the middle of the typical Austin chalk in Travis County and has been collected in this zone at more or less widely separated localities from Dallas County to Guadalupe County, a distance of 250 miles; the zone has an observed maximum thickness of at least 35 feet. In the Austin chalk, immediately below this zone, is another zone characterized by an abundance of the imprints and shells of *Inoceramus undulato-plicatus* Roemer, and in places this species has been observed to range upward into the *Gryphaea wratheri* zone; the lower zone is also relatively thin (thickness  $50 \pm$  feet) and an even greater known geographic extent than the upper zone, having been recognized at numerous localities from the vicinity of Whitewright, Grayson County, Tex., to Cow Creek, in southern Kinney

County, Tex., a distance of 450 miles. The well-known species *Gryphaea aucella* Roemer occurs in great numbers within a few feet above the *G. wratheri* zone, but Roemer's species has a greater vertical range than *G. wratheri*, having been found in considerable numbers at higher levels to a horizon within 20 or 25 feet of the top of the Austin chalk in the Travis County section; a few shells that appear to be indistinguishable from *G. aucella* have been found in the lower part of the Austin chalk, particularly in Grayson County. Two localities in a sandy facies of the Bonham marl in northeastern Texas have yielded specimens of *Gryphaea wratheri*.

In Alabama shells that seem to be indistinguishable from *Gryphaea wratheri* are present in considerable numbers in the upper part of the Tombigbee sand member of the Eutaw formation, where they are associated in places with *Ostrea johnsoni* and elsewhere with *O. cretacea* Morton. Apparently, however, the Alabama occurrences are not exactly synchronous with the *Gryphaea wratheri* zone in Texas, for other considerations seem to indicate that the Tombigbee sand corresponds in age to a somewhat higher zone in the upper part of the Austin; however, the exact age relation of the *G. wratheri* zone in Texas to the Tombigbee sand has not yet been certainly determined.

The shells of *Ostrea johnsoni* are present in great numbers in the upper 15 feet or less of the Tombigbee sand member of the Eutaw formation between Selma, Dallas County, and Montgomery, Montgomery County, Ala., where they are associated in places with *Gryphaea wratheri*. The species has not been found outside of Alabama. Another much smaller species of oyster, *O. cretacea* Morton, occurs in great numbers farther west, in Perry, Hale, and Greene Counties, in the upper 15 or 20 feet of the Tombigbee sand, and also farther east, in Macon and Russell Counties, in glauconitic sand of the upper Tombigbee, but for some unexplained reason the two species, *O. cretacea* and *O. johnsoni*, have not been seen together at any locality.

*Ostrea travisana* occurs typically in Travis County, Tex., in the upper part of the Austin chalk within 10 or 15 feet of the base of the overlying Taylor marl. Outside of Travis County it has been found near the

top of the Austin at several localities between Bell County and Maverick County, and it occurs in Lamar County, in northeastern Texas, in a phosphatic bed at the base of the Brownstown marl immediately above the Blossom sand; it is worthy of especial note that this phosphatic bed lies some 200 feet or more below the Gober tongue of the Austin chalk, which, though continuous with the main body of the Austin, rises higher in the section than the uppermost part of the typical Austin section in Travis County.

The species *Ostrea elegantula* White was originally described from the breaks of the "Red or Canadian River" in northeastern New Mexico. The species is present in 10 collections in the National Museum from localities of either uppermost Colorado or lowermost Montana age in northeastern New Mexico (pp. 7-8), 6 of which were obtained by W. T. Lee and 4 by N. H. Darton; three of them (colls. 6778, 7172, 7194) are recorded by Lee.<sup>1</sup> The species has also been collected by T. W. Stanton<sup>2</sup> near San Carlos, Presidio County, Tex., from beds believed to be of about the same age as those which yielded the species in New Mexico; at this locality the oyster was associated with *Mortoniceras* cf. *M. delawarensis* (Morton).

Five localities in the upper part of the Blossom sand in Red River County, Tex., distributed along a distance of 19 miles, have yielded *Ostrea elegantula*. The containing bed lies within 10 or 15 feet below the base of the overlying Brownstown marl.

In Alabama the species has been found in an excellent state of preservation in marine glauconitic sand at two localities near Hatchetubbee, in Russell County. This sand, though similar lithologically to the Tombigbee sand member of the Eutaw formation, is estimated to be at least 100 feet stratigraphically higher and is a sandy facies representing the eastward extension of the basal part of the Selma chalk; in the vicinity of Hatchetubbee the sand is closely and conformably overlain by calcareous sandy clay of Selma age.

In the absence of other evidence to the contrary the occurrences of *Ostrea elegantula* recorded in this paper may be interpreted as indicating the approximate age equivalence of the containing beds in Alabama, northeastern Texas, western Texas, and New Mexico.

Each of the four species of Ostreidae treated in this paper is rather narrowly restricted in stratigraphic range and of more or less extended geographic range and is therefore of value as a zonal or index fossil. *Ostrea elegantula*, which has the greatest known geographic range of the four, appears to have come suddenly into the Gulf and New Mexican regions from some as yet undetermined previous habitat and to have survived for only a short time; however,

its relationship to *Ostrea anomiooides* Meek suggests that it may have had its evolutionary development in the early Upper Cretaceous seas of the Western Interior. *Ostrea travisana*, which appeared in the western Gulf region as a fully developed, conspicuously sculptured form and held its place there for only a brief period, may have had its origin in a European Upper Cretaceous sea where several analogous species lived at about the same time. *Ostrea johnsoni*, whose geographic range is the least of the four, came into the eastern Gulf region from an unknown source and, like the others, was able to hold its own for a short time only; however, this species is related to two larger species, *O. subspatulata* Forbes and *O. owenana* Shumard, which are found in later Upper Cretaceous formations.

*Gryphaea wratheri* may have had its evolutionary development within the Gulf region, for it is closely related to and may be a variant of *G. aucella* Roemer. *G. aucella* ranges throughout the full thickness of the Austin chalk but is most numerous in the upper part of the chalk above the *G. wratheri* zone.

Of the collections enumerated 40 were made by the writer, either alone or in company with others. Other persons who participated in making the collections, either alone or with others, include T. W. Stanton, C. A. White, R. T. Hill, T. W. Vaughan, N. H. Darton, W. T. Lee, C. W. Cooke, L. C. Johnson, A. C. McLaughlin, D. H. Walker, Jack Turrentine, J. K. Prather, W. P. Popenoe, and A. C. Munyan.

The oysters were photographed in part by Harry S. Ladd, at the United States National Museum, and in part by N. W. Shupe, of the United States Geological Survey. The prints were retouched by Frances Wieser, of the Geological Survey.

#### *Gryphaea wratheri* Stephenson, n. sp.

Plate 1, figures 1-4

Shell small for the genus, subcircular to broadly subovate in outline, inequilateral, strongly inequivalue. Left valve moderately and broadly convex, steepest on the anterior slope, most gently inclined toward the rear; the left valve of the holotype exhibits a shallow radial depression extending from just back of the beak obliquely downward and backward to the posteroventral margin; this feature is exceedingly variable in strength on different individuals and is entirely wanting on many of them. Beak of left valve weakly to moderately prominent, strongly incurved, direct, situated well in advance of the midlength; scar of attachment generally small but ranging on different individuals up to an observed maximum of 37 millimeters (rare), the larger scars markedly modifying the form of the shell.

<sup>1</sup> Lee, W. T., U. S. Geol. Survey Prof. Paper 101, pp. 177, 193, 202, 1917 [1918].

<sup>2</sup> Stanton, T. W., U. S. Geol. Survey Bull. 164, pp. 80, 81, 1900.

Right valve flattish to broadly concave; beak small, flattish, and inconspicuous.

Area small, triangular, much longer than high; resilifer relatively large, more strongly impressed on the left than on the right valve. Adductor scar of medium size, subcircular to subovate in outline, moderately impressed, situated about midway of the height, a little back of the midlength. The band of junction of the two valves on the inner surface ranges in width on average-sized shells from a minimum of 2 millimeters adjacent to the upper anterior margin, to a maximum of about 13 millimeters within the rear margin; roughened areas are present on both the anterior and posterior dorsal ends of this band on each valve. A small slightly impressed pedal scar is present 2 to 4 millimeters below the inner end of the resilifer.

Surface of left valve marked with fine growth lines and with widely spaced nonprominent growth lamellae, which become coarser toward the ventral margin. Surface of right valve ornamented on its lower half by coarse upturned growth lamellae, which converge and pinch out as they pass upward at both the front and the rear; the surface is further marked by a few fine, weak, widely spaced radial lines, such as characterize some other species of this genus in differing degrees of strength.

Dimensions of the holotype: Length 36.2 millimeters, height 36 millimeters, thickness measured from the bottom of the concavity of the right valve through the most convex part of the left valve 12 millimeters. An occasional shell reaches a length of 48 or 50 millimeters.

Among the Upper Cretaceous *Gryphaeas*, this species is most nearly related to *Gryphaea aucella* Roemer, but it differs in its larger average size, its broader and proportionately more depressed form, and its somewhat rougher surface.

In the vicinity of Austin, Travis County, Tex., the species is present in a restricted zone well above the middle of the Austin chalk as there developed. This zone has been traced northward to the vicinity of White Rock Lake, in Dallas County, a distance of 180 miles. The maximum observed vertical range of the species along this zone (*Gryphaea wratheri* zone) is in a section along U. S. Highway 77, a mile northeast of Sterrett, Ellis County; here the species ranges throughout 35 feet of interbedded hard chalk and softer marly chalk exposed in a gully 23 feet deep just west of the highway and in a cut 12 feet high on the east side of the highway. As seen in an exposure on South Cow Bayou, about 2½ miles east of Bruceville, McLennan County, the base of this zone lies in the upper part of the zone of *Inoceramus unduloplacatus*, a narrow zone traceable in the Austin chalk from the Rio Grande in Maverick County to White-

wright, in Grayson County, a distance of 450 miles. A few feet above the top of the *Gryphaea wratheri* zone is a layer of chalk containing the shells of *Gryphaea aucella* Roemer in great numbers; this relation has been observed along Little Walnut Creek in the vicinity of Austin, Travis County; on a branch of Deer Creek, 2 miles southeast of Eddy, in Bell County; and in the drainage basin of White Rock Creek, in the northeastern outskirts of Dallas, Dallas County. The species has been collected at two localities in a glauconitic, sandy layer in the Bonham marl (of upper Austin age) in Fannin County.

Shells of this species are abundant in the upper 15 or 20 feet of the Tombigbee sand member of the Eutaw formation in Alabama. The uppermost layer of the Tombigbee sand, as it has usually been defined, in the area between Eutaw and Montgomery, consists of 4 to 8 feet of strongly calcareous, glauconitic sand containing scattered but rather abundant phosphatic nodules and phosphatic internal molds of mollusks. This layer may mark a time of decrease in the amount of clastic material deposited in a shallow sea, or it may even indicate emergence and erosion along a part of the belt of outcrop; however, farther west, at Plymouth Bluff, on the Tombigbee River, 4 miles west of Columbus, Miss., where the Tombigbee-Selma contact is clearly exposed, phosphatic material is wanting, and there appears to be a gradual transition from sand to chalk; it seems unlikely, therefore, that the phosphatic bed in Alabama indicates more than a diastem or, at the most, an erosion interval of short duration. If a true unconformity is present at the contact the phosphatic bed should more logically be classed as the basal bed of the Selma chalk. Whatever the interpretation, *Gryphaea wratheri*, *Ostrea cretacea* Morton, and perhaps other species are found both in the phosphatic layer and in 10 or 15 feet of the undoubted Tombigbee sand below this layer. *G. wratheri* has been identified from the localities enumerated below.

**Types:** Holotype, U. S. N. M. 75506; 2 figured paratypes, U. S. N. M. 75507, 75507a; 36 unfigured paratypes (22 left and 14 right valves), U. S. N. M. 75508. Named in honor of William E. Wrather, of Dallas, Tex.

**Distribution in Texas.**—Upper middle part of Austin chalk (Santonian): Cut in Gaston Avenue (U. S. Highway 67), just northeast of the intersection of West Shore Drive, 0.7 mile west of the dam of White Rock Reservoir, Dallas County (14075,<sup>2a</sup> type locality); hill south of the Orphans' Home road, 0.45 mile west of White Rock Creek, at eastern edge of Dallas (14148); bottom of deep gully 23 feet below level of U. S. Highway 77, 1 mile northeast of Sterrett, Ellis County (17152); south of Red Oak Creek, southern part of Dallas quadrangle, near Sterrett (3655); "blue rock" at a depth of

<sup>2a</sup> Numbers in parentheses under the heading "Distribution" here and on the following pages are the collection numbers of the United States Geological Survey, unless otherwise indicated.

34 feet, in a dug well near Sterrett (3656); on small branch paralleling the Missouri-Kansas-Texas Railroad at southwest edge of Waco, McLennan County (7561); northward-facing slope of Castleman Creek Valley, in gully north of northeast-southwest road, 20 feet below road level, 2.6 miles south-southeast of Hewitt, McLennan County (17151); Bullhide Creek about 10 miles southwest of Waco, McLennan County (2908); Bullhide Creek 0.6 mile below a northeast-southwest road 2½ miles northeast of Lorena, McLennan County (13808); South Cow Bayou, left bank, about 0.85 mile below the crossing of a northeast-southwest road, about 2¼ miles east of Bruceville, McLennan County (17150); ditch in northeast-southwest road about 1¼ miles northeast of Bruceville, McLennan County (17121); shallow quarry east of Fiskville road 1½ miles south of Fiskville, Travis County (7592); Walnut Creek below the Dessau road crossing, Travis County (7581); Williamson Creek between the upper and lower Lockhart road crossings, Travis County (Hill collection no. 51); left bank of Cibolo Creek about 1 mile above Schertz, Guadalupe County (7653).

Sandy bed in Bonham marl (Austin age): Road to Prospect Church, in bed of branch half a mile south of the church, 3 miles north by west of Dodd City, Fannin County (9695); north of Lone Elm church and school, 3½ miles northeast of Lannius, Fannin County (9699).

*Distribution in Alabama.*—Upper part of Tombigbee sand: 2 miles southeast of Eutaw (595) and in railroad cut a quarter of a mile east of Eutaw station (596), Greene County; Choctaw Bluff, Warrior River, Greene County (273, 6425); Erie Bluff, Warrior River (6428B); sec. 15, T. 18 N., R. 8 E., near Hamburg, Perry County (321); public road a quarter of a mile south of old Hamburg (6441); Bluegut Creek near Selma, Dallas County (141); SE¼ sec. 18, T. 17 N., R. 12 E., about 7 miles east-northeast of Selma (142); Kenan's mill, about 3 miles northwest of Selma (147, 149, 6829); Batte Smith Bluff, Alabama River, 8½ miles (air line) east of Selma (302, 6830, 6831); Cunninghams Bluff, Alabama River, about 10 miles (air line) east of Selma (293); House Bluff, Alabama River, 15 miles west-southwest of Prattville, Autauga County (296, 6442B); Hall's field, sec. 24, T. 17 N., R. 13 E., Autauga County (300); field just east of cut of Louisville & Nashville Railroad 2 miles southwest of Union Station, Montgomery (6832).

#### *Ostrea travisana* Stephenson, n. sp.

Plate 2, figure 5; plate 3, figures 1-5

- 1884. *Ostrea diluviana* Linnaeus. White, U. S. Geol. Survey 4th Ann. Rept., p. 295, pl. 40, fig. 1; pl. 41, figs. 1, 2.
- 1893. *Ostrea diluviana* Linnaeus. Cragin, Texas Geol. Survey 4th Ann. Rept. (Invertebrate paleontology, Cretaceous), p. 203.
- 1898. *Ostrea (Alectryonia) diluviana* Linnaeus. Hill and Vaughan, U. S. Geol. Survey 18th Ann. Rept., pt. 2, pl. 62, fig. 1.
- 1901. *Ostrea (Alectryonia) diluviana* Linnaeus. Hill, U. S. Geol. Survey 21st Ann. Rept., pt. 7, pl. 45, fig. 2.
- 1902. *Ostrea (Alectryonia) diluviana* Linnaeus. Hill and Vaughan, U. S. Geol. Survey Geol. Atlas, Austin folio (no. 76), illus. sheet, fig. 42.
- 1924. *Ostrea* sp. aff. *O. diluviana* Linnaeus. Deussen, U. S. Geol. Survey Prof. Paper 126, pl. 10, fig. 1.
- 1928. *Alectryonia* sp. aff. *A. diluviana* Linnaeus. Adkins, Texas Univ. Bull. 2836, p. 104.

All the illustrations given in the papers cited above pertain to the same shell (U. S. N. M. 8300), which is recorded as having come from Bell County, Tex.

The species appears to belong to the subgeneric group to which Fischer von Waldheim<sup>3</sup> gave the name *Alectryonia*, but I have not been able to consult the original description. Presumably the principal distinguishing characteristic of the group is the strongly costate sculpture and the series of geometrically V-shaped projections and notches on the margin of each valve, the one series of which fits reciprocally into that of the other when the two valves are closed (see pl. 3, fig. 5).

Shell large, thick, and exceedingly variable in outline, form, and coarseness of ornamentation; in some of the senile specimens in the collections the shell has grown thick and massive. The holotype, a right valve, is shorter in the length dimension than shells of average outline but is chosen because of its completeness and its known stratigraphic position near the top of the Austin chalk. The paratype shown in plate 2, figure 5, which was found closely associated with the holotype, is a much longer and a more coarsely ornamented right valve. The large, incomplete paratype shown in plate 3, figures 3-5, which was collected by Robert T. Hill and his associates, in 1894, would have served better as a holotype, except that its stratigraphic position is not so exactly known; it was found near an igneous dike cutting the Selma chalk, and its position is believed to be approximately the same as that of the holotype.

Typical shells curve noticeably toward the rear. Both valves exhibit a more or less prominent and sharply developed umbonal ridge, which lies near or in advance of the midlength and which may or may not flatten out toward the postero-ventral margin. The two valves are rather strongly and nearly equally inflated, though the left valve may be a little plumper than the right; the anterior slope is generally much steeper than the posterior one. The scar of attachment on the left valve varies greatly in size and is very large on some shells. On most shells there is a postero-dorsal winglike extension, but this is an exceedingly variable feature on different individuals. The beak is not very prominent on either valve and is generally situated anterior to the midlength of the hinge line.

On the holotype the hinge line at the base of the area is 33 millimeters long. The area is roughly triangular, with its longest dimension on the base, and is 11 millimeters broad at right angles to the hinge line below the beak; the resilifer is triangular, relatively broad, and most deeply impressed on the left valve. Adductor scar large, deeply impressed, elongated in the direction of the height, narrowest above, with upraised margins, situated close to the posterior

<sup>3</sup> Fischer von Waldheim, Gotthelf, Museum-Demidoff (mis en ordre systématique et décrit par G. Fischer), ou Catalogue . . . des curiosités de la nature et de l'art, données à l'Université impériale de Moscou, par P. de Demidoff, tome 3 (in 1 vol.), illustrated, 1807.

margin and very high in the shell. Pedal scar tiny, situated a few millimeters below the inner, anterior edge of the resilifer. The margins of the shell present a series of deeply indented, geometrically V-shaped notches, those of the two valves fitting reciprocally into each other (pl. 3, fig. 5).

The surface of each valve is strongly and similarly ornamented with prominent, narrow costae that are V-shaped in cross section; away from the beak costae are added by bifurcation and intercalation, mainly, though not exclusively, along the umbonal ridge; the costae tend to become irregularly noded along their crests. The ribbing varies greatly in coarseness on different individuals from the same and from different localities, the number of ribs ranging from 20 to 35. The ornamentation on the right valve of the specimen shown in plate 3, figure 3, indicates a pathologic condition, perhaps due to an injury; apparently the part of the mantle that gives rise to the shell along the line of the umbonal ridge was shoved forward, thus initiating a new stage of growth back of the ridge.

Dimensions of the holotype as oriented with the hinge line in the horizontal position: Length 84 millimeters, height 102 millimeters, convexity 31 millimeters. Dimensions of the incomplete paratype (pl. 2, fig. 5) from the locality of the holotype: Length 110 millimeters, height 105+ millimeters, convexity 26 millimeters. Dimensions of the large incomplete paratype from Onion Creek, Travis County, Tex. (pl. 3, figs. 3-5): Length 90+ millimeters, height 120+ millimeters, thickness 66 millimeters. These measurements emphasize the great variability in outline and form of the individuals of the species.

This species has been found at several widely separated localities in the upper part of the Austin chalk, from Maverick County to Bell County, Tex. The holotype and one paratype were collected on Little Walnut Creek in Travis County within 10 feet of the top of the Austin. In northeastern Texas the species was found, originally by T. W. Stanton, near Paris, Lamar County, in glauconitic sandy marl forming the base of the Brownstown marl of that area, immediately above the Blossom sand; several collections have subsequently been made at this locality. The containing bed is believed to correspond approximately in age to that which yielded the species on Little Walnut Creek, Travis County.

As indicated in the synonymy, several American authors have referred this species to *Ostrea diluviana* Linnaeus,<sup>4</sup> which was originally described from the Upper Chalk of Sweden. Linnaeus' species, as later figured by Nilsson,<sup>5</sup> though similarly ornamented, is

more slender and more strongly curved than *O. travisana*, the umbonal ridge is sharper and more slender, and the two are believed to be distinct. The figures given by Hisinger<sup>6</sup> indicate a broadly ovate shell more like *O. travisana*, but the adductor scar is proportionately larger and more broadly ovate, and is not quite so near the posterior margin.

*Alectryonia deshayesi* Fischer,<sup>7</sup> from the Santonian of the Crimean Peninsula, south Russia, appears to be a close analog of *O. travisana*. As figured by H. Coquand,<sup>8</sup> *Ostrea deshayesi* has a larger and broader adductor scar which is not quite so high on the inner surface, and a more elongated resilifer.

*Ostrea santonensis* D'Orbigny,<sup>9</sup> from the lower Senonian of France, appears also to be closely analogous to *O. travisana*.

It is worthy of note that both *O. deshayesi*, from the Santonian, and *O. santonensis*, from the lower Senonian, occupy about the same stratigraphic position in Europe as does *O. travisana* in America.

Types: Holotype, U. S. N. M. 75509; 1 figured paratype, U. S. N. M. 75510; 1 figured paratype, U. S. N. M. 75511.

*Distribution in Texas.*—Upper part of Austin chalk (upper Santonian): Bell County (U. S. N. M. 8300, figured as indicated in the synonymy); old Sprinkle road (abandoned) on westward-facing slope of Little Walnut Creek Valley near iron bridge, 2 miles southwest of Sprinkle, Travis County (14159, locality of holotype and one paratype); Cameron road, eastward-facing slope of Walnut Creek valley, three-fifths mile west of Sprinkle, Travis County (14068); near Austin, Travis County (Hill collection no. 7); Onion Creek, half a mile below the lower Lockhart road crossing near a big dike, Travis County (Hill collection no. 43, locality of one paratype); Cibolo River 1½ miles above Galveston, Harrisburg & San Antonio Railway bridge at Schertz, Guadalupe County (7654); Tequesquite Creek a few hundred yards below the crossing of the Eagle Pass-Del Rio road, Maverick County (8229, 10856).

Basal phosphatic sandy bed of Brownstown marl: On a small creek a quarter to half a mile south of the crossing of the Texas & Pacific Railway and the Texas Midland Railroad, at the southwest border of Paris, Lamar County (7508, 13078, 17148).

#### *Ostrea johnsoni* Stephenson, n. sp.

Plate 1, figures 11, 12; plate 2, figures 1-4

Shell of medium size, thick in the umbonal region, becoming thin and frail at the ventral margin, subovate in outline, elongated in the direction of the height, subequilateral, slightly inequivale. Left valve slightly more convex than the right one. On the right valve a broad ridge or fold originates at or below

<sup>4</sup> Hisinger, W., Lithaea svecica seu Petrificata sveciae, p. 49, tab. 14, figs. 5a, b, 1837.

<sup>5</sup> Fischer, G. (de Waldheim), Bull. nat. Moscou, tome 8, pl. 2, 1834.

<sup>6</sup> Coquand, H., Monographie du genre *Ostrea*, terrain crétacé, p. 88, pl. 23, fig. 1, 1869.

<sup>7</sup> D'Orbigny, A., Paléontologie française, Terrain crétacé, Lamellibranches, p. 736, pl. 484, figs. 1-3, 1846.

<sup>4</sup> Linné, Caroli a, Systema naturae, ed. 12, tome 1, pars 2, p. 1148, 1766.

<sup>5</sup> Nilsson, S., Petrificata suecana, pars prior, p. 32, pl. 6, figs. 1A-B, fig. 2, 1827.

the midheight and extends with increasing breadth to the ventral margin; opposed to this ridge on the left valve is a broad depression. Beak of left valve of medium prominence, dull-pointed, weakly incurved, roughened on the tip by a small scar of attachment, situated centrally; beak of right valve small, non-prominent, overtopped by the beak of the left valve. Dorsal margin of left valve broadly arched; that of right valve nearly straight. The anterior and posterior margins of the shell diverge somewhat from the ends of the hinge and pass below into the rather sharply rounded ventral margin, the trend of which in some adults is sinuous as a result of the broad reciprocal fluting of the two valves. In larger, typical adult shells the margins of the two valves are reciprocally and broadly sinuous all the way around below the ends of the hinge, the sinuosities including nine bends, five convex to the right and four to the left as the shell is held with the beaks upward and the front edge away from the observer; in most shells of less than three-fourths adult size the sinuosities of the margins are seen only in their incipient stages; however, an occasional half-grown shell has these curves conspicuously developed; on the other hand, the margins of many adults are straight or only weakly sinuous.

Hinge line of holotype about 25 millimeters long; area of left valve 10 millimeters high above hinge line, that of right valve 8 millimeters high. Resilifer broad, deep on the left valve, shallow on the right. Area finely striated with growth lines. Adductor scar large, elongate-ovate, the elongation directed obliquely upward toward the rear, situated posteriorly below the midheight. The pedal scar appears as a small pit on the inner surface, 2 to 5 millimeters below the inner edge of the resilifer.

In addition to the sharply developed growth lines the surface of each valve presents a series of gentle, concentric undulations, the crests of which are 5 to 10 millimeters apart in the vicinity of the midheight; these tend to smooth out toward the margins; an occasional specimen exhibits fine radial lining in the umbonal region.

Dimensions of the holotype: Length 54 millimeters; height 75 millimeters; thickness 31.5 millimeters; the largest specimen measured is 83 millimeters high.

In outline, in surface features, and in the shape and low position of the adductor scar this species resembles *Ostrea subspatulata* Forbes, which occurs in the Peedee formation of North Carolina and in the upper part of the Ripley formation in eastern Alabama and adjacent parts of Georgia; however, *O. johnsoni* averages scarcely half as large as *O. subspatulata*, lacks a strong bend to the left in the ventral portion, has a sinuous margin in the typical adult, and is more finely sculptured.

The shells of this species are abundant in the upper 15 feet or less of the Tombigbee sand member of the Eutaw formation and have been collected at 9 localities in this zone from the vicinity of Selma, Dallas County, to the vicinity of Montgomery, Montgomery County, Ala., an air-line distance of 40 miles. Fossils associated with the species include the echinoid genus *Hardouinia?* and the mollusks *Gryphaea wratheri* Stephenson, *Evoxyra upatoiensis* Stephenson, *Baculites asper* Morton, and *Placenticeras* aff. *P. guadalupae* (Roemer).

Types: Holotype, U. S. N. M. 75512; 1 figured paratype, U. S. N. M. 75513; 2 figured paratypes, U. S. N. M. 75514, 75514a; 15 unfigured paratypes, U. S. N. M. 75515. Named in honor of the late L. C. Johnson, a pioneer student of Cretaceous and Tertiary geology in Alabama.

*Distribution in Alabama.*—Upper part of Tombigbee sand member of Eutaw sand in Alabama: Ravine half a mile west of Kenan's mill, 3 or 3½ miles northwest of Selma, Dallas County (6828); bluff on Valley Creek 100 yards above the crossing of U. S. Highway 80, northwest of Selma (16997); SE¼ sec. 18, T. 17 N., R. 12 E., about 7 miles east-northeast of Selma (142); Bluegut Creek near Selma (141); Batte Smith Bluff, Alabama River, Dallas County (302; 6830, locality of holotype, 1 figured paratype, and 15 unfigured paratypes; 17044); at and in fields near House Bluff, Alabama River, Autauga County (296, 6442B; 17011, locality of 2 figured paratypes); Woods Bluff, Alabama River (304); Cunninghams Bluff, Alabama River (293); Coatomo Creek, 0.9 mile northeast of Mount Moriah Church, in NW¼ sec. 32, T. 16 N., R. 17 E., Montgomery County (17010, lower 5 feet of section; 17009, upper 3 feet of section).

#### *Ostrea elegantula* White

Plate 1, figures 5-10

1876. *Ostrea elegantula* Newberry, Geological report, in Macomb, J. N., Report of the exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green Rivers, p. 33. (Named without description or illustration, and therefore at this stage a nomen nudum.)  
 1884. *Ostrea elegantula* Newberry. White, U. S. Geol. Survey 4th Ann. Rept., p. 295, pl. 36, figs. 5-7. (Authorship ascribed to Newberry, who, however, has neither a published nor a manuscript claim to authorship.)  
 1903. *Ostrea anomioides* var. *nanus* Johnson, School of Mines Quart., vol. 24, p. 185, pl. 1, figs. 10a-d, 1903.  
 1908. *Ostrea anomioides* var. *nanus* Johnson. Shimer and Blodgett, Am. Jour. Sci., 4th ser., vol. 25, p. 61, 1908.

The following description is based mainly on shells from Alabama which are well preserved, in contrast to the poor state of preservation of the types and also of most of the other material from the type region in New Mexico.

Shell small, thin, often translucent in transmitted light, broadly subovate to subquadrate in outline, squarish above, inequilateral, strongly inequivalue. Left valve of medium convexity, greatest inflation below the beak, above the midheight; anterior slope

steep above, becoming slightly less steep toward the margin; upper posterior slope more gentle, flattening and broadening toward the margin to form a slight winglike extension. Right valve nearly flat. Beak of left valve slightly prominent, incurved, direct, situated about two-fifths the length of the shell from the anterior extremity; beak of right valve small, flat, non-prominent.

Area very small, triangular, longest on its inner margin; resilifer relatively broad, shallow, most strongly impressed on left valve. Adductor scar small, ovate, situated back of the midlength at about the midheight. The pedal scar appears on each valve as a small pit high on the inner surface about 2 millimeters below the inner end of the resilifer. Both the inner antero- and postero-dorsal margins are faintly crenulated for short distances away from the ends of the hinge line.

Surface of left valve ornamented with a series of delicate, slightly upraised, elegantly crinkled concentric lamellae, spaced 1 to 2 millimeters apart; the crinkles on different lamellae are aligned radially and represent weak radial costae. Surface of right valve covered with gentle, narrow, concentric undulations on which very faint crinkling may be detected.

Dimensions of the left valve shown in plate 1, figures 5-7: Length 17.5 millimeters, height 21 millimeters, convexity 5 millimeters. This specimen is about maximum size for the Alabama shells, but some of the Texas shells are as much as 25 millimeters high, and the two cotypes, right and left valves, are respectively 31.2 and 26 millimeters high; among the New Mexico collections an occasional shell may reach as much as 40 millimeters in height.

In the well-preserved Alabama material the individual shells exhibit considerable variation in form, outline, and strength and coarseness of ornamentation. When these differences are taken into consideration it does not seem practicable to separate the Alabama and Texas shells from White's species from New Mexico.

The two cotypes are recorded as having come from a section on the "Red or Canadian River" in northeastern New Mexico. One is a left valve with the outer shell layers partly scaled off but retaining faint impressions of the characteristic fine, crinkled ornamentation like that so well preserved on the Alabama shells; the other is a right valve which, except for its larger size, is like the right valves from Alabama. The concentric growth lines on the left valve seem to indicate that the posterior wing is weakly developed on this cotype, but this wing is present in typical form on other shells from the type region in northeastern New Mexico; these specimens were identified by T. W. Stanton. Although Newberry recorded this species as associated with other species of mollusks of upper

Benton age, T. W. Stanton and J. B. Reeside<sup>10</sup> state that all the later collections came from beds that lie stratigraphically near the boundary between the Colorado and Montana groups; they believe that the original record is in error.

*Ostrea elegantula* is present in 10 collections in the National Museum from localities in northeastern New Mexico, 6 of which were obtained by W. T. Lee and 4 by N. H. Darton; 3 of them (collections 6778, 7172, 7194) are recorded by Lee.<sup>11</sup> The species has also been collected by T. W. Stanton<sup>12</sup> near San Carlos, Presidio County, Tex., from beds believed to be of about the same age as those which yielded the species in New Mexico.

*Ostrea anomiooides* Meek,<sup>13</sup> which was originally described from the Missouri River below Gallatin, Mont., is obviously closely related to *O. elegantula*, but the type material in the National Museum indicates a stronger development of narrow, concentric ribs, or folds, and a very weak development of the fine crinkling of the concentric lamellae. Inasmuch as present available evidence suggests that Meek's species came from beds of lower Colorado age,<sup>14</sup> and in view of the differences in ornamentation just noted, it seems reasonable to regard *O. anomiooides* as distinct from *O. elegantula*.

In Texas the species has been collected from 5 localities in the upper part of the Blossom sand in Red River County along a distance of 19 miles.

Types: Two cotypes, U. S. N. M. 18611; from the breaks of the Canadian River, in northeastern New Mexico. On the back of one of the labels accompanying the types T. W. Stanton has written: "It is questionable whether this really came from the Colorado group. Many specimens apparently referable to *Ostrea elegantula* were collected by Lee in the Hagan coal field, near Una del Gato, New Mexico." The beds that yielded the oyster in the Hagan coal field are included by Lee in the Mesaverde formation and are interpreted to be of lower Montana age. One plesiotype from the base of the Mesaverde formation in the Hagan coal field is figured, U. S. N. M. 75517. Two plesiotypes from marine sand of lower Selma age near Hatcheechubbee, Russell County, Ala., are figured, U. S. N. M. 75516 and 75516a.

*Distribution in New Mexico.*—Upper part of Mancos shale (transition beds): 2 miles southwest of Madrid (7164); about a mile southwest of Waldo (7165); road from Cabezon to Raton Springs (7194); east flank of Ortiz Mountain, near Omara mine (7180).

<sup>10</sup> Oral communications.

<sup>11</sup> Lee, W. T., U. S. Geol. Survey Prof. Paper 101, pp. 177, 193, 202, 1917 [1918].

<sup>12</sup> Stanton, T. W., U. S. Geol. Survey Bull. 164, pp. 80-81, 1900.

<sup>13</sup> Meek, F. B., U. S. Geol. Survey Terr. 6th Ann. Rept., for 1872, p. 488, 1873. White, C. A., U. S. Geol. Survey Terr. 12th Ann. Rept., for 1878, p. 10, pl. 11, figs. 4a, 4b, 1883.

<sup>14</sup> Stanton, T. W., U. S. Geol. Survey Mon. 32, pt. 2, p. 633, 1899.

Basal part of Mesaverde formation: Garcia & Goebel mine, 30 feet above coal seam, northwest of Socorro (9606); same locality 40 feet above coal seam (9607); Herring mine, 50 feet above coal seam, 20 miles northeast of Socorro (9608); 40 feet above coal seam,  $1\frac{1}{4}$  miles south of Perry Cox place, 15 miles north of Carthage (9764); Hagan coal field, from sandstone below the coal (6778, 1 specimen figured); Hagan coal field, 500 feet south of mine opening (7172).

*Occurrence in Presidio County, Tex.*—Overturned beds near shaft of San Carlos coal mine,  $2\frac{1}{2}$  miles southeast of store at San Carlos (1468).

*Distribution in Red River County, Tex.*—Upper part of Blossom sand: Cut in Reed's store road just south of Pecan

Bayou, about 2 miles north of White Rock (13561, 16675); field west of road 0.4 mile south of Vandalia (13079, 17149); small earth tank east of Dimple road near foot of northward-facing slope of branch of Tanyard Bayou, 4.2 miles north by west of public square at Clarksville (17126); old Clarksville road 2.2 miles east-southeast of Detroit (17153); head of ravine east of old Clarksville road 1.4 miles southeast of Detroit (17125).

*Distribution in Alabama.*—Marine sand of lower Selma age: Cut of Central of Georgia Railway half a mile east of Hatchechubbee, Russell County (6825, locality of two figured specimens; 17005); east end of cut in State Highway 26, 5.1 miles west of Hatchechubbee (17003).

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**PLATES 1-3**

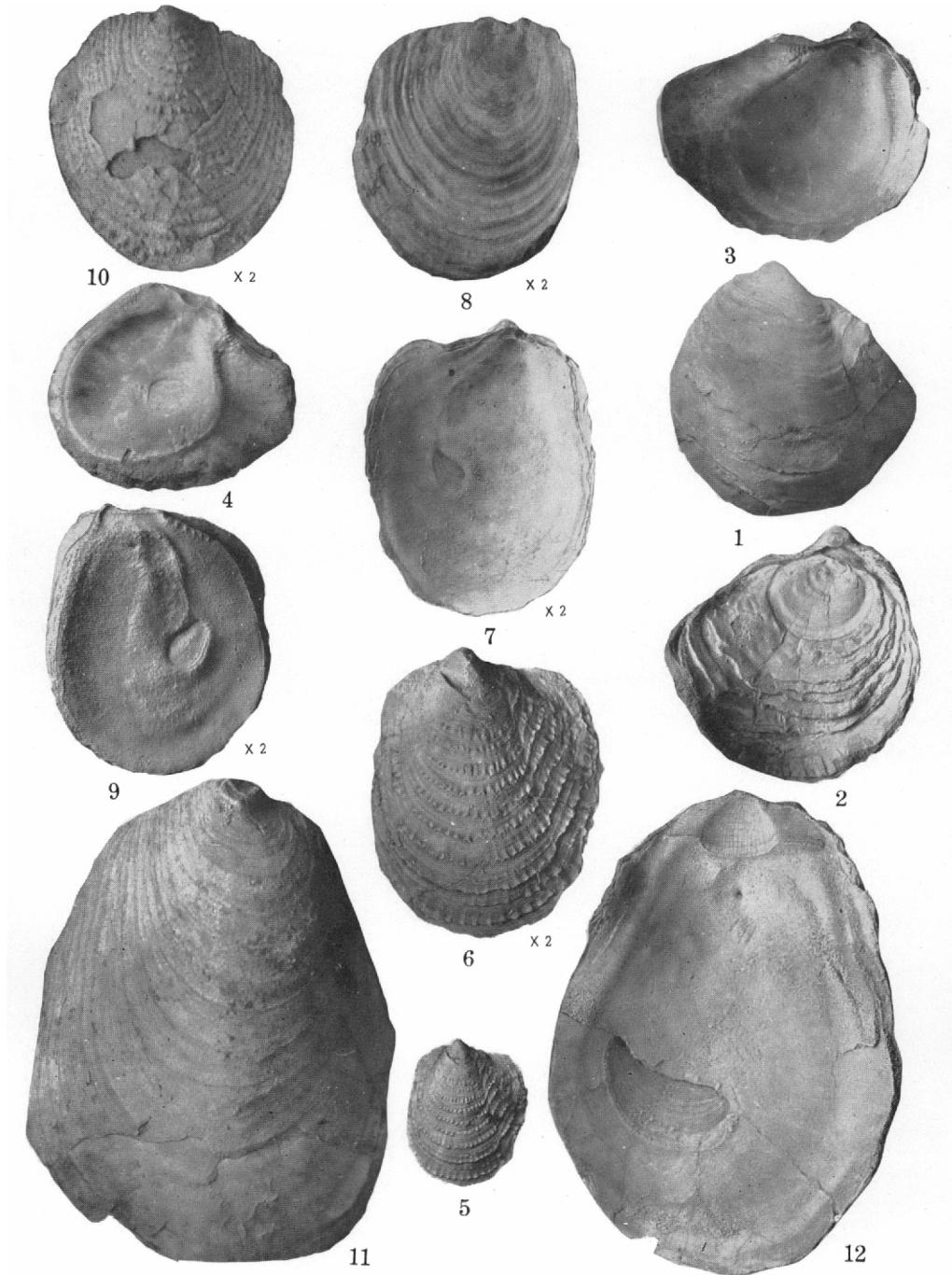
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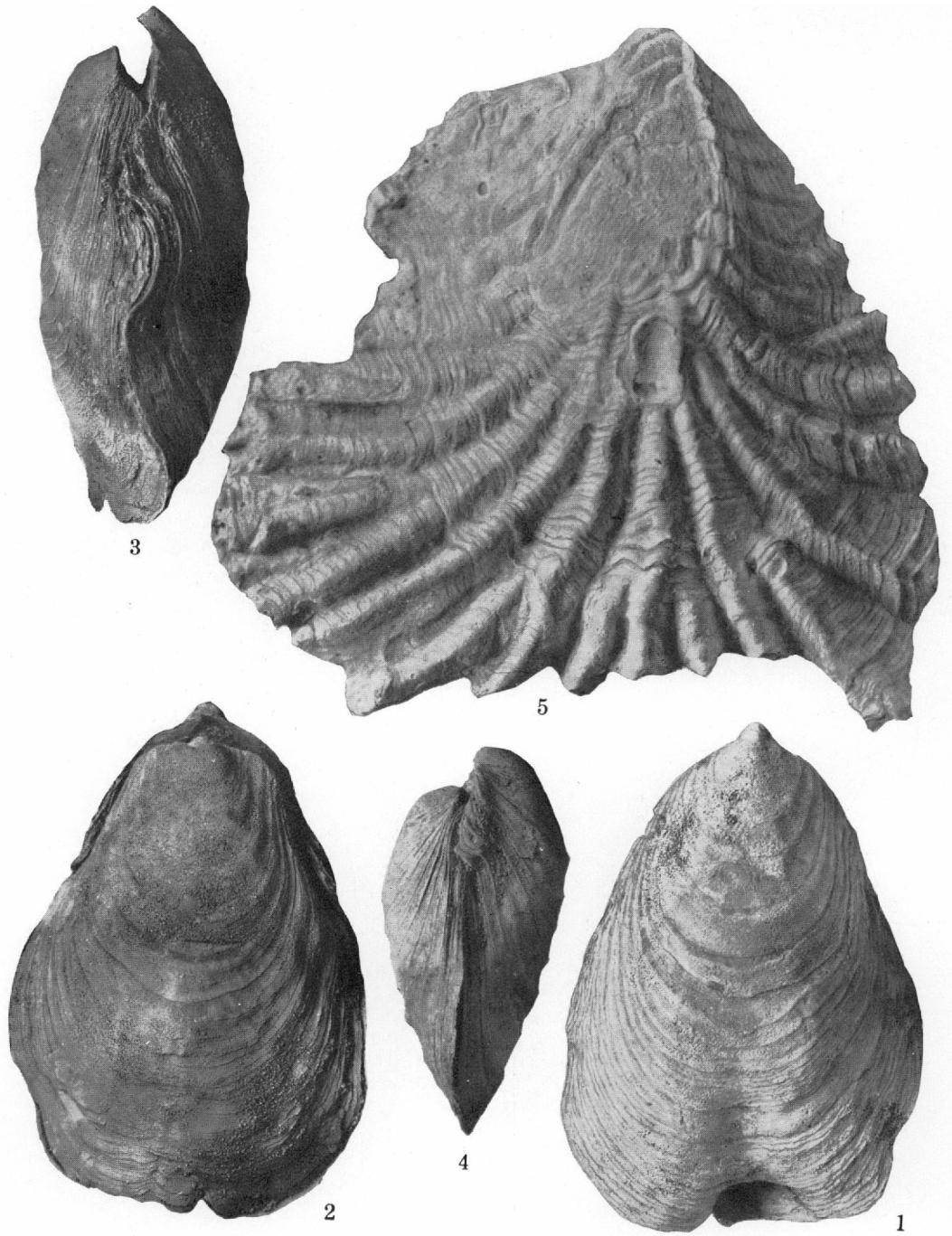
## PLATE 1

[Figured material is deposited in the United States National Museum]

- FIGURES 1-4. *Gryphaea wratheri* Stephenson, n. sp. 1, Exterior of left valve of holotype (U. S. N. M. 75506); 2, exterior of right valve of holotype; 3, interior of a paratype, a left valve (U. S. N. M. 75507); 4, interior of a paratype, a right valve (U. S. N. M. 75507a).
- 5-10. *Ostrea elegantula* White. 5, Exterior of a left valve from cut of Central of Georgia Railway half a mile east of Hatchechubbee, Ala. (U. S. N. M. 75516); 6, enlargement of the same shell; 7, interior of the same shell; 8, exterior of a right valve from the same locality (U. S. N. M. 75516a); 9, interior of the same right valve; 10, exterior of an imperfect left valve from sandstone below the coal, in Hagan coal field, N. Mex. (U. S. N. M. 75517).
- 11-12. *Ostrea johnsoni* Stephenson, n. sp. 11, Exterior of a paratype, a left valve (U. S. N. M. 75514); 12, interior of a paratype, a left valve (U. S. N. M. 75513).



NEW UPPER CRETACEOUS OSTREIDAE FROM THE GULF REGION



NEW UPPER CRETACEOUS OSTREIDAE FROM THE GULF REGION.

## PLATE 2

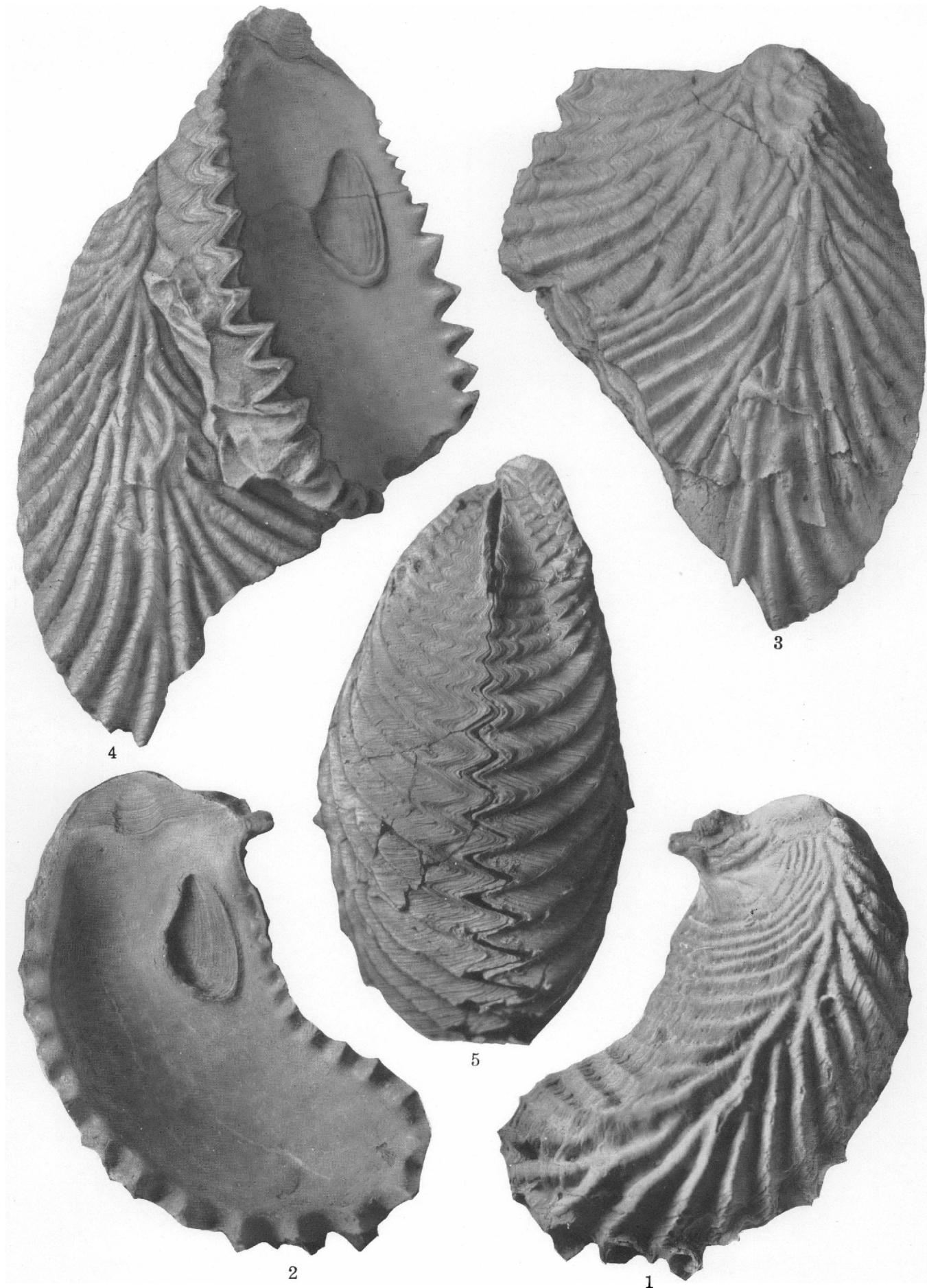
[Figured material is deposited in the United States National Museum]

FIGURES 1-4. *Ostrea johnsoni* Stephenson, n. sp. 1, Exterior of left valve of holotype (U. S. N. M. 75512); 2, exterior of right valve of holotype; 3, front edge view of holotype; 4, front edge view of a small paratype (U. S. N. M. 75514a).  
5. *Ostrea travisana* Stephenson, n. sp. Exterior of paratype, a right valve of more than average length (U. S. N. M. 75510).

### PLATE 3

[Figured material is deposited in the United States National Museum. All figures slightly reduced]

FIGURES 1-5. *Ostrea travisana* Stephenson, n. sp. 1, Exterior of holotype, a right valve (U. S. N. M. 75509); 2, interior of holotype; 3, exterior of right valve of a paratype from Onion Creek, Travis County, Tex. (U. S. N. M. 75511); 4, exterior of left valve of the same paratype and right valve of another individual to which the paratype is attached; 5, front edge view of the same paratype.



NEW UPPER CRETACEOUS OSTREIDAE FROM THE GULF REGION.



# FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE

By DAVID WHITE<sup>1</sup>

## ABSTRACT

The Wedington sandstone member of the Fayetteville shale has yielded fragmentary remains of fossil plants at several localities in the Winslow quadrangle, Arkansas. These forms, though many of them are indifferently preserved, are extremely significant in that they represent the first Mississippian land flora to be reported in the Midcontinent region. The age of the beds containing the flora is established by invertebrates, as well as by plants, to be early upper or middle Chester. The flora is related to that of the Chester group of the Eastern Interior basin and to beds of Chester age in the Appalachian trough through certain of its filicinean, calamarian, and lycopodiaceous forms. Likewise it is similar, in certain features, to standard lower Carboniferous floras of Europe. The Mississippian aspect of the flora is modified somewhat by the presence of a lower Pottsville or Namurian element, pointing to upper Chester age. This flora, however, contains no forms in common with the large assemblage of plants described by Lesquereux from the Bloyd shale (middle Pottsville) of the same region.

It is suggested that the plants grew in an environment not entirely favorable to the development of large size. The climate was probably marked by a seasonal deficiency of rainfall.

The flora, as it is now known, includes 35 species. It contains representatives of the Filicales, the Lycopodiales, the Equisetales, the Sphenophyllales, and the Pteridospermae.

## STRATIGRAPHY AND DISTRIBUTION OF THE PLANT-BEARING BEDS

"Wedington sandstone" is the name given by Adams<sup>2</sup> to a sandstone in the upper part of the Fayetteville shale, a formation of upper Mississippian (Chester) age in northwestern Arkansas and eastern Oklahoma. It is classified as a member of the Fayetteville shale, though on account of frequency of repetition, it is often casually mentioned in this paper as the Wedington sandstone. The type locality of the sandstone is Wedington Mountain, in northern Washington County, Ark., in the southwest corner of the Fayetteville quadrangle.<sup>3</sup> The sequence of the beds in the Winslow quadrangle,<sup>4</sup> immediately adjacent on the south, from which the plant material has been obtained, is briefly summarized as follows:

### *Sequence of beds in Winslow quadrangle, Arkansas*

#### Pennsylvanian:

##### Morrow group:

|   | Feet    |
|---|---------|
| Bloyd shale: Blue shale, gray and yellowish shale, and carbonaceous shale, including two marine limestones—the Kessler above and the Brentwood below—and a thin dark intervening shale—the coal-bearing shale—which includes the Washington County coal | 100-220 |
| Hale formation: Shale, sandstone, and thin limestone, marine  | 100-200 |

#### Unconformity.

#### Mississippian:

|  |         |
|--|---------|
| Pitkin limestone: Gray coarse-textured fossiliferous limestone   | 10-40   |
| Fayetteville shale: Black thinly laminated carbonaceous shale containing calcareous concretions and limestone locally near base. (The Wedington sandstone member is a heavy light-gray to brown cross-bedded sandstone, normally capped by greenish to bluish shale, at the top of the Fayetteville shale) | 150-300 |
| Unconformity.  |         |
| Boone limestone: Light-gray limestone, containing chert in beds and lenses   | 100+    |

Normally the Wedington sandstone member is overlain by bluish shale that weathers yellowish and has a maximum thickness of 60 feet. In some places in northwestern Arkansas the shale is lacking and the Pitkin limestone, the youngest Mississippian formation of the region, rests directly on the Wedington sandstone or even on underlying beds of the Fayetteville shale.

The sandstone is lenticular and is 150 feet or less in thickness. It reaches nearly its maximum thickness in the vicinity of Prairie Grove and Lincoln, in the northwest corner of the Winslow quadrangle, where the fossil plants here described were found. It is a hard, resistant sandstone, varying from white to rusty dark gray and greenish gray, is usually rather coarse, and in places is ripple-marked and cross-bedded. Certain layers carry considerable mica, and the plant-bearing beds in the region contain numerous white to dark-blue clay pebbles of moderate size and generally well rounded, so that, locally at least, the Wedington sandstone member is conglomeratic.

<sup>1</sup> This report was essentially completed by Dr. White before his death, Feb. 7, 1935. The additions and corrections which have since been made are small editorial modifications.

<sup>2</sup> Adams, G. I., Zinc and lead deposits of northern Arkansas: U. S. Geol. Survey Prof. Paper 24, p. 27, 1904.

<sup>3</sup> Adams, G. I., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Fayetteville folio (no. 119), p. 4, 1905.

<sup>4</sup> Purdue, A. H., U. S. Geol. Survey Geol. Atlas, Winslow folio (no. 154), 1916.

The distribution of the Fayetteville shale is shown approximately on the geologic maps of Arkansas<sup>5</sup> and Oklahoma<sup>6</sup> and is described by Croneis,<sup>7</sup> who, on the basis of the marine invertebrates, correlates the Wedington sandstone member with the Chester group. Marine invertebrates are relatively rare in the sandstone, where the fossil plants are found in comparative abundance. Lists of invertebrate fossils are given by Purdue and Miser<sup>8</sup> and by Croneis.<sup>9</sup> The sandstone is likewise regarded by the paleontologists of the United States Geological Survey as of Chester age.

The plants buried in the Wedington sandstone bear evidence of destructive water wear. The identifiable debris consists mainly of fragments of the resistant outer cortex and roots of *Lepidodendron* and pieces of woody species belonging to the calamarian group. Large numbers of seeds having a hard outer shell were washed into the sand here and there, and a few broken and badly worn fragments of cones also are found. Fernlike plants, probably belonging to the pteridosperms, were present, but only very small fragments have yet been found in the sandstones and interbedded shales, though portions of large water-worn petioles of at least two genera have been collected.

The occurrence of rather abundant plant debris together with numerous shale pebbles points to the probable contemporaneous exposure of land not far from the fossiliferous localities, in spite of the fact that a few brachiopods also are mingled with the vegetable fragments. Such exposures not remote from the plant-bearing deposits accord with the description by Purdue and Miser of deformations taking place in the Harrison and Eureka quadrangles after the greater part of the Fayetteville shale had been deposited.<sup>10</sup> Apparently the Wedington sandstone marks a minor orogenic movement in this region near the end of Chester time.

#### PLANT LOCALITIES

Plants were first found in the Wedington by H. D. Miser in 1928 at localities near Lincoln, Ark. These and other places, some of them near Prairie Grove, Ark., he revisited in 1929 in company with C. L. Cooper and in 1930 in company with L. G. Henbest and me, when most of the present collection was gathered. The plant localities were revisited in 1931 by Mr. Miser, accompanied by Charles B. Read, and again in 1932 by Mr. Miser. The collected material consisted mostly of sandstone but included some plant-bearing shale interbedded in the sandstone.

Owing apparently to the destruction of the more fragile plant material before its final burial in the sand,

the Wedington flora admits the recognition of but few species, yet it is of unusual interest, for it is the first indubitably Mississippian land flora to be discovered in the Midcontinent region. Therefore the species are described and illustrated in detail in the following pages, in order that the record may be of use to stratigraphers as well as paleontologists who may be concerned with comparing the Wedington flora with others, especially those of the Jackfork sandstone and the Stanley shale in the same region, concerning the age of which there is wide difference of opinion.

The precise localities from which Wedington plants were obtained are as follows:

1. Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lots 8075 and 8140), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).
2. Cane Hill, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8144).
3. About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8266).
4. Lincoln-Summers road, 4 miles west of Lincoln, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8267).
5. Six-tenths of a mile south of junction of State Highway 99 and United States Highway 62, 4 miles west of Lincoln, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8268).

#### GENERAL COMPOSITION OF THE WEDINGTON FLORA

The flora here described is the first land flora to be made known from beds of unquestioned Mississippian age in the entire southwestern portion of the United States. Accordingly, its correlative value and its importance as a paleobotanic datum plane with which to compare other fossil floras of the upper Mississippian and lower Pennsylvanian of the region exceed its meager worth as illustrating the plant life of the region in Wedington time.

Though some of the species in this flora are adequately represented in the collections, there is an unfortunately large percentage of forms of which only few and very small fragments—too meager, in fact, for satisfactory identification or description—have been obtained. Most of these are ferns or fernlike types. In treating them I have leaned toward describing as new species those that are not recognized as old ones, often basing specific differentiations on glaringly insufficient material, and have illustrated them very fully. This treatment should promote the discovery of additional and more ample illustrative material, which in turn should lead to the more definite and permanent identification and description of the genera and species. This procedure will assure greater completeness and clarity of the systematic as well as the distributional records.

<sup>5</sup> Branner, G. C., Geologic map of Arkansas, Arkansas Geol. Survey, 1929.

<sup>6</sup> Miser, H. D., Geologic map of Oklahoma, U. S. Geol. Survey, 1926.

<sup>7</sup> Croneis, Carey, Geology of the Arkansas Paleozoic area: Arkansas Geol. Survey Bull. 31, p. 69, 1930.

<sup>8</sup> Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (no. 202), p. 13, 1916.

<sup>9</sup> Croneis, Carey, op. cit., p. 71.

<sup>10</sup> Purdue, A. H., and Miser, H. D., op. cit., p. 16.

The genera and species in the present collections are listed below:

- Adiantites minima White, n. sp.
- Cardiopteris hirta White, n. sp.
- Cardiopteris sp.
- Neuropteris sp.
- Rhacopteris sp.
- Rhodea cf. R. subpetiolata (Potonié) Němejc.
- Rhodea cf. R. moravica (Ettingshausen) Stur.
- Sphenopteris cf. S. communis Lesquereux.
- Sphenopteris (Palmatopteris) erectiloba White, n. sp.
- Sphenopteris (Calymmatotheca) mississippiensis White, n. sp.
- Sphenopteris cf. S. obtusiloba Brongniart.
- Sphenopteris cf. S. schimperiana Goeppert.
- Telangium? sp.
- Rhynchogonium fayettevillense White, n. sp.
- Carpolithus inquirenda White, n. sp.
- Lepidodendron henbesti White, n. sp.
- Lepidodendron occidentale White, n. sp.
- Lepidodendron purduei White, n. sp.
- Lepidodendron cf. L. veltheimianum Sternberg.
- Lepidodendron wedingtonense White, n. sp.
- Lepidodendron sp. 1.
- Lepidodendron sp. 2.
- Stigmaria arkansana White, n. sp.
- Stigmaria wedingtonensis White, n. sp.
- Bothrodendron sp.
- Lepidophyllum sagittatum White, n. sp.
- Lepidostrobus occidentalis White, n. sp.
- Lepidocystis chesterensis White, n. sp.
- Archaeocalamites fayettevillensis White, n. sp.
- Archaeocalamites gracilens White, n. sp.
- Archaeocalamites umbralis White, n. sp.
- Archaeocalamites wedingtonensis White, n. sp.
- Archaeocalamites? sp.
- Chlamidostachys chesterianus White, n. gen. and sp.
- Sphenophyllum? sp.

The Wedington flora is of mixed composition. It comprises ferns and fernlike plants, calamarian forms representing *Archaeocalamites*, and lepidophytes, of which *Lepidodendron* is the most abundant. No typical Pennsylvanian *Calamites* and no representatives of the genera *Asterophyllites*, *Annularia*, *Mariopterus*, *Alethopteris*, *Sigillaria*, or *Cordaites* have yet been found.

Though most of the species in the Wedington flora are here described for the first time, nearly all are closely related to species previously known, either in the upper Mississippian or in the lowest Pennsylvanian.

#### AGE OF THE FLORA OF THE WEDINGTON SANDSTONE MEMBER

The age of the beds containing the Wedington flora is not now subject to question, being approximately established by the sequence of marine faunas, with an associated flora, in the series of formations which compose type sections of the upper Mississippian and lower Pennsylvanian for this region.

The plant-bearing sandstones of the Wedington are normally intercalated in marine shales which, where not eroded, are in turn overlain by 15 to as much

as 100 feet of Pitkin limestone, formerly known as the †*Archimedes* limestone.<sup>11</sup> The Pitkin formation, rich in marine life, embracing a few Pennsylvanian forms in a fauna overwhelmingly Mississippian in facies, comprises the beds of latest Mississippian age yet recognized in the Southwestern Interior basin. On the evidence of the marine invertebrates, examined by many paleontologists, it is referred to the upper Chester, whereas the Fayetteville shale, which in its upper part embraces the Wedington sandstone member, is regarded as of middle and upper Chester age. A slight unconformity at the base of the Pitkin permits the limestone locally to rest directly on the Wedington sandstone member, or even on underlying shale of the Fayetteville.

From the paleobotanist's point of view, so far as the criteria are yet in hand, the Wedington is evidently bound to the upper Mississippian by its large-pinnuled *Rhacopteris*, which has very close relatives in the beds of Chester age in the Appalachian trough as well as in western Europe; by its species of *Cardiopteris*, which differ but slightly from one widely spread in the upper Mississippian of the Appalachian trough and the Eastern Interior basin; by its *Archaeocalamites gracilens* and the possibly associated *Chlamidostachys chesterianus*, which have European relatives in the upper Mississippian *Pothocites*; by its *Lepidodendron occidentale*, which differs only in the greater altitude of its leaf scar from the typical *Lepidodendron volkmannianum*, found both in Europe and in the American Chester, where it is characteristic of that stage in the Appalachian trough and the Eastern Interior basin; by its *Lepidophyllum sagittatum*, which represents a group of rather small, narrow, tapering, sword-pointed leaves of the Old World and Appalachian upper Mississippian; by its *Lepidocystis chesterensis*, present in the beds of Chester age in the Appalachian trough and possibly specifically identical with a form in the Mississippian limestone of Silesia; by its *Stigmaria wedingtonensis*, a form with radiately areolate leaf scars associated with the *Lepidodendron volkmannianum* group; and by its *Rhynchogonium fayettevillense*, which is most closely related specifically to European forms from the Mississippian limestone of Silesia, the Calciferous Sandstone of Scotland, and the Mississippian of the Arctic zone. All these forms are characteristically and exclusively Mississippian. Furthermore, the distribution of the forms specified above in beds of Chester age in the Appalachian and Eastern Interior basins leaves no room for doubt as to the correlation of the Wedington with the Chester group, the upper division of the Mississippian series in the Eastern Interior basin. These plant forms would proclaim the Chester

<sup>11</sup> A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

age of the deposits even if there were no associated invertebrate fossils to point out the position of the Wedington in the Mississippian column of the Southwest.

On the other hand, the flora is connected with the Pennsylvanian by a large element present in the Namurian or the next higher stages of the lower Pennsylvanian, included in the American Pottsville group. Among these mention may in particular be made of *Sphenopteris (Calymmatotheca) mississippiensis*, which approaches extremely closely the earliest phase of the group of forms generally included under *Sphenopteris* or *Calymmatotheca hoeninghausii*. In the same category may be placed the *Adiantites*, the *Rhodea*, the *Neuropteris*, the group *Mesocalamites*, in which most of the forms of *Archaeocalamites* from the Wedington find their place; also *Lepidodendron wedingtonense*, which appears to have direct ancestral connection with *Lepidodendron wortheni* and *L. brittsii*, at the base of the Allegheny formation; *Lepidodendron cf. L. rimosum*; *Lepidostrobus occidentalis*, closely related to *Lepidostrobus variabilis* Lindley and Hutton; and several lepidodendroid forms, including that showing a cone scar and tentatively assigned to *Bothrodendron*, which fall within the comprehensive group generally referred by paleobotanists under the collective term *Lepidodendron veltheimianum*.

Several of the plants enumerated above appear to be present in the uppermost Mississippian of Europe as well as of America, though they range upward into the Namurian and some of them into the Westphalian, which is nearly equivalent to the middle and upper Pottsville of the Appalachian trough. On the whole, however, though the flora in hand exhibits ties connecting it with the basal Pennsylvanian, and especially the Namurian, its exclusively Mississippian representatives are sufficient in type and in number to demand its reference to the Chester Mississippian, though if considered only from the present knowledge of the fossil flora, the Wedington sandstone would be classed as upper Chester.

#### RELATIONS OF THE WEDINGTON FLORA TO THAT OF THE COAL-BEARING SHALE OF THE MORROW GROUP OF WASHINGTON COUNTY, ARKANSAS

The geographically nearest flora of Pennsylvanian age which has been described and with which the flora of the Wedington sandstone member may be compared is the well-known flora recorded from what was formerly known as the coal-bearing shale of Washington County, Ark., which occurs in the same region and in the same vertical section as the Wedington sandstone.

The Morrow group, in which the coal-bearing shale has its place, is in this region not over 400 feet thick. It rests usually upon the Pitkin limestone, or where the Pitkin has been removed by erosion it may lie upon the Wedington sandstone member or even on the lower

part of the Fayetteville shale. At the base of the Morrow group is the Hale formation, consisting of shales, sandstones, and thin limestones, 80 to 300 feet in total thickness; above which lies the Bloyd shale, reaching a maximum thickness of 175 feet and containing near its base the Brentwood limestone member (whose maximum thickness in the Fayetteville quadrangle is 80 feet) and higher in the section the Kessler limestone member (in some places only 2 to 4 feet thick but reaching a maximum thickness of 70 feet in the Fayetteville quadrangle). Between these limestone members is an interval, usually 10 to 20 feet but in places 100 feet, occupied by shales that contain a thin coal formerly mined at several points in the Fayetteville quadrangle. This shale is known as the coal-bearing shale and the coal as the Washington County coal. More than 120 species, composing a well-balanced flora, were described or recorded by Lesquereux<sup>12</sup> as coming from this stage and vicinity. In his reports the plants are recorded as from a subconglomerate stage, then believed to be upper Mississippian, as the base of the Winslow formation, which lies upon the Morrow group, a short distance above the Kessler limestone, is marked by a quartz conglomerate regarded at that time as the †Millstone grit, the base of the Pennsylvanian or upper Carboniferous.

A review of the plants from the coal-bearing shale by me in 1893 resulted in the reference of that shale to a stage in the upper part of the middle Pottsville or possibly the extreme basal portion of the upper Pottsville and the consequent transfer of the Kessler limestone and overlying beds to the Pennsylvanian. Later, on account of the large Pennsylvanian element in the fauna, the lower portion of the Bloyd formation, embracing the Brentwood limestone, with its associated shales and sandstones, and the Hale sandstone, were placed in the Morrow group and likewise referred to the basal Pennsylvanian. All the formations carry abundant marine local faunas, which are listed by Miser.<sup>13</sup> The general faunas of the Morrow group and their stratigraphic distribution have been discussed somewhat fully by Mather.<sup>14</sup>

It is noteworthy that so far as the Wedington flora is known at the present moment, no species in it is found also in the large flora of the coal-bearing shale in the Morrow group. This fact accords with the length of the interval between the early upper or possibly the latest middle Chester and a stage lying probably in the upper part of the middle Pottsville. Certainly

<sup>12</sup> Lesquereux, Leo, Botanical and paleontological report on the Geological State Survey of Arkansas, in Owen, D. D., Second report of a geological reconnaissance of the middle and southern counties of Arkansas, pp. 295-399, Philadelphia, 1860; Description of the coal flora of the Carboniferous formation in Pennsylvania and throughout the United States: Pennsylvania 2d Geol. Survey Rept. P, 3 vols. and atlas, 1870-84.

<sup>13</sup> Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (no. 202), pp. 14-15, 1916. See also Croneis, Carey, Geology of the Arkansas Paleozoic area: Arkansas Geol. Survey Bull. 3, 1930.

<sup>14</sup> Mather, K. F., The fauna of the Morrow group of Arkansas and Oklahoma: Denison Univ., Sci. Lab., Bull. 18, pp. 59-284, 1915.

the equivalent at least of the entire Lee formation, over 1,200 feet thick, embracing the lower part of the Pottsville group of the Appalachian trough, was deposited in the Appalachian region in Pennsylvanian time before beds contemporaneous with the coal-bearing shale were there laid down.

Of the plant life of that portion of the Morrow lying below the coal-bearing shale very little is known. However, a small lot of specimens embracing *Lepidodendron* stems, for the most part in spongy sandstone with soft iron residues filling the cavities left by the macerated plants, was collected by H. D. Miser and now rests among the Geological Survey collections of fossil plants. No distinct leaf scars showing nerve traces and appendages remain. Even the outlines of the bolsters are obscure in some of the specimens. Their superficial features, however, associate these *Lepidodendron* stems with *L. aculeatum*, the comprehensive *L. veltheimianum*, the *L. obovatum* group, and possibly *L. jaraczewskii*. There is also present a single fragment apparently definitely referable to *Archaeocalamites scrobiculatus* as its characters are in close agreement with those of the form with sharply cut nodes and continuous ribs described as *Archaeocalamites transitionis*. The paleobotanic evidence is insufficient for a definite correlation, but it justifies the tentative assumption that the Hale formation is of basal Westphalian, if not, in fact, Namurian age.

#### ENVIRONMENT OF THE WEDINGTON FLORA

As to the environment in which the Wedington flora lived, little that is definite can be noted. The composition and distribution of the members of the Morrow group (Pennsylvanian), which succeeds the Pitkin limestone, suggest a nearly baseleveled Ozarkia, along the south flank of which were a series of shoal-water deposits that at times, at least, may have been barrier-lagoonal in nature. Scarcity of conglomeratic material negatives any considerable elevation of the northern land, which, as indicated by the relative freshness of the plant remains buried in the sandstone, must have been comparatively near.

Apparently most of the plants drifting into the shallow water of the Wedington sandstone environment were small; the calamarian stems were all small, the lepidophytes include very few impressions of large stems, no large stem referable to fern or pteridosperm is present, and no *Cordaites* leaves have been detected.

As will be noted in the descriptions, the cuticles of most of the ferns and fernlike plants are rugose, and many of them are provided with spines or short bristle-like hairs, some scattered sparsely and some relatively closely on both pinnules and rachises, even of small and relatively delicate fronds. The leaf bases of most of the lepidophytes are very highly protuberant, in some specimens almost extraordinarily so. Furthermore, the outer covering of these plants was rather distinctly

horny as well as rigid. The branches of *Lepidodendron henbesti* were slender and crooked, and near the ends the branchlets were so close (less than 2.5 centimeters apart) as to suggest a tangled or matted yet rather rigid growth. The seeds classed as *Rhynchogonium* are provided with an extension of the outer integument in a group of narrow acute teeth, suggesting a closed calyx, but the inner and thicker testa is cut in short blunt teeth, which appear to have rolled outward at the time of maturity of the seed, when also the calyx opened, presumably to permit fertilization, after which the calyx seems to have closed, as, very likely, also did the teeth guarding the opening to the pollen chamber of the seed. It is perhaps noteworthy that the cones described as *Chlamidostachys* bore broad winged bracts, along which the sporangiophores were distributed, and that by means of these wings and the hoodlike expansion of the terminal portion of the bract the fructifications seem to have been tightly wrapped and protected.

Though practically nothing is known of the internal structure of the plants, the inference may be drawn that the environment was not wholly favorable to the development of large size in growth of plants and trees and that the climate was probably marked by a seasonal deficiency of rainfall. Such a conclusion appears to harmonize with the occurrence of hardened and well-rounded pebbles of clay and fine-grained silt, mingled with the plants in the sandstone, and with the slightly gypseous content of the enveloping Fayetteville shale.

#### DESCRIPTIONS OF THE SPECIES

##### Genus ADIANTITES Schimper, emended, 1869

In connection with my description<sup>15</sup> of the seed *Wardia*, borne on certain fernlike fronds from the lower Pottsville of southern West Virginia, I applied the name *Aneimites* (Dawson) Schimper to these fronds as the generic name properly applicable, the name *Adiantites*, by which similar fronds had most frequently been designated, being then regarded as nomenclaturally untenable. For reasons that follow I discontinue this application of the name *Aneimites* in favor of *Adiantites*, the use of which, though on none too secure foundation, seems preferable to the coinage of a new generic name, otherwise necessary. Briefly, the essential points in the history of its use are as follows:

*Adiantites* was proposed by Goeppert<sup>16</sup> in 1836 to include 20 species, embracing chiefly ginkgoes, cyclopterids, and sphenopterids. Since that date all the species which in accordance with the accepted rules of nomenclature might be regarded as types of Goeppert's genus have been transferred to other genera. Mean-

<sup>15</sup> White, David, The seeds of *Aneimites*: Smithsonian Misc. Coll., vol. 47, pt. 3, no. 1550, p. 323, 1904.

<sup>16</sup> Goeppert, H. R., Systema filicum fossiliuum; Die fossilen Farrnkräuter: Acad. Caesarea Leopoldino-Carolina Nova Acta, vol. 17, Suppl., p. 216, Breslau, 1836.

while Schimper,<sup>17</sup> in 1869, proposed the genus *Adiantides* Schimper "(*Adiantites* auct.)", to which he referred either directly or as synonyms the species enumerated by Goeppert in Goeppert's final group.<sup>18</sup> Under the nomenclatural rules formerly followed by most paleobotanists the retention of Goeppert's term for this final residual, which included but four species, was permissible, without regard to generic type. Inasmuch as Schimper in his new genus gives type status to one of the species brought forward from Goeppert's list, his revision is here accepted. However, as the name *Adiantides* proposed as new by Schimper is evidently a mere modification of the spelling of the earlier name in a form that is not permissible under the rules followed by most paleontologists, the term *Adiantites* as spelled by Goeppert must be retained, though the restriction and definition of its conception and scope as emended by Schimper are recognized.

The subgeneric name *Aneimites*, proposed and long used by Dawson,<sup>19</sup> was made to embrace several species from the Upper Devonian, the Mississippian, and the Pottsville. However, *Cyclopteris* (*Aneimites*) *acadica* Dawson,<sup>20</sup> from the lower Mississippian of Nova Scotia, first published in 1860 and more fully described and illustrated in 1873,<sup>21</sup> is shown to have a bifurcated petiole, and the inferior ultimate pinnules, which are short petiolate, are remarkably recurved in a way that is characteristic of the subgenus. As *Cyclopteris* (*Aneimites*) *acadica* had, in connection with the description of other plants by Dawson, been designated as the type of the subgenus *Aneimites*,<sup>22</sup> and as the mode of division of the frond of this species seems to differ generically from that of the fronds under consideration, from the upper Mississippian and lower Pottsville, the use of *Aneimites* for the latter is precluded, in spite of the elevation of the term to generic rank by Schimper<sup>23</sup> in 1874, with priority given to Dawson's type species.

So far as known, *Aneimites*, restricted to accord with the generic characters of *Aneimites acadica*, is confined to the lower Mississippian, whereas *Adiantites* is apparently confined to the upper Mississippian, where it is represented by the plant here described as *Adian-*

*tites minima*, and to the Pottsville, where are found *Adiantites fertilis* and several other related species.

The genus *Adiantites* is typified in Goeppert's *Adiantites cuneatus*,<sup>24</sup> which Schimper made a synonym of Brongniart's *Sphenopteris nervosa*,<sup>25</sup> placing the latter at the head of the genus "*Adiantites*." Characteristic of the genus is the species described by Ettingshausen<sup>26</sup> as *Adiantum antiquum*, which was more elaborately illustrated by Stur<sup>27</sup> under the name *Adiantites antiquus* (Ettingshausen). The essential generic characters are as follows:

Fronds tri- or quadripinnate with slender rachis; primary divisions alternate, often very open; pinnules cuneate to cuneate-obovate, truncate or rounded at the apex or divided into two to five cuneate lobes, usually slightly pedicellate with narrow, relatively terete, and sometimes very narrowly margined rachis; nerves numerous, flabellately divergent, or with imperfect development of a principal nerve strand in the lower portion of the pinnule or lobe, the nervilles being generally slender, several times dichotomous, and straight or slightly curved.

#### *Adiantites minima* White, n. sp.

Plate 4, figure 38

Major divisions not seen; penultimate rachis strong, rigid, dorsally low-rounded, and lineate with distinctly decurrent nerve strands descending from the ultimate pinnae; ultimate pinnae alternate, oblique, at an angle of about 60°, close, slightly overlapping, small, linear-lanceolate, slightly acute, with relatively broad, rigid or slightly flexuose, very narrowly alate axis; pinnules small, alternate, slightly decurrent, broadly cuneate to obovate, cuneate when sublobate, slightly broad-pedicellate, oblique, slightly outward-curved, slightly obliquely round-truncate or broadly rounded at the apex, 3 or 4 millimeters long and 2 or 3 millimeters wide, the lobes, two or three in number, about 2.5 millimeters long and 1 to 2 millimeters wide, somewhat divaricate; lamina thick, very minutely rugose, nearly flat, and decurrent in a narrow border along the rachis; nervation partly flabellate without the development of a strong primary nerve, the secondary nerves being derived at a wide angle in the decurrent base of the pinnule or near the base of each lobe, the nervilles being nearly straight and forking low in the lobe to furnish generally two or three nearly straight nervilles to the lobe.

This species is remarkable for the small size of its pinnules and lobes. The lobes, though relatively broad and robust as compared with those of other species of *Adiantites*, are in their arrangement, mode of development, and nervation characteristic of the

<sup>17</sup> Schimper, W. P., *Traité de paléontologie végétale*, tome 1, p. 424, 1869.

<sup>18</sup> Goeppert, H. R., op. cit., p. 226; "c. Frons tripinnata."

<sup>19</sup> Dawson, J. W., On an undescribed fossil fern from the lower coal measures of Nova Scotia: *Canadian Naturalist*, vol. 5, p. 461, 1860.

<sup>20</sup> Dawson, J. W., On an undescribed fossil fern from the lower coal measures of Nova Scotia: *Geol. Soc. London Quart. Jour.*, vol. 17, p. 5, 1860; On the conditions of the deposition of coal, more especially as illustrated by the coal formation of Nova Scotia and New Brunswick: *Idem*, vol. 22, p. 153, pl. 8, fig. 32, 1866.

<sup>21</sup> Dawson, J. W., Report on the fossil plants of the Lower Carboniferous and Millstone Grit formations of Canada, p. 26, pl. 7, figs. 52-63, *Canada Geol. Survey*, 1873.

<sup>22</sup> Dawson, J. W., The fossil plants of the Devonian and Upper Silurian formations of Canada, p. 48, *Canada Geol. Survey*, 1871.

<sup>23</sup> Schimper, W. P., op. cit., tome 3, p. 489, 1874. Schimper gives first place to *Aneimites acadica* (Dawson), which is followed by *Aneimites adiantoides*, of which Ettingshausen's *Adiantum antiquum* (*Die fossile Flora des mährisch-schlesischen Dachschiefer*, p. 98, pl. 7, fig. 1, 1865) is made a synonym.

<sup>24</sup> Goeppert, H. R., op. cit., p. 226.

<sup>25</sup> Brongniart, Adolphe, *Histoire des végétaux fossiles*, tome 1, p. 174, pl. 56, fig. 2, 1828.

<sup>26</sup> Ettingshausen, C. von, *Die fossile Flora des mährisch-schlesischen Dachschiefer*: K. Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 25, p. 22, pl. 7, fig. 1, 1865.

<sup>27</sup> Stur, Dionysius, *Die Culm-Flora*: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 66, pl. 16, figs. 4-6, pl. 17, figs. 3-4, 1875.

genus. On account of their very small size, the plant is suggestive of portions of *Sphenopteris divaricata* or some of the relatively large and cuneately lobed pinnules referred by some authors to the *Sphenopteris hoeninghausii* group.

The general aspect of the narrowly alate rachis is shown in figure 38, plate 4, as are some of the aspects of the pinnules. Although the pinnules approximate in size some of those characteristic of *Sphenopteris hoeninghausii*, they are readily distinguished by the flat lamina and the more distinctly cuneate lobes.

Among the known species of *Adiantites*, *A. minima* appears most closely related to *Adiantites fertilis*,<sup>28</sup> to the smallest pinnae and pinnules of which the fragments in hand are strikingly similar. The Arkansas plant differs, however, in its shorter and relatively broader pinnules, which are thicker and in general rather more open. In the Pottsville plant, *Adiantites fertilis*, the leaf is thin and the nervation slender and relatively distant.

The fruit *Wardia*, found attached to *Adiantites fertilis* and generically in association with other species of the genus at other localities in the Pottsville group, has not yet been found in the Wedington. It will probably be discovered on further search. The genus is characteristic of and mainly confined to the Pottsville (Westphalian).

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075).

Type: U. S. Nat. Mus. 39477.

#### Genus CARDIOPTERIS Schimper, 1869<sup>29</sup>

##### *Cardiopteris hirta* White, n. sp.

Plate 4, figures 29, 31, 32, 33, 34, 35, 37

Pinnules relatively small, mostly about 11 millimeters in length, rounded, somewhat polymorphous, ranging from ovate or broadly oval to very broadly ovate or even slightly reniform, the younger ones generally longer than broad, the older frequently as broad or even broader than long, occasionally very faintly sublobate in one or two rounded and hardly differentiated lobes; lamina usually overlapping or clasping at the base, nearly flat, slightly arched at the border, rather thick, minutely rugose and provided with numerous stiff, relatively coarse hairs generally about 2 millimeters in length, for the most part oriented parallel to the nervation, which they partly obscure; nervation flabellate from the narrow point of attachment; nerves rather coarse, frequently striate, forking three to five times, according to the size of the pinnule, at a very narrow angle, while passing nearly straight or but slightly arching to the margin and approximately equidistant in all parts of the pinnule.

<sup>28</sup> White, David, The seeds of *Anemites*: Smithsonian Misc. Coll., vol. 47, pt. 3, p. 323, pls. 47, 48, 1904.

<sup>29</sup> Schimper, W. P., Traité de paléontologie végétale, tome 1, p. 451, 1869.

Most common among the small fragments and detached pinnules of ferns in the collection are relatively small isolated pinnules of a species of *Cardiopteris*, obviously related to *Cardiopteris polymorpha* (Goeppert) Schimper. The pinnules, which are generally rounded, rarely exceed 12 millimeters in length, and the smallest are less than 6 millimeters and scarcely more than 5 millimeters in breadth. All are characterized by the presence of short, stiff hairs, generally parallel to and even obscuring the nervation.

The most common and characteristic form of this species is seen in figure 35, plate 4, in which two clasping pinnules are probably not far from their original position. Another specimen, viewed dorsad and exhibiting the characteristic overlapping of the lobes, is shown in figure 32, plate 4, and the details of venation of a relatively large pinnule, slightly sublobate at the distal margin, are seen in figure 37.

Some relatively broad specimens of *Cardiopteris hirta* show slight sublobation, and two of the smallest pinnules are illustrated in figures 29, 33, and 34, plate 4. No fragments of rachis to which pinnules are attached have been noted in the collection.

The rugosity and hairs characteristic of the species are shown in the enlargements, figures 31 and 37, plate 4, as is the nervation.

*Cardiopteris hirta* is closely related to *Cardiopteris polymorpha* (Goeppert) Schimper, though its pinnules are generally much smaller than those of *C. polymorpha* and are, in particular, distinguished by the broad striate nerves on which are superposed the short, stiff hairs.

The average pinnule of this species rather closely resembles the smallest of the pinnules figured by Stur<sup>30</sup> from the Waldenburg series as *Cardiopteris* sp. It is, however, much smaller than the larger Waldenburg pinnules, which are much more broadly reniform and much larger.

The ordinary pinnules of *Cardiopteris hirta* are rather strikingly similar in size, form, and even in nervation to some of the pinnules described as *Cardiopteridium spetsbergense* by Nathorst,<sup>31</sup> though there is no evidence that the more distinctly cordate or cyclopterid pinnules from the Wedington were associated with much larger heteromorphous pinnules, rather broadly attached or even petiolate and provided in some specimens with midribs, as was the case with the plant made by Nathorst the basis for his genus *Cardiopteridium*, which is found in the Mississippian of Spitsbergen.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Types: U. S. Nat. Mus. 39478–39482.

<sup>30</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8 Heft 2, p. 182, pl. 11, fig. 6, 1877.

<sup>31</sup> Nathorst, A. G., Nachträge zur paläozoischen Flora Spitzbergens: Zur fossilen Flora der Polarländer, Teil 1, Lief. 4, p. 16, pl. 9 (see especially figs. 14 and 15), 1914.

***Cardiopteris* sp.**

Plate 4, figures 40, 41

The small fragment shown in plate 4, figures 40 and 41, is one of two specimens comprising portions of torn leaves that apparently represent a species of *Cardiopteris* in which the leaves are much larger than in *Cardiopteris hirta*, already described. In this form the pinnule, which is apparently slightly thinner than in the other species, has, as will be noted on comparing the figures, somewhat more distant nervation, which is less equidistant in the interior of the pinnule as compared to the marginal region. In this specimen leaf hairs do not seem to be present.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Types: U. S. Nat. Mus. 39483.

**Genus NEUOPTERIS (Brongniart) Sternberg, 1825<sup>32</sup>*****Neuropteris* sp.**

Plate 4, figures 26, 27, 28

Among the small fragments of pinnae and the detached pinnules found in the collections are several that are apparently referable to the genus *Neuropteris*, though they are inadequate for satisfactory identification or specific description. Like the pinnules of the earlier representatives of this genus, they are broadly attached, and near the apex of the pinna or in the very young pinnules they are more or less confluent. A sublobate terminal pinnule is illustrated in figure 28, plate 4. Young pinnules broadly attached and probably decurrent have likewise been observed. The nervation of these pinnules is distinctly neuropterid, with generally well-developed median nerves, even where some of the nervilles, especially in the decurrent parts of the lamina, are derived from the rachis. The nerves are coarse and slightly irregular. They fork once or twice at rather wide angles while bending outward toward the margin, which they generally meet at an oblique angle. As is shown in the enlargement, figure 26, plate 4, the nervation is partially obscured by the presence of numerous short bristlelike hairs scattered over both the dorsal and ventral surfaces of the pinnule. These hairs are relatively large at the base, are stiff, and taper rather rapidly upward to a sharp point. They are about 1 or 1.25 millimeters in length, and they generally lie parallel to the nervation, but occasionally their disposition is irregular.

The form represented by these specimens appears rather more rounded at the apex, and the pinnules are generally smaller than those in the material from the Mississippian of Europe figured as *Neuropteris antecedens*, though the larger of the fragments from the

<sup>32</sup> Brongniart, Adolphe, Mus. histoire nat. Paris Mém., tome 8, p. 233, 1822. Sternberg, Kaspar, Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, Tentamen, p. xvii, 1825.

Wedington sandstone is in many respects comparable to one of the specimens figured by Stur in plate 15, figure 4, of "Die Culm-Flora." Neuropterid forms of the type illustrated by Ettingshausen<sup>33</sup> as *Neuropteris heterophylla* Brongniart and by Stur<sup>34</sup> as *Neuropteris antecedens* date far back in Mississippian time. Assuredly, however, not all the fronds illustrated by Stur as *Neuropteris antecedens* Stur can have belonged to a single species.

The Wedington plant is further characterized by the rigid bristlelike hairs borne on both surfaces of the lamina, which itself is coriaceous.

Though the pinnules agree in form with some of those of the *Neuropteris pocahontas* group in the lower Pottsville of the Appalachian trough, all differ from that group, which is not provided with hairs, by the much more distant, more broadly forking, and less strongly arched nervation.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Types: U. S. Nat. Mus. 39484, 39485.

**Genus RHACOPTERIS Schimper, 1869<sup>35</sup>*****Rhacopteris* sp.**

Plate 4, figures 1, 6

A single specimen in the collection embracing portions only of three consecutive pinnules, shown in figure 1, plate 4, rather clearly represents a large-pinnuled species of *Rhacopteris*. As seen in the illustration and enlarged photograph, figure 6, plate 4, the leaf is thick, even leathery, and granular-rugose. It is shallowly dissected in very oblique or nearly vertical lobes which turn slightly outward. The overlapping pinnules represented in this specimen were probably 2 centimeters or more in length and 1.25 to 1.5 centimeters or more in width. The coarse, gently arching, and rather evenly curved nerves are in relief on both the dorsal and ventral surfaces. They are rather distant, nearly equidistant one from another, and they appear to fork three to five times at a narrow angle in passing from the midrib, which is not well developed in the upper part of the pinnule, to the apex of the lobe.

In the size and indicated shape of the pinnules and both the texture and the nervation, this plant approaches very closely an undescribed species in the Mississippian of the Appalachian trough.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Type: U. S. Nat. Mus. 39486.

<sup>33</sup> Ettingshausen, C. von, Die fossile Flora des mährisch-schlesischen Dachschiefers: K. Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 25, p. 20, text fig. 4, pl. 6, fig. 1, 1865.

<sup>34</sup> Stur, Dionysius, op. cit., Heft 1, pl. 15.

<sup>35</sup> Schimper, W. P., Traité de paléontologie végétale, tome 1, p. 481, 1869.

Genus *RHODEA* Presl, 1838<sup>36</sup>*Rhodea* cf. *R. subpetiolata* (Potonié) Němejc

Plate 4, figures 2, 3

A few small fragments, one of which is photographically illustrated in plate 4, figures 2 and 3, are, on account of the asymmetry of the pinnules, in which the inner basal lobes are longer and larger, referred with some doubt to the genus *Rhodea*. Though the pinnules are small and the lobes fewer, less truncate, and less unequal, they are slightly suggestive of *Rhacopteris subpetiolata* Potonié,<sup>37</sup> transferred by Němejc<sup>38</sup> to *Rhodea*.

In some of the specimens the pinnules have a generally rhomboidal outline. The lobes are rather deeply dissected, narrowly wedge-shaped, and more or less obliquely rounded, with slight indication of truncation at the apex. The distal basal lobe appears broader, a little larger, and less oblique than the proximate lobe. The lamina is slightly arched ventrad and very narrowly decurrent along the upper portion of the outer rachis. The larger lobes are provided with median nerves, from which nearly straight nervilles pass at relatively oblique angles, forking once, whereas the narrow upper lobes appear to be provided with but a single nerve.

Though much smaller, the pinnules in the specimen illustrated are most suggestive of *Rhodea subpetiolata* (Potonié), from the Waldenburg series and the coal basins of central Bohemia,<sup>38</sup> with which the Arkansas plant may be associated pending the discovery of specimens adequate for its definite identification and description.

Superficially the Wedington specimens resemble the specimen illustrated by Feistmantel<sup>39</sup> in plate 15, figure 14, of his paper on the plants from the Carboniferous limestone at Rothwaltersdorf under the name *Hymenophyllites furcatus* Brongniart. The resemblance is, however, remote, if dependence is put on the enlarged figure 14a of the same plate as illustrating the detailed lobation and nerves.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075).

Types: Figured specimens, U. S. Nat. Mus. 39487

*Rhodea* cf. *R. moravica* (Ettingshausen) Stur

Plate 4, figures 19, 24, 25

The collection from the Wedington contains several very small fragments of a sphenopterid with small pinnules cut as if skeletonized in very narrow, delicate,

<sup>36</sup> Presl, Karl, in Sternberg, Kaspar, op. cit., Hefte 7, 8, p. 109, 1838.

<sup>37</sup> Potonié, H., Über einige Carbonfarne: K. preuss. geol. Landesanstalt Jahrb., 1899, p. 28, 1892; Die floristische Gliederung des deutschen Carbon und Perm: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 21, p. 21, fig. 6, 1896.

<sup>38</sup> Němejc, F., *Rhodea subpetiolata* Pot. sp., a new leaf type in the coal basins of central Bohemia: Acad. tchèque sci. Bull. internat., année 28, pp. 56-61, pl. 1, text figs. 1, 2, 1927.

<sup>39</sup> Feistmantel, Ottokar, Das Kohlenkalkvorkommen bei Rothwaltersdorf in der Grafschaft Glatz und dessen organische Einschlüsse: Deutsche geol. Gesell. Zeitschr., Band 25, pp. 463-551, 1873.

rather broadly divergent but somewhat irregular lobes, which may fork widely in linear, slightly flexuous subdivisions very nearly equaling in width the mother lobes. The very small specimen seen in figure 19, plate 4, illustrates these features. The material is insufficient for definite specific determination.

It is, however, perhaps specifically identical with some of the specimens figured by Ettingshausen<sup>40</sup> as *Trichomanes moravicum* Ettingshausen, which was transferred by Stur<sup>41</sup> to the genus *Rhodea*.

The fragment with the more open lobes is very closely comparable to one of the specimens from the Moravian-Silesian roofing slates illustrated by Stur<sup>42</sup> as *Rhodea goepperti* (Ettingshausen) sp. There is, however, nothing else in the collection which closely resembles other specimens described by Stur under the same name.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Types: Figured specimens, U. S. Nat. Mus. 39488, 39489.

Genus *SPHENOPTERIS* (Brongniart) Sternberg, 1825<sup>43</sup>*Sphenopteris* cf. *S. communis* Lesquereux

Plate 4, figure 9

A single fragment of *Sphenopteris*, which in its mode of ultimate subdivision and, to some extent, in the form and aspect of its connate, oblique, and but slightly dissected pinnules, which are ovately rounded at the top and slightly cuneate, rather closely resembles the plant from the Morrow group described by Lesquereux under the name *Sphenopteris communis*. The fragment is shown in figure 9, plate 4. Like the Morrow species, this one is somewhat rugose-villous, with partly masked, oblique, somewhat diffused, and relatively close nervation.

Further specimens are needed for the proper characterization and identification of this plant.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075).

Type: Figured specimen, U. S. Nat. Mus. 39490.

*Sphenopteris* (*Palmatopteris*) *erectiloba* White, n. sp.

Plate 4, figures 10, 16

Ultimate divisions alternate, linear, very oblique, parallel, rigid, with dorsally terete, ventrally shallowly depressed, narrow, straight rachis; pinnules very oblique, nearly erect, lineate to very narrowly cuneate obovate, dissected in two to five narrow cuneate lobes,

<sup>40</sup> Ettingshausen, C. von, Die fossile Flora des mährisch-schlesischen Dach, schiefer: K. Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 25, p. 100-101, pl. 6, fig. 4, 1865.

<sup>41</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 42, pl. 11, fig. 7, 1875.

<sup>42</sup> Idem, pl. 11, figs. 3-7.

<sup>43</sup> Brongniart, Adolphe, Mus. histoire nat. Paris Mém., tome 8, p. 233, 1822. Sternberg, Kaspar, op. cit., Tentamen, p. xv, 1825.

which in turn are very deeply dissected in the larger units, which are slightly arched ventrad, round obtuse at the apex, with lateral margins nearly parallel; lamina rather dense, minutely rugose, sparsely provided with rather slender short bristlelike hairs on the dorsal surface, and decurrent to form a very narrow bordering wing along the rachis.

Owing to the small size of the fragments here described, the mode of division of the frond and the satisfactory generic reference of the species are not at present determinable. The very oblique position, the close spacing, and the rigidity of the narrow pinnae are shown in figure 16, plate 4, which includes portions of two ultimate pinnae, extremely oblique and parallel, attached to a penultimate axis. The lobes are apparently rapidly dissected in the course of their development into narrowly cuneate lineate divisions, in which the lateral borders converge very slowly in passing downward. Bidentate lobes, in which the division is incipient, are relatively rare in the specimens.

The fragment here described deserves comparison with the forms referred by authors to *Palmatopteris*, including *P. furcata*. It is also comparable to the plant from the Westphalian series in the Durham coal field of England described by Kidston<sup>44</sup> as *Rhodea eltringhami*. Similar erectness of the lobes of the skeletonized sphenopterid is found in the Mississippian as well as the Pennsylvanian both in the Old World and in America.

Among the lower Pennsylvanian species to which the plant in hand may be compared, mention should be made of *Sphenopteris ettingshausenii* Stur?, some of whose pinnules are small, fasciculate, and erect, though generally less compact and broader.<sup>45</sup>

In general form and mode of development of the very oblique ultimate pinnae and the pinnules, the species in hand agrees with the older Mississippian sphenopterids. It is particularly comparable to *Sphenopteris schimperiana* Goeppert as illustrated by Vaffier,<sup>46</sup> and it suggests comparison with some of the figures of forms from the upper Culm referred by Bureau<sup>47</sup> to *Diplotrema furcatum*.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Types: U. S. Nat. Mus. 39491.

***Sphenopteris (Calymmatotheca) mississippiensis* White, n. sp.**

Plate 4, figures 4, 5, 11, 13, 14, 15, 17, 18, 20, 21, 22, 23, 30, 36, 39

Mode of primary division unobserved; main axis rigid and having a width of 1 centimeter or more, with

<sup>44</sup> Kidston, Robert, Fossil plants of the Carboniferous rocks of Great Britain: Great Britain Geol. Survey Mem., Paleontology, vol. 2, pt. 3, p. 236, pl. 58, figs. 4, 4a, 4b, 1923.

<sup>45</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 29, pl. 7, fig. 1, 1875.

<sup>46</sup> Vaffier, A., Étude géologique et paléontologique du Carbonifère inférieur du Mâconnais: Univ. Lyon Annales, nouv. sér. 1, Sci. méd., fasc. 7, pl. 4, figs. 1, 1a, 1b, 1c; pl. 5, figs. 1, 1a, 1b, 1c, 1901.

<sup>47</sup> Bureau, Édouard, Bassin houiller de la basse Loire, fasc. 2, Description des flores fossiles, atlas, pl. 24 bis, figs. 1, 2, 3, 1913. (In the series "Études des gîtes minéraux de la France.")

rather thick carbonaceous residue, in which *Dictyoxylon* structure is apparent; petioles lineate, with rather thick carbonaceous residue, the surface of which is provided with rather distant fairly strong though moderately slender spines; ultimate pinnae small, mostly rather short, generally with rather broad rachis, which is ventrally shallowly and broadly sulcate and lineate, dorsally rounded, and slightly flexuose in the upper portions; pinnules small, ovate-deltoid to oval-ovate and oval-deltoid, very open, slightly pedicellate, generally close, alternate, nearly touching or slightly overlapping, shallowly cut in three to five or six divaricate lobes, which become broadly cuneate or slightly squarrose, truncated, or very shallowly sinused at the apices, some of which are creased or slightly reflexed, and slightly acute at the distal angle; lamina thick, faintly rugose, frequently depressed ventrally just within the border of the lobes, as if fertile, slightly inflated ventrad, very narrowly decurrent along the rachis in the ultimate divisions, and sparsely provided with short bristlelike spines situated on low round protuberances; nervation rather coarse and forking at a wide angle to provide a nervile for each lobe or tooth.

The thin deposits of shale interbedded with the Wedington sandstone contain rather numerous very small fragments of a *Sphenopteris* whose close relationship to the *Sphenopteris (Calymmatotheca) hoeninghausii* group is shown not only by the form and arrangement of the ultimate pinnae and the pinnules but by the associated impressions of *Dictyoxylon* stems and the carbonized remains or the impressions of fragments of petiole sparsely clothed with small slender thornlike spicules of the type found on *S. hoeninghausii*. All the frond fragments are very small, and none of them show the mode of primary division of the frond; but nevertheless their number and characters are such as to admit not only specific description but the confident consideration of the species as representing an early form of the *Lyginopteris* type of frond in this very late Mississippian deposit. The *Lyginopteris (Dictyoxylon)* type is found also in a species from the Carboniferous limestone (upper Mississippian) from Rothwaltersdorf, in Glatz, referred in 1873 to *Sphenopteris hoeninghausii* by Feistmantel.<sup>48</sup>

Fragments illustrating the ordinary size of the ultimate pinnae and the relations and lobation of the pinnules in the middle or lower portions of the frond are shown in figures 13 and 17, plate 4. The photographic enlargement of the former, figure 14, plate 4, shows both the pits left at the bases of the spicules on the ventral surface of the specimen, from which the epidermal residue has in part been scaled, and the depressions that have the appearance of sporangia, located immediately within the margin of the sharply depressed or creased ventral surface of the lamina. The

<sup>48</sup> Feistmantel, Ottokar, Das Kohlenkalkvorkommen bei Rothwaltersdorf in der, Grafschaft Glatz und dessen organische Einschlüsse: Deutsche geol. Gesell. Zeitschr. Band 25, p. 504, pl. 14, figs. 7, 7a, 1873.

small fragment, figure 22, plate 4, which apparently was borne in the lower part of a pinna, probably in the middle or basal portion of the frond, exhibits the largest pinnules observed in the collection. In this as in other specimens the locations of the bases of the short spines that occur also on the midrib and on the rachis, as well as the decurrent lamina, are visible.

The fragment seen in figure 30, plate 4, in which the pinnules are more elongated, is probably derived from the upper part of the frond. On account of the less truncate lobation, which is not so distinctly divaricate and distant in this specimen, there is some room for question as to its specific identity with the others figured. The rachis is, however, distinctly spinose. The lamina is marked by the bases of the minute spicules or spines, and indications of developing squarrose lobation may be seen. The fragment shown in figure 20, plate 4, representing a small apical portion of an ultimate pinna from the lower part of the frond, in dorsal view, illustrates the relatively minute size of the pinnules and their lobation, which will at once be recognized as characteristic of the early *Sphenopteris hoeninghausii* group. The midrib, somewhat flexuose, is seen in dorsal relief.

A rather elongated form of pinnule, agreeing with that in figure 30, plate 4, though very much smaller, is shown in figure 17, plate 4. These figures indicate the generally relatively small form and the comparatively delicate detail of lobation in this Mississippian form. The spicular bases and the impressions of several of the flattened spicules, which in comparison with the very small pinnule are relatively large, may be observed in the photographic enlargement, four times natural size, figure 21, plate 4.

A rather indistinct cluster of what appear to be sporangia, apparently of the *Calymmatotheca* type, is shown magnified four times in figure 15, plate 4. It has the aspect of rather compactly though irregularly arranged sporangia grouped in a roundish glomerule that may be pedicellate. The reference of this specimen as possibly representing the polleniferous capsules of the species is tentative. Yet the frond described is unquestionably referable to *Calymmatotheca*.

Figure 4, plate 4, shows a part of an axis in which the dictyoxylon cortex is seen both in the impression and in the carbonized residue. The anastomosing strands shown in the enlargement, figure 5, plate 4, are strong, and the areas enclosed by the mesh vary in size, some of them being relatively large. Traces of the probably glandular and spicule-bearing protuberances are plainly visible near the centers of some of these areas.

In form and general aspect the fragments in hand carrying the small pinnules are similar to some of the ultimate pinnae described by Gothan<sup>49</sup> as *Lyginopteris*

<sup>49</sup> Gothan, Walther, Die Steinkohlenflora der westlichen paralischen Carboniere Deutschlands: Inst. Paläobotanik u. Petrographie der Brennsteine Arbeiten, Band 1, Heft 2, p. 72, pl. 21, fig. 1, Preuss. geol. Landesanstalt, 1931; Die oberschlesische Steinkohlenflora, Teil 1, Farne und farnähnliche Gewächse: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, pl. 13, fig. 1, 1913.

*hoeninghausii*, but the pinnae in the Wedington form are more compactly placed and more fully lobate, notwithstanding their small size.

The average pinna of this species somewhat resembles in size and even in shape one of the fragments from the Waldenburg beds originally figured by Stur as *Calymmatotheca stangeri* Stur.<sup>50</sup>

Localities: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264). About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Types: U. S. Nat. Mus. 39492-39500.

***Sphenopteris cf. S. obtusiloba* Brongniart, 1829<sup>51</sup>**

Plate 4, figure 12

Among the forms of *Sphenopteris* represented by small fragments, too incomplete for identification and description, are two small sections of ultimate pinnae, one of which is illustrated in figure 12, plate 4.

The nervation of the pinnules is mainly derived from a primary nerve that is relatively strong, especially toward the base of the pinnule. The nervilles fork two or three times, while arching more or less, in passing from the midrib or the base of the pinnule to the border.

As to the inclusion of this form in the group represented by *Sphenopteris obtusiloba* or *Sphenopteris trifoliata*, there is little room for doubt. The largest pinnule is rather distinctly subtrilobate. The fragment shown in figure 12, plate 4, accords with the more distal pinnules or those in the upper part of the ultimate pinnae of the above-mentioned group. Obviously, however, the fragments are not definitely referable to either of the above-named species.

In some respects the figured specimens are somewhat comparable with the specimens from the Moravian-Silesian slates described by Stur<sup>52</sup> as *Sphenopteris foliolata*, which is, however, rather more like an extremely lax phase of *Sphenopteris obtusiloba*, though it clearly is not referable to that species. In the Silesian material the pinnules are more nearly reniform and are more crowded and less decurrent.

The fragment illustrated is superficially comparable also to that figured by Bureau from the upper Culm of the basin of the lower Loire<sup>53</sup> as *Sphenopteridium dissectum* Schimper.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075).

Type: Figured specimen, U. S. Nat. Mus. 39501.

<sup>50</sup> Stur, Dionysius, op. cit., Heft 2, p. 155, pl. 9, fig. 4, 1877.

<sup>51</sup> Brongniart, Adolphe, Histoire des végétaux fossiles, tome 1, p. 204, 1829.

<sup>52</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 22, pl. 5, figs. 3-5, 1875.

<sup>53</sup> Bureau, Édouard, Bassin houiller de la basse Loire, fasc. 2, atlas, pl. 7, fig. 3, 1913.

**Sphenopteris cf. S. schimperiana Goeppert<sup>54</sup>**

Plate 4, figures 7, 8

A few small fragments, one of which is illustrated in figures 7 and 8, plate 4, though insufficient for reliable determination, offer such distinctive characters as to deserve illustration, in the hope that publication may lead to the discovery of more complete specimens. As shown in figure 7, one fragment shows a detached pinnae or possibly merely a lobe of a pinnae, fasciculate in type, in which the lobes, whose collective profile is rounded, are rather deeply cut, closely placed, cuneate in position, relatively rounded at the apex, and almost equally wide in all parts. The carbonaceous residue, a portion of which remains, is thick and slightly rugose, and the nerves fork at a rather narrow angle.

On account of the very close resemblance of the fragments described above to the details of the plant figured by Feistmantel<sup>55</sup> as *Hymenophyllites schimperianus* from the Carboniferous limestone at Rothwaltersdorf, in Silesia, I tentatively place them under that specific name, though the agreement with the descriptions and figures published by Goeppert<sup>54</sup> and Schimper<sup>56</sup> is more remote.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Type: Figured specimen, U. S. Nat. Mus. 39502.

**Genus TELANGIUM Benson, 1904<sup>57</sup>****Telangium? sp.**

Plate 5, figure 2

Under the reference cited above is photographically illustrated what appears to have been a loose glomerule of fusiform, acutely tapering sacs. The single specimen in hand was evidently macerated, and the resulting hollows in the sand are filled with sand grains and loose limonitic powder. At the bottom and toward the upper border of the mold are seen the impressions of portions of clawlike appendages, which I interpret as probably sporangial. The inner surfaces of these sporangia (?) are relatively smooth. There is no trace of a median nerve or other vascular tissue in the sporangial impressions.

The small fragment in hand is probably referable to the genus *Telangium*, though it is rather closely comparable to some of the specimens described as *Calymmatotheca*. The example illustrated deserves comparison especially with *Telangium affine* (Lindley

<sup>54</sup> Goeppert, H. R., Ueber die fossile Flora der Silurischen, der Devonischen und unteren Kohlenformation oder des sogenannten Uebergangsgebirges: Acad. Caesarea Leopoldino-Carolina Nova Acta, vol. 27, p. 66, pl. 37, figs. 2a, 2b, 1859.

<sup>55</sup> Feistmantel, Ottokar, Das Kohlenkalkvorkommen bei Rothwaltersdorf in der Grafschaft Glatz und dessen organische Einschlüsse: Deutsche geol. Gesell. Zeitschr., Band 25, p. 513, pl. 15, figs. 13, 13a, 1873.

<sup>56</sup> Schimper, W. P., Les végétaux fossiles, in Koechlin-Schlumberger, J., and Schimper, W. P., Le terrain de transition des Vosges, p. 341, pl. 29, 1862.

<sup>57</sup> Benson, Margaret, *Telangium scotti*, a new species of *Telangium* (*Calymmatotheca*) showing structure: Annals of Botany, vol. 18, p. 162, 1904.

and Hutton) Benson as illustrated by Kidston<sup>58</sup> from the oil shale group of the Calciferous Sandstone series of Scotland.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White in 1930 (U. S. Geological Survey lot 8075).

Type: Figured specimen, U. S. Nat. Mus. 39503.

**Genus RHYNCHOGONIUM Heer, 1876<sup>59</sup>**

The seeds described below as *Rhynchogonium fayettevillense* are apparently indistinguishable generically both from those illustrated and described by Heer from the Mississippian of Spitsbergen as *Rhynchogonium* and specifically as *R. crassirostre* and *R. costatum*, on the one hand, and that described by Zalessky<sup>60</sup> from the Mississippian Msta stage of northern Russia under the name *Boroviczia*, on the other. Though admitting the very close similarity in characters and the obvious relationship of his genus to that much earlier described by Heer, Zalessky concluded, though not without doubt, that the Russian form was probably of true generic rank, by virtue of the apparently more elaborate integuments. Subsequently, however, Nathorst,<sup>61</sup> after reexamination and redescription of *Rhynchogonium* and close comparison of the Spitsbergen seed with *Boroviczia*, rejected the structural distinction and concluded that the genera were extremely closely related, but that they might, however, be usefully separated by reason of the prolonged beak, which is more sharply differentiated in *Rhynchogonium* than in *Boroviczia*. He also uses the name *Boroviczia* for two species of seeds from Spitsbergen.

As will be seen in the description of *Rhynchogonium fayettevillense*, its form, though comparable to that of *Rhynchogonium costatum* Heer, is intermediate between *R. costatum* and the ovate *Boroviczia karpinskii*. In the Wedington seed the lobes or segments marked by longitudinal costae prevailingly number 10 instead of 8, as in the Arctic seed. The free lobes forming what Zalessky described as the "calyx" appear to be an extension of the outer vascular integument, which below the point of union of the teeth or lobes may be coherent with the very thick inner testa.

*Boroviczia* is represented by a species found in the upper Pottsville at Campbells Ledge, near Pittston, Pa., and in my judgment it is also distinctly congeneric with the fruits described by Lindley and Hutton<sup>62</sup> as *Carpolithus sulcatus*, which was referred by Kidston to

<sup>58</sup> Kidston, Robert, Memoir on the fossil plants of the Carboniferous rocks: Great Britain Geol. Survey Mem., Paleontology, vol. 2, pt. 5, p. 446, pl. 101, figs. 1, 5, 1924.

<sup>59</sup> Heer, Oswald, Flora fossilis arctica, vol. 4, Abt. 1, p. 19, 1876.

<sup>60</sup> Zalessky, M. D., Über Früchte aus den Unterkarbon-Ablagerungen des Msta, Beckens in Nord-Russland: Acad. imp. sci. St.-Petersburg Bull., tome 22, no. 3-p. 115, 1905. (See *Boroviczia karpinskii*, p. 114, figs. 1-9.)

<sup>61</sup> Nathorst, A. G., Nachträge zur paläozoischen Flora Spitzbergens: Zur fossilen Flora der Polarländer, Teil 1, Lief 4, p. 22, 1914.

<sup>62</sup> Lindley, John, and Hutton, William, Fossil flora of Great Britain, vol. 3, pl. 220, 1837.

the genus *Rhynchogonium*.<sup>63</sup> To the same genus, further, is to be referred a specimen in the Lacoe collection, in the United States National Museum, representing *Trigonocarpum ellipticum* Goepert, from the Carboniferous limestone of Rothwaltersdorf, in Silesia.

From the examination of the specimens in hand, there appears to be no adequate basis for the generic distinction between *Boroviczia* and the earlier established genus *Rhynchogonium*, to which in the following pages I have given precedence.

**Rhynchogonium fayettevillense White, n. sp.**

Plate 8, figures 1-8, 12-14, 22

Seeds ovate-oval to ovate-triangular in longitudinal profile, 11 to 18 millimeters in length, 4 to 11 millimeters in width, round at the bottom, apiculate to tapering-acute at the top, with broad chalaza, above which originate 6 to 12 nearly equal ribs, which become sharper and crested or narrowly alate in passing upward, the intervening areas or segments being slightly concave, especially near the ribs, parted near the top in tapering narrow lobes, which may converge, though distinct, to a sharp point or which may be slightly reflexed or flared in a short funicular neck; outer surface rather finely and somewhat irregularly striate; inner surface of outer testa very finely striate with the rows of minute punctations, which are slightly elongated in the longitudinal direction.

The seeds here described occur in great numbers in portions of the plant-bearing Wedington sandstone, where they appear to have accumulated in pockets in the rapidly deposited sand. They differ greatly in size, as may be seen by a glance at the photographs, but in spite of these considerable differences I am disposed to regard most of them as belonging to a single species, in which many of the specimens are presumably very young. The small specimens seem to have been more easily compressed than the large ones, but I observe no specific character other than size in accordance with which they may be differentiated, and in the matter of size the gradational sequence appears to be complete.

Several seeds of average dimension are shown in a group in figure 2, plate 8. The larger specimens in this group are of the average dimension. Figure 7, plate 8, illustrates the comparatively large chalaza. Figure 3, plate 8, shows a large and apparently mature specimen in which the overlobes of the segments of the outer testa are converged to a point and prolonged with considerable delicacy. This specimen represents the extreme length of the tapering lobes. The free ends of the lobes of the outer integument, some of which appear short and blunt, as if shriveled or possibly

rolled backward somewhat, are seen in figures 1 and 13, plate 8.

In several of the specimens, especially those of smaller size, the fruit is rather indistinctly, or rarely distinctly, triangular. However, the dominance of three primary ribs is nearly always lost in passing upward, so that the angles, usually 7 to 10 in number, are nearly equal in prominence. The crest simulates a wing but thickens rapidly backward from the edge. None of the seeds are attached to any fragment of stem or rachis. The relations of the seed to any one of the pteridospermatic types present in the flora is a matter of speculation. All but a small number of the specimens are in sandstone, and of these none are flattened, though many of them are somewhat deformed under pressure. Evidence as to the internal structure is lacking. However, from the aspect of the free upper portions of the segments of the outer test, it appears rather probable that the pollenic chamber was large, that the micropylar neck was relatively soft and nonresistant, and that the apices of the lobes, which flare outward in most of the specimens, may have turned upward and inward, covering, if not closing, the micropylar canal in the mature specimens after fructification. In fact, I am slightly inclined to believe that the free upper portions of the outer envelope may have opened and flared distinctly outward only at maturity of the ovule.

The seeds, though representing the old form genus *Rhabdocarpos* Goepert and Berger, are possibly related to *Hexapterospermum* Brongniart or possibly even to *Lagenostoma* Williamson.

The seed from the Wedington is very closely related in its characters to that described by Goepert as *Trigonocarpum ellipticum*, especially as that species is exemplified in the Lacoe collection of the United States National Museum by a specimen (no. 26795) from Rothwaltersdorf, in Silesia. The European form is, however, almost exactly oval and is less distinctly ribbed.

Congeneric with the plant described above and rather closely related to it, though considerably larger, is the fruit from the upper Pottsville at Campbells Ledge, near Pittston, Pa., described by Lesquereux<sup>64</sup> as *Carpolithus cistula*. The Wedington form agrees in size as well as other characters rather more closely with specimens collected near Colinton, near Edinburgh, Scotland, and presumably from the Calciferous Sandstone series, identified by Kidston, who transmitted the specimens to the Lacoe collection, now in the United States National Museum (nos. 26465, 26466, 26467, and 26469) as *Carpolithus sulcatus* Lindley and Hutton. The Wedington seed should also be compared with that from the lower Carboniferous of Scot-

<sup>63</sup> Zalessky, M. D., op. cit., p. 120.  
<sup>64</sup> Lesquereux, Leo, Description of the coal flora of the Carboniferous formation in Pennsylvania and throughout the United States: Pennsylvania 2d Geol. Survey Rept. P., vol. 2, p. 595, 1880.

land described by John Walton as *Holcospermum ellipsoideum*, whose generic identity with *Rhynchogonium*, as suggested by Walton,<sup>65</sup> is hardly to be doubted. To the genus *Rhynchogonium* should also be referred the fruit described by Bureau<sup>66</sup> as a sporangium of *Lepidophloios laricinus* Sternberg. The cleft calyxlike beak of the plant from the upper Culm of the basin of the lower Loire is plainly shown in Bureau's figure, which in form resembles Zalessky's *Boroviczia*, though in size the fruit closely resembles *Rhynchogonium cistula* (Lesquereux).

Localities: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lots 8075, 8140), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264). About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Types: U. S. Nat. Mus. 39504-39513.

#### Genus CARPOLITHUS Linnaeus, 1768

##### *Carpolithus inquirenda* White, n. sp.

Plate 8, figures 9, 10, 15

Seeds very small, ovate-round, 3 to 3.5 millimeters long and 2.5 to 3 millimeters wide, rounded at the base, slightly apiculate with rather thick envelope, which is sclerotic with radiating nerves at the base.

The fruit illustrated in figures 9, 10, and 15, plate 8, is represented by only two specimens in the collection. It might readily be mistaken for a small sporangium except for the fact that, as indicated in the photograph, plate 8, figure 9, the integumental residue is relatively thick and apparently thickest at the base, which is marked by rather strong, though not very distinct, longitudinal radial nervation. Further, the apex of the fruit is slightly apiculate. The specimen shown in figure 9, plate 8, is partly split longitudinally at the apex. That seen in figure 15, plate 8, is similarly beaked at the top and flattened at the base. There is, therefore, little room for doubt that the fruit is a seed.

The fruit here described is extremely close to those described by Lesquereux under the name *Carpolithes perpusillus*, from Campbells Ledge, Pa., and by Lindley and Hutton as *Carpolithes ovoideus* as identified by Lesquereux in English material. The specimens from Pennsylvania are generally somewhat smaller than the Wedington form, but the British specimens are distinctly larger, though strikingly similar.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Types: U. S. Nat. Mus. 39515, 39516.

<sup>65</sup> Walton, John, Contributions to the knowledge of lower Carboniferous plants, pt. 3: Royal Soc. London Philos. Trans., ser. B, vol. 219, p. 368, pl. 26, figs. 40, 40a, Sept. 9, 1931.

<sup>66</sup> Bureau, Édouard, Bassin houiller de la basse Loire, fasc. 2, Description des flores fossiles, atlas, pl. 74, fig. 6, 1913. (In the series "Études des gîtes minéraux de la France.")

#### Genus LEPIDODENDRON Sternberg, 1820<sup>67</sup>

##### *Lepidodendron henbesti* White, n. sp.

Plate 6, figures 1, 4-9

Stems and branches of rather small size, very rameose, branches irregular, often unequal, at angles of about 60°, the branchlets sometimes but 2.5 or 3 centimeters apart in the small twigs and not in the same plane; leaf cushions broadly diamond-shaped, rhombic in the small twigs, with rather strongly protruding leaf scar, which is situated considerably below the transverse axis of the bolster and which is very narrowly separated from those on either side; leaf scar relatively high on leaf cushion, generally facing slightly distad in the smaller branches and usually appearing at the extreme upper apex in the flattened specimens, very broad, the lower border nearly straight or slightly round dentate at the medial line; lateral angles acute and but faintly decurrent, the lateral borders convex above the lateral angles and passing nearly straight, with very slight inward curvature, to the slight obtuse upper angle, which appears slightly notched around the ligular pit; nerve trace and lateral cicatricules small, close to the lower margin of the leaf scar, or placed one-third of the altitude of the leaf scar; leaf cushions broadly rounded below the leaf trace and generally rather faintly round carinate, the lateral fields being relatively flat or gently arched; lateral appendages generally rather faint, though sometimes well marked in the impressions, narrow, relatively long, and slightly convergent downward; ligular pit generally distinct and marked in the impressions by a protruding point inclined slightly downward close to the apex of the scar.

The general aspect of the bolsters and leaf scars of this species is shown in figure 5, plate 6, which represents the partial width of a branch that appears to be of moderate size. Not all of the fragment is shown in the photograph. As is shown in the change in the direction of the bolsters, this fragment is branching at the top. Another branch is indicated at the extreme left about 4 centimeters below the top, and the base of yet another branch appears on the opposite side nearly 10 centimeters above the top of the fragment shown in the photograph. The stem is slightly zigzag, to correspond to the ramification. The frequency of division of the small branches of the species is well illustrated in figure 6, plate 6, and the counterpart, figure 9 of the same plate, which exhibits certain features not shown in the other specimen. In one of the smaller branches seen in the collection, divisions appear to have been at intervals of 2 to 3 centimeters.

The leaf trace, usually partially concealed in the somewhat compressed bolsters, is shown in figures 4 and 5, plate 6. In portions of both these specimens the parichnoian appendages are indistinctly seen. In

<sup>67</sup> Sternberg, Kaspar, Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, Heft 1, p. 23, 1820.

some of the partly flattened bolsters the impressions of the appendages are not only made to overlap a little on the lower border of the leaf scar, but some of them are continuous with the internal mold of the lateral cicatricules.

As shown in figure 5, plate 6, the leaf cushion is ordinarily nearly flat or slightly convex, with a very poorly defined, slightly rounded keel, which, where more distinct, owes its prominence to the impression of the vascular sheath as much as to any actual keel on the outer surface of the bolster. In the specimen shown in figure 5 the lower border of the leaf scar is nearly horizontal or but slightly round-dentate on the medial line. The impression of the orifice of the ligular pit seen in many of the bolsters overlaps behind the tip of the leaf scar, so as to produce the effect of notching the leaf scar. It is probable, however, that the uncom-pressed leaf scar is but slightly round-notched at the apex.

The impressions of the cortical neural tracts dilate broadly downward, so that the leaf cushions appear to be divided into a downward-broadening median and two relatively short lateral fields, which adjoin the border of the leaf scars. This appearance is probably incidental to the condition of preservation and the collapse of the neural sheath. Some of the parichnoian appendages seem to coalesce with the border portions of the neural sheath.

The very broad or nearly square outline of the bolster impressions of the smaller branches is illustrated in figures 1, 6, 7, 8, and 9, plate 6. The aspect of the leaf scar and its relative proportions are shown in figure 1, which illustrates a small fragment of branch impression. This represents nearly the smallest of the branches of this species yet found in the collection.

The species described above is characterized by the rather distinctly diamond-shaped outline of the bolster, by the very broad deltoid leaf scars, the lower borders of which are nearly straight, by the relatively flat or but slightly round-carinate configuration of the area below the leaf scar, and by the rather elongated and faint appendages, which are not visible in all specimens. The irregular closely spaced branching, which lies in different planes, also appears characteristic.

At the type locality, about 2 miles southwest of Prairie Grove, only fragments of the impressions of stems or branches of relatively small diameter appear to represent this species. Pieces of several larger stems that might at first be referred to this form are on close inspection found to be faintly transversely corrugated across the broadly rounded lower portion of the bolster. I have therefore placed them with *Lepidodendron wedingtonense*, notwithstanding close similarities between the leaf scars, which in these forms are very strongly protuberant and suggest those of *Lepidodendron henbesti*. On the other hand, the typical *Lepido-*

*dendron wedingtonense* is very distinctly corrugated both above and below the leaf scar. The collection of additional material may point the way to a different taxonomic association of these fragments with much larger, more strongly protruding, and in some specimens faintly corrugated leaf cushions.

In its frequency of branching and the very broadly rhombic or nearly squarrose impressions of the bolsters, *Lepidodendron henbesti* is comparable superficially with some of the impressions of small branches from the Allegheny formation of the Pennsylvanian, referred by Lesquereux to *Lepidodendron dichotomum*. That species differs saliently, however, by its distinctly carinate bolsters and by the more rhomboidal form of leaf scar.

Localities: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140). About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Types: U. S. Nat. Mus. 39514, 39517-39522.

***Lepidodendron occidentale* White, n. sp.**

Plate 5, figures 5, 8

Bolsters in rows, alined nearly vertical and transverse; leaf cushions contiguous, broadly ovate, with rather clearly marked sinuate lateral boundary lines, distally, rather obliquely, and broadly round-truncate a very short distance above the leaf scar, nearly flat or in the lower part slightly higher along a rather broad medial zone, which is transversely corrugated but not carinate; leaf scar rather prominent, facing slightly upward with both distal and proximate borders arched, relatively straight on the sides and forming acute lateral angles, which bend slightly downward to define a roughly obovate area that includes the leaf scar and the lower fields; vertical diameter of leaf scar approximately two-thirds that of the transverse; medial scar large, a little above the middle of the leaf scar; lateral traces at the same level and a little distant; lateral appendages slightly elongated vertically and relatively broad; ligular pit large, a little above the obscurely and shallowly sinused upper angle of the leaf scar.

Several fragments in the collection (lot 8145) from the locality about 2 miles southwest of Prairie Grove, two of which are illustrated in figures 5 and 8, plate 5, represent this form, which evidently falls within the somewhat comprehensive group generally identified as *Lepidodendron volkmannianum*. The larger fragment (fig. 5) is not sufficient to prove that the alinement of the bolsters is at once vertical and transverse, though assuredly it approaches close to those directions. The traces in the leaf scar are nearly midway of its height and are alined slightly above the lateral angles. In other words, the upper and lower halves of the leaf scar are hardly symmetrical, though they at first suggest

symmetry. The generally round, sometimes even slightly indented upper border that appears to be characteristic of *Lepidodendron volkmannianum* Sternberg is not seen in the two specimens in this collection. On the impressions of several of the bolsters slightly elongated shallow depressions extending downward short distances from the upper borders of the field offset the lateral cicatricules and offer slightly questionable evidence of the presence of the lateral parichnoian appendages. On all the fragments in hand the transverse corrugation is mainly confined to the broad medial zone of the leaf cushion.

On account of the obviously close relationship of the Wedington tree to the Old World type of *Lepidodendron volkmannianum* Sternberg, I was at first disposed to refer it tentatively to that species. However, inspection of the original figure given by Volkmann,<sup>68</sup> together with the descriptions and illustrations of the European type as given by Sternberg,<sup>69</sup> the founder of the species, Presl,<sup>70</sup> Stur,<sup>71</sup> and others, shows that the tree from the Wedington sandstone differs from the European type in such significant respects as to prohibit its inclusion under the same name. As figured both by Volkmann and by Sternberg, the European plant is much shorter in the vertical diameter of its leaf scar, and the upper angle of the leaf scar is very much more rounded, so as to produce a curved profile, in alinement with which the lateral angles are somewhat extended. In the Wedington trunk, on the contrary, the distal angle is well developed, the vertical diameter is much longer in proportion, and the lateral angles not so prolonged. However, the European type as shown by Volkmann and Sternberg is transversely corrugated along a relatively narrow median zone, almost exactly as in the specimens here described.

The Old World species as generally described and figured appears to be present in the Chester group of the Eastern Interior basin and in the beds of Chester age in the Appalachian trough. Specimens with vertically short leaf scars apparently conforming to the European type are figured by Noé<sup>72</sup> from the Chester group near Princeton, in western Kentucky.

The material from Kentucky deserves comparison with the fragments figured by Stur<sup>73</sup> as *Lepidodendron volkmannianum* from the Waldenburg series. The lateral appendages seem to be lacking in the European material representing the *L. volkmannianum* as generally illustrated, but points which are possibly construable as lateral appendages may be observed in Stur's plate 40, figure 2.

<sup>68</sup> Volkmann, G. A., *Silesia subterranea*, pl. 15, fig. 4, Leipzig, 1720.

<sup>69</sup> Sternberg, Kaspar, *Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt*, Tentamen, p. x, pl. 53, figs. 3a, 3d, 1825.

<sup>70</sup> Presl, Karl, in Sternberg, Kaspar, op. cit., Hefte 7, 8, p. 179, pl. 68, fig. 8, 1838.

<sup>71</sup> Stur, Dionysius, *Die Culm-Flora*: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, p. 286, pl. 18, fig. 4; pl. 23, figs. 2-5, 1877.

<sup>72</sup> Noé, Adolf, *The flora of the western Kentucky coal field*, in Weller, Stuart, *Geology of the Princeton quadrangle: Kentucky Geol. Survey*, ser. 6, vol. 10, p. 129, fig. 2, p. 130, fig. 4, Frankfort, 1923.

<sup>73</sup> Stur, Dionysius, op. cit. (*Die Culm-Flora*), Heft 2, p. 288, pl. 18. (See fig. 4.)

The species from Arkansas differs but little from that figured by Bureau<sup>74</sup> as *Lepidodendron volkmannianum* from the basin of the lower Loire, except that the latter has rather wider bolsters as well as somewhat shorter leaf scars.

A closely related species is that figured under the name *Lepidodendron turbinatum* Lesquereux.<sup>75</sup>

On account of the relatively large size of the leaf scar, the generally obovate configuration of the truncated bolster, and the relief of the leaf scar, the form in hand presents some superficial resemblance to the foreshortened bolsters of *Lepidodendron clypeatum*. That species differs, however, by the distinct keel, which is transversely notched, by the phyllotaxy, and by other features that are equally distinct though less conspicuous.

Locality: About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8266).

Types: U. S. Nat. Mus. 39523, 39524.

#### *Lepidodendron purduei* White, n. sp.

##### Plate 5, figure 9

Bolsters foliaceous, fusiform or narrowly acute, contiguous, very obliquely protruding, slightly overlapping, noncarinate, dorsally strongly and evenly rounded, slightly beaked at the summit at the point of emission of the nerve; leaves attached at the lateral margins around the upper third of the protruding cushion, slightly wider at the base than the bolster at the widest part, very oblique or nearly erect, about 5 millimeters wide and 2.5 centimeters long, tapering gently from a point abreast of the apex of the bolster to the acute tip, with wide medial nerve and apparently broadly and roundly sulcate ventrally toward the base; ligular pit distinct; appendages not observed.

A single fragment, shown in figure 9, plate 5, is the sole representative of what is apparently a very interesting species. The erosion of the specimen permits the observation of the impressions of the appressed and nearly erect leaves, both along the upper border of the fragment and near its base. The cortices of the cushions are apparently hard and rounded, except near the apex, which is slightly carinate; leaf scars are not clearly indicated, for the reason that the leaves are still attached to the extremely obliquely directed overlapping apical portions of the bolsters.

As shown in the figure, the leaves are attached along the upper third or more of the length of the bolster. Where the underlying bolsters are broken away, the leaves are seen to continue from the upper borders of the bolster with a slight dilation in width near the

<sup>74</sup> Bureau, Édouard, op. cit. (*Bassin houiller de la basse Loire*), pl. 77, figs. 1-3, 1913.

<sup>75</sup> Lesquereux, Leo, *Report on the fossil plants of Illinois: Illinois Geol. Survey, Paleontology*, vol. 2, p. 453, pl. 44, fig. 6, 1866; *Description of the coal flora of the Carboniferous formation in Pennsylvania and throughout the United States: Pennsylvania 2d Geol. Survey Rept. P.*, vol. 2, p. 382, pl. 64, fig. 5, 1880.

base, after which they taper gradually and evenly to the rather slender, acute apices. The leaf is ventrally round-sulcate over the midrib in the lower portion, and the lateral grooves, presumably holding the stomata and connecting with parichnoian developments, are rather narrow and faintly defined. The ligular pit is represented by a short needlelike protruding east, seen on one or two of the bolster impressions. In a few places vague oval or rounded patterns, suggestive of the illustrations of leaf scars published in some of the earlier literature, are faintly indicated, but nothing which I can regard with confidence as outlining the vertical width of the foliar attachment or the parichnoian features is present.

Among other American species of *Lepidodendron*, this fragment appears to represent a form more closely related to *Lepidodendron lanceolatum* Lesquereux than to any other representative of the genus. Among the Old World types it is strikingly comparable to that described by Ettingshausen<sup>76</sup> as *Lepidodendron haidingeri*.

The fragment from the Wedington sandstone is very similar both in the form of its bolsters and in the persistent broad, sharp-tapering upward-growing leaves to the specimen from the upper Culm figured by Bureau<sup>77</sup> as *Lepidodendron lycopodioides* from the lower Loire. It deserves comparison also with the leafy branches figured by the same author as *Lepidodendron veltheimianum*.<sup>78</sup>

Though represented by but a single fragment, the characters exhibited in the bolster and leaf of this stem appear to define a species hitherto undescribed. It is named in honor of the late Prof. A. H. Purdue, who for many years was engaged in the study of the geology of the region embracing the Wedington sandstone in northwestern Arkansas and who was author of the Winslow folio.

*Locality:* About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8266).

Type: U. S. Nat. Mus. 39525.

*Lepidodendron cf. L. veltheimianum* Sternberg<sup>79</sup>

Plate 5, figure 4

A slightly oval discoid impression of the attachment scar and border zone marking the position of a sessile lepidophytic cone is shown in figure 4, plate 5. The details of the scar are not well revealed by the sandy matrix.

The fragment is closely comparable to some of the cone scars left on the trunks of *Lepidodendron* of types referred by various authors to *Lepidodendron veltheimianum*, and in default of information showing to which

if any of the forms from the Wedington sandstone this is specifically referable, I tentatively list it under the collective name. Comparisons may be made with the strobiliferous stems from the Waldenburg beds illustrated under *L. veltheimianum* by Stur.<sup>80</sup> Similar cone scars have been described under *Bothrodendron* and *Sigillaria*, but without portions of the surrounding cortex bearing leaf scars characteristic of their respective genera the generic as well as the specific reference is questionable. Superficially the impression in hand is suggestive of the cone scars occurring on the rather large trunks described by Lesquereux from the Carbondale formation of Illinois under the name *Ulodendron*.

*Locality:* Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140).

Types: Figured specimen, U. S. Nat. Mus. 39526.

*Lepidodendron wedingtonense* White, n. sp.

Plate 7, figures 1-4, 6, 7, 9, 10; plate 9, figure 6

Trunks attaining moderately large size, branching rather frequently, often unequally, at a moderately wide angle; leaf cushions so arranged that those in the alternate rows are aligned nearly transversely to the axis, fusiform in plan, slightly wider above the middle, very strongly and very obliquely protuberant, generally low-rounded dorsally, rarely slightly round-carinate along the medial line, irregularly and rather closely corrugated transversely both in the lower fields and above the leaf scar, and becoming separated at an early age by narrow marginal zones or borders which in the older parts of the trunk are clearly twisted at a low angle, each cushion being bounded by a separate strand; cushions appearing narrowly ovate with generally complete concealment of the leaf scar in the compressed specimen, by reason of the foreshortening of the upper part of the bolster; leaf scar borne at the summit of the protruding cushion and usually facing slightly upward, though sometimes inclined downward at a low angle, relatively broad, nearly straight across the base, laterally acute, and passing with very slight outward curvature of the margin to the high upper angle, which is rather narrowly rounded; vertical axis about two-thirds the transverse; nerve and parichnoian traces distinct and generally placed considerably below the medial line of the leaf trace, the nerve trace generally larger and slightly higher than the parichnoian traces, the distance between which is generally less than one-third of the width of the leaf scar; nerve sheaths ascending very obliquely in the cushions, appressed and acute in the *Knoria* stage; parichnoian appendages hardly visible in the impressions, invariably faint, rather narrowly elongated and convergent downward.

<sup>76</sup> Ettingshausen, C. von, Die Steinkohlenflora von Radnitz in Böhmen: K.-k. geol. Reichsanstalt Abh., Band 2, Abt. 3, p. 55, pls. 22, 23, 1854.

<sup>77</sup> Bureau, Édouard, op. cit., pl. 31, fig. 1; pl. 32; pl. 34, fig. 1.

<sup>78</sup> Idem, pl. 30 bis, fig. 1b, 1913.

<sup>79</sup> Sternberg, Kaspar, op. cit. (*Flora der Vorwelt*), Tentamen, p. xii, pl. 52, fig. 3, 1825.

<sup>80</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, p. 278, pl. 22, figs. 1a, 1b, 2, 3a, 3b, 1877.

The aspect of the fragments of this species is shown in figure 6, plate 7, in which the bolsters are slightly larger than the average, and figure 1, plate 7, in which they are smaller. Figure 1 illustrates the marked protrusion of the cushions in an obliquely ascending direction. Both of the figured specimens, which are impressions made by the bolsters as buried in the sand, show the corrugation of the cushions and the readiness with which the leaf scars may be totally concealed in compressed specimens. Only where the mold is slightly broken away is any portion of the leaf scar itself visible. A branch much smaller than the main axis or lower branched division is seen to emerge in the example shown in figure 1. The presence of elongated leaf cushions in the lower portion of the branch that is visible indicates probably a twig rather than the attachment of a cone. Both specimens show the characteristic diminution of the transverse corrugation as the leaf scar is approached from below. In fact, the cushion is in some specimens so nearly smooth below the leaf scar that in fragments completely compressed the upper part of the field might erroneously be taken for a part of the leaf scar which, owing to the rounded upper outline of the impression, might present a rather close similarity to the scars of *Lepidodendron wortheni* Lesquereux or some of the phases referred to *Lepidodendron volkmannianum* Sternberg.

In figure 4, plate 7, is seen the sandstone cast of the inner cortex of the specimen illustrated in figure 1. This shows the *Knoria* aspect, in which the neural tracts with surrounding transpiration tissue are seen to ascend very obliquely through the mesocortex. The end view of this cast of the partly compressed stem indicates approximately the very small size of the woody cylinder of the stem.

Leaf cushions of relatively large size are shown in figure 9, plate 7, and illustrate the ropy marginal zones bordering the bolsters as they become slightly distant in the older portions of the trunk. These marginal bands anastomose, but the strands can generally be traced from cushion to cushion. Some of the bordered cushions of the old bark are somewhat elongated.

The form of leaf scar characteristic of *Lepidodendron wedingtonense* is shown uncovered in figure 9, plate 7. This specimen illustrates the relatively larger size of the nerve trace as compared with the lateral cicatrices. The traces appear to be relatively close to the lower border of the leaf scar on account of the slight deformation of the bolster under compression. The very broadly pyramidal profile of the upper border of the leaf scar as here shown is characteristic of the species.

The aspect of the smaller branches of the tree when they are partly compressed is illustrated in figures 2 and 7, plate 7. As shown in figure 7, the transverse corrugation of the bolsters is evident, even in the rela-

tively small branches. The phase in which the tissue underlying the outer cortex overlies the leaf scar and in *Bergeria* forms the outline of the leaf-cushion tract is illustrated by the specimen seen in figure 6, plate 9.

In the few specimens in which the cushions are but slightly compressed the leaf scars face nearly at right angles to the axis and protrude abruptly, some of them nearly 5 millimeters, from the general level of the leaf cushion. In fact, the protrusion of some of the leaf cushions is greater than their width.

Certain specimens have been observed which are interesting on account of the obscurity of the transverse corrugations in the lower portion of the cushions. The fields, which are but faintly carinate, appear to have been stretched slightly longitudinally.

This species, apparently the most common lepidophyte in the Wedington sandstone, is rather clearly a descendant of the *Lepidodendron volkmannianum* Sternberg stock, which is generally present in the upper and middle Chester wherever fossil plants have been found in beds of that age in the Midcontinent and Appalachian troughs. Many of the flattened impressions are strongly similar to the Old World species, though they are generally narrower, tapering more slenderly at the base. In the compressed stems the lower part of the bolster is rarely indented sufficiently to bring even a portion of the leaf scar into view. Besides the relative narrowness of the bolster and the much greater altitude and more pyramidal form of the leaf scar, the ropy marginal zones in the well-developed portions of the bark help readily to distinguish the species from *Lepidodendron volkmannianum* Sternberg. The faintly round-carinate form seen occasionally in the rounded leaf cushion also is distinctive.

On the other hand, though the angle of the leaf spiral is lower, it appears rather evident that the Wedington plant is closely related—perhaps lineally—to the Pennsylvanian species from the Midcontinent region described as *Lepidodendron wortheni* Lesquereux<sup>81</sup> and *Lepidodendron brittsii* Lesquereux.<sup>82</sup> Both these forms appear to have shorter leaf scars that are of lower altitude and more rounded. The ropy marginal borders seen even in relatively young branches have not, I believe, been observed in either of the two Pennsylvanian species just mentioned. It is probable that neither of these species has so strongly protruding leaf cushions as those of *Lepidodendron wedingtonense*.

Another form of *Lepidodendron* with transversely corrugated bolsters is that from Mâcon erroneously illustrated by Vaffier<sup>83</sup> under the name *L. acuminatum*.

<sup>81</sup> Lesquereux, Leo, Report on the fossil plants of Illinois: Illinois Geol. Survey, Paleontology, vol. 2, pl. 49, figs. 4, 5, 1866; Description of the coal flora of the Carboniferous formation in Pennsylvania and throughout the United States: Pennsylvania 2d Geol. Survey Rept. P., vol. 2, pl. 64, figs. 8, 9, 1880.

<sup>82</sup> Lesquereux, Leo, op. cit. (Coal flora), vol. 2, pl. 63, figs. 1, 2, 1880. White, David, Fossil flora of the Lower Coal Measures of Missouri: U. S. Geol. Survey Mon. 37, p. 188, pl. 52, figs. 1, 2; pl. 53, fig. 1; pl. 54, figs. 1, 2, 1899.

<sup>83</sup> Vaffier, A., Étude géologique et paléontologique du Carbonifère inférieur du Mâconnais: Lyon Univ. Annales, nouv. sér., 1, Sci. méd., fasc. 7, p. 133, pl. 9, 1901.

The characters of the leaf scars of Vaffier's specimens are not distinctly shown.

*Lepidodendron henbesti* is distinguished from *Lepidodendron wedingtonense* by its generally more distinctly diamond-shaped leaf cushions, by its closer crowding of the leaf cushions, apparently without intervening border zones even in the older stems, by the small traces placed very low in the leaf scar, by the more numerous though generally not well-developed keels on the relatively flat cushions, and by the very slightly and irregularly zigzag branches, which divide much more frequently, at generally wider angles. In *Lepidodendron henbesti* the branches become very slender, hardly more than 3 millimeters in diameter, and branches 5 millimeters in diameter may give off subdivisions not more than 2.5 centimeters distant from one another. In this species, too, the leaf scar is relatively large, and the very young cushions, which may be nearly rhombic, are not transversely corrugated.

Locality: About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Types: U. S. Nat. Mus. 39527-39535.

**Lepidodendron sp. 1**

Plate 8, figure 23

A single fragment in the collection offers characters such as apparently prohibit its reference to any of the forms described in the preceding pages. It is characterized by cushions that are not only slender but protrude so far and so obliquely as to give the fragment the aspect of a *Halonia*. The details are shown clearly in the squeeze of the sandstone impression or mold photographed in plate 8, figure 23. The details of the leaf scar are indistinct, the leaves being still attached to the bolsters. The leaves, as indicated by the impression, are oblique and stand at an angle of less than 45° to the axis; they are relatively narrow and probably 8 or 10 centimeters in length, tapering gradually from the base to the slightly obtuse point. It may be assumed that the scars left by the detached leaves on the older stems will be relatively narrow in proportion to their height.

The plant in hand is easily distinguished from *Lepidodendron purduei* by the rigid, linear, elongated leaves. Apparently the cushions are relatively much narrower than in that species.

Locality: Cane Hill, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8144).

Type: Figured specimen, U. S. Nat. Mus. 39536.

**Lepidodendron sp. 2**

Plate 7, figure 8

Represented only by the carbonized residue of a portion of a small branch; bolsters distant from one

another nearly one-third of their width, broadly diamond-shaped, acute at the base, slightly raised above the intervening cortex, with somewhat protruded leaf scar above the middle or, in the compressed and foreshortened cushions, near the upper end, in which case the leaf trace and lower fields form a broadly ovate pattern, angular or obliquely truncated at the base; bolsters narrowly carinate a short distance below the leaf scar but some of them flatly arched as they approach the proximal angle; leaf scar relatively small, roughly rhomboidal in outline, right-angled or slightly obtuse-angled at the base, acute laterally, with drooping lateral crests, the upper borders slightly arched to form a rounded upper angle, the vertical diameter being about half the lateral; nerve trace near the center of the scar, punctiform; lateral cicatricules punctiform, nearly on the level of the nerve trace and distant from one another nearly half the longer diameter of the scar; lateral appendages faintly developed; ligular pit small, close to the upper angle of the leaf scar.

The single fragment of a small stem in which the cortical residue is preserved, as shown in figure 8, plate 7, is remarkable for the notable distance between the bolsters in contrast to the size of the stem. It is interesting as illustrating within the limits of a small fragment the foreshortening of the bolsters in its lower portion, those higher on the axis being broadly diamond-shaped, with the exposure of the fields above the leaf scar. The form of the foreshortened bolsters, the relative size, and, to an extent, the shape of the leaf scar are comparable to those of the bolsters and leaf scars seen in some fragments referred by authors to *Lepidodendron volkmannianum*. There is, however, no trace of transverse corrugation in this specimen, even where the lower fields form a nearly flat area and the keels, some of which are seen below the leaf scars, are very nearly flat.

The small size and vertical shortness of the leaf scars preclude all reference of this fragment to *Lepidodendron henbesti*, and, on the other hand, there is no trace of the fusiform pattern or the transverse corrugation of *Lepidodendron wedingtonense*. Although no specimens showing the mature phases of the species represented by this fragment are at hand, and the fragment itself is none too well preserved, it is hoped that the illustration may aid in the recognition in some later collection of specimens that will more fully characterize the species and permit its satisfactory description or its identification with one already established.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140).

Type: Figured specimen, U. S. Nat. Mus. 39537.

Genus *STIGMARIA* Brongniart, 1822 <sup>84</sup>

Two species of *Stigmaria* have been found in the Wedington sandstone. In both, the root scars are relatively distant, though not so conspicuously remote as in the forms of *Stigmaria* in the lower zones of the Mississippian. In both the Wedington forms the umbilical scars are slightly smaller than in the typical Pennsylvanian species.

*Stigmaria wedingtonensis* is at once seen, by its coarse reticulation and the narrow zone of radiate areolation about the root scars, to be referable to the *stellata* group of *Stigmaria*, which is in general characteristic of the upper Mississippian. The other species, which for convenience is here called *S. arkansana*, is relatively smooth except where maceration and collapse have caused some irregular longitudinal wrinkling of the cuticle.

On the basis of the structure, which plainly was adapted to serve the purposes of transpiration as well as for maintaining the trunk in upright position, the application of the term "roots" to the upper subterranean divisions radiating from the base of the trunk, forking repeatedly and bearing the so-called "appendages" or true roots, has been questioned by some paleobotanists.

On account of its resemblance to the "roots" of *Lepidodendron volkmannianum*, which belong to the *stellata* group, and on account of the obviously close relation of *Lepidodendron occidentale* to *Lepidodendron volkmannianum*, it is believed that *Stigmaria wedingtonensis* is probably referable to *L. occidentale*, though it belonged possibly to *Lepidodendron wedingtonense*, with which also it is associated. On the other hand, *Stigmaria arkansana* was perhaps attached to the tree here described as *Lepidodendron henbesti*.

*Stigmaria arkansana* White, n. sp.

Plate 5, figure 6; plate 9, figure 8

Surface relatively smooth with little indentation of the rootlet scars; surface of the parent "root" slightly rugose; umbilical scars relatively small, rather distant, with very narrow border rings.

The outer impression of the root of the species is shown in the small fragment illustrated in plate 9, figure 8, and a larger fragment, representing the sub-epidermal cast and embracing in its area the counterpart of the original of plate 9, figure 8, is shown in plate 5, figure 6.

The umbilical scars are slightly smaller in proportion to the size of the divisions of the "root" than in most of the later forms characteristic of the Pennsylvanian. The species is possibly to be associated with *Lepidodendron henbesti*, which is present at the same locality.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D.

Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140).

Types: U. S. Nat. Mus. 39538, 39539.

*Stigmaria wedingtonensis* White, n. sp.

Plate 5, figure 7; plate 9, figure 3

Root surface very coarsely pustulate-shagreened in short, broad areas which are close, irregular in arrangement, though in places roughly alined, and which vary but little in diameter with reference to distance from the root scar. Root scars relatively small and distant from one another, the umbilical cicatrix bordered by a narrow, rather sharply defined zone of small, radially slightly elongated tubercles.

This form of *Stigmaria*, which clearly is of Mississippian lineage, being related to the *stellata* group, is represented by but few fragments in the collection. The rather coarse meshing is shown on the mold, figure 7, plate 5, more distinctly than on the impression illustrated in figure 3, plate 9. The root scars, as shown in figure 7, plate 5, are apparently nearly in the plane of the intervening surface. The zone of small, radially arranged and pustulate-appearing areas is narrower than in most species of the *stellata* group. A notable feature, shown in figure 7, plate 5, is the smaller size and closer spacing of the root traces toward what is apparently the lower end of the parent "root", which, it may be inferred, is tapering in the same direction.

This species, which is believed to have been attached to *Lepidodendron occidentale*, is distinguished from the Pennsylvanian species of *Stigmaria* and from the one here described as *Stigmaria arkansana* by the coarsely pustulate-areolate surface of the parent root and by the narrow rings of radiate tubercles about the umbilical cicatrices. The species differs also from Pennsylvanian forms of *Stigmaria* by the slightly smaller and more distant umbilical scars, though this characteristic is not so marked as in the stellate forms from the earlier stages of the Mississippian.

Locality: About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Types: U. S. Nat. Mus. 39540, 39541.

Genus *BOTHRODENDRON* Lindley and Hutton, 1933 <sup>85</sup>*Bothrodendron* sp.

Plate 7, figure 5

Leaf scars slightly raised on obliquely ascending, narrow, more or less faintly developed cushions, in relatively oblique alinement; leaf cushion oval, round at the base, deeply notched in V-shaped pattern at the top, apparently with distally radiating lines about the ligular pit; leaf scar situated in the upper part of the cushion, small; lateral cicatricules long, very

<sup>84</sup> Lindley, John, and Hutton, William, The fossil flora of Great Britain, vol. 2 pls. 80, 81 (description); pl. 117, p. 97, 1833.

<sup>85</sup> Brongniart, Adolphe, Mus. histoire nat. Paris Mém., tome 8, p. 228, 1822.

narrow, rather distant, arching slightly outward, converging slightly at the lower ends, which are not far above the base of the leaf scar; cuticle apparently rugose.

Two fragments in the collections are rather clearly referable to the genus *Bothrodendron*. A cortical mold (pl. 7, fig. 5) shows very obliquely ascending vascular tracts terminating in none too well defined leaf scars. Though the details of the scar are by no means so well preserved as is desirable, the lateral cicatricules are fairly distinct, and there appears to be no doubt as to the presence of a ligular pit in the deep, acutely V-shaped notch at the upper end.

Another fragment, representing only a part of the width of an old stem, in which the cuticle had become irregularly torn longitudinally, probably in the natural process of growth, represents a welted or irregularly seamed impression broadly encrusted with carbonaceous residue. This phase of stretched cortex is of the type sometimes referred by Lesquereux to the genus *Ulodendron*. Here and there a few faint traces of leaf scars agree with the cortical impression shown in figure 5, plate 7.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140).

Type: Figured specimen, U. S. Nat. Mus. 39542.

#### Genus LEPIDOPHYLLUM Brongniart, 1828<sup>66</sup>

##### *Lepidophyllum sagittatum* White, n. sp.

Plate 6, figure 3; plate 9, figure 2

Bract very narrowly triangular, acuminate, 4 millimeters wide at base, 3.5 centimeters long, tapering upward, with nearly straight or faintly concave margins, from the widest point, which is slightly above the base, and dorsally slightly round-convex, with distinct round midrib tapering upward and bordered by shallow and rather broad grooves; also marked dorsally by faint depressions slightly within the border; sporangiophore and sporangium uncorrelated.

The specimen illustrated in figure 3, plate 6, which is enlarged twice in order to show some detail, belongs to the Mississippian group of forms of *Lepidophyllum*, in which the bract, of moderate size, is narrowed more strongly and tapers gradually and more acutely than in the Pennsylvanian forms. In general size the bract in hand is comparable to the smaller representatives of the *Lepidophyllum lanceolatum* group of the Pennsylvanian. It is distinguished, however, by the narrowly triangular outline in which the margins pass nearly straight, with uniform convergence, from a point just above the base to the slender acute apex.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by

H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lots 8075 and 8140).

Types: U. S. Nat. Mus. 39543, 39544.

#### Genus LEPIDOSTROBUS Brongniart, 1828<sup>66</sup>

##### *Lepidostrobus occidentalis* White, n. sp.

Plate 5, figures 1, 3; plate 8, figure 20

Cones linear, narrow, dense, rigid, round at the apex; bracts very delicate, about 11 millimeters long, 1 millimeter wide, linear-lanceolate, narrowed toward a relatively elongated distally protruding base or heel; sporangiophores in oblique spirals, apparently nine, nearly at right angles to the slender axis, very narrow just above the point of attachment, broadening gently in very narrowly obtuse form, with relatively straight borders, to the base of the bract; sporangia narrow, elongated, slightly cordate at the distal end when compressed; spores not identified.

The species here described is represented by a few fragments only, which apparently fall within the comprehensive group generally rather loosely described under the term *Lepidostrobus variabilis* Lindley and Hutton.

The specimens have been badly water-worn, the bracts being nearly all abraded and generally even frayed. A fragment of stripped axis about 15 centimeters in length is incomplete. It indicates a linear, much elongated, rather rigid type of cone. As shown twice the natural size in figure 20, plate 8, which illustrates the detail of the impression of the axis, the ventral angle at the base of the sporangiophore is marked by a protruding narrow wedge or spine, which may be interpreted as ligular. The bases are relatively prominent. As seen in figure 3, plate 5, the sporangiophores stand nearly at right angles to the axis in all the fragments observed. Notwithstanding the advanced erosion, faint indications of the bracts, including the rather prolonged heels, are visible. At several points collapsed sporangial sacs appear to be present. These are narrow, smooth, and matte and, in the flattened state, have a rounded collar that does not appear to be closely adherent to the base of the sporangiophore. Unfortunately additional material illustrating the bracts, sporangia, and spores is lacking. The dark discoid object in the lower part of the cone seen in figure 3, plate 5, is a detached scar of *Stigmaria* lodged in the midst of the *Lepidostrobus*, as is shown also in the photograph of the counterpart, figure 1, plate 5.

Localities: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140). About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145). Six-tenths of a mile south of junction of State Highway 99 and United States Highway 62, 4 miles west of Lincoln, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8268).

Types: U. S. Nat. Mus. 39545-39547.

<sup>66</sup> Brongniart, Adolphe, *Prodrome d'une histoire des végétaux fossiles*, p. 87, 1828.

Genus LEPIDOCYSTIS Lesquereux, 1880<sup>87</sup>*Lepidocystis chesterensis* White, n. sp.

Plate 6, figure 2

Sporangia small, rather narrowly obovate triangular, about 4.5 millimeters long and 3 millimeters wide, slightly rigid, with thin wall faintly rounded along the dorsal axis, which is longitudinal, shallowly and narrowly sulcate up nearly to the distal end, which is marked by a transverse oval depression just within the margin.

The aspect of the interesting and widespread form of sporangium here described is suggestive of a detached bolster related to *Lepidodendron* or *Bothrodendron*. The carinate dorsal axis rises to its highest point just beneath the transverse oval depression. This feature is illustrated in the impression of the specimen in figure 2, plate 6. In spite of the fact that the sporangial impression appears to be thin, it is nevertheless relatively rigid. Only occasionally is this fossil, which is common in the upper Mississippian of the Appalachian trough, deformed or folded. It is invariably isolated. The dimplelike depression at the upper end of the narrow dorsal crease may represent the ligular pit. The crease itself probably corresponds to the axis of the sporangiophore, and the transverse depression, present in all specimens and invariably characteristic of the type, may conform to the head of the sporangiophore or the heel of the bract. I have, however, never found *Lepidocystis chesterensis* in contact with the axis or sporangiophore; yet there can be little doubt as to its function as a spore holder. No megaspores are, however, in contact with the specimens in hand.

The American species just described is obviously of the same nature as the fossil from the Carboniferous limestone of Rothwaltersdorf described by Feistmantel<sup>88</sup> as *Cardiocarpum rostratum*.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075).

Type: U. S. Nat. Mus. 39548.

Genus ARCHAEOCALAMITES Stur, 1875<sup>89</sup>

Calamarian remains, as might be expected from the arenaceous environment, are relatively common in the Wedington sandstone. Four types of stem fragments are found, all having rather clearly marked though not very thick woody zones, all essentially smooth or but faintly lineate or striate on the outer surface, and all marked by pith casts more or less

<sup>87</sup> Lesquereux, Leo, op. cit. (Coal flora), p. 54, 1880.

<sup>88</sup> Feistmantel, Ottokar, Das Kohlenkalkvorkommen bei Rothwaltersdorf in der Grafschaft Glatz und dessen organische Einschlüsse: Deutsche geol. Gesell. Zeitschr., Band 25, p. 540, pl. 17, fig. 38, 1873.

<sup>89</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 9, 1875.

distinctly of the *Bornia* type, in which the nodes are relatively indistinct and foreshortened in some specimens to a mere transverse crease, whereas most of the pith ribs when exposed are seen to be continuous from internode to internode except as, in the enlarging stem, costae corresponding to the introduction of new vascular wedges are introduced in the internodes of increasing diameter.

Costae are seldom even faintly distinguishable in the impression of the exterior of the stem.

The larger stems from the Wedington seem all to fall within the range of variations to be found in the illustrations given by different authors under the name *Bornia radiata* (Brongniart) Schimper or *Archaeocalamites scrobiculatus* (Schlotheim) Seward. None of them agree, however, with the original illustration of *Calamites scrobiculatus* published by Schlotheim.<sup>90</sup> In the Old World type the pith ribs are much fewer and flatter, and the nodes are scarcely creased transversely, the cicatricules being punctiform, longitudinally elongated, and situated between the ribs. Schlotheim's type represents an earlier form and correspondingly lower stage.

In the type illustration of *Bornia radiata*, as published by Brongniart<sup>91</sup> under the name *Calamites*, the pith cast is sharply and deeply constricted at the nodes, and though the ribs are numerous and similar in aspect to those of *Archaeocalamites wedingtonensis*, the admission of the Wedington species under the same name is prohibited by its lack of the widely flaring, stellate, leafy nodal sheath illustrated and described very distinctly by the French author. It may be added that Brongniart's plant cannot, without violence to modern refinement in classification, be included under the same specific name with Schlotheim's *Calamites scrobiculatus*, which is further illustrated by Zeiller<sup>92</sup> in typical material.

In his great work on the Culm flora Stur<sup>93</sup> has described and figured a somewhat comprehensive series of stems representing several species, as I view them, under the name *Archaeocalamites radiatus*, the generic name being established for the group. Also he figures a large number of leafy stems with elongated dichotomously dissected *Sphenophyllum*-like leaves, including those described by Ettingshausen<sup>94</sup> as *Schizaea transitionis*. None of the stems from the Wedington sandstone are very close to those figured by Stur, though a leaf, possibly related to one of the stems and here

<sup>90</sup> Schlotheim, E. F., Die Petrefactenkunde auf ihren jetzigen Standpunkt, p. 402, pl. 20, fig. 4, 1820.

<sup>91</sup> Brongniart, Adolphe, Histoire des végétaux fossiles, p. 122, pl. 26, fig. 4, Paris, 1828.

<sup>92</sup> Zeiller, René, Végétaux fossiles du terrain houiller: Explication Carte géol. France, tome 4, pt. 2, p. 17, 1879; atlas, pl. 159, fig. 2, 1878.

<sup>93</sup> Stur, Dionysius, op. cit., Heft 1, p. 2, pl. 1, figs. 3-8; pls. 2, 3, 4; pl. 5, figs. 1, 2, 1875; Heft 2, p. 74, pl. 2, figs. 1-6; pl. 3, figs. 1, 2; pl. 4, figs. 1, 1b; pl. 5, fig. 1, 1877.

<sup>94</sup> Ettingshausen, C. von, Die fossile Flora des mährisch-schlesischen Dachsteins: K. Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 25, pl. 17, fig. 5, 1865.

described as *Archaeocalamites?* sp., closely approaches Ettingshausen's *Schizaea*.

Associated with the *Archaeocalamites* stems are strobili bearing bifurcated sporangiferous bracts of sphenophylloid aspect, here described as a new genus, *Chlamidostachys*. They have much the general superficial aspect of those first described as *Pothocites* Pater-son and later assigned as fertile strobili to *Archaeocalamites* and are almost certainly related to them, notwithstanding some apparently important differences. The structure of these strobili is somewhat complicated, and on account of the partial maceration of the material and the gritty matrix, information as to the distal portions of bracts and the structure is still inadequate.

Though all the calamarian stems in the Wedington are referable to *Archaeocalamites*, the aspect of *Archaeocalamites wedingtonensis* and in particular of *Archaeocalamites umbralis* is suggestive of the developing typical calamitean stem, in which not only are the nodes distinct and the costae mainly alternate but the internodes are not so crowded one against the other and the interlacing of the lax vascular strands is usually easily observable. Evidence of leaf scars at the upper ends of the costae of the pith casts is distinctly observed only in *Archaeocalamites umbralis*. In *Archaeocalamites wedingtonensis* and *Archaeocalamites fayettevillensis* the presence of leaves is indicated only by neutral pits of pin-point size connecting with the trace of the vascular system between the costae. In the rather remarkable little stem described as *Archaeocalamites gracilis*, however, some, at least, of the nodes are distinguished externally by protrusions of the outer woody zone that have the aspect of rapidly tapering blunt spines. These protrusions, which may be merely the bases of abraded appendages, are borne, few in number, in verticils at the conspicuously dilated nodes. In view of the thick wood of the plant it is possible that these are the remains of branches provided with thick wood at their very bases.

One only of the stem fragments, tentatively referred to *Archaeocalamites wedingtonensis*, is provided with distinct verticils of small oval nodal scars. None of the calamarian stems of the Wedington exhibit so frequent alternation of costae at the node as is seen in *Calamites ramifer* Stur and other forms, including most of those referred to *Archaeocalamites* in the basal Pennsylvanian of the Appalachian trough.

#### *Archaeocalamites fayettevillensis* White, n. sp.

Plate 9, figure 10

Stems of rather small size, smooth or finely striate externally, with moderately distant internodes, which are faintly indicated externally and are marked with a very narrow, sharp, shallow depression in the pith cast, across which the very narrow, rather closely placed costae pass with relatively rare alternation.

This species, represented by but few specimens in the collection, one of which is shown in figure 10, plate 9, is rather easily differentiated from the associated forms by the narrow and slightly crowded ribs. As seen in the illustration, the external impression of the stem is nearly smooth, with extremely faint indication of costation and, as in associated species, with faint expression of articulation. Articulation is, however, plainly seen in the pith cast, which is slightly constricted at the immediate node, which is very narrow. The costae are nearly as narrow as those in the larger fragments of the very slender species described below under the name *A. gracilis*. No evidence of branching or appendages is seen. Details as to leaf scars and appendages await the discovery of additional material.

The specimen illustrated invites comparison with one of the fragments figured by Stur<sup>95</sup> as *Calamites ramifer*, though that specimen is much more finely costate than the other pith casts described under the same name, besides which the nodes in the Arkansas specimen are much less distinctly calamarian in aspect.

Localities: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075). About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Type: U. S. Nat. Mus. 39549.

#### *Archaeocalamites gracilis* White, n. sp.

Plate 9, figures 1, 5, 9

Stems very slender, tapering downward extremely gently to a slender pointed base; rather distantly articulate, finely lineate on the outer surface of a thin woody outer cylinder, and dilated rather abruptly at the nodes, some of which are marked by verticils of several small rounded tubercular protrusions corresponding to short, extremely open, rapidly tapering bases of appendages or branches; pith cast slightly constricted at the nodes, which become increasingly closer in the tapering base and distinctly costate, with very narrow, slender, straight, rather prominently rounded costae, some of which appear slightly crowded.

This very graceful and interesting species is rather rare at the localities at which collections of plants were made from the Wedington sandstone. It is, however, easily recognized by the very slender stems, the narrow costae of the pith cast, the closely and distinctly lineate impression of the outer cortex, and the dilation of the cortex at the nodes, many of which are marked, as shown in figures 1, 5, and 9, plate 9, by short, blunt, rapidly tapering processes that apparently represent the bases of appendages or bracts, and which are marked internally by small oval impressions suggesting tubercles in small numbers, forming verticils at some of the

<sup>95</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Heft 2, pl. 21, fig. 4, 1877.

nodes. Such verticils are imperfectly shown in the upper part of figure 9. In this fragment, which is one of the largest seen among the specimens of this species, the rather typical sharply indented archaeocalamitian node is seen in the lower part.

The fragment illustrated in figure 5, plate 9, is so smooth on the outer surface that it might readily be passed as the slender petiole of a fern or some other plant. Careful examination reveals indications of the pith costae. The dilated node near the upper end of the fragment, from which the pith cast has been removed, shows a semispinous appendage or appendicular base on each side and pits marking the neural tract of two others in the slightly compressed mold. In the specimen photographed in figure 1, plate 9, is seen the rounded edge of a slightly flattened stem. Here the thickness of the carbonized outer cylinder is shown and the dilation of the cylinder at the node in the upper part of the fragment. In this example, as in that shown in figure 9, plate 9, the pith cast itself is constricted at the node, but the costae are continuous, the stem being nearly uniform in size. From the uniformity in size of the stem and the apparent absence of introduced costae at the node, as well as from the fact that the woody residue is in this form developed as in others, it is concluded that the stem is mature and of full size. The costae of the pith cast are faintly seen to be very finely lineate.

One unfigured specimen is unusually interesting in that it shows the long, tapering, slender bases of several stems which converge and which possibly were attached at a single node of a rhizome or parent stem. As with other specimens, the impression of the stem, in which the cuticle was in contact with the matrix, reveals no trace of costae. However, both the costation and the constricted nodes of the pith are well shown at the left. It should be noted that this impression extends, with very slight diminution in the extreme lower portion, very nearly to the lower edge of the rock fragment, and the dilations at the nodes are apparent nearly as far as the cast can be traced in place, though they are not so prominent at the lower end of the mold.

*Archaeocalamites gracilentus* differs so markedly from all other calamarian material in the collection that its differentiation is exceedingly evident. No other species has such marked nodal dilation as this, and none bears spinelike processes arranged in verticils at the nodes.

The similarity between the stems here described as *Archaeocalamites gracilentus* and those from the Moravian-Silesian roof slates described by Ettingshausen<sup>96</sup> as *Calamites tenuissimus* Goeppert is remarkably close. Information is lacking, however, as to the pith casts of the plant from the roofing slates, but, on the other hand, no leaves such as those figured by Ettingshausen

are observable on the American material, which superficially resembles even more closely the stems described by Paterson<sup>97</sup> and Kidston<sup>98</sup> as belonging to *Pothocites grantonii*.

The slender stems here described invite comparison with the axes of the cones from the Wedington, to which the name *Chlamidostachys* is given, for both on account of the characters of those axes and the analogies between *Chlamidostachys* and *Pothocites*, which is borne by a stem very similar to *Archaeocalamites gracilentus*, it seems not improbable that *A. gracilentus* may have supported the strobili mentioned above. No trace of bifurcation, such as is reported in the stem of *Pothocites*, is observed in the Wedington specimens, but in both forms the stem is very slender, being comparable in size, with rather long internodes, which are striate externally, with costate piths, and which may be provided at the nodes with protuberant processes or short blunt spines, marking the origin of probable branches. Between the two types of cones also there are notable similarities, which are pointed out in the description of *Chlamidostachys* (p. 39). Therefore, the discovery of additional material may show union between *Archaeocalamites gracilentus* and *Chlamidostachys chesterianus*. *Pothocites* is regarded as the fruit of *Archaeocalamites scrobiculatus* (Schlotheim) Seward, its leaves being identified by Kidston with *Sphenophyllum tenerrimum* Ettingshausen. However, the variation in the types of fruit and in the leaves referred to *Archaeocalamites scrobiculatus* or its synonym *Bornia radiata* only emphasizes the view already stated that this name covers an aggregate of species that should be susceptible of differentiation.

Locality: About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145). Fragments apparently referable to the species are included also in U. S. Geological Survey lot 8075, collected at Bob Kidd Hollow, 3.2 miles southwest of Prairie Grove, Ark.

Types: U. S. Nat. Mus. 39550-39552.

#### *Archaeocalamites umbralis* White, n. sp.

Plate 9, figure 4

Stems comparatively small, slender, tapering rather gently downward in the lower part, with relatively short segments two to three times as long as thick, dilated slightly at the nodes, with distinct outer vascular zone of moderate thickness, and nearly smooth externally between the nodes; articulations distinct in the pith cast, marked with thickening and slight dilation of the vascular cylinder; internodal pith cast slightly enlarged just above and just below the articulation and marked by about 20 comparatively broad, prominently rounded ribs that are rather obtusely rounded distally, though

<sup>97</sup> Paterson, Robert, Description of *Pothocites grantonii*, a new fossil vegetable from the coal formation: Bot. Soc. Edinburgh Trans., vol. 1, p. 45, pl. 3, 1841.

<sup>98</sup> Kidston, Robert, On the affinities of the genus *Pothocites* Paterson, with the description of a specimen from Glencarholm, Eskdale: Annals and Mag. Nat. History, 5th ser., vol. 11, p. 304, 1883.

generally aligned across the node and marked a little below the node by rather large but generally faint leaf scars; intercostal or canicular furrows narrow and rather deep; surface of ribs of pith cast very finely and apparently irregularly striate; outer cortex very finely lineate.

The type of stem illustrated in figure 4, plate 9, appears to be not rare in the upper part of the Mississippian of eastern America, though in the collection from the Wedington sandstone it is represented by only a few fragments that are clearly referable to this species. The nodes are slightly dilated and marked by thickening of the vascular cylinder, in which the articulations are relatively distinct. The thickness of the outer cylinder is especially notable toward the base of this specimen.

The species is further characterized by the short nodes and the relatively broad costae of the pith cast, which are rather distinctly rounded at the upper ends. The ribs are dorsally high-rounded, with relatively narrow intervening sulci. The articulation in this stem is more clearly shown in the pith casts than in any of the other species from the Wedington sandstone, though the internodes of the pith are closely set and the ribs generally in continuous alinement. The aspect of the pith cast is more distinctly calamarian than that of the associated species, yet the node itself lacks the prevalent intertwining of the neural strands seen in the later types found in the Pennsylvanian. The compactness of the articulations and the general continuity of the costae of the pith, combined with the rather thick vascular cylinder, associate the plant with the later forms of *Archaeocalamites*. The impression of the outer cortex, a portion of which is shown in figure 4, plate 9, shows little trace of costation and but faint evidence of articulation.

*Archaeocalamites umbralis* resembles in general form and size the lower portion of a stem figured by Stur<sup>99</sup> as *Calamites haueri*. In Stur's species, however, from the Waldenburg series, the ribs are partly alternate, with distinct leaf traces and well-marked nodes of the calamarian type.

Localities: About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145). A portion of a pith cast nearly twice the size of that figured but presenting the same costal characters and tentatively referred to the species, although exhibiting undulation of the ribs, probably the result of mechanical deformation, is present in U. S. Geological Survey lot 8140 from Bob Kidd Hollow, 3.2 miles southwest of Prairie Grove, Ark.

Type: U. S. Nat. Mus. 29553.

***Archaeocalamites wedingtonensis* White, n. sp.**

Plate 9, figures 7, 12, 13

Stems of moderate size, tapering rather gently toward the base and divided into internodes varying

from three times to twice the diameter of the stem, the nodes being hardly visible in the external impression and marked by faint narrow transverse depressions on the pith cast; outer surface generally smooth, rather distinctly and distantly lineate, with minutely striate interspaces; pith cast distinctly costate where free from remains of external tissue, with straight and regular, generally low-rounded costae, dorsally rather distinctly lineate, nearly all in continuous alinement in the larger stems, and separated by rather broad sulci in which the casts of the canals are generally distinct and rather large; leaf scars apparently small and obscure.

This species is one of the commonest in the Wedington sandstone. The general aspect of the cast is shown in figure 12, plate 9. The distinctness of specific characters varies with the state of preservation and, in particular, according to the maceration of the outer cylinder with consequent masking of the characters. In some of the specimens, such as that shown in figure 7, plate 9, both costation and nodes are completely concealed beneath the residue of the outer tissue and cuticles. This feature is shown also in portions of the reverse of the specimen, seen in figure 12, plate 9, where the partly macerated woody cylinder shows little but the impression of the finely lineate cuticle, which is finely striate between the rather distinct lines. All expression of costation is lost, and the nodes are hardly discernible with certainty in the specimen shown in figure 13, plate 9, though some specimens clearly reveal the costation on a portion of the somewhat macerated pith. The external impressions of such examples may easily be mistaken for the impressions of petiolar fragments of ferns.

Evidence of the presence of leaves or branches is generally obscure. Minute pustular scars are visible at the upper ends of the ribs in some of the fragments, and small scars, hardly larger than pin points, mark corresponding connections with the pith cast. Several of the specimens show very faint and rather small depressions, apparently corresponding to branches or the attachment of fructifications at the joints. That illustrated in figure 7, plate 9, though somewhat macerated and deformed, shows the depressions more clearly than any other in the collection. In this example we see a row of very small, closely placed, slightly discoid impressions elongated somewhat in the longitudinal direction and marked by punctate neural scars somewhat above the middle. It is possible that the fertile strobili described on page 38 as *Chlamidostachys chesterianus* were borne by the type of stems here distinguished as *Archaeocalamites wedingtonensis*, though it is probable that they were connected with *Archaeocalamites gracilis*, for reasons stated under the heading of that species.

<sup>99</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abb., Band 8, Heft 2, p. 90, pl. 5, figs. 3a, 3b, 1877.

*Archaeocalamites wedingtonensis* is distinguished by the relatively large size of the stem as compared with the associated species; by the typical *Bornia* type of nodal demarcation, the node being, however, very slightly constricted; and by the low-rounded costae of the pith cast, which are distinctly lineate, whereas the intercostal sulci are moderately broad and the neural casts usually distinct and relatively large. Furthermore, the residues of the outer zone, including the woody cylinder and the external envelopes, usually completely mask the costation of the pith cast, frequently concealing also the presence of the nodes themselves. The stems are very much larger and the ribs narrower, less closely placed, and less distinctly marked at the nodes than in *Archaeocalamites umbralis*, in which the nodes are somewhat dilated. On the other hand, the costae of the pith cast are much broader and more distantly spaced than in *Archaeocalamites fayettevillensis*.

The ribs of the pith casts of the species from the Wedington are proportionately considerably narrower than in the Old World specimens figured as *Asterocalamites scrobiculatus* (Schlotheim) Seward or its supposed synonyms. An exceptionally near approach to the stem in hand is found in one of the specimens figured by Schimper<sup>1</sup> as *Calamites radiatus*.

Localities: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lots 8075 and 8140), and by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264). Cane Hill, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8144). About 2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8145).

Types: U. S. Nat. Mus. 39554-39556.

#### *Archaeocalamites?* sp.

Plate 9, figure 11

On account of its very close similarity to some of the foliage referred by various authors to *Archaeocalamites scrobiculatus*, the leaf fragment shown in figure 11, plate 9, is tentatively referred to the genus *Archaeocalamites*, with the recognition of the consequent implication that one species in the Wedington flora may be identical or very close to a European form gathered by authors into the group species *Archaeocalamites scrobiculatus* (Schlotheim) Seward. That not all the forms under this collective name are specifically identical is proved by the differences in their leaf characters and in their fruits. The figured specimen is the sole representative *Archaeocalamites* leaf in the collections from the Wedington. There is no stem of *Sphenophyllum* or fern similar in leaf. The bracts and the sporangia of the associated cones, *Chlamidostachys*, are distinctly sphenophyllloid.

<sup>1</sup> Schimper, W. P., Les végétaux fossiles, in Koechlin-Schlumberger, J., and Schimper, W. P., Le terrain de transition des Vosges, pl. 1 (see fig. a only), 1862.

Except that the Arkansas leaf is very much smaller, it agrees closely with the plant described by Ettingshausen<sup>2</sup> as *Schizaea transitionis*. It is three times dichotomously divided, but the greater part of the left lobe of the first subdivision is broken away. The divisions are relatively rigid, nearly equal in width, slightly flexuose, bifurcating at a narrow angle, and slightly divaricate. The terminal divisions taper and are acute, with slightly thickened margins. The lamina is not very thick and is nearly flat. The primary nerve bifurcates at a very narrow angle not far below the points of division of the leaf. The nerves passing into the tertiary divisions originate by bifurcation in the upper part of the secondary division and pass nearly parallel through the tertiary.

Both as to size and form the fragment illustrated may be compared especially with the illustrations given by Stur to show the foliate stems from the Moravian-Silesian roofing slates.<sup>3</sup>

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8075).

Type: Figured specimen, U. S. Nat. Mus. 39557.

#### Genus CHLAMIDOSTACHYS White, n. gen.

##### *Chlamidostachys chesterianus* White, n. sp.

Plate 8, figures 11, 17, 18, 19, 21

Strobili large, reaching a length of 10 centimeters or more and varying in width from 2.5 to 3 centimeters or more; hardly rigid, cylindrical, rounded at the apex, with fluted axis 2.5 to 3 millimeters wide, articulated transversely at distances of 2.5 to 2 millimeters, the costae being continuous in alinement on each side of the articulation; nodes provided with verticils of approximately nine sporangiophores; sporangiophores open nearly at right angles to the axis, some slightly reflexed, some inclined slightly distad, thick, narrowest very near the base, broadening upward, slightly concave ventrally, low round-arched dorsad, forking or giving off narrow linear lateral branches, those in the lower portion very oblique, those at a distance of about 7 millimeters from the axis very open and dividing in four or five subdivisions, apparently arranged in peltate form and splitting parallel to the main axis of the cone or at nearly a right angle to the basal portion of the sporangiophore; form of peltate subdivisions apparently variable, obtuse-ovate to round-ovate and ovate-elliptical, some of them 5 millimeters or more in length, and invariably appressed so as to define the outer surface of the strobilus; lower portions of the sporangiophore provided with a broad, thin wing, which curves upward and slightly inward to form a cylindrical or semicylindrical chamber in which oval

<sup>2</sup> Ettingshausen, C. von, Die fossile Flora des mährisch-schlesischen Dachschiefer: K. Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 25, p. 27, pl. 7, fig. 5, 1865.

<sup>3</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft. 2, pl. 3, p. 8, 1877.

or oblong-lanceolate sporangia, in groups of four or five, are borne in asteriform arrangement about short pedicels springing obliquely from point to point along the ventral side of the basal portion of the sporangiophore; sporangia, whose groups are sparsely scattered on the surface of the sporangiophore, dehiscent by a ventral slot or elongated opening, reaching from the base halfway or quite to the apex and varying in width, those on the upper divisions of the sporangiophore, including the lower portions of the broad peltate ultimate subdivisions, being generally smaller than those nearer the axis of the cone, though much elongated groups simulating sori appear to be borne on the ventral surface of some of the appressed outer lobes, so as to form low rounded prominences on the outer surface of the cone.

The fertile strobili here described present certain features strongly resembling the strobili of *Pothocites* as originally described by Paterson<sup>4</sup> and as later critically revised by Kidston.<sup>5</sup> In fact, noticing rounded protuberances and obscure resemblances to scattered "stellate bodies" on the surface of the strobilus, I was at first disposed to place the Arkansas specimens in the Scotch genus. Further examination, however, showed clearly that the American material belonged to a distinct undescribed genus. In both genera we have slender cylindrical cones with closely appressed bracts, arching in low rounded prominences, arranged in longitudinal series. As originally described some of these rounded protuberances, each corresponding to a bract, are capped by structures resembling quadripartite sporangia, in which the sporangia, lanceolate or linear-oblong in shape, are spread out flat about the central point of attachment and are open longitudinally for their entire length. Kidston, who reviewed the species, all from the Calciferous Sandstone series and mostly from Glencarholm, near Eskdale, near Edinburgh, described the sporangia as generally four in number, borne on the concave under surface of the quadrangularly peltate dilation of a sporangiophore that originates in the axis of the cone. The cone itself is borne by a slender rigid smooth stem, which is described as branching. *Pothocites grantonii* Paterson,<sup>4</sup> *Pothocites patersoni* Etheridge,<sup>6</sup> and *Pothocites calamitoides* Kidston,<sup>7</sup> together with an unnamed species of *Pothocites* described by Etheridge,<sup>6</sup> were finally referred by Kidston to the single species *Pothocites grantonii*, which he ascribed to the single species *Bornia radiata*, more generally known as *Asterocalamites scrobiculatus*.

<sup>4</sup> Paterson, Robert, Description of *Pothocites grantonii*, a new fossil vegetable from the coal formation: Bot. Soc. Edinburgh Trans., vol. 1, p. 45, pl. 3, 1841.

<sup>5</sup> Kidston, Robert, On the affinities of the genus *Pothocites* Paterson: Annals and Mag. Nat. History, 5th ser., vol. 10, pp. 404-405, 1882; On the affinities of the genus *Pothocites* Paterson, with the description of a specimen from Glencarholm, Eskdale: Idem, vol. 11, pp. 297-314, pls. 9-12, 1883; Bot. Soc. Edinburgh Trans. and Proc., vol. 16, pp. 28-38, pls. 1-4, 1885.

<sup>6</sup> Etheridge, Robert, Note on the further discovery of a species of *Pothocites* (Paterson) in the lower Carboniferous rocks near West Calder: Bot. Soc. Edinburgh Trans., vol. 12, p. 151, 1874.

<sup>7</sup> Kidston, Robert, On the affinities of the genus *Pothocites* Paterson: Annals and Mag. Nat. History, 5th ser., vol. 10, p. 404, 1882.

Much remains to be learned regarding the structure of the cone from the Wedington sandstone. The features exhibited, however, show that it differs generically from *Pothocites*, though it was, I suspect, similarly borne on a slender pipestemlike stalk, which in this paper is described as *Archaeocalamites gracilis*. In *Pothocites* the axis of the cone is described as cylindrical, the sporangiophores being in 10 (?) vertical rows. Further, the sporangiophores are interrupted at regular intervals of about 2 centimeters (?), where a verticil of normal sterile filiform dichotomous bracts marks the abrupt constriction of the cone, the axis of which may be exposed for a very short interval. However, the most important generic distinction lies in the broad, slightly fleshy, and thinly alate sporangiophore of *Chlamidostachys*, which widens cuneately upward with branching nervation in sphenophylloid fashion and which becomes lacinately cut in sphenophylloid loba-tion at the dilated and generally closely appressed upper portion. The sporangia, oval or round-oval, are borne in groups of four or five on short pedicels springing from the nerves on the ventral surface of the lower fertile portion of the bract. I have seen no evidence of any peltate enlargement at the top of the pedicel. In fact, in the flattened specimens the sporangia, which apparently open longitudinally, present an aspect suggestive of *Astrotheca*. In a few specimens the abruptly appressed upper portion of the bract presents a low-rounded surface comparable to the protuberances on *Pothocites*, and in a few specimens, owing possibly to the displacement of the tips of the lobes of the bract, the impression presents a roughly stellate configuration in which three or four lobes suggest the external patterns drawn by Paterson and Kidston from the Scotch specimens. It is not too much to say that these resemble canoe-shaped sporangia lying flat on the surface of the cone and opening longitudinally along their ventral axes, as in *Pothocites*. This aspect may be accidental and mechanical. The explanation awaits the collection and detailed examination of additional material. On the other hand, it does not appear to the writer that a satisfactory explanation has yet been given of the stellate structures on the outer surface of *Pothocites*, which are arranged in four or five vertical rows and also in distantly spaced verticils, while the groups of sporangia, several times as numerous, are crowded. Certainly they do not appear to accord with the quadrisporangiate group borne on short sporangiophores springing from the axis of the cone, as described by Kidston.

So far as the general structure of *Chlamidostachys* is revealed by the specimens in hand, it defines a type of fructification more nearly comparable to that of *Sphenophyllum* than to any of the equisetalean or calamarian genera. Certain features of the cone suggest *Bowmannites* or even *Cheirostrobos*. It will be noted that the axis of the cone of *Chlamidostachys* appears to be articulated, that the bracts springing

from the nodes are verticillate, and that the internodes are distinctly fluted, as in the calamarian cone. In view of the sphenophylloid type of leaf, such as that described as *Archaeocalamites* sp. (pl. 9, fig. 11), associated with the branches of *Asterocalamites*, and in view of the structure, so far as at present known, of *Chlamidostachys*, the question arises whether there are not now classed under the term *Bornia* or its synonymns *Archaeocalamites* and *Asterocalamites*, plants which cannot properly be included among the Equisetales or Calamariales and which are more nearly related, though perhaps intermediate, to the Sphenophyllales. On the assumption that *Chlamidostachys* is really associated with the archaeocalamitean type of forked leaf and that the Wedington cone is borne on an archaeocalamitean stem, consideration should, according to my view, be given to the revision of the classification of the sphenophylloid group of *Archaeocalamites* and its possible systematic differentiation.

*Asterophyllites spaniophyllus* Feistmantel,<sup>8</sup> from the Carboniferous limestone at Rothwaltersdorf, which was referred by Stur<sup>9</sup> as the fruit of *Archaeocalamites radiatus*, has a verticil of spiral leaves filling five verticils of fertile bracts but without constriction of the cone, as in the Scotch *Pothocites*.

Bureau argues that *Archaeocalamites scrobiculatus* is a comprehensive type which, like the genus *Cordaites*, produces a diversity of fruits representing species far more numerous than is indicated by the stems and foliage. To a fruit from the upper Culm of the basin of the lower Loire Bureau<sup>10</sup> gives the name *Bornia pachystachys* and regards it as associated with *Bornia transitionis*, under which he places *Archaeocalamites scrobiculatus*. However, in Bureau's *Bornia pachystachys*, as in *Bornia grand'euryi* Renault<sup>11</sup> and *Bornia esnostenensis* Renault,<sup>12</sup> the cones are without bracts, the

<sup>8</sup> Feistmantel, Ottokar, Das Kohlenkalkvorkommen bei Rothwaltersdorf in der Grafschaft Glatz und dessen organische Einschlüsse: Deutsche geol. Gesell. Zeitschr., Band 25, p. 498, pl. 14, fig. 5, 1873.

<sup>9</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, p. 74, 1877.

<sup>10</sup> Bureau, Édouard, Bassin houiller de la basse Loire, fasc. 2, Description des flores fossiles, p. 240; atlas, pl. 65, figs. 1, 2; pl. 66, figs. 1-5; pl. 67, figs. 1-5a, 1914. (In the series "Études des gîtes minéraux de la France.")

<sup>11</sup> Bureau, Édouard, Les fructifications du genre *Bornia*: Soc. sci. nat. ouest France Bull., 3<sup>e</sup> sér., tome 3, p. 122, pl. 5, fig. 6, 1913.

<sup>12</sup> Renault, B., Bassin houiller et permien d'Autun et d'Epinac, fasc. 4, pt. 2, Flore fossile, p. 82, 1896; atlas, pl. 43, figs. 1-10, 1893. (In the series "Études des gîtes minéraux de la France.")

sporangia being borne in groups of four to six on more or less distinctly peltate sporangiophores springing directly from the axis.

The diversity of fructification referred to the *Archaeocalamites* stock is further illustrated by Nathorst's *Pothocitopsis*, another type of cone, apparently without bracts, from the lower Carboniferous of Spitsbergen,<sup>13</sup> regarded by its author as closely related to *Pothocites*.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser, L. G. Henbest, and David White, 1930 (U. S. Geological Survey lot 8140).

Types: U. S. Nat. Mus. 39558-39562.

#### Genus SPHENOPHYLLUM Koenig, 1825<sup>14</sup>

##### *Sphenophyllum?* sp.

Plate 8, figure 16

A plant fragment photographically illustrated in figure 16, plate 5, though problematical and solitary, is of such unusual interest that attention should be drawn to it, if only for the purpose of encouraging the search for additional specimens. A single slender curved stalk or petiole broadens rapidly about 3 millimeters from the base into a lamina that is apparently cut nearly to the base in two lobes, one of which<sup>4</sup> is broken away but which were probably equal or nearly equal. The left lobe appears to present the characters of *Sphenophyllum*. It is cuneate, narrowing, with convex borders, rather rapidly at the base, the margins diverging but slightly in the upper part, and truncate and cut in four or five blunt sphenophylloid teeth at the apex. A single nerve forks at the base of the lobe and again at a very narrow angle somewhat higher, to furnish a nerve that passes upward into the marginal teeth. The lamina is thick and granular-rugose. It is of course possible that the fragment may belong to a dichotomous pinnule of a fern or pteridospermic leaf.

Locality: Bob Kidd Hollow, south of United States Highway 62, 3.2 miles southwest of Prairie Grove, Ark.; collected by H. D. Miser and C. B. Read, 1931 (U. S. Geological Survey lot 8264).

Type: Figured specimen, U. S. Nat. Mus. 39476.

<sup>13</sup> Nathorst, A. G., Nachträge zur paläozoischen Flora Spitzbergens: Zur fossilen Flora der Polarländer, Teil 1, Lief. 4, p. 78, pl. 3, figs. 5 and 6, 1914. (See *Pothocitopsis tertillii*.)

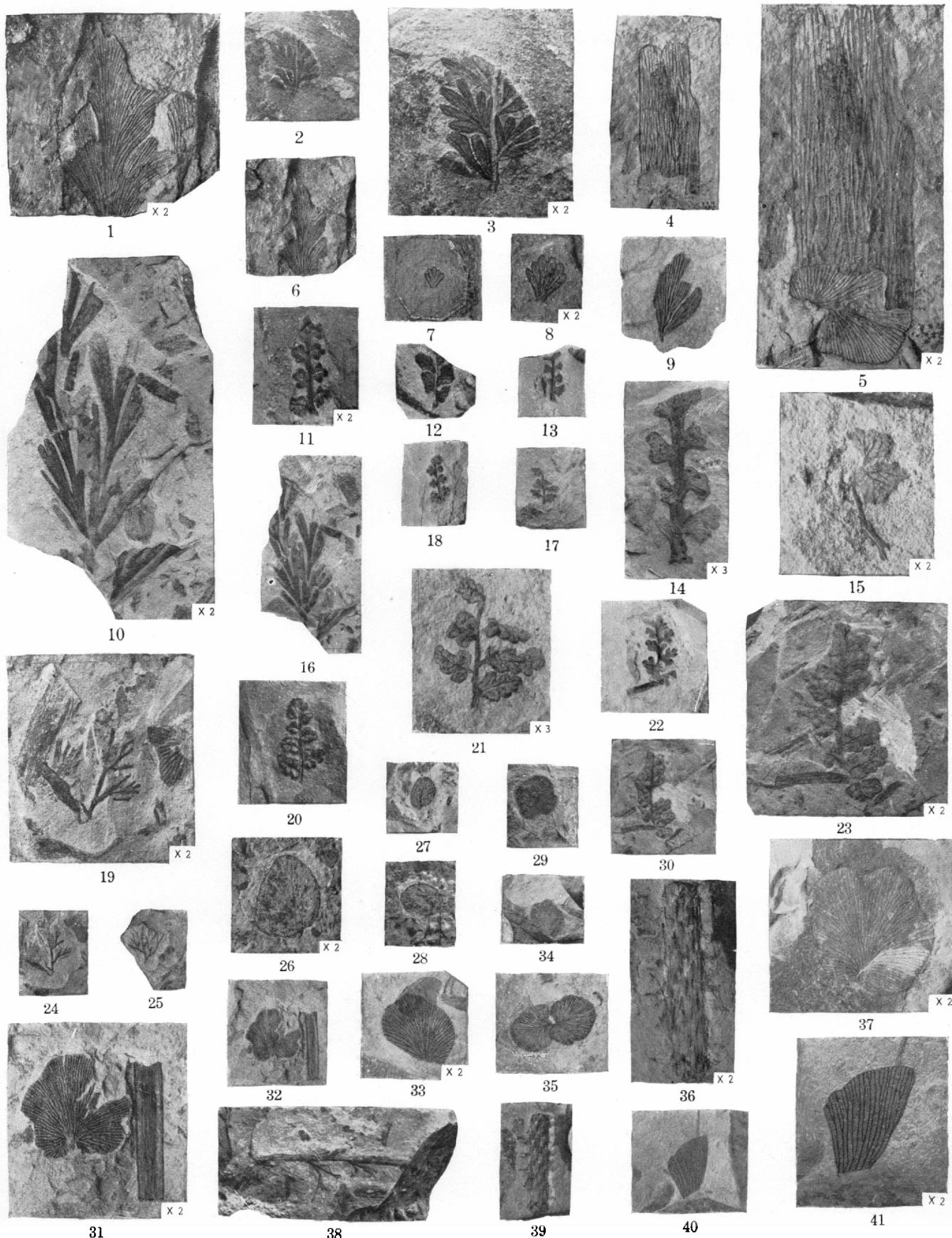
<sup>14</sup> Koenig, C., Icones fossilium sectiles, p. 42, 1825.

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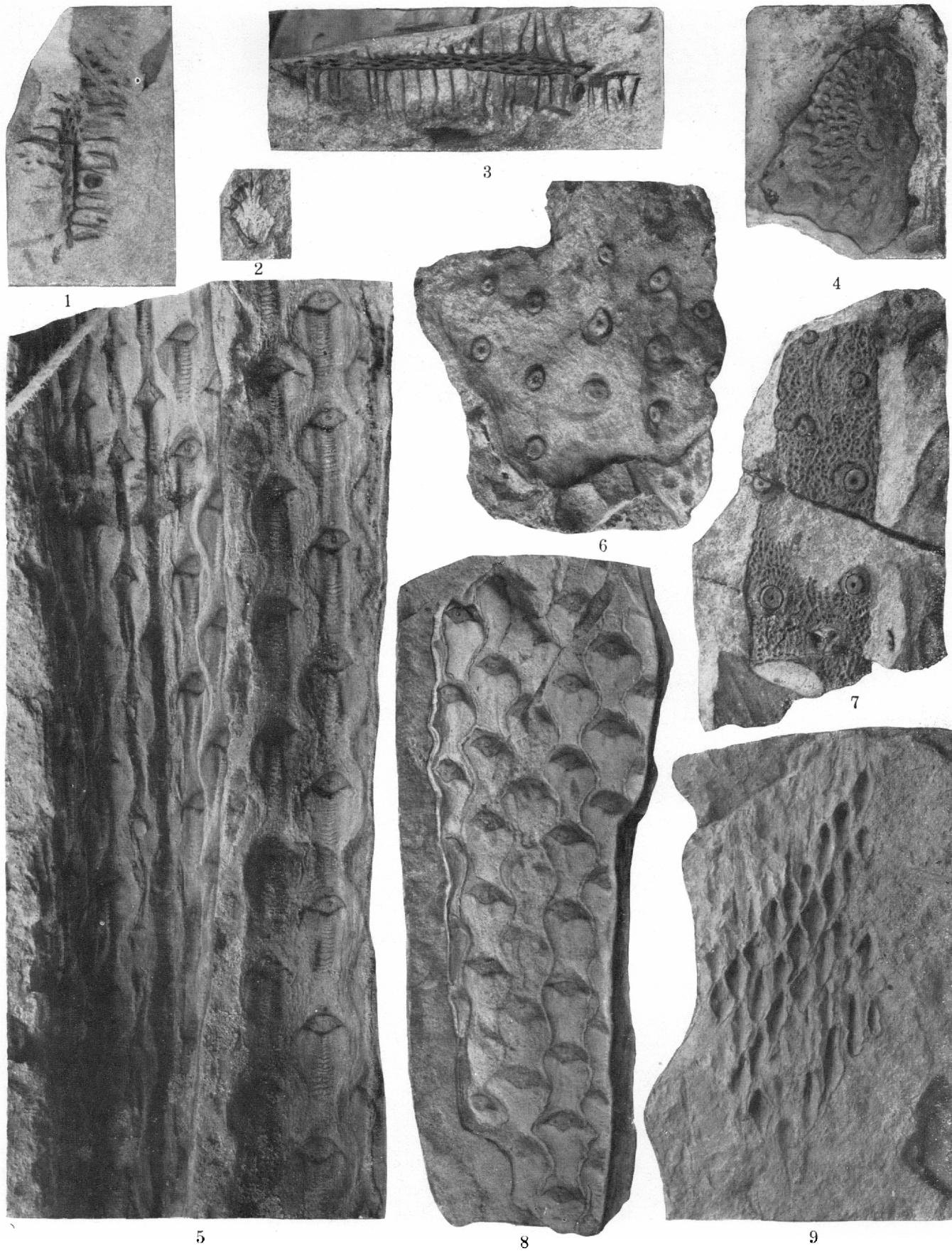
**PLATES 4-9**





FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE.

- 1, 6. *Rhacopteris* sp.  
 2, 3. *Rhoea* cf. *R. subpetiolata* (Potonié) Nêmeje.  
 4, 5; 11, 18; 13, 14; 15; 17, 21; 20; 22; 23, 30; 36, 39. *Sphenopteris mississippiensis* White, n. sp.  
 7, 8. *Sphenopteris* cf. *S. schimperiana* Goepert.  
 9. *Sphenopteris* cf. *S. communis* Lesquereux.  
 10, 16. *Sphenopteris* (*Palmatopteris*) *erectiloba* White, n. sp.  
 12. *Sphenopteris* cf. *S. obtusiloba* Brongniart.  
 18, 24; 25. *Rhoea* cf. *R. morasica* (Ettingshausen) Stur.  
 26, 27. *Neuropteris* sp.  
 29; 31; 32; 33, 34; 35; 37. *Cardiopteris hirta* White, n. sp.  
 38. *Adiantites minimus* White, n. sp.  
 40, 41. *Cardiopteris* sp.

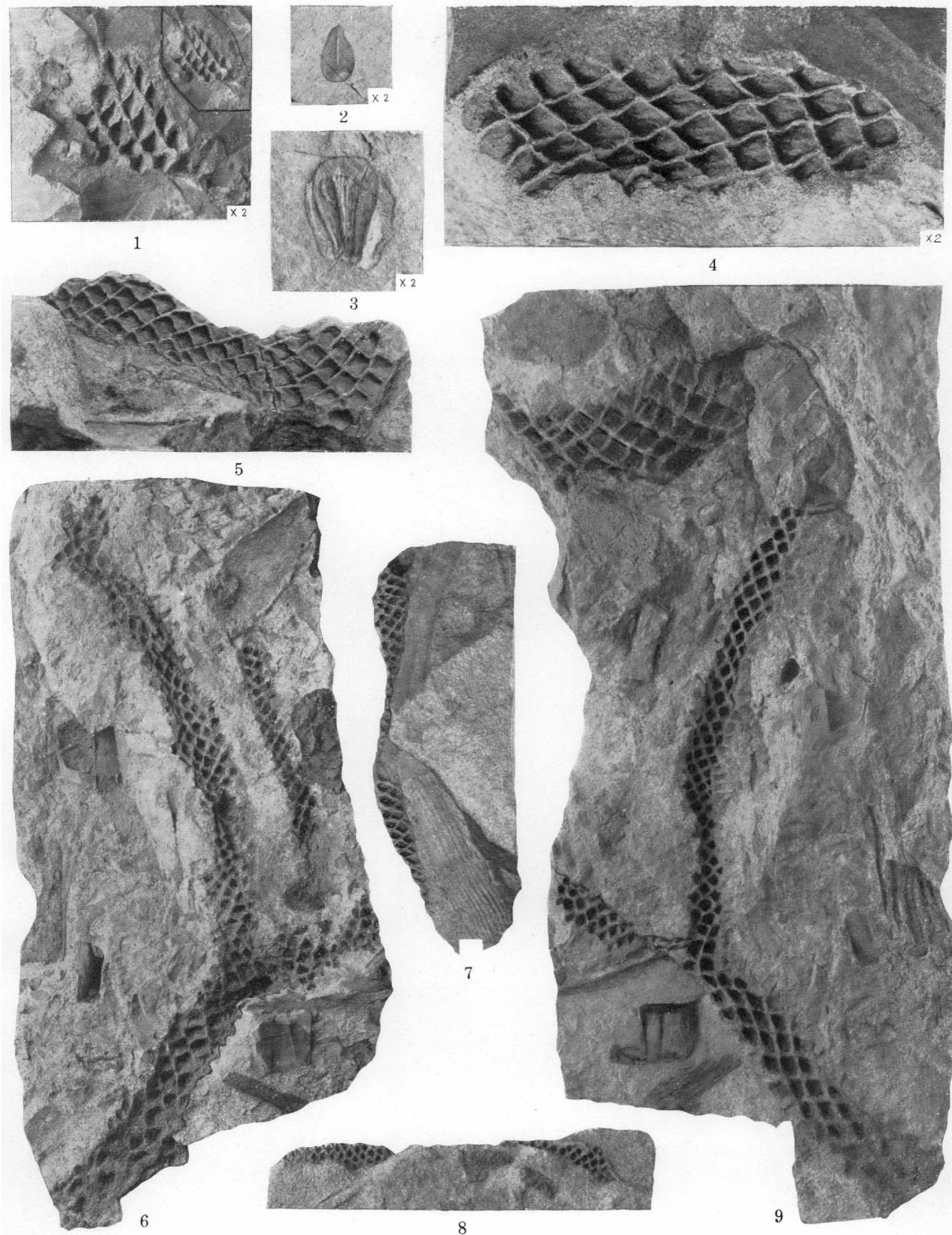


FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE.

1; 3. *Lepidostrobus occidentalis* White, n. sp.  
 2. *Telangium(?) sp.*  
 4. *Lepidodendron* cf. *L. veltheimianum* Sternberg.

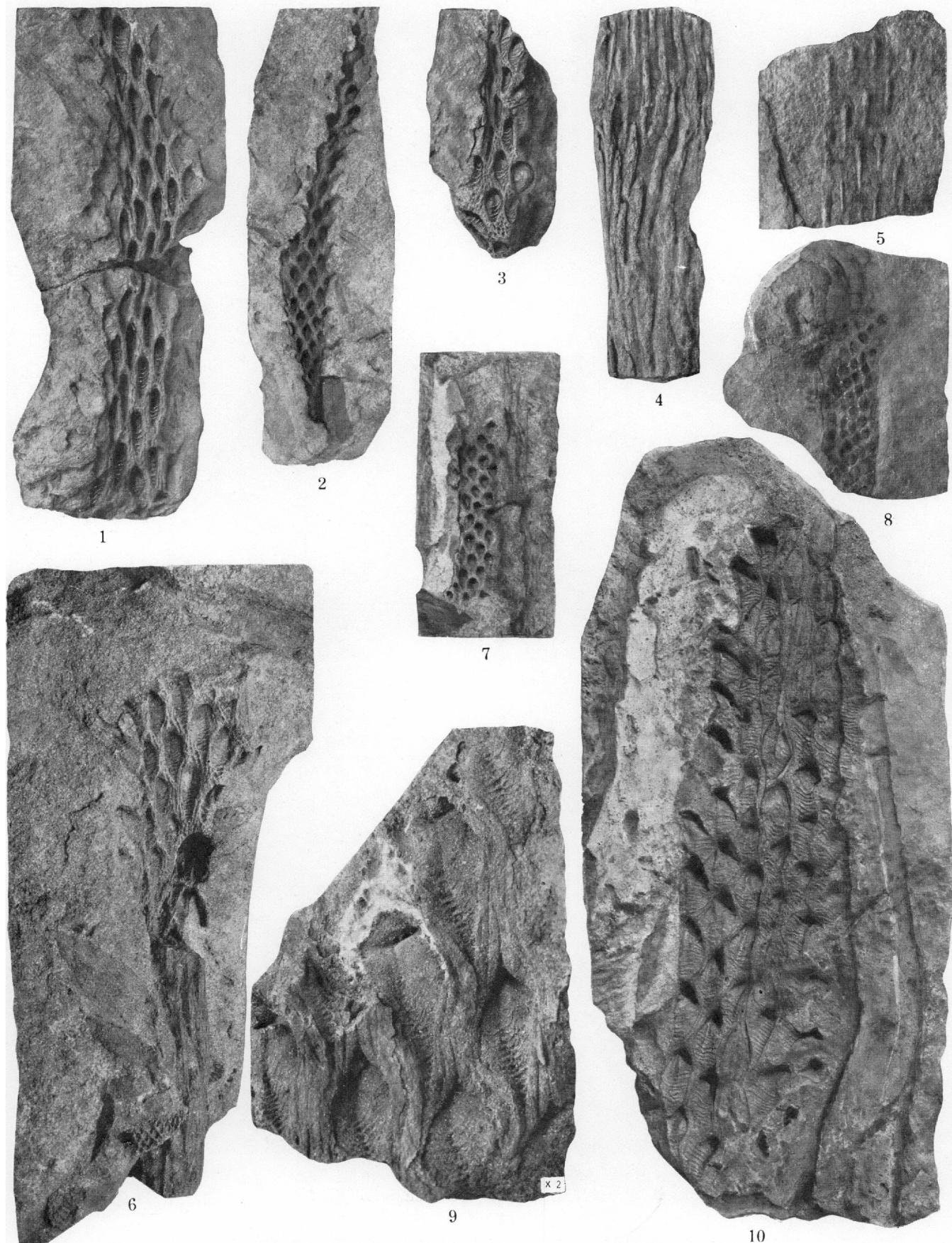
5; 8. *Lepidodendron occidentale* White, n. sp.  
 6. *Stigmaria arkansana* White, n. sp.

7. *Stigmaria wedingtonense* White, n. sp.  
 9. *Lepidodendron purduei* White, n. sp.



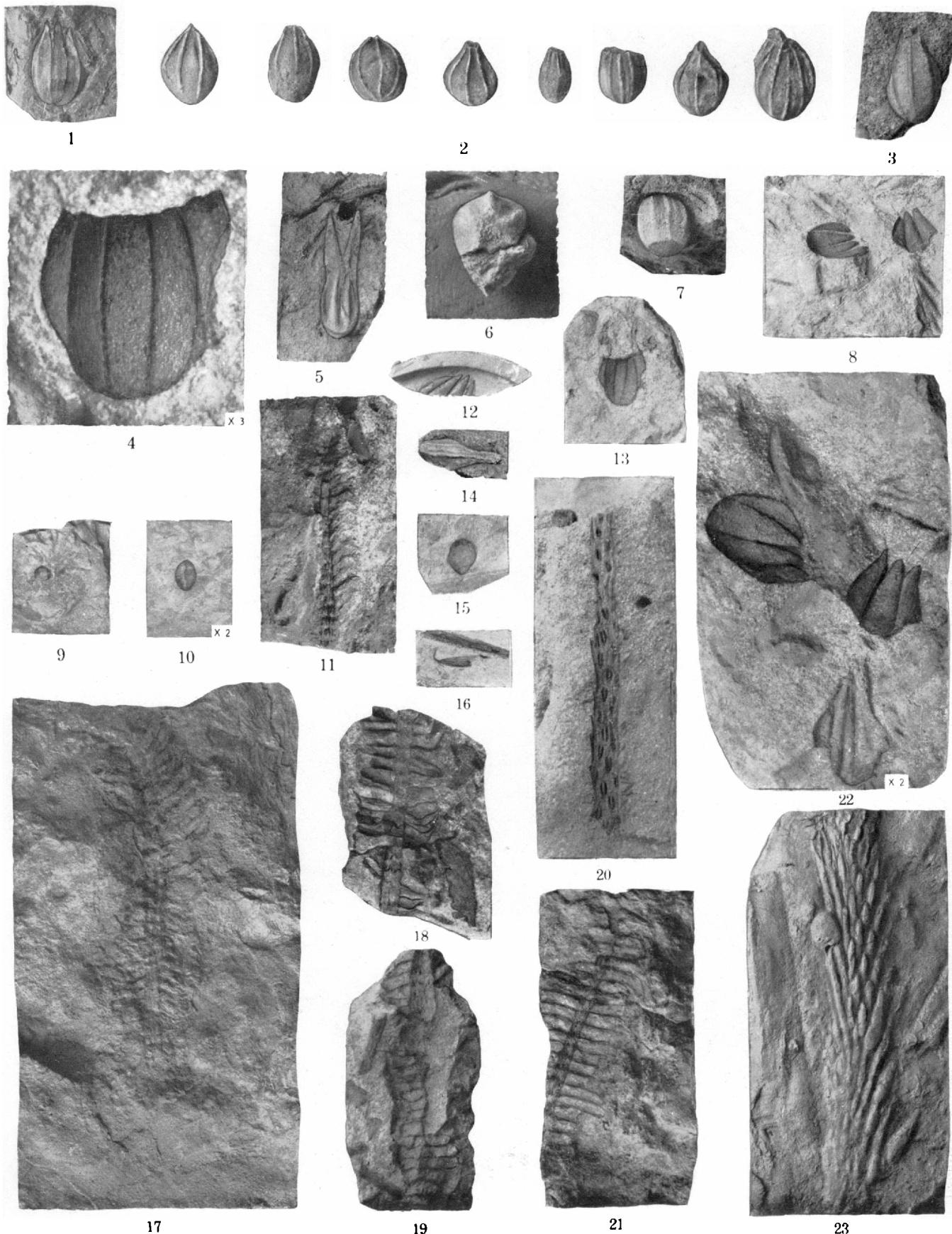
FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE.

1; 4; 5; 6, 9; 7, 8. *Lepidodendron henbestii* White, n. sp.      2. *Lepidocystis chesterensis* White, n. sp.      3. *Lepidophyllum sagittatum* White, n. sp.



FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE.

1; 2; 3; 4; 6; 7; 9; 10. *Lepidodendron wedingtonense* White, n. sp.5. *Bothrodendron* sp.8. *Lepidodendron* sp.



FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE.

1; 2; 3; 4; 5; 6; 7; 8; 22; 12; 13; 14. *Rhynchogonium fayettevillense* White, n. sp.  
 9, 10; 15. *Carpolithus inquirienda* White, n. sp.  
 11; 17; 18; 19; 21. *Chlamidostachys chesterianus* White, n. gen. et sp.

16. *Sphenophyllum?* sp.  
 20. *Lepidostrobus occidentalis* White, n. sp.  
 23. *Lepidodendron* sp.



FOSSIL FLORA OF THE WEDINGTON SANDSTONE MEMBER OF THE FAYETTEVILLE SHALE.

1; 5; 9. *Archaeocalamites gracilens* White, n. sp.  
2. *Lepidophyllum sagittatum* White, n. sp.  
3. *Stigmaria wedingtonensis* White, n. sp.

4. *Archaeocalamites umbralis* White, n. sp.  
6. *Lepidodendron wedingtonense* White, n. sp.  
7; 12; 13. *Archaeocalamites wedingtonensis* White, n. sp.

8. *Sigmaria arkansana* White, n. sp.  
10. *Archaeocalamites fayettevillensis* White, n. sp.  
11. *Archaeocalamites* sp.

# FOSSIL PLANTS FROM THE STANLEY SHALE AND JACKFORK SANDSTONE IN SOUTHEASTERN OKLAHOMA AND WESTERN ARKANSAS

By DAVID WHITE<sup>1</sup>

## ABSTRACT

Notwithstanding the ties between the plant species from the Stanley and Jackfork formations and the lower Pottsville floras of the Appalachian trough, I was long disposed to regard these two formations as of very late Mississippian age, largely on account of their close paleobotanic relations to the Culm floras of the Waldenburg and Ostrau series, in the Silesian region, then classed as Lower Carboniferous. The detailed study, completed in 1932, of all the available plant material, including a collection by H. D. Miser of small fern fragments from the upper Stanley near Gillham, Ark., shows that the upper Stanley flora is distinctly later than the flora of the Wedington sandstone member of the Fayetteville shale or than any other known Mississippian flora in eastern North America. The flora is predominantly of lower Pottsville composition.

Meanwhile, the Ostrau-Waldenburg series was in 1927 transferred by the Heerlen Congress to the Upper Carboniferous. The Jackfork and Stanley are paleobotanically older than the coal-bearing shale member in the Morrow group, which is of middle Pottsville age, being post-Lee and post-Raleigh in the Pottsville group of the Appalachian trough. The conclusion that the Jackfork and Stanley may be largely if not wholly equivalent in time to the lower part of the Morrow group finds support in the few plant fragments common to the Hale sandstone.

## INTRODUCTION

Since the study of the Stanley shale and the Jackfork sandstone with detailed mapping was begun, 35 years ago, relatively little paleontologic material has been brought to light to show the age of either of these formations. At first both formations were supposed to be Ordovician, fossil shells of that age being found in transported boulders deposited in a formation apparently overlying the Stanley and Jackfork. It is, however, now the belief of all the geologists and paleontologists who have examined the region that both formations are of Carboniferous age, and nearly all, if not all, are in agreement as to the assignment of both formations to the Pennsylvanian series.

Several small collections of very fragmentary and in many specimens very indistinct plant fragments have been gathered from these formations by different

geologists since 1902. I gave most of those fragments a preliminary examination some years ago, and my tentative conclusion, quoted by Girty,<sup>2</sup> Ulrich,<sup>3</sup> and Miser,<sup>4</sup> was that the formations were either referable to the latest Mississippian or that they represented a stage in the Pennsylvanian older than any yet known paleobotanically in America. I suggested that the beds might have been laid down during the period of post-Mississippian emergence, which is not represented by plant-bearing deposits yet discovered on this continent. The object of this report is to place this unfortunately meager paleobotanic evidence on record, to attempt an interpretation of its significance as to age, and to encourage the search for additional and more ample floral representations.

## THE FORMATIONS

The Stanley shale was described by Taff<sup>5</sup> in 1902, and the type locality, in the Tuskahoma quadrangle, was the village of Stanley, in Pushmataha County, Okla. The formation consists of dark fissile shale, blue black to black when fresh and bluish or greenish when weathered, interbedded with thin to massive, generally fine-grained and micaceous gray or bluish-gray sandstones which in places weather grayish green or drab. The lower part of the formation, which is siliceous and cherty, contains, near the base, beds of tuff said by Miser<sup>6</sup> to be three to five in number and to range from 6 to 85 feet in thickness.

The formation is reported to be 6,000 feet thick in the vicinity of Atoka, Okla., and in Pike County, Ark. Honess<sup>7</sup> reports a thickness of over 10,000 feet in McCurtain County, in southeastern Oklahoma. In both Arkansas and Oklahoma the Stanley rests unconformably either on the Arkansas novaculite (lower part

<sup>1</sup> From the manuscript of the present paper Dr. White abstracted and published in 1934 (*Am. Assoc. Petroleum Geologists Bull.*, vol. 18, no. 8, pp. 1010-1017, August 1934) a paper entitled "Age of Jackfork and Stanley formations of Ouachita geosyncline, Arkansas and Oklahoma, as indicated by plants." The present paper was one of several manuscripts still in his hands at the time of his death, February 7, 1935. The modification of an editorial nature required to place this manuscript in form for publication has been done by some of his colleagues.

<sup>2</sup> Girty, G. H., The fauna of the Caney shale of Oklahoma: U. S. Geol. Survey Bull. 377, p. 8, 1909.

<sup>3</sup> Ulrich, E. O., Fossiliferous boulders in the Ouachita Caney shale and the age of the shale containing them: *Oklahoma Geol. Survey Bull.* 45, pp. 47-48, 1927.

<sup>4</sup> Miser, H. D., and Honess, C. W., Age relations of the Carboniferous rocks of the Ouachita Mountains of Oklahoma and Arkansas: *Oklahoma Geol. Survey Bull.* 44, pp. 14-16, 1927.

<sup>5</sup> Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (no. 79), 1902.

<sup>6</sup> Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas: *Am. Jour. Sci.*, 5th ser., vol. 2, p. 71, 1921.

<sup>7</sup> Honess, C. W., Geology of southern Le Flore and northwestern McCurtain Counties, Okla.: *Oklahoma Bur. Geology Circ.* 3, pp. 6-9, 1924.

Devonian, upper part Devonian?), with a very thin basal conglomerate containing novaculite pebbles, or on the Hot Springs sandstone,<sup>8</sup> a thin formation which in turn is unconformable upon the novaculite.

The Stanley shale is ripple-marked and current-bedded at many horizons and is regarded by Honess<sup>9</sup> and by Miser and Purdue<sup>10</sup> as a shoal-water delta deposit laid down by northward-flowing streams. Locally it carries considerable organic debris, mainly of vegetable origin, which evidently had been subjected to prolonged drifting, maceration, and even trituration. Much of the debris is not determinable generically. Good preservation even in very small fragments is rare, though in some localities final burial of the plant detritus was evidently rapid.

The Stanley shale is overlain transitionally and apparently conformably by the Jackfork sandstone.

The Jackfork sandstone, described by Taff,<sup>11</sup> with type locality in Jackfork Mountain, southeastern Pittsburg County, and the adjoining portions of Atoka and Pushmataha Counties, Okla., is a ridge-forming formation consisting of massive, compact fine-grained to coarse-grained dark-gray to light-gray sandstones, micaceous and gritty, especially near the base, including small amounts of shaly sandstone and green, black, or blue arenaceous or argillaceous shale. Many of the sandstones weather brown or drab. The published thicknesses assigned to the formation range from 5,000 to 6,600 feet.

The Jackfork sandstone is said to lie conformably upon the Stanley shale. It is in turn overlain, apparently conformably, by the Johns Valley shale, a deposit with thin intercalated sandstones, locally 1,500 feet thick, formerly designated in most geologic literature the "Caney shale." Locally the marine or true Caney itself rests on the Jackfork. The invertebrate fauna in the upper part of this Caney is classed as Morrow (Pennsylvanian), and that obtained from the lower part is generally correlated with the Moorefield, Batesville, and Fayetteville formations<sup>12</sup>—all of which led to the former view that the Jackfork and Stanley are of Mississippian age, and they were so mapped by Miser<sup>13</sup> and Branner.<sup>14</sup> A recent contention of the opponents of this view is that the shale yielding the Mississippian fossils owes its superposition on the Jackfork to thrust or landslides.

The Jackfork and Stanley formations themselves have yielded very meager marine invertebrate faunas,

<sup>8</sup> Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Hot Springs folio (no. 215), 1923.

<sup>9</sup> Honess, C. W., The Stanley shale of Oklahoma: Am. Jour. Sci., 5th ser., vol. 1, pp. 78-79, 1921.

<sup>10</sup> Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap quadrangles, Ark.: U. S. Geol. Survey Bull. 808, pp. 133-134, 1929.

<sup>11</sup> Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (no. 79), 1902.

<sup>12</sup> Girty, G. H., The fauna of the Caney shale of Oklahoma: U. S. Geol. Survey Bull. 377, 1909. Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Oklahoma Bur. Geology Bull. 2, p. 56, 1924.

<sup>13</sup> Miser, H. D., Geologic map of Oklahoma, U. S. Geol. Survey, 1926.

<sup>14</sup> Branner, G. C., Geologic map of Arkansas, Arkansas Geol. Survey, 1929.

which have hitherto been viewed as consistent with the lower Caney fauna, though insufficient for definite age determination.<sup>15</sup>

The Johns Valley shale is remarkable for the presence of included exotic boulders, comprising fragments of fossiliferous limestone ranging from small cobbles to masses as great as 370 feet long and containing fossils of Ordovician, Silurian, and Mississippian age. These inclusions, many of which are rounded, subangular, or angular and gouged, scraped, or merely scratched and striated and which are distributed over a considerable area, are regarded as (1) ice-transported, (2) products of submarine rock slides, (3) subaerial escarpment talus, or (4) resulting from thrust-fault drag, according to the view of the geologist interrogated. Most of the regional geologists seem to favor either the second or the fourth hypothesis.

The general geology of the Ouachita Basin has been represented by H. D. Miser on the geologic map of Oklahoma, published by the United States Geological Survey in 1926, and by G. C. Branner on the geologic map of Arkansas, published by the Geological Survey of Arkansas in 1929. Summary descriptions of the geologic formations and of the geologic structure, together with synopses of the evidence and varying conclusions as to ages and rock sequences, have been compiled by Miser and Honess<sup>16</sup> and later by Miser.<sup>17</sup> Miser in his recent paper presents new age interpretations, based by George H. Girty and Bruce H. Harlton on invertebrate faunas, and also presents his revised conclusions as to the structural history. These new interpretations are in essential agreement with the conclusions I reached in the detailed study of the fossil plants completed in 1932. The reader is referred to the papers by Miser<sup>17</sup> and Harlton<sup>18</sup> for further non-paleobotanic information.

#### SOURCES OF THE PALEOBOTANIC MATERIAL STUDIED

The fossil plants from the Stanley shale and Jackfork sandstone consist mainly of fragments of sandstone bearing impressions of *Lepidodendron* or calamarian stems. These fragments, picked up casually from time to time by different geologists and paleontologists, are generally more or less defaced as the result of weathering, though many of the specimens were badly macerated and not specifically identifiable when they were buried.

A single collection consisting of carbonized plant remains in sandy micaceous shales was obtained by

<sup>15</sup> Miser, H. D., and Honess, C. W., Age relations of the Carboniferous rocks of the Ouachita Mountains of Oklahoma and Arkansas: Oklahoma Geol. Survey Bull. 44, pp. 5, 16, 17, 18, 1927.

<sup>16</sup> Miser, H. D., and Honess, C. W., op. cit., pp. 5-27.

<sup>17</sup> Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 971-1009, August 1934.

<sup>18</sup> Harlton, B. H., Carboniferous stratigraphy of the Ouachitas—a special study of the Bendian: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 1018-1049, August 1934.

H. D. Miser from the Whitley cut along the Kansas City Southern Railway,  $2\frac{1}{2}$  miles by road south of Gillham, in western Arkansas. In these dark bluish-gray shales the plants are extremely fragmentary, as if triturated, and generally they are badly macerated. Final deposition appears to have been reasonably rapid, however, and most of the impressions are accompanied by thin carbonaceous residues. With the exception of two or three small fragments, this collection is the only one containing remains of ferns or fernlike plants. Most of the fern specimens are less than 1 centimeter in length. Frequently but a part of a lobe of a pinnule is represented on the piece of shale. The identification of the material is therefore a difficult matter, and the determinations are notably subject to revision whenever more complete and better material is found.

A list of the collections, with special reference to their geographic location, is given below. A few of the specimens were collected by Taff and Ulrich in 1902. It is not known whether some of the specimens casually gathered by different geologists and paleontologists were obtained from the upper, lower, or middle portions of the formations.

#### JACKFORK SANDSTONE

Devils Hollow, near Talihina, Okla., secs. 32 and 33, T. 4 N., R. 21 E., Tuskahoma quadrangle. Lower part of Jackfork as mapped by Taff. Collected by H. D. Miser in April 1927 (lots 8333 and 8340); by H. D. Miser and Charles Miller in June 1927 (lot 8336); by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (lots 8014, 8015, and 8016).

South side of sec. 6, T. 7 N., R. 25 W., Pike County, Ark., 7 miles north of Murfreesboro. Base of the Jackfork sandstone. Collected by Bryan Parks, of the Arkansas Geological Survey, in 1932 (lot 8328).

Parnell Hill, sec. 6, T. 7 S., R. 25 W., Pike County, Ark. Collected by J. P. Hansell, March 1, 1932 (lot 8329).

Stream sandstone boulder from Jackfork sandstone, grounds of Choctaw-Chickasaw Sanitarium, mouth of Devils Hollow, northwest corner of sec. 3, T. 3 N., R. 21 E., Tuskahoma quadrangle, Oklahoma. Collected by Dr. W. E. Van Cleve, superintendent of the sanitarium, in 1927 (lot 8332).

Three miles southeast of Stringtown, Atoka quadrangle, Oklahoma. Collected by H. D. Miser in June 1927 (lot 8334).

St. Louis-San Francisco Railway 5 miles north of Antlers, Antlers quadrangle, Oklahoma. Collected by H. D. Miser, May 9, 1927 (lot 8335).

Crest of mountain 1 mile north of Clayton, Tuskahoma quadrangle, Oklahoma. Collected by H. D. Miser in May 1927 (lot 8337).

Crest of Kiamichi Mountain on old road due south of Talihina, Tuskahoma quadrangle, Oklahoma. Collected by H. D. Miser in 1927 (Miser's lot 02).

Sandstone ridges between Johns Valley and Eubanks, Antlers quadrangle, Oklahoma. Collected by H. D. Miser in 1927 (Miser's lot 03).

#### JACKFORK SANDSTONE OR ATOKA FORMATION

Fossils in sandstone nearly 2,000 feet above the base of the Jackfork sandstone, southwest corner of sec. 16, T. 4 N., R. 24 E.,

Windingstair quadrangle, Oklahoma. Collected by J. A. Taff, August 18, 1899? (lot 8331).

$SW\frac{1}{4}$  sec. 10, T. 4 N., R. 23 E., Windingstair quadrangle, Oklahoma. Collected by J. A. Taff, August 19, 1899 (lot 8339).

#### STANLEY SHALE

Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway,  $2\frac{1}{2}$  miles south of Gillham, De Queen quadrangle, Arkansas. Collected by H. D. Miser in 1914 and 1923 (lot 6874).

Upper part of Stanley shale, 4 miles east of Tuskahoma, Okla. Collected by David White in 1909 (lot 5669).

Bottom of 40-foot well at C. E. Moorland's house, 8 miles east of Atoka, Okla. Collected by David White in 1911 (lot 6240). [The direction should probably be northeast.—Ed.]

#### JACKFORK SANDSTONE OR STANLEY SHALE

$NE\frac{1}{4}NE\frac{1}{4}$  sec. 32, T. 2 N., R. 20 E., Tuskahoma quadrangle, Oklahoma, in creek bed. Lower part of heavy black-shale bed (Stanley?). Collected by E. O. Ulrich, J. A. Taff, C. D. Smith, and M. K. Shaler, August 10, 1904 (lot 3508).

#### PRESENT AND FORMER VIEWS ABOUT THE AGE OF THE FORMATIONS

The purpose of this paper is to present my conclusions as to the age of the Jackfork and Stanley formations based on the study of the plant material in hand in 1931,<sup>19</sup> when the study was nearly completed.

On the paleobotanic evidence, I refer not only the Jackfork to the Pennsylvanian, but also the upper half and, by implication, the non-plant-bearing lower half of the Stanley as well. Previously I had regarded the Stanley and possibly the Jackfork as uppermost Mississippian, for reasons mentioned beyond.

In 1904 E. O. Ulrich, then accompanying J. A. Taff in the study of the Tuskahoma quadrangle, Oklahoma, found in the upper part of the Stanley (or lower part of the Jackfork?) a few fragments of *Lepidodendron* which he recognized as Carboniferous, probably Pennsylvanian, and on his recommendation both the Jackfork and Stanley were immediately transferred from the Ordovician to the Carboniferous bracket of the geologic column. These specimens, with some additional material collected by me in the same region and east of Atoka, were then interpreted as probably very late Mississippian. In answer to subsequent persistent inquiry, and with more stem casts and seeds collected by H. D. Miser, I expressed the view that the beds might have been laid down in very late Mississippian time or during an early part of the period of post-Mississippian emergence, which is not represented by plant-bearing deposits yet recognized elsewhere on this continent. This opinion was based largely on the parallelism in floral composition and the presence of closely related or identical floral elements in the Jackfork and Stanley and in the very fully elaborated floras of the Waldenburg and Ostrau series

<sup>19</sup> Submission of my report (1931) embodying the descriptive paleobotanic data for publication by the United States Geological Survey awaited the completion of the plant illustrations.

(Culm) of the former Austro-Silesian region, which were then regarded as uppermost lower Carboniferous, though the floras of the Ouachita region had very much in common with those of the lower Pottsville in the Appalachian trough.

Meanwhile, Schuchert<sup>20</sup> put himself on record as in favor of the Pennsylvanian age of the deposits, largely on account of the presence, in a small collection, of *Lepidodendron* and *Calamites*. The same fossils, including a few invertebrates from the Stanley shale, were examined also by Ulrich,<sup>21</sup> who stated: "There is nothing in the collection that may be justly cited as definitely opposed to the correlation of the Stanley with the lower Pottsville or basal Morrow, which conclusion I reached in my 'Revision' (1911)<sup>22</sup> mainly on physical and diastrophic considerations."

It is due to the deep interest and continuing efforts of H. D. Miser toward the solution of the problem that considerable additional plant material, including small fragments of ferns, was discovered in the upper part of the Stanley shale near Gillham, Ark., as well as calamarian, lepidophytic, and seed casts in the Jackfork, most of which have been obtained from Devils Hollow, near Talihina, Okla. My opinion, based on a preliminary inspection of this material and still influenced largely by the supposed late Mississippian age of the Silesian Culm floras, was that the plants from the Stanley, in particular, might be

of Chester age, but the paleobotanical data available are insufficient to justify their conclusive reference to the Mississippian. The examination suggests the possibility of the deposition of a great thickness of sandstone and shale derived from the north Texas land mass [Llanoria], on the south, during the period of post-Mississippian uplift and deformation and the earliest stages of Pennsylvanian subsidence.<sup>23</sup>

This view is in harmony with that previously expressed by Ulrich,<sup>24</sup> that the Stanley might represent the emergent phase of the Pennsylvanian-Mississippian diastrophic movement, a view that has recently been adopted by Van der Gracht.<sup>25</sup>

The subsequent detailed study of the Jackfork and Stanley fossils that are available in the Survey collections has strengthened—in fact, essentially confirmed—the tentative correlation of the Stanley shale with the upper Culm of Europe, while emphasizing the extremely close relation between the flora of the Jackfork and that of the oldest American Pennsylvanian.

<sup>20</sup> Schuchert, Charles, quoted by Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: *Oklahoma Geol. Survey Bull.* 32, pp. 177-178, 1923.

<sup>21</sup> Ulrich, E. O., quoted by Honess, C. W., op. cit., p. 178.

<sup>22</sup> Ulrich, E. O., Revision of the Paleozoic systems: *Geol. Soc. America Bull.*, vol. 22, pp. 477, 528, 1911.

<sup>23</sup> Miser, H. D., and Honess, C. W., Age relations of the Carboniferous rocks of the Ouachita Mountains of Oklahoma and Arkansas: *Oklahoma Geol. Survey Bull.* 44, p. 16, 1927.

<sup>24</sup> Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney shale" and the age of the shale containing them: *Oklahoma Geol. Survey Bull.* 45, pp. 23-24, 1927.

<sup>25</sup> Van der Gracht, W. A. J. M. van Waterschoot, The Perm-Carboniferous orogeny in the south-central United States: K. Akad. Wetensch. Amsterdam Verh., Afd. Natuurk., 2d sec., deel 27, no. 3, p. 10, Amsterdam, 1931; Am. Assoc. Petroleum Geologists Bull., vol. 15, no. 9, pp. 991-1057, September 1931.

#### EVIDENCE OF THE PALEOBOTANIC MATERIAL NOW AVAILABLE AS TO THE AGE OF THE STANLEY SHALE AND JACKFORK SANDSTONE

Before discussing the evidence in detail of the fossil plants as to the ages of the Stanley shale and the Jackfork sandstone, it is important to note that since I made the statement quoted in the second paragraph preceding this, as published by Miser and Honess in 1927, two important factors have entered into the problem of the correlation of these formations.

The first of these is the discovery and description of a flora<sup>26</sup> in the Wedington sandstone member, of Chester, probably upper Chester age, of the upper part of the Fayetteville shale in northwestern Arkansas, and the consequent recognition that the flora of the Stanley as well as that of the Jackfork is distinctly younger than the Wedington flora.

The second factor is the revision of the boundary line between the Upper Carboniferous and Lower Carboniferous in portions of western Europe by the Heerlen Congress in 1927 and the transfer from the Lower to the Upper Carboniferous of several well-known plant-bearing formations formerly classed as Culm.<sup>27</sup>

Because many geologists are not familiar with reports submitted to the Heerlen Congress and especially with the conclusions it adopted, a short digression, summarizing several points of importance to the discussion of the floras in hand, will be given before resuming the consideration of the effect on the time classification of the Jackfork sandstone and the Stanley shale of the transfer from the uppermost Lower Carboniferous to the basal Upper Carboniferous of the above-mentioned European plant beds. These European formations, with whose fossil floras the plant associations in the late Lower Carboniferous and oldest Upper Carboniferous of all countries, including our own, have generally been compared, include the Lanarkian of Scotland, the upper Culm of the basin of the lower Loire, the Moravian-Silesian roofing slates, the Ostrau series of upper Silesia, and the Waldenburg series of lower Silesia. The floras of the Ostrau and Waldenburg were described by Stur and are now so well known as to constitute base lines for use in comparison.

#### REVISION OF THE BOUNDARY BETWEEN LOWER CARBONIFEROUS AND UPPER CARBONIFEROUS IN EUROPE

The "Congress for the advancement of studies of the stratigraphy of the Carboniferous"<sup>28</sup> was held at Heerlen, Holland, June 7 to 11, 1927, under the aus-

<sup>26</sup> White, David, Fossil flora of the Wedington sandstone member of the Fayetteville shale: U. S. Geol. Survey Prof. Paper 186-B, 1937.

<sup>27</sup> It should be kept in mind by the reader of this paper that Dr. White accepted the thesis of the essential equivalence of the American Mississippian and Pennsylvanian, respectively, to the European Lower and Upper Carboniferous, as revised by the Heerlen Congress of 1927.—Editor.

<sup>28</sup> Congrès pour l'avancement des études de stratigraphie carbonifère, Heerlen, 7-11 juin, 1927, Compte rendu, pp. i-liii, 1-852, with plates, charts, and maps, Liège, 1928.

pices of the Minerals Section of the Geological and Mining Society of the Netherlands and Her Colonies. Invitations were extended to geological surveys of countries having Paleozoic coals and to geologists of those countries interested in the stratigraphy and paleontology of the Carboniferous. No geologist of the United States seems to have been present.

The object of the congress was to compare the stratigraphy of the Carboniferous in the different coal-field countries of Europe, with a review of the different methods of investigation and of the correlative criteria, and to establish the more exact identification and correlation of the different stages or members of the Carboniferous.

After the presentation and discussion of reports the congress voted unanimously to use the term "Dinantian" for the Lower Carboniferous and to reject the term "Culm", a term used in different senses, and to designate different stages in different countries. By unanimous action, also, the Dinantian was divided into Visean (=zone of *Glyphioceras*) and Tournaisian (=zone of *Pericyclus*), the upper limit of the Visean being drawn at the summit of the zone containing *Glyphioceras spirale (granosum)*.

The decision of the congress was unanimous to distinguish three stages in the Upper Carboniferous, for the lowest of which the name "Namurian" was selected, for historical reasons. The name "Westphalian" was reserved for the middle stage, and the upper stage was called "Stephanian."

By unanimous action the Namurian as defined by the congress includes the Millstone grit and a part, at least, of the Carboniferous limestone series in England; the Bruille and Flines beds of France; the Chokier<sup>29</sup> and Andenne beds of Belgium; the beds containing the lower Gulpen flora, with *Eumorphoceras*, and the Epen beds, with *Reticuloceras* and a characteristic flora, in Holland; the lower part of the Barren series (Flözleeres) in Westphalia; the lower part of the Ostrau beds of upper Silesia; and the Waldenburg beds of lower Silesia. The upper limit of the Namurian coincides with the horizon of *Gastrioceras subcrenatum*, which in the Rhenish-Westphalian basin is the roof of the Sarnsbank bed.

The upper limit of the Devonian was drawn at the summit of the zone of *Gonioclymenia*.

The boundary between the Stephanian and Permian is determined principally on a paleobotanic basis, it being recognized that *Walchia* occurs in the upper Stephanian as well as in the Permian, but that *Callipteris* is typically Permian.

The limit between the Stephanian and Westphalian was, by unanimous agreement of the congress, drawn at a level corresponding to the Holz conglomerate of the Saar Basin.

<sup>29</sup> Similarly the Walhorn beds are to be associated with the Chokier in the upper Carboniferous, as also probably the Golonog sandstones of Silesia.

Defined primarily in terms of the distribution of the goniatites, the stratigraphic classification of the Carboniferous accepted by the Heerlen congress is as follows:

|                     |             |  |
|---------------------|-------------|--|
|                     | Permian     |  |
|                     | Stephanian  | Holz conglomerate  |
| Upper Carboniferous | Westphalian | C.<br>Marine horizon of Petit Buisson-Aegir.<br>B.<br>Marine horizon of Katharina-Poissonnière.<br>A.  |
|                     | Namurian    | Horizon of <i>Gastrioceras subcrenatum</i> (Sarnsbank)<br>Zone of <i>Reticuloceras</i> (R. incl. mut.)<br>γ, Bisat).<br>Zone of <i>Homoceras</i> (H, Bisat) ---<br>Zone of <i>Eumorphoceras</i> (E, Bisat) -<br>IV + IVε (Vα). |
|                     | Dinantian   | <i>Glyphioceras spirale (granosum)</i><br>Zone of <i>Glyphioceras</i> = Visean (Schmidt, IIIα, β, γ).<br>Zone of <i>Pericyclus</i> = Tournaisian (Schmidt, II and I).  |
| Devonian            |             | Zone of <i>Gonioclymenia</i> at top.   |

As is immediately obvious, a principal result of the revisions adopted by the Heerlen congress is the lowering of the boundary between Lower Carboniferous and Upper Carboniferous in many regions of Europe and the concomitant transfer of certain formations and zones, mostly classed formerly as Culm, with their floral characteristics, from the Lower to the Upper Carboniferous.

As to the merits of all the consequent changes in the stratigraphic classification adopted by the congress, which included many of the foremost, most experienced, and best informed among the paleozoologists, paleobotanists, and stratigraphers actively engaged in the study of the European coal fields, I am unqualified to judge—all the more because the boundaries are defined largely in accordance with the evidence of the inverte-

brates. It is to be regretted, however, that the shift in formations brings into the Upper Carboniferous, as revised, several plant types, including especially the *Cardiopteris polymorpha* group and *Lepidodendron volkmannianum*, previously characteristic of the upper Lower Carboniferous of Europe and still unknown above the Chester in the Carboniferous basins of America.

In view of this apparent disparity, we may conclude that in Europe the upper boundary of the Lower Carboniferous is drawn lower than the upper boundary of the American Mississippian, unless the lower part of the Morrow group, which below the coal-bearing shale is paleobotanically almost unknown, contains plant remains representative of and in part, at least, synchronous with the floras of the Namurian of Europe. On the other hand, it is more than possible that the greater part of the Namurian terranes were deposited during a portion of the post-Mississippian diastrophic movement—either the latest phase of the Mississippian recession or the earliest Pennsylvanian poised and regression—not yet stratigraphically or paleobotanically recognized in this country. This explanation, which is in agreement with my views, finds support in the strongly marked contrast between the latest Mississippian and the earliest known Pottsville floras—a contrast that can be due only to a considerable hiatus in time or a notable change in the environment as well as in the plant life. The Parkwood of the Birmingham district of Alabama may be referable to this interval, as has been proposed by Ulrich.

The Pottsville is shown by its floras to be coterminous—very closely, at least—and mainly synchronous with the Westphalian, though the oldest recognized Pottsville, the lower part of the lower Pottsville, in southwestern Virginia and southwestern West Virginia, may extend below the base of the Westphalian as now defined.

#### PLANTS FROM THE STANLEY AND JACKFORK FORMATIONS

A list of the species recognized in the collections now in the United States Geological Survey and the United States National Museum and described in this report is given below. As some of the forms are very meagerly represented and the preservation of many is very unsatisfactory, the identifications are subject to revision whenever better specimens or material more amply representative of the species is brought to light. For the formational references of the scattered collections, the geologic source of which was not stated by the collectors or as to which there has been doubt, I am indebted to H. D. Miser, who is most familiar with the areal geology of the region and who has himself gathered most of the specimens.

This list, which is alphabetically arranged, includes floras of both formations. The occurrence of species

in the Stanley shale is indicated by S and in the Jackfork sandstone by J. All information available as to the plant locality, date of collection, etc., is given on page 45.

- Adiantites stanleyanus* White. S
- Adiantites* sp. S
- Alloiopteris arkansana* White. S
- Aphlebia parksii* White. J
- Aphlebia* sp. S
- Archaeocalamites coralloides* White. S
- Archaeocalamites stanleyensis* White. S, J
- Bothrodendron* sp. J
- Calymmatotheca* sp. S
- Calamites inopinatus* White. J
- Calamites menae* White. S, J
- Calamites miser* White. S, J
- Fern rachides*. S
- Heterangium?* sp. S, J
- Lepidodendron subclypeatum* White. S, J
- Lepidodendron* cf. *L. wedingtonense* White. J
- Lepidostrobus peniculus* White. S, J
- Neuropteris antecedens* Stur? J
- Neuropteris elrodi* Lesquereux. S
- Rhabdocarpus* (*Lyganostoma?*) *costatulus* White. J
- Rhabdocarpus secalicus* White. S
- Rhodea goepperti* (Ettingshausen) Stur. S
- Rhodea* cf. *R. tenuis* Gothan. S
- Rhynchogonium choctavense* White. J
- Sigillaria* (*Rhytidolepis*) sp. J.
- Sphenophyllum arkansanum* White. S
- Sphenopteridium dawsoni* (Stur). S
- Sphenopteris* sp. S
- Sphenopteris* cf. *S. mississippiana* White. S
- Palmatopteris subgeniculata* Stur? S
- Stigmaria* sp. S
- Trigonocarpum gillhami* White. S, J
- Trigonocarpum vallisjohanni* White. S, J
- Wardia suspecta* White. S

Of the 34 species in the list, 26 are from the Stanley, 16 are from the Jackfork, and 8 are common to both formations. All but one in the last category are confined to the calamarian, lepidophytic, and seed groups. Nearly all the filicoid forms are from the Stanley, the conditions of deposition of the sandstone of the Jackfork being less favorable both for their preservation and for their ultimate discovery. The presence of seeds, probably of pteridospermic origin, points to the presence of seed-bearing ferns in the Jackfork formation. Also, the fact that of the six seeds described three are common to both the Stanley and Jackfork gives reason to expect that the pteridosperms yet to be found will show as close a relation with the Stanley as is seen in the calamarian and lepidophytic groups. On the whole, basing a calculation on the very scanty data in hand, we may tentatively assume that about one-half of the plant species present in the Jackfork sandstone are also to be found in the Stanley shale. It remains to be seen later whether the plants in the Jackfork point to a stage distinctly younger than those of the Stanley.

Of the combined floras, 15 species are ferns or pteridosperms, 6 are included in or allied to the Cala-

mariales, 7 are lepidophytes, and 6 are seeds of pteridosperms or gymnosperms. The flora, though small, is comprehensive and should collectively be sufficient to determine with reasonable certainty the age, as between Mississippian and Pennsylvanian, both of the Jackfork and of the Stanley.

#### RELATIONS OF THE STANLEY AND JACKFORK FORMATIONS TO THE MORROW GROUP OF ARKANSAS

In the entire southwestern region of the United States, which embraces the Western Interior basin, there are but two floras as yet described from the upper Mississippian or basal Pennsylvanian with which to make regional comparisons of the plants from the Jackfork and Stanley. One is a meager flora from the Wedington sandstone member of the Fayetteville shale, of Chester (late Mississippian) age, probably late medial Chester, in northwestern Arkansas;<sup>30</sup> the other is the well-known flora of the coal-bearing shale found in the middle or upper portion of the Morrow group, of Pennsylvanian age, in the same region.

The plants from the coal-bearing shale—precisely from the roof of the Washington County coal, which occurs in the shale and which has been exploited at a number of points in Washington County—were recorded at the time of preparation by Lesquereux of the volumes on the coal flora<sup>31</sup> as belonging below the †Millstone grit,<sup>32</sup> and therefore of “subconglomerate” age—that is, Mississippian.

The Hale sandstone and the Brentwood and Kessler limestone members of the Bloyd shale contain highly varied marine invertebrate faunas, in which Mississippian types mingle with others of Pennsylvanian age. My review of the plants from the coal-bearing shale in 1893 led to their reference to the Pottsville (Westphalian) group, and specifically to a stage in the upper part of the middle Pottsville or possibly at the base of the upper Pottsville. The consequent transfer of the coal-bearing shale with the overlying Kessler limestone and the associated upper Bloyd shales and sandstones to the Pennsylvanian was followed by the segregation of the Morrow by Adams and Ulrich,<sup>33</sup> at first as a formation and later by Purdue<sup>34</sup> as a group, of basal Pennsylvanian strata.

In northwestern Arkansas and northeastern Oklahoma the Morrow group rests unconformably upon the Pitkin limestone, sometimes known as the “Archimedes limestone” (maximum thickness 100 feet),

which is the youngest formation of Mississippian age in the Western Interior basin. The Morrow group, itself 200 to 400 feet thick in the Fayetteville quadrangle, consists, in ascending order, of the Hale formation and the Bloyd shale. The Hale formation comprises mainly shale with some sandstone and thin limestones, in all ranging from 80 to 300 feet in thickness, in the Eureka Springs quadrangle. It carries a marine fauna and a few plants (p. 50). On it rests the Bloyd shale, which reaches a maximum thickness of 75 feet and which includes three members of unusual interest—at the base the Brentwood or †Pentremital limestone, which has a maximum thickness of 80 feet in the Fayetteville quadrangle; next, the coal-bearing shale, 10 to 20 feet thick; and above that the Kessler limestone, which has a maximum thickness of 70 feet in the Fayetteville quadrangle but averages only 2 to 4 feet in the quadrangles to the east. In some places the Kessler limestone forms the top of the Bloyd shale, but in others it is overlain by as much as 50 feet of shale and sandstones, which complete the Morrow group.

Resting with unconformity on the Morrow group lies the Winslow formation, comprising about 6,000 feet of sandstones and shales as developed in the Winslow quadrangle, south of the Fayetteville quadrangle. This formation begins with quartz conglomeratic material, on account of which, together with the mixture of Mississippian and Pennsylvanian invertebrates in the Kessler and lower stages of the Morrow group, it was formerly treated as the base of the †Upper Carboniferous (Pennsylvanian), the “subconglomerate beds”, including the coal-bearing shale and other members of the Morrow group below, being then regarded as †Lower Carboniferous (Mississippian).

It is important to remember that the Winslow formation, overlying the Morrow group with slight evidence of unconformity, is laterally continuous with and for the most part, at least, equivalent to the Atoka formation, about 3,000 feet in thickness; also that the Atoka overlies the Wapanucka limestone (300 feet thick), which carries shells classed as of Morrow age.

Paleobotanically the Morrow group (Pennsylvanian), which rests unconformably on the Pitkin limestone, of Chester age, is known almost solely by the flora of the coal-bearing shale, a thin member in the lower part of the Bloyd shale and at about the middle of the group. Next to the shale at Mazon Creek, Ill., the coal-bearing shale of Washington County, Ark., is paleobotanically the most fully explored deposit in the Carboniferous of the United States. In Arkansas about 125 plant species have been found in it, and these clearly and unmistakably indicate correlation of the terrane with the shales above the Lookout sandstone in Alabama and Tennessee; the Norton formation, above the Lee,

<sup>30</sup> White, David, Fossil flora of the Wedington sandstone member of the Fayetteville shale: U. S. Geol. Survey Prof. Paper 186-B, 1937.

<sup>31</sup> Pennsylvania 2d Geol. Survey Repts. P and PP, 1879, 1884.

<sup>32</sup> A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

<sup>33</sup> Adams, G. I., and Ulrich, E. O., Zinc and lead deposits of northern Arkansas: U. S. Geol. Survey Prof. Paper 24, pp. 28-29, 1904.

<sup>34</sup> Purdue, A. H., U. S. Geol. Survey Geol. Atlas, Winslow folio (no. 154), p. 3, 1907.

in southwestern Virginia; the Sewell formation of central and southern West Virginia; and the lower part of the Upper Lykens group of coals in the southern anthracite region of Pennsylvania. All these are of middle Pottsville age, as also is the Caseyville sandstone of southern Illinois and western Kentucky. A study of the relations and distribution of the elements in the Jackfork and Stanley floras shows that the deposits are distinctly older than the plant life of the coal-bearing shale of the Morrow group, including but two species that have been definitely recognized as present also in the shale.

In view of the middle Pottsville age of the coal-bearing shale of the Morrow group, as shown by the fossil floras, it may be provisionally concluded that the lower portions of the group are more or less fully equivalent to the lower Pottsville of the Appalachian trough. Unfortunately, little is known either as to the flora of that portion of the Morrow group lying below the coal-bearing shale or as to marine faunas in the lower Pottsville of the eastern basins. A few stem casts and impressions of *Lepidodendron* found by Miser in the Hale sandstone, the basal unit of the Morrow group, point toward the complete inclusion of the Morrow in the Pennsylvanian, but these plant remains are not of a nature to permit a more precise reference of the Hale.

The Jackfork is referred to the early Pottsville, earlier than the coal-bearing shale of the Morrow group—specifically the lower Pottsville, which embraces the Lookout sandstone of Georgia and Tennessee, the Lee formation of Virginia, the Pocahontas, Fire Creek, and Raleigh coal groups of West Virginia, and the Lower Lykens coal group of the southern anthracite field in Pennsylvania. Probably the whole of the Stanley shale falls in the same unit of the lower Pennsylvanian.

The Jackfork sandstone has not yet revealed any plant association that can be regarded as Mississippian in age—not to mention a stage so low in the Mississippian as that to which the lower part of the Caney shale is generally referred.

The Atoka sandstone of Oklahoma, also derived from Llanoria, passes laterally into the Winslow formation of Arkansas and is evidently in large part equivalent to it. The Atoka lies on the Johns Valley shale locally and is described as resting on the Caney shale near Wesley and Ti, Okla.; on the Wapanucka limestone (of Morrow age) between Le Flore and Stringtown, Okla.; and even on beds as old as the Woodford chert near Bengal, Okla. The Winslow rests unconformably on the Morrow group and is nowhere seen on any formation of later date, whence it is believed that the Atoka, as well as its near equivalent the Winslow, is, for the most part, at least, of post-Morrow age.

Little paleobotanic material has been gathered from the Atoka, but the small amount examined belongs to a stage as high as the coal-bearing shale of the Morrow, or probably higher. There remains, therefore, no evidence of weight to prove that the Jackfork and Stanley formations are of Mississippian age, except the apparent superposition of Mississippian shale on the Jackfork. That this superposition, observed at only a few points, is normal rather than by thrust I profoundly doubt. Otherwise, there is a marine Chester fauna in beds correlated with the Moorefield shale, the Fayetteville shale, and the Batesville sandstone, overlying Llanoria-derived beds which I can view only as in their entirety Pennsylvanian and as probably not earlier than the earliest known Pottsville of the Appalachian trough. A very rude estimate of the volume of sediments composing the remaining portions of the Jackfork sandstone and the Stanley shale indicates more material than would suffice to construct a mountain range 12,000 feet high, with appurtenant spurs and foothills, reaching from Atoka, Okla., to Little Rock, Ark., a distance of about 200 miles. That such orogenic movement, synclinal deformation, and erosion took place within very late Chester time and constituted a distinct episode completed so shortly before the post-Mississippian uplift without being a part of that uplift is highly improbable.

It may be asked, however, whether we have to do with an adventitious or precocious flora or a hold-over fauna. There is nothing in the general make-up of the flora, in the characters developed, or in the association of the genera and species that appears abnormal or out of order. On the other hand, the few marine invertebrates reported from the lower Pottsville of the Appalachian trough offer little evidence for use in any attempt to correlate lower Morrow or other probably basal Pennsylvanian formations of any other region.

#### RELATIONS TO THE WEDINGTON AND OTHER CHESTER FLORAS

In general, the fossil land floras of the Mississippian of North America are very imperfectly known. A few species were described by Dawson<sup>35</sup> from the lower Carboniferous of the Canadian maritime provinces. A few have been described by Meek<sup>36</sup> and Lesquereux<sup>37</sup> from the Pocono (basal Mississippian) or from slightly younger stages in the Appalachian trough, and a number of forms have been described by Lesquereux<sup>38</sup> and

<sup>35</sup> Dawson, J. W., Report on the fossil plants of the Lower Carboniferous and Millstone grit formations of Canada, pp. 5-42. Canada Geol. Survey, 1873.

<sup>36</sup> Meek, F. B., Descriptions of new species of fossil plants from Alleghany County, Va.: Philos. Soc. Washington Bull., vol. 2, appendix 8, pp. 1-19, pls. 1-2, 1875.

<sup>37</sup> Lesquereux, Leo, Description of the coal flora of the Carboniferous formation in Pennsylvania: Pennsylvania 2d Geol. Survey Rept. P., vols. 1 and 2, 1880; vol. 3, 1884; atlas, 1879.

<sup>38</sup> Lesquereux, Leo, Paleontological report of the fossil flora of the Coal Measures of the western Kentucky coal field: Kentucky Geol. Survey 3d Rept., pp. 499-556, pls. 6-7, 1857.

Noe<sup>39</sup> from the Chester of Illinois, Indiana, and western Kentucky. Unpublished material from several stages of the Appalachian Mississippian, collected by D. B. Reger in West Virginia and by me in southwestern Virginia and eastern Pennsylvania, is partly described in manuscript.

The only land flora of known upper Mississippian age yet described from the trans-Mississippian portion of the United States is that found in the Wedington sandstone member near the top of the Fayetteville shale of northwestern Arkansas, recently described.<sup>40</sup> This flora, comprising 36 species, consists (a) of forms identical with or very closely allied to others characteristic of the upper Chester in other regions; (b) of unique forms; and (c) largely of plants related more or less closely to Pennsylvanian forms.

In the first category are species of *Rhacopteris*, two forms of *Cardiopteris*, an archaeocalamarian strobilus comparable to *Pothocites*, a *Lepidodendron* nearly inseparable from *L. volkmannianum*, a *Lepidocystis* characteristic of the upper Chester in the Appalachian trough and found also in the Lower Carboniferous limestone at Rothwaltersdorf, Silesia, and a species of *Rhynchogonium*, most closely bound to forms in the uppermost Lower Carboniferous of Scotland and in the Lower Carboniferous of northern Russia and Spitsbergen.

Some of the ferns or fernlike types, such as the *Rhodea*, are identical with or closely related to species described from what was formerly known as the "Culm" of central Europe. The Lepidodendrons not mentioned above are new species, some of which, like the *Lepidostrobus* and *Lepidophyllum*, are Mississippian in general features and nearest relations. The ambiguous group *Lepidodendron veltheimianum*, of both the Culm and the lower Westphalian, is also present. The Archaeocalamariae consist of forms having a large percentage of alternating ribs. Some of the species agree with forms that have usually been included in the Culm species *Archaeocalamites scrobiculatus*, though they are obviously younger than the typical phase of that species, coming from distinctly Lower Carboniferous beds both in Europe and in America.

Some of the forms mentioned above as characteristic of the Chester are present and known only from beds of that age in the Appalachian trough, as well as in Illinois, southern Indiana, and western Kentucky, where the typical *Lepidodendron volkmannianum* also is present. It should be added, however, that *Cardiopteris*, formerly regarded as exclusively Mississippian, is rarely present in Culm beds recently included by European paleobotanists in the Namurian (basal Upper Carboniferous).

On the basis of the characteristic Mississippian types already noted, the Wedington flora would readily be referred to the Chester, and probably to the upper Chester, by most if not all paleobotanists. It has no form common also to the Pocono. It is a middle if not an upper Chester flora and is characterized by forms identical with or closely related to the upper Chester floras of the Eastern Interior basin and the northern Appalachian trough.

None of the plants noted as characteristic of the Mississippian are present in the floras of the Jackfork and Stanley formations. No representatives of the genera *Cardiopteris*, *Rhacopteris*, and *Chlamidostachys* (cf. *Pothocites*) are present. No forms of the group represented by *Lepidodendron volkmannianum* and *Lepidocystis chesterianus* have been found. *Rhynchogonium* is represented by a different and considerably larger species, but the genus is present also in the upper Pottsville. The calamarian stems show as frequent or even more frequent alternation of ribs at the joints and are more clearly affiliated with the Pennsylvanian forms than are those of the Wedington, though some of them might be placed in *Archaeocalamites scrobiculatus*, which is by some authors very comprehensively grouped in a collective species to include forms present in the Namurian (Culm) and the lower Westphalian.

A single lepidophyte, *Lepidodendron* cf. *L. wedingtonense*, in the Jackfork is provisionally placed under the name of a Wedington species, but the identification is too uncertain for the attachment of appreciable stratigraphic weight. *Sphenopteris mississippiana*, an early representative of the *Sphenopteris hoeninghausii* group, and *Rhodea goepperti* are common both to the Wedington and to the Jackfork and Stanley floras. *Sphenopteris mississippiana* is perhaps indistinguishable from *Sphenopteris hoeninghausii*, forma typica, of the Namurian (Culm), of which *Rhodea goepperti* appears to be characteristic.

There appears to be no other species yet found in the flora of the Jackfork or the Stanley which is found also in the Wedington flora.

The comparison of the Jackfork and Stanley floras with the flora of the Wedington sandstone member of the Fayetteville shale shows (1) the absence from the Jackfork and Stanley of all clearly Mississippian types present in the Wedington and of all forms yet recognized as characteristic of the Chester in other parts of America, (2) the presence in either the Stanley or the Jackfork of but two or possibly three forms found also in the Wedington, and (3) nothing whatever indicative of an earlier age than that of the Wedington, which is middle Chester if not upper Chester.

The examination and comparisons leave no recourse but to conclude that both the Stanley shale and the Jackfork sandstone are younger than the Wedington

<sup>39</sup> Noe, A. C., The flora of the western Kentucky coal field, in Weller, Stuart, Geology of the Princeton quadrangle: Kentucky Geol. Survey, ser. 6, vol. 10, pp. 127-148, text figs. 1-24, 1923.

<sup>40</sup> White, David, Fossil flora of the Wedington sandstone member of the Fayetteville shale: U. S. Geol. Survey Prof. Paper 186-B, 1937.

sandstone member. The difference is relatively distinct, though the floral representations in hand are unfortunately small. There appears, therefore, to remain little or no doubt that the Stanley as well as the Jackfork is younger than the entire Fayetteville shale and its Mississippian correlatives.

#### SYSTEMATIC DESCRIPTIONS

##### Genus *ARCHAEOCALAMITES* Stur, 1875<sup>41</sup>

The stems, all with moderately thick woody cylinders, which are referred with some doubt to the genus *Archaeocalamites*, are only with difficulty distinguished from the genus *Calamites*, for many of the ribs of the pith cast are found to alternate at the very compact node. On the other hand, however, the nodes in the carbonized material, such as that shown in *Archaeocalamites stanleyensis*, are hardly apparent except where the carbonaceous residue of the woody cylinder has been removed.

No foliage or fructification of the types recognized as distinguishing *Archaeocalamites*, or *Asterocalamites*, as it is sometimes known, is present in the collection. A solitary stem of the *Sphenophyllum* type is with reasonable certainty correlated with the leaf verticils from the same locality that belong rather clearly to the genus *Sphenophyllum*, though they do not differ widely from certain forms, such as *Sphenophyllum tenerimum*, referred by Old World paleobotanists as foliage of *Archaeocalamites*.

The thickening of the node from which branches are given off, as in figure 9, plate 13, also seems to align the species *A. stanleyensis* with the genus *Archaeocalamites* rather than with *Calamites*. On the other hand, the stems from the same locality which I have described as *Calamites miseri* and *Calamites menae*, while distinguished by their broader ribs, well-developed leaf traces, shorter internodes, and thinner wood, show frequent continuity of ribs across the nodes, which in *C. menae*, a ramose type, are constricted, much as in *Archaeocalamites scrobiculatus*.

The stem fragments which I describe as *Calamites menae* are rather definitely related to the species *Calamites miseri*, from the same locality. Both of these might be referred to *Archaeocalamites*, and both are possibly identical with forms referred by authors to that genus. I have separated them therefrom on account of the broader, more frequently alternating ribs, the thinner wood, and the sometimes large, prominent leaf scars at the upper ends of the pith costae.

##### *Archaeocalamites coraloides* White, n. sp.

Plate 14, figure 23

Stems rather slender, rigid, segmented in internodes in length measuring about twice the diameter; pith

<sup>41</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 9, 1875.

nodes very slightly constricted and very narrow, marked by rather narrow transverse constrictions; costae of pith cast very numerous, 60, more or less, in number, in the internode, rounded, rigid, mostly continuous at the node, with small oval nerve traces.

This species, though represented by a single pith cast, appears to be readily distinguished from other calamarian stems of similar size by the large number of small, rather closely placed, dorsally rounded costae, which number about 60 in the entire circumference. No other stem known to me in the Mississippian or Pennsylvanian of the Southwest is so evenly and narrowly costate. No satisfactory data are at hand relating to the probable thickness of the outer woody and cortical tissues. However, from some of the analogies, including the rather large number of continuous ribs and the narrow vertical depressions between the ribs at the nodes, it seems probable that the stem originally possessed a rather thick outer cylinder and that the characters of the plant were those of *Archaeocalamites* rather than *Calamites*. Through its narrow, fine costae *Archaeocalamites coraloides* is possibly most closely related to the stems tentatively described as *Archaeocalamites gracilis* from the Wedington sandstone.

Locality: Parnell Hill, sec. 6, T. 7 S., R. 25 W., Pike County, Ark.; collected by J. P. Hansell, March 1, 1932 (U. S. Geological Survey lot 8329).

Figured specimen: U. S. Nat. Mus. 39440.

##### *Archaeocalamites stanleyensis* White, n. sp.

Plate 13, figures 7-11

Stems of moderate size, rigid in aspect, with very finely and irregularly striated outer cylinder, which is thick, leaving a dense carbonaceous residue when preserved; pith casts in moderate relief with closely placed, relatively narrow, round-terete, rather coarsely striate costae, the greater number of which alternate or are set somewhat obliquely at the very compact and slightly depressed, very narrow node; nodes apparently rather distant, slightly enlarged or broadly dilated, apparently by development of the woody cylinder, at the branched nodes, which are infrequent; branches 2 or 4 to the node, with relatively large points of insertion on the pith casts and much thickened outer tissues, which taper rapidly upward from the very thick base; fructification and leaves unknown.

The common calamarian type of the Stanley shale from the railway cut near Gillham, Ark., is shown in figure 10, plate 13. When the outer cylinder is preserved as coaly matter or limonitic incrustation, the ribs are with difficulty discernible externally, though occasionally they are obscurely expressed through the very irregular striate cortex, as shown in the figure. Close examination with the lens indicates probable segmentation of the specimen into three internodes, but the ribs are for the most part so nearly continuous

that it is difficult to detect the nodes. Scaling of the cortical and woody residue reveals a portion of the node in which most of the ribs are more or less obliquely placed where not distinctly alternating, the node being very close-knit and hardly constricted. In the un-compressed specimens, such as those illustrated in figures 7 and 11, plate 13, there is but slight evidence of constriction of the nodes, two of which are shown in figure 7. The internodes are relatively slightly longer in the pith cast photographically illustrated in figure 11.

In the broadest stem, 3½ centimeters as flattened, found in the collection obtained near Mena, no costation is visible through the impression, to which very little carbonaceous matter now adheres. A slight constriction of the node in the pith is shown in figure 8, plate 13, which is the reverse of figure 10.

An interesting feature of the stem of this species is seen in the marked dilation of the cylinder and cortical tissues at those nodes at which branches are given off, as illustrated in figure 9, plate 13. Two branches originate in this verticil, which forms a part of the only rameous fragment of this species recognized in the collection. Its reference to this genus and species rests upon the thick carbonaceous residue as much as upon other characters.

To the genus *Archaeocalamites* and even to *A. stanleyensis* I refer a number of stems from the coarser Stanley shale or the sandstones of the Jackfork sandstone, in which the costation of the pith is very indistinct or is wholly masked by the external tissues, as in the species above described. At the same time, however, the evidence of regular pith costation is so obscure that doubt remains even as to the generic identification.

*Archaeocalamites stanleyensis* is distinguished by its relatively narrow, closely placed, rounded and irregularly striate costae, most of which alternate or are set obliquely with sharp ends at the close-knit nodes, which are narrowly lineate, with very slight depression, and which are rather distant from one another, though generally they are hardly visible beneath the outer thick irregular striate woody and cortical tissues, so that frequently the nodes are very difficult to detect beneath the residues of the outer cylinder. It is distinguished from *Archaeocalamites wedingtonensis*, from the Wedington sandstone, by its narrower, more compact costae, which alternate in greater numbers at the node, and by the thickness of the outer tissues, which are so dense as frequently to conceal entirely the nodes of the pith cast. The plant in hand differs from that to be described from the same deposit as *Calamites miseri* by the relatively thin outer cylinder and the relatively short nodes at which the very broad and flatly rounded, distinctly striate costae are marked by large oval-round leaf traces. On the other hand, in *Calamites menae*, later discussed, the nodes are relatively short and may have two or more branches at

each node, the nodes being more constricted than in *A. stanleyensis*, their impressions in the pith cast being narrowly and slightly indented, as in some of the forms referred by authors to *Archaeocalamites*. The relatively short costae and the leaf scars are apparent in all the observed specimens of *C. menae*.

Localities: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, DeQueen quadrangle, Ark.; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874). Bottom of 40-foot well at C. E. Moorland's house, 8 miles east of Atoka, Okla.; collected by David White, 1911 (U. S. Geological Survey lot 6240). Devils Hollow, near Talihina, Okla., SE¼ sec. 32, T. 4 N., R. 21 E., Tuscaloosa quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014).

Figured specimens: U. S. Nat. Mus. 39435-39439.

Genus CALAMITES (Walch) Schlotheim, 1820 <sup>42</sup>

*Calamites inopinatus* White, n. sp.

Plate 12, figures 1, 13-15

Stems very short, articulate, apparently of varying diameter and branching irregularly or in irregular series; nodes 3 to 10 millimeters or more in length, close-knit, the ribs being close-set, continuous for the most part, rounded, and practically contiguous; internodes very irregular in length; branch scars not very numerous and not more than two to any node; several intervening nodes may have no branch scars.

*Calamites inopinatus* is possibly a multirameous or fertile portion of a form described as *Calamites miseri* on account of its relatively wide ribs and short nodes. Intermediate stages between *C. miseri* and the stem in hand, shown in figures 1, 13, and 15, plate 12, are wanting. Figure 15 shows both the irregularity in the length of the internodes and the continuity of most of the ribs, which are truncated by a sharp transverse shallow depression, hardly wider than a knife. Nowhere is it definitely observed that two branch scars originate in the same node. In the fragment shown in figures 1 and 13 a branch scar appearing at the lower left is apparently the only branch scar in this fragment of stem. The ribs and the nodes are well shown in this portion of the pith cast, and the general aspect of the stem impression in the species is indicated in the none too well preserved fragment shown in figures 1 and 13.

Although it is similar in certain respects to some of the stems from the older Pennsylvanian described as *Calamites approximatiformis* and *Archaeocalamites radiatus*, I know of no associated or earlier plant in which the internodes are so short and in which irregularity of diameter of the stem as well as of mode of branching is so obvious as in the stems here illustrated.

Localities: Lower part of Jackfork sandstone, SE¼ sec. 33, T. 4 N., R. 21 E., Tuscaloosa quadrangle, Oklahoma; collected

<sup>42</sup> Von Schlotheim, E. F., Die Petrefactenkunde, p. 398, 1820.

by H. D. Miser, April 30, 1927 (U. S. Geological Survey lot 8340). Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskahoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014).

Figured specimens: U. S. Nat. Mus. 39426-39428.

**Calamites menae White, n. sp.**

Plate 14, figures 16, 17, 21

Stems rather slender, articulated in relatively short internodes, which are shorter or about one and one-half times longer than wide, with thin outer cylinder, hardly contracted at the nodes, which on the pith cast are marked by narrow, shallow transverse creases, at the upper margins of which are placed the branch scars, usually two in number; pith cast distinctly costate, the ribs being rather closely placed and finely and regularly striate-rounded or slightly angular, obtuse at the ends in the nodes, where most of them alternate more or less distinctly; leaf scars rather small, oval or oblong at the end of the costae or more or less distinctly leading into the angles between the costae.

The salient features of this species are the relatively short internodes, which are of about equal length, being rather less or sometimes one-half more in length than the breadth of the stem. The aspect of the pith impression, as seen in figures 16 and 17, plate 14, is strongly suggestive of *Archaeocalamites*, and the form might be referred to that species, notwithstanding its branch scars and the frequently continuous or nearly continuous costae, on account of the sharp transverse indentation of the node. The leaf scars at the upper ends of the very bluntly terminating ribs are shown more distinctly on some fragments.

*Calamites menae*, though having points of resemblance to *Calamites miseri*, such as the relative length of node, is apparently separable from *C. miseri* by its narrower ribs, which are closer and very much more close-knit at the nodes, the nodes being transversely creased, somewhat as in some of the forms of *Archaeocalamites*. In fact, the specimens of *C. menae* have a greater resemblance to that genus than those of *C. miseri*. On the other hand, while *C. menae* resembles specifically *Archaeocalamites stanleyensis* in the aspect of the pith nodes and of the ribs, it is distinguished by the narrower costae, which interdigitate or alternate with acute points, with but faint leaf impressions originating from the intercostal sinuses at the nodes, the ribs themselves being relatively narrower. Though both species appear to bear two branch scars on the branching nodes, which are consecutive in some stems of *C. menae*, the latter lacks the great thickening of the outer cylinder and, in particular, the dilation of the woody matter at the base of the branches, which are seen in *A. stanleyensis*. Therefore, in spite of the apparent similarity in number of branches at the ramosc nodes, I have little hesitation in describing them as differing not only

specifically but generically, with, however, the recognition that other authors may regard them as congeneric.

Localities: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874). St. Louis-San Francisco Railroad 5 miles north of Antlers, Antlers quadrangle, Oklahoma; collected by H. D. Miser, May 9, 1927 (U. S. Geological Survey lot 8335).

Figured specimens: U. S. Nat. Mus. 39433, 39434.

**Calamites miseri White, n. sp.**

Plate 14, figures 13, 22, 24-26

Stems usually gently curved, of moderate or rather small size, with rather thin outer woody tissue, and articulated in relatively compact nodes which are hardly constricted; ribs of pith cast short, very broad, low-rounded, rather regularly and distinctly lineate longitudinally, alternating or set more or less obliquely, with broad obtuse angles, at the nodes, and with large oval-round and prominent leaf scars usually present and occasional faint root scars at the bases of the costae.

The aspect of the common fragments of this species is shown in the several figures. The intercostal furrows are rounded, distinct, and relatively narrow, and the costae themselves are finer and irregularly rugose-striate externally, the inner impression being coarsely and rather distantly lineate, about 10 lines to the costa, and intermediately finely striate. The leaf scars are obvious on nearly all these specimens, including those shown in figures 13 and 22, plate 14, which represent relatively large though slightly compressed trunks or stems in which the carbonaceous residue is seen to form but a thin film. In several of the specimens the internodes are relatively longer than in the illustrated fragments. The young stem or branch shown in figure 24, of which the reverse or impression is shown in figure 22, evidently belongs to the same species, as is shown by the characters of the nodes, ribs, and leaf scars. Distinct alternation of the nodes is seen in the photographic enlargement of a part of the impression in figure 25.

Though presenting very close-knit and hardly constricted nodes, across which many of the pith ribs appear continuous, the species here described belongs with little doubt to the genus *Calamites* and is associated with a group of species of that genus occurring in beds of lower Pottsville age. By its very wide ribs and not very distant nodes *Calamites miseri* suggests some of the stems commonly identified as *Calamites cannaeformis*, which is sometimes dilated at the nodes. As compared with that species the stems in hand are distinguished by the relatively shorter nodes, across which a larger proportion of the ribs are continuous or nearly so, and by the relatively great width of the costae.

In some respects the fragments of *Calamites miseri* are strongly comparable to the small stems with distinct

details shown by Stur<sup>43</sup> and by Kidston and Jongmans<sup>44</sup> as *Calamites haueri* Stur. The form with longer, rigid, and well-rounded ribs approaches closely that illustrated by Kidston and Jongmans<sup>45</sup> as *Calamites schutzeiformis* var. *typicus*.

Localities: Upper part of Stanley shale, Whitley cut or Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874). Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskanoma quadrangle; lower part of Jackfork sandstone as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014). Sandstone nearly 2,000 feet above the base of Jackfork sandstone, southwest corner sec. 16, T. 4 N., R. 24 E., Windingstair quadrangle, Oklahoma; collected by J. A. Taff, August 18, 1899(?) (U. S. Geological Survey lot 8331). St. Louis-San Francisco Railroad 5 miles north of Artlers, Antlers quadrangle, Oklahoma; collected by H. D. Miser, May 9, 1927 (U. S. Geological Survey lot 8335). SW $\frac{1}{4}$  sec. 10, T. 4 N., R. 25 E., Windingstair quadrangle, Oklahoma; collected by J. A. Taff, August 19, 1899 (U. S. Geological Survey lot 8339).

Figured specimens: U. S. Nat. Mus. 39429-39432.

#### Genus SPHENOPHYLLUM Koenig, 1825<sup>46</sup>

##### *Sphenophyllum arkansanum* White, n. sp.

Plate 14, figures 10, 12, 14, 15, 19, 20

Stems curved more or less, rather closely articulate and rather distinctly round-tricostate, the ribs distinctly parallel lineate; nodes 1 to 2 centimeters distant, moderately dilated; leaf verticils joined in a relatively broad collar at the base which is normal to the axis; leaves very open or flaring to nearly a right angle to the axis, six in number, relatively broad, and dorsally rounded at the base, forking at a wide angle about 1 millimeter from the axis, the divisions probably forking again; primary nerves two, one for each of the principal lobes, distinct to the base or very nearly so, forking to give one division for each subordinate lobe, in which it is dorsally depressed.

Although the leaf verticils of this delicate as well as interesting species of *Sphenophyllum* are apparently slightly abraded, the preserved characters readily distinguish it not only in the collection but from other related species. Figure 14, plate 14, photographically illustrates one of the larger stem fragments showing the tricostate stems, the dilation of the nodes, and the rather distinct lineation of the costae. A fragment of the leaf verticil adheres to the lowest node. A more slender fragment with shorter internodes is seen in figure 15, where again shreds of leaves still adhere to some of the nodes. In a single instance only is branching observed. The collections include very slender branches which, but for the costation of the stems and

<sup>43</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, pl. 5, fig. 4, 1877.

<sup>44</sup> Kidston, Robert, and Jongmans, W. J., A monograph of the *Calamites* of western Europe, Atlas, p. 7, pl. 144, figs. 2-3, 1915.

<sup>45</sup> Idem, pl. 68, fig. 1.

<sup>46</sup> Koenig, C., Icones fossilium sectiles, p. 42, 1825.

the dilation at the nodes, might readily be mistaken for *Asterophyllites*, so rigid are the remaining vestiges of leaves.

A leaf verticil which appears slightly shriveled at the periphery is shown in figures 19 and 20. In two of the leaves the twin primary nerves are separated very nearly if not quite to the narrow funicular collar that takes part in the formation of the diaphragm of the stem. The primary nerve diverges gently toward the point of bifurcation of the leaf, beyond which each division apparently gives off subordinate nervilles to supply tapering nerves to the ultimate divisions. In this specimen these divisions seem to be reduced or shriveled as if fertile. It is probable that the normal leaf verticil was as much as 1.15 or 1.5 centimeters in diameter, the lobes of the leaf being relatively rigid.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39441-39444.

#### Genus BOTRODENDRON Lindley and Hutton, 1933<sup>47</sup>

##### *Bothrodendron* sp.

Plate 13, figures 4, 6

The specimen shown in figure 6, plate 13, is one of two fragments from the Jackfork sandstone that are apparently referable to the genus *Bothrodendron*. At first glance the fragment of axis suggests *Lepidodendron* or *Stigmaria*. Closer examination shows that the emergent rhombic cushions are marked slightly above the middle by roundish or oval leaf traces, which are shown in figure 4. Though the details are indistinct, it is seen that the nerve traces are sigillarioid or bothrodendroid, the lateral parichnoian traces being relatively long and convergent downward. The leaf scar is rather deeply notched at the apex. The superadjacent depression rather plainly seen marks the ligular pit.

The fragment in hand presents points of striking similarity to one from the lower Culm of the lower Loire of France figured by Bureau<sup>48</sup> as *Stigmaria ficoides* Brongniart var. *elliptica* Goeppert.

Locality: Three miles southeast of Stringtown, Atoka quadrangle, Oklahoma; collected by H. D. Miser, June 3, 1927 (U. S. Geological Survey lot 8334).

Figured specimen: U. S. Nat. Mus. 39450.

#### Genus LEPIDODENDRON Sternberg, 1820<sup>49</sup>

##### *Lepidodendron subclypeatum* White, n. sp.

Plate 12, figures 16, 17; plate 13, figure 5

Leaf cushions large, squarrose to elongate diamond-shaped, ordinarily prominently protuberant, with

<sup>47</sup> Lindley, John, and Hutton, William, The fossil flora of Great Britain, vol. 2, pls. 80, 81 (description); pl. 117, p. 97, 1933.

<sup>48</sup> Bureau, Édouard, Bassin de la basse Loire, fasc. 2, atlas, pl. 3, fig. 5, 1913. (In the series "Études des gîtes minéraux de la France.")

<sup>49</sup> Sternberg, Kaspar, Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, Heft 1, p. 23, 1820.

narrow rounded keel marked by several transverse frets in the lower part and carinate and deltoid-pitted above the leaf scar, the keels becoming sinuous at the upper and lower extremities; leaf scar distinctly large, generally strongly protruded from some distance above the middle of the bolster, often concealed in part in the flattened impressions by being crushed downward against the flanks of the fields next below them. As compared with the size of the bolster the leaf cushion is large and broad, the proximal borders nearly alined laterally and rounded downward to a rather broad, shallow, medial cusp, the distal lateral borders being turned down somewhat at the lateral angles and a little strongly convex at a slight distance above the angles and less convex or even slightly concave near the upper angle, which is shallowly notched or faintly truncated; nerve trace distinct, generally papillose, located between one-third and one-half of the altitude of the leaf scar and flanked by two rather closely spaced parichnoian traces, which are slightly lower than the leaf trace; lingular pit distinct in deltoid depression above the upper sinus of the leaf scar, parichnoian lobes usually rather indistinct and a little more distant than the parichnoian traces on the leaf trace, oblong-oval or slightly arched laterad.

The species here described is the most common representative of *Lepidodendron* in the Jackfork sandstone. Owing to the highly protuberant leaf scars and the conditions of compression of the cortex, the species presents three most prevalent conditions of preservation. The first and most common is that shown in figure 17, plate 12, in which the bolsters are apparently compressed nearly at right angles to the axis, so that they present a nearly squarrose or slightly rhombic outline in which the upper left is slightly concave, the upper right appearing less so. In this form the lower end of the bolsters is obliquely truncated and the upper end is concealed by overlap. This form provides, however, the most favorable exhibition of the characteristics of the very large leaf scar itself, which at first glance suggests the leaf scar of *Lepidodendron rhodeanum*. In this phase of impression the angles of the leaf scar coincide with the lateral angles of the bolsters to form an extremely broadly ovate pattern which at once suggests a similar phase of *Lepidodendron obovatum* Sternberg. The lower margins of the leaf scar are seen to be either nearly in alinement or rather strongly concave to conform to the rounded cuspatate proximal angle of the scar. The distal lateral borders are rather strongly convex upward near the lateral angles, flattening gradually or even becoming slightly concave before reaching the distal angle, which is notched to conform to the ligular pit.

The nerve trace near the center of the vertical diameter of the leaf scar reveals rather distinctly the elongated parichnoian tracts on the bolster. In a

few specimens the stage of maceration has preserved remnants of the transpiration envelopes leading from the parichnoian traces of the leaf scar downward through the bolster, where they seem to be united in a large sheath which probably surrounds the nerve trace also.

The stage of preservation and even the bolsters and the leaf scars shown in figure 17, plate 12, are very similar to the common and typical phase described by Lesquereux from the upper Pottsville of Pennsylvania as *Lepidodendron clypeatum*, which was referred by Zeiller, rather questionably as it seems to me, to *Lepidodendron obovatum*. Surely, however, a close relationship exists between *Lepidodendron subclypeatum*, *L. clypeatum*, and *L. obovatum*.

A phase of preservation, or rather of compression, in which the very large bolsters of this species are compressed so as to reveal the upper fields of the leaf cushion, is shown in figure 5, plate 13. Here the true position of the leaf scar in the upper part of the bolster is approximately indicated, though compressive folding results in the partial concealment of the upper portion of the leaf scar itself. Where uncovered, the leaf scar is found to have the same large pyramidal form, with similar orientation of traces, seen in the more squarrosely impressed bolsters shown in figure 17, plate 12. The specimen shown in figure 5, plate 13, is strikingly similar to the corresponding form of *Lepidodendron clypeatum* illustrated by Lesquereux. Fragments of the Bergeria stage of preservation in which the tissues immediately beneath the outer horny bark of the bolster are preserved are seen in figures 16 and 17, plate 12, and figure 5, plate 13.

A third phase of compression of the bolster in which the lower portion of the field is more fully preserved than in the specimen shown in figure 17, plate 12, and in which the upper fields are not seen is presented in figure 16 of the same plate. In this example the general aspect of the bolster, the form of the leaf scar, uncovered at the lower left, and the fretted keel suggest both *Lepidodendron aculeatum* and *Lepidodendron obovatum*. The leaf scar, however, is broader than in *L. aculeatum*, and the ropy margins of the bolsters so characteristic of *L. aculeatum* are hardly developed. On the other hand, the leaf scar is much more convex along the upper lateral borders and in general narrower than in *L. obovatum* or in *L. clypeatum*, which is suggested by the profile offered by the impressions of the lower fields and bolsters.

The lateral parichnoian appendages, photographically shown in figure 17, plate 12, are somewhat conspicuously seen in several of the bolsters in figure 5, plate 13, and are much less distinctly indicated in figure 16, plate 12. Forms closely similar to those shown in figure 17, plate 12, and figure 5, plate 13, in particular are illustrated by Stur and others under

the name *Lepidodendron veltheimianum*, which, even as restricted by Zeiller, appears to represent a too comprehensive species. The specimen shown in figure 16, plate 12, represents with little doubt one of the types generally referred to *L. veltheimianum*. The parichnoian lobes, however, are easily distinguished on careful examination.

Very close to the species in hand and possibly to be considered as inseparable from it are some of the forms referred by authors to Sternberg's *Lepidodendron obovatum*, especially as that species was redefined by Zeiller.<sup>50</sup> Unfortunately both the use of the name and the recognition of the characters of the Old World plant are greatly—perhaps hopelessly—confused by Sternberg's wrong citation of figures. The real diagnostic features of the species have never been consistently kept clear.

The stem impressions from the Jackfork are perhaps inseparable from the form from the Brookwood coal at Searles, Ala., referred by me to *Lepidodendron obovatum*. They seem, however, to differ from Sternberg's type, and by their somewhat narrower leaf cushions, slightly smaller leaf scars, and the slightly higher positions of the traces on the leaf scar they are distinguished from the true *Lepidodendron clypeatum* of Lesquereux.

Localities: Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskahoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser and Charles Miller, June 1927 (U. S. Geological Survey lot 8336), and by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lots 8014 and 8016). Crest of mountain 1 mile north of Clayton, Tuskahoma quadrangle, Oklahoma; collected by H. D. Miser, May 1927 (U. S. Geological Survey lot 8337). Stream sandstone boulder from Jackfork sandstone, grounds of Choctaw-Chickasaw Sanitarium, mouth of Devils Hollow, northwest corner sec. 3, T. 3 N., R. 21 E., Tuskahoma quadrangle, Oklahoma; collected by Dr. W. E. Van Cleve, superintendent of sanitarium, 1927(?) (U. S. Geological Survey lot 8332). Upper part of Stanley shale 4 miles east of Tuskahoma, Okla.; collected by David White, 1909 (U. S. Geological Survey lot 5669). Miser's no. 01, possibly from Caney shale, Johns Valley, Antlers quadrangle, Oklahoma; Miser's no. 03, sandstone ridges between Johns Valley and Eubanks, Antlers quadrangle, Oklahoma; and Miser's no. 02, crest of Kiamichi Mountain on old road due south of Talihina, Tuskahoma quadrangle, Oklahoma.

Figured specimens: U. S. Nat. Mus. 39445-39447.

#### *Lepidodendron cf. L. wedingtonense* White

Among the fragments from the Jackfork sandstone is a single specimen which invites comparison with *Lepidodendron wedingtonense*, from the Wedington sandstone member of the Fayetteville shale. The bolsters are rather distinctly diamond-shaped and flat across the lower fields, with extremely prominent and very broad leaf scars borne a little way above the

middle. The leaf cushions are flatly carinate, and the keels curve upward and downward tangent to the adjacent bolsters. The leaf scars, one of which is uncovered, have much the form of the scar of *Lepidodendron volkmannianum*, in which the lateral lower borders are slightly concave and prolonged to acute declining points that impart an obovate outline to the impression. The distal angle is low, and the distal lateral margins are nearly straight or slightly convexed. The position of the leaf trace is nearly midway in the height of the leaf scar, and the parichnoian traces are very small and close on each side.

The reference of this specimen to *Lepidodendron wedingtonense* is tentative and by way of comparison. It is based chiefly on superficial resemblance due possibly to the compression of the very highly protuberant cushions. The leaf scars of the Chester form appear to be relatively narrower and much higher in altitude, while the cicatricules are considerably below the middle of the scar. Unfortunately the preservation of the specimen leaves room for doubt as to whether the leaf cushions are corrugated as in *L. wedingtonense*. Should additional material reveal transverse corrugation over the whole width of the bolster, the relation to the Wedington species will be regarded as very much closer.

Locality: Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskahoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014).

#### Genus LEPIDOSTROBUS Brongniart, 1828<sup>51</sup>

##### *Lepidostrobus peniculus* White, n. sp.

Plate 13, figures 1-3

Strobili of moderate length, oblong or linear, about 24 millimeters in diameter, with relatively large axis about 4 millimeters in diameter, marked in very broad and distinct rhombic pattern; sporangiophores close, nearly at a right angle to the axis, 6 to 8 millimeters long, rather narrow, downward-curving or strongly reflexed near the elbow, from which the bract, not over 2 millimeters wide and about 12 to 17 millimeters in length, turns rather sharply upward and slightly inward, while tapering to the slender, relatively delicate apex; sporangium rather narrow, compactly placed between the sporangiophores; character of spores unknown.

A few fragments only represent this species. Two of these, partial counterparts, are shown in figures 1, 2, and 3, plate 13. Figure 1 shows distinctly the inner cast of the axis and the compactly placed sporangia. The details of the cone, though imperfect at best, are, however, better seen in figure 2, a portion of which is enlarged in figure 3. The photograph shows well the origin of the sporangiophores, the ventral creases in

<sup>50</sup> Zeiller, René, Bassin houiller de Valenciennes—Description de la flore fossile, p. 442, 1888. (In the series "Études des gîtes minéraux de la France.")

<sup>51</sup> Brongniart, Adolphe, Prodrome d'une histoire des végétaux fossiles, p. 87, 1828.

them, and the downward turn at the base of the very narrow, relatively delicate, tapering bract, which is traversed by a very thin central nerve.

The species here rather insufficiently described belongs to the comprehensive group referred by various authors to *Lepidostrobus variabilis* Lindley and Hutton. It is clearly distinguished from the British types by its very narrow, relatively fragile, and comparatively long bracts. From *Lepidostrobus occidentalis* the cone in hand is rather readily separated by the well-developed and very broad rhombic cushions on the rather stout axis, by the more closely placed sporangiophores, and by the much longer and more tapering bracts.

Localities: Lower part of Jackfork sandstone, south side sec. 6, T. 7 N., R. 25 W., Pike County, Ark., 7 miles north of Murfreesboro; collected by Bryan Parks, of the Arkansas Geological Survey, 1932 (U. S. Geological Survey lot 8340). Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskanoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014).

Figured specimens: U. S. Nat. Mus. 39448, 39449.

#### Genus SIGILLARIA Brongniart, 1822 <sup>52</sup>

##### *Sigillaria (Rhytidolepis) sp.*

Among the specimens collected by H. D. Miser from the Jackfork sandstone about 5 miles north of Antlers, Okla., is a portion of a slightly water-worn impression which, though hardly permitting the clear discernment of the leaf scars, apparently represents a slightly decorticated impression of a *Sigillaria* of the *Rhytidolepis* group, in which the leaf-bearing medial zones, about 6 millimeters in width, are unfortunately considerably deformed incidentally with the partial plication and horizontal compression of the ribs.

Oval leaf scars are apparently present at intervals of about 18 millimeters along the vertical rib. The leaf scars, if such they are, are about 5 millimeters in length and nearly 4 millimeters in width, and the nerve traces are located considerably above the middle of the leaf scar, in which the lateral traces are elongated vertically.

I know of no ribbed sigillarioid of the upper Mississippian of the Midcontinent region with which to compare this all too obscure specimen. It may be noted, however, that in the fragment in hand the spiral disposition of the leaves, though at a low angle with the horizontal, is not so nearly horizontal as the leaf scars on the lepidophytic stems from the lower Mississippian. Accordingly, while the specimen has little paleontologic or stratigraphic interest, its characters, so far as they are discernible, point toward Pennsylvanian affinities.

Locality: St. Louis-San Francisco Railroad 5 miles north of Antlers, Antlers quadrangle, Oklahoma; collected by H. D. Miser, May 9, 1927 (U. S. Geological Survey lot 8335).

<sup>52</sup> Brongniart, Adolphe, Sur la classification des végétaux fossiles: Mus. histoire nat. Paris Mém., tome 8, p. 222, 1822.

#### Genus STIGMARIA Brongniart, 1822 <sup>53</sup>

##### *Stigmaria* sp.

##### Plate 14, figure 18

The genus *Stigmaria* is represented in the Stanley shale by several detached root scars only. These are comparatively small, and some are provided with an areole of short radiating ridges. It is impossible to identify them specifically with confidence, but the small diameter of the root scar and the mere fact that it is bordered by a stellate areole point to the Mississippian stock, centering about *Lepidodendron volkmannianum*, and to a stratigraphic level in the Chester or in the Namurian, the lowest recognized Upper Carboniferous of Europe.

One root fragment with cicatrix is with little hesitation identified as the umbilical scar of *Stigmaria*. Apparently it is separated from the root along the border of the narrowly convex rim of the umbilical scar. A larger fragment, probably of the same nature, shows a dense ragged rim of carbonaceous matter surrounding the inner fracture margin of the vascular strand.

With the stigmarian cicatrices are associated fragments of the inner hard texta of the seeds which in another place are described as *Rhynchogonium chocavense*.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimen: U. S. Nat. Mus. 39451.

#### Genus ADIANTITES Schimper, emended, 1869 <sup>54</sup>

##### *Adiantites stanleyanus* White, n. sp.

##### Plate 10, figures 26, 28

Pinnae delicate, fragile, with slender divisions of rachis, which is ventrally sulcate, dorsally terete, and very narrowly alate; pinnules alternate, rather distant, thin, slightly pedicellate, oblique to open, narrowly cuneate, obovate to ovate above the cuneate base, asymmetric, narrowing upward to a rounded or inequilateral obtuse apex or sublobate in the lower part, the lobes obliquely rounded or round-truncate; nervation thin, radiate, nearly parallel, and equidistant; primary nerve passing through the upper half of the larger pinnules, lateral nervilles given off low in the pinnule, at a narrow angle, and passing nearly straight, while forking once or twice, to the margin.

Forms characteristic of the pinnules of this species are shown in figures 26 and 28, plate 10. The plant is obviously closely related to that figured by Stur <sup>55</sup> as *Adiantites oblongifolius* Goeppert. In fact, the relationship appears so close that I was at first disposed

<sup>53</sup> Idem, p. 228.

<sup>54</sup> Schimper, W. P., Traité de paléontologie végétale, tome 1, p. 424, 1869.

<sup>55</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, pl. 17, figs. 2-5, 1877.

to refer the fragments from the Stanley shale to the same species. However, close inspection shows that in the American plant the large pinnule is in general more pointed and more narrowly cuneate, the smaller pinnules being distinctly cuneate, notwithstanding their narrowed and obliquely rounded apices. Though the American material is obviously nearer in its characters to that figured from the Austrian Culm by Stur, it differs conspicuously from the more obovate pinnules with rounded apices originally described by Goeppert.<sup>56</sup> Between those pinnules and *Adiantites stanleyanus* the specific distinction is obvious.

The plant in hand is in many respects very close to an unpublished species found in the lower Pottsville (Pocahontas formation) of West Virginia.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimen: U. S. Nat. Mus. 39373.

#### *Adiantites* sp.

Plate 11, figures 14, 16, 19

Ultimate divisions of rachis rigid, narrowly alate, ventrally sulcate, with trifoliate pinnules standing higher ventrad than the rachis, narrowly decurrent, broadly rounded or even cyclopterid to obovate, narrowing downward, often trifoliate, ventrally low-rounded, rugose, nervose, sometimes slightly erose; nervation rather flabellate at the base, forking one to three times while passing upward, equidistant, and curving slightly toward the border.

As indicated by the fragments shown in the figures, the plant in hand rather certainly represents a species of *Adiantites* in which the pinnules are short and compact, the lobes broadly united, and the somewhat flabellate nervation nearly straight and equidistant in all parts of the lamina. But for the details of the ultimate rachis and the lamina, including the lobation and nervation of the lamina, the plant in hand might be compared with some of the small forms from the Pottsville included under the generic name *Cheilanthes*.

The example photographed in figures 16 and 19, plate 11, represents one of the short, broadly rounded, and rather distinctly trifoliate forms. That shown in figure 14, not without doubt referred to this group, seems to represent one of the larger trilobate pinnules in the upper part of the frond.

Although I know of no species to which the form in hand is especially closely related, the material seems insufficient to serve as a basis for a new species. The form is quite distinct from the more elongated cuneate types. It is more compactly trifoliate than any form in the Wedington, and not only is the lobation different,

but the nervation is nearly twice as close as in *Adiantites stanleyanus*.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39374, 39375.

#### Genus ALLOIOPTERIS Potonié, 1897<sup>57</sup>

##### *Alloipteris arkansana* White, n. sp.

Plate 10, figures 3, 10, 11, 13, 20, 21, 23, 27; plate 11, figures 9, 10, 22, 23

Frond rather delicate, upper ultimate pinnae linear, tapering to a narrow point, with rather broadly connate, contiguous pinnules; pinnae of superior order, linear, flexuose or slightly zigzag, with rather narrowly connate pinnules which are contiguous or slightly overlapping, with dorsally sharply round axial nerve, the nerves of the pinnules coming out at an oblique angle, dorsally in relief, and zigzagging strongly at a very open angle to furnish a relatively strong nervile for each of the narrowly angular acute lobes, of which there are usually two and sometimes three in the lower subdivision of the largest pinnules; lamina depressed over the nerves, decurrent on each side of the pinnule at the base of the pinnule, narrowly decurrent along the ultimate rachis, slightly convex ventrad, and marked both over and on each side of the axis and nerves by sparse punctations which, because they appear as depressions in the larger divisions, are possibly to be interpreted as small glands.

The upper ultimate pinnae of this plant, portions of which are shown in figures 21, 23, and 27, plate 10, are by their form, the axial characters, the highly angular, semizigzag character of the median nerve, and the distinct nervation rather clearly referable to the genus *Alloipteris*. When, however, the pinnules are more fully developed, as in figures 10, 11, and 13, plate 10, the denticulation is distinct, and the pinnules and pinnae are suggestive of *Alloipteris essingii*. The largest of the pinnules observed are those shown in figures 9 and 10, plate 11. These, like the preceding, are rather closely similar in their form and nervation to the plants described by Stur<sup>58</sup> as *Oligocarpia queriefolia* (Goeppert) and by Gothan<sup>59</sup> as *Alloipteris queriefolia* (Goeppert). The pinnules are hardly so distinctly asymmetric, however, as in the upper Silesian plant.

As shown in the photographic enlargement, figure 10, plate 11, the apices of the pinnules appear to carry small nearly round sporangia of the *Reinschia* type.

<sup>57</sup> Potonié, Henry, Lehrbuch der Pflanzenpaläontologie, p. 138, 1897.

<sup>58</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, p. 209, pl. 15, figs. 7-12, 1877.

<sup>59</sup> Gothan, Walter, Die oberschlesische Steinkohlenflora, Teil 1, Farne und farnähnliche Gewächse: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, p. 107, pl. 21, fig. 1, 1913.

The details of the fructification are, however, rather obscure.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39378-39383.

**Genus APHLEBIA Presl, 1838<sup>60</sup>**

**Aphlebia parksii White, n. sp.**

Plate 10, figures 17, 22

Small form, strongly excentric in outline, triangular ovate, primarily divided into three lobes, the main or median lobe much longer than the two lateral, which are broader than long, the largest lobe shallowly cut into two or three outward-curved, very short, broad, obtusely rounded or rounded-truncate lobes, those of the middle division slightly sublobate; lamina thick, rugose, finely striate parallel to the nervation, which is derived from thick primary nerves entering the base of each division and forking immediately at a narrow angle into rather distant and rather thick secondary nerves, which fork once to three times in passing outward into the lobes.

The specimen photographed and illustrated in figures 17 and 22, plate 10, is the only example of this form in hand. Its characters are so clear, however, as to justify its description in the hope that it may lead to the discovery of other specimens showing its variations and its relations to the ordinary pinnae of the species to which it was attached. On the evidence of the rather distinct coarse nervation and the broad, entire or but slightly denticulate lobes, it appears probable that *Aphlebia parksii* belongs to a species of *Neuropteris* or possibly a *Sphenopteridium*. As seen in figure 17, the lobes of the lower right-hand division are marked by short, sharp teeth, while the corresponding lobe on the opposite division is entire. Two oblong and deep cavities lying along the primary nerves near the base of the central division very strongly suggest vacant sporangia.

Locality: Base of the Jackfork sandstone, south side of sec. 6, T. 7 N., R. 25 W., Pike County, Ark., 7 miles north of Murfreesboro; collected by Bryan Parks, of the Arkansas Geological Survey, 1932 (U. S. Geological Survey lot 8328).

Figured specimen: U. S. Nat. Mus. 39393.

**Aphlebia sp.**

Plate 10, figures 29, 30; plate 11, figure 15

Several specimens in the collection represent a small compact plumose type of *Aphlebia* which is rather easily distinguished by the somewhat radiate arrangement of the lobes, their lanceolate form, and the coarse, upward-turned, distant, and dorsally terete nerves, which point into the upper divisions of the frond.

<sup>60</sup> Presl, Karl, in Sternberg, Kaspar, Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, p. 112, 1838.

The upper surface of a fragment is seen in figure 29, plate 10. Figure 15, plate 11, shows a specimen from the same locality in which the subdivisions are more linear, narrower, and more nearly erect.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39394, 39376.

**Genus HETERANGIUM Corda, 1845<sup>61</sup>**

**Heterangium? sp.**

Plate 11, figures 21, 28; plate 14, figure 11

Among the fragments of stem and root found in the Jackfork sandstone are several which, like that shown in figure 11, plate 14, are marked by short transverse hacklelike indentations filled with carbonaceous matter suggesting the sclerotic disks of *Heterangium*. However, the evident vascular system and, especially, the relatively narrow vascular axis so evident in many of the Pennsylvanian stems showing *Heterangium* structure are here lacking. Doubt therefore remains as to the generic identification.

The specimen figured is strikingly comparable to the petiolar impression from the upper Culm illustrated by Bureau<sup>62</sup> as *Dactylotheca aspera* Zeiller.

Localities: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874). Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskaoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014).

Figured specimens: U. S. Nat. Mus. 39404, 39405.

**Genus NEUROPTERIS (Brongniart) Sternberg, 1825<sup>63</sup>**

**Neuropteris antecedens Stur?**

Plate 11, figure 6

The very small fragment shown in figure 6, plate 11, though insufficient for satisfactory specific identification, is so far in agreement with the fragments figured by Stur<sup>64</sup> that it is tentatively referred to his species, although the apex of the terminal is broader and indicative of a probably shorter terminal than appears to be characteristic for Stur's species, which was found in the Moravian-Silesian roof slates. The apparent differences in the form of the terminal pinnule are on the side of *Neuropteris pocahontas*, with which the specimen is possibly in equally close agreement.

<sup>61</sup> Corda, A. J., Beiträge zur Flora der Vorwelt, pp. 22-23, 1845.

<sup>62</sup> Bureau, Édouard, Bassin de la basse Loire, fasc. 2, atlas, pl. 28, fig. 2, 1913. (In the series "Études des gîtes minéraux de la France.")

<sup>63</sup> Brongniart, Adolphe, Mus. histoire nat. Paris Mém., tome 8, p. 233, 1822. Sternberg, Kaspar, Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, Tentamen, p. xvii, 1825.

<sup>64</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 53, pl. 15, 1875.

With reference to the specimen figured by Stur in plate 15 of his Culm-Flora, I feel constrained to express the conviction that the forms illustrated in figures 5 and 6 are specifically different from those shown in figures 1 to 4, being in some respects, as to their pinnules rather than their pinnae, more nearly related, perhaps, to the form described by Stur as *Neuropteris dluhoschii* and illustrated by him in figure 9, plate 11, of the second part of his Culm-Flora.

The extremely close approach, evident even in this very small fragment, to a species characteristic of the lower Pottsville is significant.

Locality: Base of the Jackfork sandstone on top of the Stanley shale, south side of sec. 6, T. 7 N., R. 25 W., Pike County, Ark., 7 miles north of Murfreesboro; collected by Bryan Parks, of the Arkansas Geological Survey, 1932 (U. S. Geological Survey lot 8328).

Figured specimen: U. S. Nat. Mus. 39408.

#### *Neuropteris elrodi* Lesquereux

Plate 10, figures 18, 19; plate 11, figure 8

Pinnules lanceolate-triangular, somewhat falcate, tapering from the base to the obtusely pointed apex, ventrally convex on both sides of the midrib, slightly inflated at the cordate base, with rather strong median nerve deeply depressed on the ventral side, in relief dorsad, persisting very nearly to the extreme apex of the pinnule; lamina minutely rugose; nervilles strong, originating at a very acute angle and forking once or twice, rarely a third time, while arching rapidly and rather closely spaced to the border, which most of the nervilles meet at a right angle.

Though a single pinnule, illustrated in figures 18 and 19, plate 10, is the sole representative of this species in the collection in hand, its agreement with the form from beds of middle Pottsville age described by Lesquereux<sup>65</sup> as *Neuropteris elrodi* is so nearly complete as to justify the expectation that additional specimens, when they are found, will confirm the present tentative identification. *Neuropteris elrodi* is unusually clearly characterized by the narrowly triangular, more or less distinctly arcuate pinnules, cordate at the base, conspicuously round-convex ventrad on each side of the depressed midrib, and bluntly pointed at the apex; the rather irregular nerves, though originating very obliquely, arch outward while forking once or twice, so that through the greater part of the distal half of the lamina on each side of the midrib they pass nearly at a right angle to the border.

The typical form of *Neuropteris elrodi* is rare in the Pottsville of the Appalachian trough, but as variations of subspecies it has a rather wide geographic as well as stratigraphic range, the latest phase, perhaps deserving a distinct specific name, being found in the uppermost

<sup>65</sup> Lesquereux, Leo, Description of the coal flora of the Carboniferous formation in Pennsylvania: Pennsylvania 2d Geol. Survey Rept. P., vol. 1, pp. 107-108, pl. 13, fig. 4, 1880.

Pottsville of northern Pennsylvania. In the middle Pottsville of the Tennessee coal field there is a form with straight, narrowly triangular but much larger pinnules, which was later described by Lesquereux<sup>66</sup> under the same name. This form, specimens of which have been distributed in Europe, differs from the true *Neuropteris elrodi* by the straight pinnules and by the more broadly attached, oval or ovate and slightly flabellate-nerved ultimate lateral pinnules. It is specifically distinct from that originally described under this name by Lesquereux, to which the plant from the Stanley shale is tentatively referred.

The Tennessee plant has been referred, not without reason, by Zeiller<sup>67</sup> and Potonié<sup>68</sup> among other European paleobotanists, to *Neuropteris schlehani* Stur<sup>69</sup> in connection with their reference to that species also of the fragment figured by Stur<sup>70</sup> as *Neuropteris dluhoschii*. Some of the pinnules in the fragment of a pinna shown in Stur's figure under *N. dluhoschii* are seen to be slightly upturned near the apex. Their close approach to the true *Neuropteris elrodi* is unquestionable. On the other hand, the fragments illustrated by Stur in the same plate as *N. schlehani*, while distinctly alethopteroid, have pinnules most of which are even slightly pedicellate and which, though traversed very nearly to the apex by the ventrally depressed and persistent median nerves, are not so evidently narrowed at the apex as the specimen named *N. dluhoschii* or the American material first described as *N. elrodi*. In short, *Neuropteris elrodi* may be identical with *N. dluhoschii* of Stur, but it is assuredly distinct specifically from some of the plants referred by European authors to *N. schlehani*, if not from the type specimens described by Stur as *N. schlehani*.

It is, furthermore, reasonably evident that, while Stur's *Neuropteris dluhoschii* is very closely related to *Neuropteris elrodi* and is possibly quite as closely connected with the fragments illustrated and described by Stur as *Neuropteris schlehani*, it is even further from the plant from the Warrior coal field of Alabama originally described by Lesquereux<sup>71</sup> as *Neuropteris smithii* than is the original *N. schlehani*, under which *N. smithii* also is generally cited—quite erroneously, I believe—in synonymy by Zeiller,<sup>72</sup> Gothan,<sup>73</sup> and other European paleobotanists. As now extended *N. schlehani* is made to include a variety of forms, some of which are large, some small, and some that have oblong or oval ter-

<sup>66</sup> Lesquereux, Leo, op. cit., vol. 3, pp. 735-736, 1884.

<sup>67</sup> Zeiller, René, Bassin houiller de Valenciennes—Description de la flore fossile, pp. 280-283, pl. 46, fig. 3; pl. 47, figs. 1-2, 1888. (In the series "Études des gîtes minéraux de la France.")

<sup>68</sup> Potonié, Henry, Die floristische Gleiderung des deutschen Carbon und Perm: K. preuss. Landesanstalt Abh., neue Folge, Heft 21, p. 30, fig. 22, 1876.

<sup>69</sup> Stur, Dionysius, Die Culm-Flora; K. k. geol. Reichsanstalt Abh., Band 8, Heft 2, p. 175, pl. 11, figs. 7 and 8, 1877.

<sup>70</sup> Idem, p. 184, pl. 11, fig. 9.

<sup>71</sup> Lesquereux, Leo, op. cit., vol. 1, pp. 106-107, pl. 13, figs. 1-3, 1880.

<sup>72</sup> Zeiller, René, op. cit., pp. 280-283, 1888.

<sup>73</sup> Gothan, Walter, Die oberschlesische Steinkohlenflora, Teil 1: K. preuss. Landesanstalt Abh., neue Folge, Heft 75, p. 202, pl. 49, figs. 2-3; pl. 53, fig. 3, 1913.

minals and ovoid, nearly flat lateral pinnules, with slightly flexuose nerves springing either in part from the rachis, as in the smaller lateral pinnules, or from a midrib that fades considerably before reaching the apex of the leaf. Some have distant, some close nervation. None of the illustrated European forms seem to agree with the original *N. smithii* as described by Lesquereux from the shales accompanying the Jefferson coal in Alabama or as found in the roof of the Beckley coal in southern West Virginia. A review both of the species appearing in different regions and at different horizons in the Pottsville of the Appalachian trough and of the species of the Old World literature on the paleobotany of the early Upper Carboniferous suggests a necessity for the restudy of the European forms generally referred to *Neuropteris schlehani* as well as the forms from the Appalachian Pottsville still grouped under *N. smithii*. Such a study should lead to the differentiation of several species which will not only present distinctive specific characters but will also prove of immediate practical stratigraphic value.

While I admit the possibility that a sequence of specimens from a single place and bed may show complete intergradation between the forms illustrated by Stur as *Neuropteris schlehani* and *N. dluhoschii*, the differences being relatively slight, it cannot be doubted that several forms referred at one time or another by Lesquereux to *Neuropteris smithii*, as well as the true type of that species, cannot properly be joined specifically with *N. schlehani*.

In passing it may be remarked that the plants illustrated by Zeiller arrange themselves with *Neuropteris schlehani*, some phases approaching a form intermediate between *Neuropteris pocahontas* and the original *Neuropteris smithii*. As illustrated by Potonié, one of whose figures is reproduced by Gothan,<sup>74</sup> *Neuropteris dluhoschii* is included with a form having obtusely rounded pinnules and fairly persistent midrib. The plant from Königshütte, upper Silesia, illustrated by Gothan<sup>75</sup> under the same name, seems to approach *Neuropteris smithii* but is easily distinguished therefrom by the more elongated and apiculate lateral pinnules, the pointed terminals, the more distinct and persistent midribs, and the more alethopteroid nervation. The pinnule from Zabrze, illustrated by Gothan,<sup>76</sup> may profitably be compared with the pinnule from the Stanley shale.

In view of the fact that specimens showing the form of the pinna, the relative positions of the pinnules, and the development of the subordinate lateral pinnules of the ultimate pinna seem not yet to have been brought to light, the characters of the plant shown in figures 5 and 6, plate 15, of the first part of Stur's Culm-Flora,

where it is erroneously referred, as I view it, to *Neuropteris antecedens*, deserve reexamination. The form from the Moravian-Silesian roof slates is more distinctly heterophyllous, with notably distant pinnules. It is further illustrated, with enlargement of nervation, by Gothan.<sup>77</sup> The elongated or typical *schlehani* form is illustrated by Bureau<sup>78</sup> from the upper Culm of the basin of the lower Loire.

It should be noted that both the Waldenburg beds in which *Neuropteris schlehani* occurs and the Moravian-Silesian roof slates carrying *Neuropteris antecedens* are now referred by many paleobotanists to the Namurian, the basal Upper Carboniferous. The inclusion of the Westphalian, which covers the Valenciennes occurrence, within the limits of Pottsville time has long been recognized.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39406, 39407.

#### Genus PALMATOPTERIS Potonié, 1891 [1893]<sup>79</sup>

##### *Palmatopterus subgeniculata* (Stur) Renier<sup>79a</sup>

Plate 11, figures 4, 13, 20, 29, 30

Several of the fragments from the railway cut near Gillham approach so closely, by their geniculate axes, their size, and especially the lobation of their pinnules, the fragments from the Ostrau beds described by Stur<sup>80</sup> as *Diplothemma subgeniculata* that I have little hesitation in referring them to that species. Examples are those shown in figures 4, 13, 20, 29, and 30, plate 11. No other species known to me approaches so closely the fragments in hand.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39401-39403.

#### Genus RHODEA Presl, 1838<sup>81</sup>

##### *Rhodea cf. R. tenuis* Gothan

Plate 11, figures 5, 12

The collection from the Stanley shale near Gillham, Ark., contains several very small fernlike fragments, one of which is illustrated in figures 5 and 12, plate 11, in which we have relatively thick and slightly flexuose, rugose-striate rachis faintly bordered by a decurrent lamina. The rugosity is produced by minute, short, sharp, spicule-like scales, which are sparsely scattered

<sup>74</sup> Gothan, Walter, Die oberschlesische Steinkohlenflora, Teil 1: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, p. 202, 1913.

<sup>75</sup> Bureau, Édouard, Bassin de la basse Loire, fasc. 2, atlas, pl. 13, fig. 2, 1913. (In the series "Études des gîtes minéraux de la France.")

<sup>76</sup> Potonié, Henry, Ueber einige Carbonfarne: K. preuss. geol. Landesanstalt Jahrb., Band 12, p. 1, 1891 [1893].

<sup>77</sup> Renier, Armand, La flore du terrain houiller sans houille dans le bassin du Coucheant de Mons: Soc. géol. Belgique Annales, tome 3, Mém., p. 156, 1906.

<sup>78</sup> Stur, Dionysius, Die Culm-Flora: K.-k. geol. Reichsanstalt Abh., Band 8, Heft 2, p. 136, pl. 12, figs. 8-9, 1877.

<sup>79</sup> Presl, Karl, in Sternberg, Kaspar, op. cit., Hefts 7, 8, p. 109, 1838.

<sup>79a</sup> Gothan, Walter, Die oberschlesische Steinkohlenflora, Teil 1: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, p. 202, 1913.

<sup>80</sup> Idem, pl. 49, fig. 2.

<sup>81</sup> Idem, pl. 49, fig. 3-A.

over the surfaces of the pinnules as well as the rachis. The pinnules are alternate, lacinately cut in narrow close lobes nearly erect to the base, and sometimes arching outward. The material, which is insufficient for satisfactory specific characterization and definition, resembles, in the general mode of division and the aspect of the pinnules, so closely that illustrated by Gothan<sup>82</sup> as *Rhodea tenuis* that it is provisionally placed with that species. There is room for doubt, however, even as to the generic identity of the material in hand.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimen: U. S. Nat. Mus. 39392.

***Rhodea goepperti* (Ettingshausen) Stur**

Plate 10, figures 6–9, 12, 14–16; plate 11, figures 7, 25, 26

*Trichomanites goepperti* Ettingshausen, K. Akad. Wiss. Wien, Math.-naturwiss. Cl., Denkschr., Band 25, p. 25, figs. 10, 11, 1865.

*Rhodea goepperti* (Ettingshausen) Stur, K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 41, pl. 11, figs. 2–7, 1875.

Sphenopteroid development with a narrow arcuate or gently curved rachis, becoming flexuose or zigzag, ventrally depressed, dorsally rounded, and always very narrowly alate; pinnules erect, alternate, open, relatively distant, forking at angles of about 60°, the lobes bifurcating once and sometimes a second time at the same angle, with slight diminution in width of the lamina; lamina rather thick, of nearly equal width in all parts of the pinnule, and sparsely provided with short spines along the median nerve and in the bordering regions.

The plant here described was, on account of its general delicacy, the zigzag branching of the segments, and the very small, very open, and nearly equally wide lobes, thought at first to be inseparable from *Sphenopteris gersdorffii*. However, a further close comparison leaves little escape from identifying the plant in hand with *Rhodea goepperti* (Ettingshausen) Stur, which is not uncommon in the lower portion of the Upper Carboniferous in central Europe, as the formations there are now classified. A typical portion of a segment showing the positions of the slightly distant alternate pinnae, the narrow, slightly cuneate lobes, broadly divided, is seen in figure 12, plate 10. The fragment photographically represented in figure 26, plate 11, illustrates the rather distant, slender, narrowly alate upper divisions. The geniculate or reflexed pinnae near the base of the frond are indicated in figure 25, plate 11. Fragments typical of the pinnules and pinnae are seen in figures 6–8, plate 10.

<sup>82</sup> Gothan, Walter, Die oberschlesische Steinkohlenflora, Teil 1: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, pl. 3, figs. 1, 2. 1913.

(strongly suggesting *S. gersdorffii*), and in figures 9 and 15, plate 10. The fragment shown in figure 16, plate 10, is the most delicate of the series.

This species has been well illustrated by Stur under the name *Rhodea goepperti* (Ettingshausen) sp. Ettingshausen, the author of the species, described it under the generic name *Trichomanites*.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39384–39391.

**Genus SPHENOPTERIDIUM Schimper, 1874<sup>83</sup>**

***Sphenopteridium dawsoni* (Stur) Potonié**

Plate 11, figure 11

*Archaeopteris dawsoni* Stur, K.-k. geol. Reichsanstalt Abh., Band 8, Heft 1, p. 66, pl. 12, figs. 2–4, 1875.

*Sphenopteridium dawsoni* (Stur) Potonié, Lehrbuch der Pflanzenpaläontologie, p. 131, 1897.

Gothan, K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, p. 8, pl. 1, figs. 1, 1a, text fig. 1, 1913.

The fragments referred to this species, one of which is illustrated, are hardly sufficient for detailed description of the species, which has been adequately illustrated by both Stur and Gothan.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimen: U. S. Nat. Mus. 39377.

**Genus SPHENOPTERIS (Brongniart) Sternberg, 1825<sup>84</sup>**

***Sphenopteris* cf. *S. mississippiensis* White**

Plate 11, figures 17, 18

The fragments here referred to *Sphenopteris mississippiensis*, first described from the Wedington sandstone member, which occurs in the upper part of the Fayetteville shale, of upper Mississippian age, are hardly sufficient for independent description, but they seem to agree so closely with the corresponding portions of the Wedington plant, or even the extremely minute early forms of *Sphenopteris hoeninghausii*, as to leave little doubt with regard to the specific reference.

Some of the earliest forms, with relatively delicate ultimate pinnae and minute slightly distant pinnules, sometimes reported as typical of the earliest or the true *Sphenopteris hoeninghausii*, are, in my judgment, very much closer to some of the fragments here figured than they are to the later robust types with relatively elongated cuneate lobes, illustrated and described by different authors under the same name. An example of the type with minute and relatively delicate ulti-

<sup>83</sup> Schimper, W. P., Traité de paléontologie végétale, tome 3, pp. 487–488, 1874.

<sup>84</sup> Brongniart, Adolphe, Mus. histoire nat. Paris Mém., tome 8, p. 233, 1822. Sternberg, Kaspar, op. cit., Tentamen, p. xv, 1825.

mate pinnules and pinnae comparable to those here figured is seen in the illustration of *S. hoeninghausii*, forma typica, in Gothan's upper Silesian flora.<sup>85</sup> The specimens from the Stanley shale near Gillham deserve close comparison with the fragments from the Wedington sandstone.<sup>86</sup>

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimen: U. S. Nat. Mus. 39372.

#### *Sphenopteris* sp.

Plate 10, figures 1, 2, 4, 5

Figures 4 and 5, plate 10, represent the upper surface of a small fragment of a rather compact ultimate pinna, the under surface of which is shown with clear detail in figures 1 and 2. There are several forms that have been described from the beds formerly regarded as Culm of central Europe to which this might be compared—with little profit, however, on account of the lack of adequate detail as well as adequate specimens.

The example shown in figures 1 and 2 is probably fertile, and if so it appears to be comparable to the genus *Discopteris*.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39370, 39371.

#### Genus *WARDIA* White, 1904<sup>87</sup>

##### *Wardia suspecta* White, n. sp.

Plate 11, figures 1-3

Seeds of moderate size, ovate, with slightly cuneate base, rather strongly convexly rounded border, the flattened interior portion or nucellus concave, longitudinally distinctly striate, rounded at the base, and narrowly canaliculate just within the upper border.

The proportions and general aspect of the seeds are photographically represented in figures 1-3, plate 11, which represent the mold and the reverse of a seed from Gillham, Ark. The seeds from the Stanley shale are in general form rather closely related to those from the lower Pottsville of the Appalachian trough, but they are not so far elongated or narrowly cuneate toward the base, and the carbonaceous residue is somewhat thicker.

By reason of the proved generic connection between *Wardia* and *Adiantites* in the Appalachian trough, it is probable that the seeds from Gillham are similarly re-

<sup>85</sup> Gothan, Walter, Die oberschlesische Steinkohlenflora, Teil 1, Farne und farnähnliche Gewächse: K. preuss. geol. Landesanstalt Abh., neue Folge, Heft 75, p. 58, pl. 13, fig. 1, 1913.

<sup>86</sup> White, David, Fossil flora of the Wedington sandstone member of the Fayetteville shale: U. S. Geol. Survey Prof. Paper 186-B, pl. 4, figs. 4, 5, 11, 13, 14, 15, 17, 18, 20, 21, 22, 23, 30, 36, 39, 1937.

<sup>87</sup> White, David, The seeds of *Aneimites*: Smithsonian Misc. Coll., vol. 47, pt. 3, p. 323, 1904.

lated to the accompanying leaves of *Adiantites*. In fact, it is rather probable that *Wardia suspecta* is the seed of *Adiantites stanleyanus*. In view of the doubt remaining, however, it seems wiser to give the seed a separate specific name.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. nos. 39399, 39400.

#### Fern rachides

Plate 10, figures 24, 25; plate 11, figures 24, 27

Several types of rachis belonging to fernlike plants appear to be worthy of special note. That shown in figure 27, plate 2, suggests some of the rachiopteroid forms of the Mississippian. It is rather strongly lineate, and the epidermis is provided with minute chafflike or shaggy scales.

On account of the pitted character of the emerging branch, both the relief and the impression of the fragment are shown in the stem seen in figure 24, plate 10. The rachis is distinctly creased in connection with the apparently very wide petiolar opening in the woody cylinder. The deep furrow in the impression is characteristic of some of the fernlike fronds of the older Mississippian.

The fragment seen in figure 24, plate 10, shows a thickened central strand bordered by rather broadly canaliculate lateral areas. The aspect of the stem and of the base of the branch, also shown, are suggestive of a rachis like that of *Rhodea*.

The bifurcating stem invites comparison with the rachis figured by Bureau<sup>88</sup> from the basin of the lower Loire as *Calymmatotheca tenuifolia* var. *linkii*.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. no. 39395-39398.

#### Genus *CALYMMATOTHECA* Zeiller, 1883<sup>89</sup>

##### *Calymmatotheca* sp.

Plate 14, figures 1, 9

The carbonized lobe synangium of *Calymmatotheca*, shown in figures 1 and 9, plate 14, is one of several sporangial remains belonging probably to the *C. hoeninghausii* group and probably to the form here identified with a little doubt as *Sphenopteris mississippiensis* White. Some of the earlier types referred by authors to *S. hoeninghausii* and regarded as typical of that species are apparently more nearly related to *S. mississippiensis* than many of the late forms, with larger and more

<sup>88</sup> Bureau, Édouard, Bassin de la basse Loire, fasc. 2, atlas, pl. 14, 1913. (In the series "Études des gîtes minéraux de la France.")

<sup>89</sup> Zeiller, René, Fructifications de fougères du terrain houiller: Annales sci. nat., Botanique, sér. 6, tome 16, p. 182, 1883.

distinctly cuneate pinnular lobes, are to *S. hoeninghausii*.

The specimens from the Stanley shale are comparable also to the smallest of the sporangia illustrated by Bureau<sup>90</sup> from the upper Culm in the basin of the lower Loire as *Calymmatotheca tenuifolia*.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimen: U. S. Nat. Mus. no. 39412.

**Genus RHABDOCARPOS Goeppert and Berger, 1848<sup>91</sup>**

**Rhabdocarpos (Lagenostoma?) costatus White, n. sp.**

Plate 12, figures 9, 10

Fruit fusiform, oval, truncate at both ends, the outer envelope traversed by close, high, erect longitudinal ribs conforming to a more or less distinctly trigonal nucleus; ribs rather narrow, thin, and sharp and persisting the whole length of the envelope.

The fruit is readily distinguished from related pieces of *Rhabdocarpos* by its slender form and the very close parallel, knife-edge sharp ribs traversing the outer envelope. No other fruit of its size is, so far as I have knowledge, so compactly ribbed.

The species is evidently related to the seeds from the upper Pottsville of Ohio described by Newberry<sup>92</sup> as *Trigonocarpum ornatum* and *T. multicarinatum*; with the former it agrees rather closely in general form and size, and with the latter it conforms in the large number of sharp ribs continuing the full length of the fruit.

Localities: Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskahoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014). Lower part of Jackfork sandstone, SE $\frac{1}{4}$  sec. 33, T. 4 N., R. 21 E., Tuskahoma quadrangle, Okla.; collected by H. D. Miser, April 30, 1927 (U. S. Geological Survey lot 8340).

Figured specimens: U. S. Nat. Mus. 39416, 39417.

**Rhabdocarpos secalicus White, n. sp.**

Plate 12, figures 4-7, 11

Seeds very small, elliptical, 5 to 6 millimeters in length and 2 $\frac{1}{2}$  to 3 millimeters in width, with rather broad basal attachment and narrowed at the apex in short micropylar neck, the external coat rather soft and more or less faintly pluricostate, the inner coat, conforming to the nucellus, rigid, convex, and tricarinate, with each of the three low ribs broadening upward slightly to its union around the micropylar tube.

The aspect of the partly collapsed seed, of which the outer distantly striate coat is collapsed, is shown in

<sup>90</sup> Bureau, Édouard, op. cit., pl. 9, figs. 4, 4 A.

<sup>91</sup> Goeppert, H. R., and Berger, Reinholdus, in Berger, Reinholdus, De fructibus et seminibus ex formatione lithanthracum, p. 20, 1848.

<sup>92</sup> Newberry, J. S., Descriptions of fossil plants: Ohio Geol. Survey Rept. 1, pt. 2, Paleontology, p. 368, pl. 42, fig. 7; p. 369, pl. 42, fig. 8, 1873. See also Lesley, J. P., Dictionary of the fossils of Pennsylvania and neighboring States: Pennsylvania 2d Geol. Survey Rept. Pt. 1, vol. 3, pp. 1215-1216, 1890.

figures 5 and 7, plate 12. Figure 7 reveals indistinctly the costae of the nutlet proper. The shape of the nutlet is still better shown in figure 5, plate 12, in which the rib on the right is shown in profile, while the three converging ribs are seen to close in about the slender rodlike micropyle.

A single segment of the nutlet, in which the hard outer portion has been broken away, is shown in figures 4 and 11, plate 12, where again the micropylar tube is in evidence.

The specimens described as *Rhabdocarpos secalicus* are possibly indistinguishable from specimens from the Morrow group of northwestern Arkansas, Lacoe collection 25972, placed by Lesquereux along with *Carpolithes latior*, a much larger fruit. Both the Morrow seed and an undescribed species from the Warrior coal field of Alabama (Lacoe collections 25945 and 25944) are apparently indistinguishable from *R. secalicus*. All, though very small, bear the costae characteristic of *Trigonocarpum*. The species in hand also invites comparison with the American material described by Lesquereux<sup>93</sup> as *Carpolithes minimus* Sternberg, which again is distinctly a *Trigonocarpum*. The Wilkes-Barre seeds referred by Lesquereux to *C. minimus* are rather shorter and less distinctly costate than those from Alabama and Arkansas already cited. The Stanley seeds agree rather closely in their diagnostic characters with the seeds from Campbells Ledge, near Pittston, Pa., described by Lesquereux<sup>94</sup> as *Rhabdocarpos latecostatus*. The chief difference lies in the more oblong outline and more distinct trigonocarpal costation of the specimens from the Stanley. *Rhabdocarpos secalicus* is also comparable with *C. latior* of Lesquereux,<sup>95</sup> especially as that species is represented by specimens identified by Lesquereux from the upper Pottsville at Campbells Ledge.

Locality: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Ark.; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39413-39415.

**Genus RHYNCHOGONIUM Heer, 1876<sup>96</sup>**

**Rhynchogonium choctavense White, n. sp.**

Plate 12, figures 2, 3, 8

Fruits small, oval-oblong to oval-ovate, 1 $\frac{1}{4}$  to 1 $\frac{1}{2}$  millimeters in length, about 8 to 10 millimeters wide, sometimes somewhat fusiform, longitudinally and narrowly costate externally, in about 10 narrow, acute longitudinal wings; inner impression smoother, more or less obscurely triangular, with low, shallow ribs extending nearly the whole length and 6 or 8 inter-

<sup>93</sup> Lesquereux, Leo, Description of the coal flora of the Carboniferous formation in Pennsylvania: Pennsylvania 2d Geol. Survey Rept. P, vol. 3, p. 825, pl. 110, fig. 68, 1884.

<sup>94</sup> Idem, p. 816, pl. 110, fig. 34.

<sup>95</sup> Idem, p. 826, pl. 110, figs. 69-70.

<sup>96</sup> Heer, Oswald, Flora fossilis arctica, vol. 4, Abt. 1, p. 19, 1876.

mediate inwardly rounded ribs that grow in strong relief toward the top, where they flare out to form a shallowly funnel-like flaring truncate top, which is about one-half of the greatest diameter of the fruit; apex capped by a broad, very shallowly conical plug.

The species here described is evidently closely related to that from the Wedington sandstone described as *Rhynchogonium fayettevillense*. However, as shown in figure 2, plate 12, it differs from that species by the slightly broader and sharper keels of the outer envelope and by the union of the thick inner teeth, which take part in the micropylar ring. The plug, which was unobserved in the specimens of the Wedington, is here seen to be broad and shallowly conical. The aspect of the nucellus with its round costae, which generally reach the entire length of the seed, is shown in figure 3, plate 12. The chalazal area is rather large, but the chalazal pit is small and slightly concealed in the base of the figured specimen. Figure 2 represents the inner impression of the heavy envelope within which a seed like that shown in figure 3 may have been removed. The nucellus is seated in the thin cavity left by the principal envelope.

Localities: Upper part of Stanley shale, 4 miles east of Tuskhoma, Okla.; collected by David White, 1909 (U. S. Geological Survey lot 5669). Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskhoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014). Lower part of Jackfork sandstone, SE $\frac{1}{4}$  sec. 33, T. 4 N., R. 21 E., Tuskhoma quadrangle, Oklahoma; collected by H. D. Miser, April 30, 1927 (U. S. Geological Survey lot 8340). Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39409-39411.

#### Genus TRIGONOCARPUM Brongniart, 1828 <sup>97</sup>

##### *Trigonocarpum gillhami* White, n. sp.

Plate 12, figure 12; plate 14, figures 5, 6, 7, 8

Fruits small, distinctly triradiate, mostly less than 7.5 millimeters long and 6 millimeters wide, ovate or oval-ovate, broadly attached at the base, tapering rapidly upward to a narrow micropylar neck less than 2 millimeters in length; angular costae three, narrow, not over 0.5 millimeter in width and running from base to apex; outer envelope leathery, rigid, densely and irregularly striate, as by close bifurcating vascular strands.

This species is rather readily recognized by its strongly convex, rigid shell, which is uniformly ovate or oval-ovate and traversed by three narrow ribs that originate in the rather broad attachment and widen

but very slightly in passing upward into the slender, narrow micropylar neck.

Localities: Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874). Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskhoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014). Upper part of Stanley shale, 4 miles east of Tuskhoma, Okla.; collected by David White, 1909 (U. S. Geological Survey lot 5669).

Figured specimen: U. S. Nat. Mus. 39418.

#### *Trigonocarpum vallisjohanni* White, n. sp.

Plate 14, figures 2-4

Oval tricostate seeds about 15 millimeters in length and 11 millimeters in greatest width, about the middle, with three narrow thin costae a little over 1.5 millimeters in width at the base, a little over 2 millimeters in width at the point of junction about the short, rather acute micropylar neck; nucellar cast smooth, convexly rounded between the costae, very slightly cuneate just above the small chalaza, and rather evenly rounded toward the apex.

Examples of the type shown in figures 2-4, plate 14, are not infrequently met in the jumble of plant fragments occupying a thin pocket with angular fragments of fine-grained blue shale at locality 8014.

The similarity of the seeds of *Trigonocarpum vallisjohanni* to those figured by Parkinson <sup>98</sup> and made the basis of the species *Trigonocarpum parkinsoni* is evident, though the Old World species, both as originally illustrated and as exemplified in specimens in the Lacoë collection from Dysart, Fifeshire, Scotland, are more distinctly oval, slightly smaller, and more distinctly apiculate than the fruits from the Jackfork sandstone.

*Trigonocarpum vallisjohanni* is distinguished by its near approach to an oval form, by the smooth intercostal spaces, and by the very thin, narrow but persistent ribs which originate at the base, measure nearly 2 millimeters in width, and pass with slight increase into the short, rather acute micropylar crests.

Localities: Devils Hollow, near Talihina, Okla., SE $\frac{1}{4}$  sec. 32, T. 4 N., R. 21 E., Tuskhoma quadrangle; lower part of Jackfork as mapped by Taff; collected by H. D. Miser, C. L. Cooper, and John Fitts, March 29, 1929 (U. S. Geological Survey lot 8014). Upper part of Stanley shale, Whitley cut on Kansas City Southern Railway, 4 miles south of Gillham, De Queen quadrangle, Arkansas; collected by H. D. Miser, October 21, 1914 (U. S. Geological Survey lot 6874).

Figured specimens: U. S. Nat. Mus. 39423-39425.

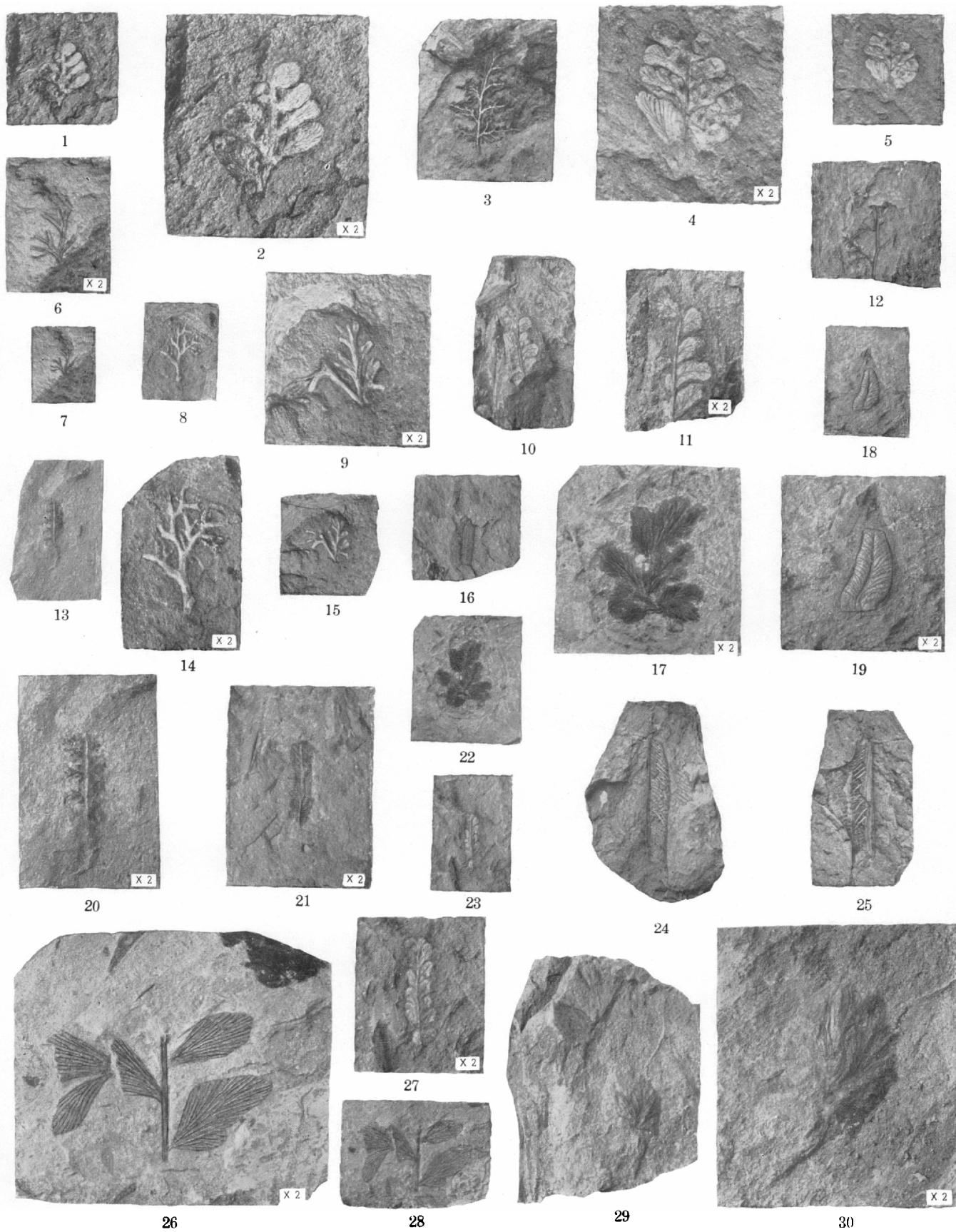
<sup>97</sup> Brongniart, Adolphe, *Prodrome d'une histoire des végétaux fossiles*, p. 137, 1828.  
<sup>98</sup> Parkinson, James, *Organic remains of a former world*, vol. 1, p. 458, pl. 8, figs. 6-8, London, 1804.

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**PLATES 10–14**

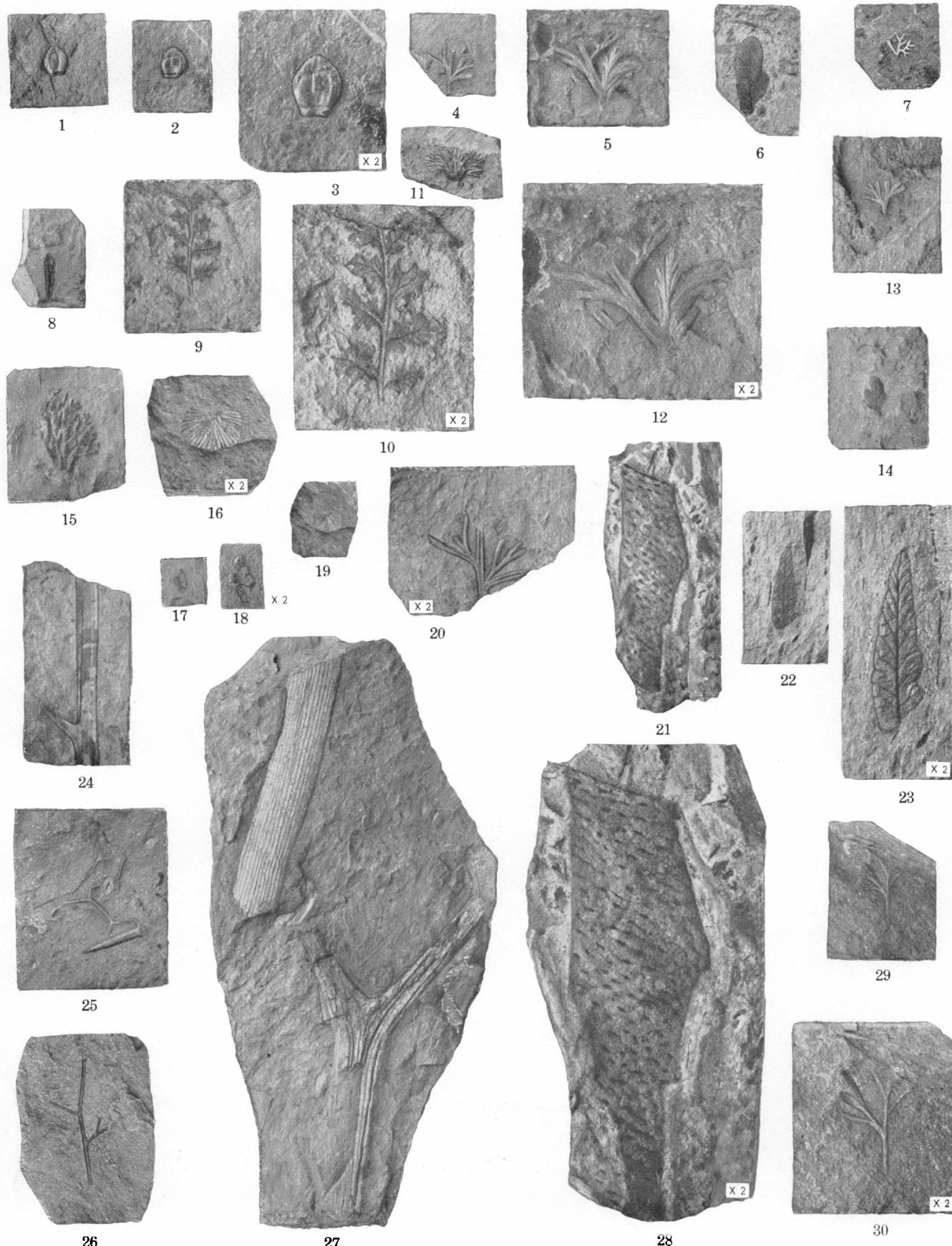




## PLANTS OF STANLEY SHALE AND JACKFORK SANDSTONE.

1, 2; 4, 5. *Sphenopteris* sp.  
3, 10, 11; 13, 20; 21, 23, 27. *Aloipteris arkansana* White, n. sp.  
6, 7, 8, 14; 9, 15; 12, 16. *Rhoda goepperti* (Ettingshausen) Stur.  
17, 22. *Aphlebia parksii* White, n. sp.

18, 19. *Neuropteris elrodi* Lesquereux.  
24, 25. Fern rachides.  
26, 28. *Adiantites stanleyanus* White, n. sp.  
29, 30. *Aphlebia* sp.



## PLANTS OF STANLEY SHALE AND JACKFORK SANDSTONE.

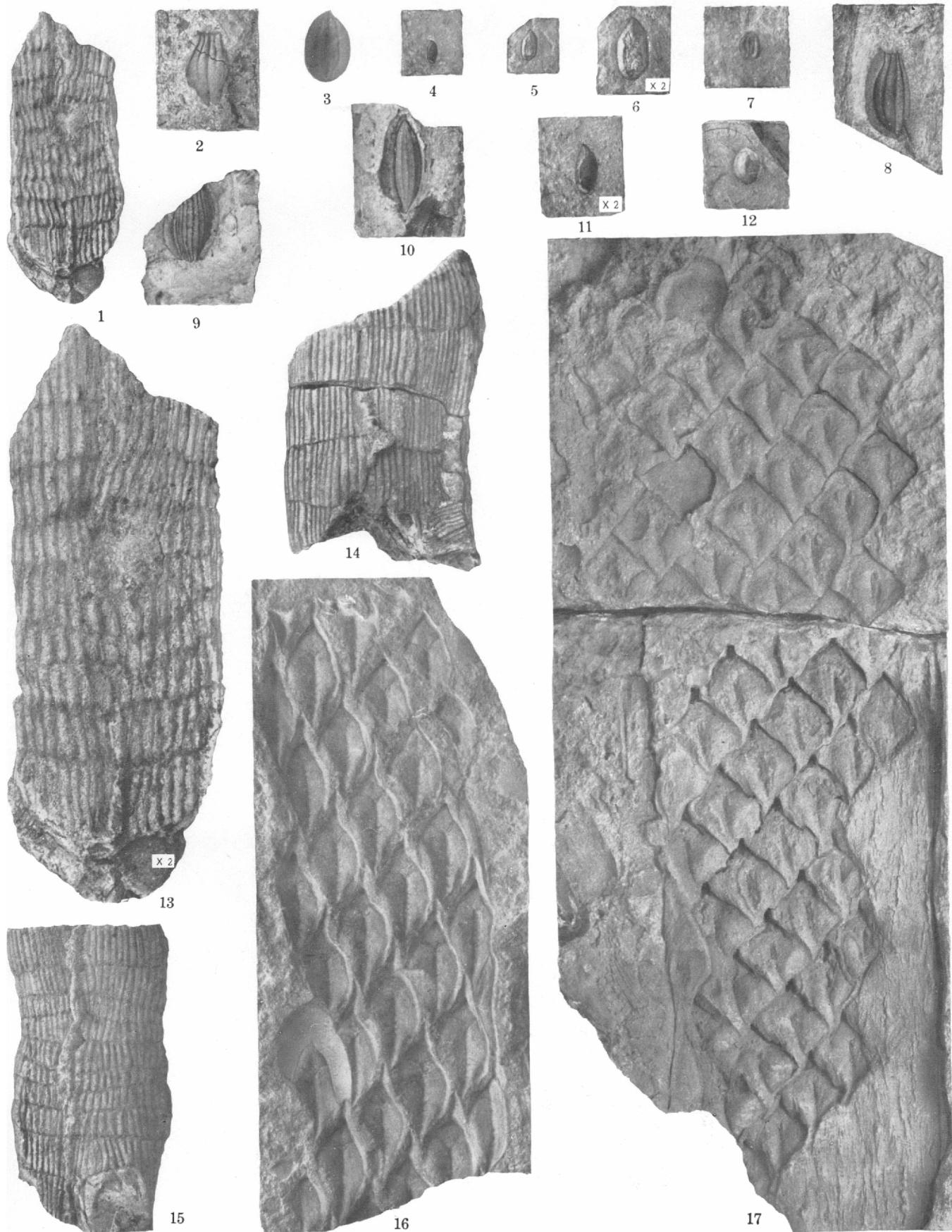
1; 2, 3. *Wardia suspecta* White, n. sp.  
4, 20; 13; 29, 30. *Palmatopteris subgeniculata* Stur?

5, 12. *Rhodea* cf. *R. tenuis* Gothan.

6. *Neuropteris antecedens* Stur?

7; 25; 26. *Rhodea goepperti* (Ettingshausen) Stur.  
8. *Neuropteris etrodi* Lesquereux.  
9, 10; 22, 23. *Atloipteris arkansana* White, n. sp.  
11. *Sphenopteridium dawsoni* (Stur) Gothan.

14; 15; 16, 19. *Adiantites* sp.  
17, 18. *Sphenopteris* cf. *S. mississippiana* White.  
21, 28. *Heterangium*? sp.  
24; 27. Fern rachides.

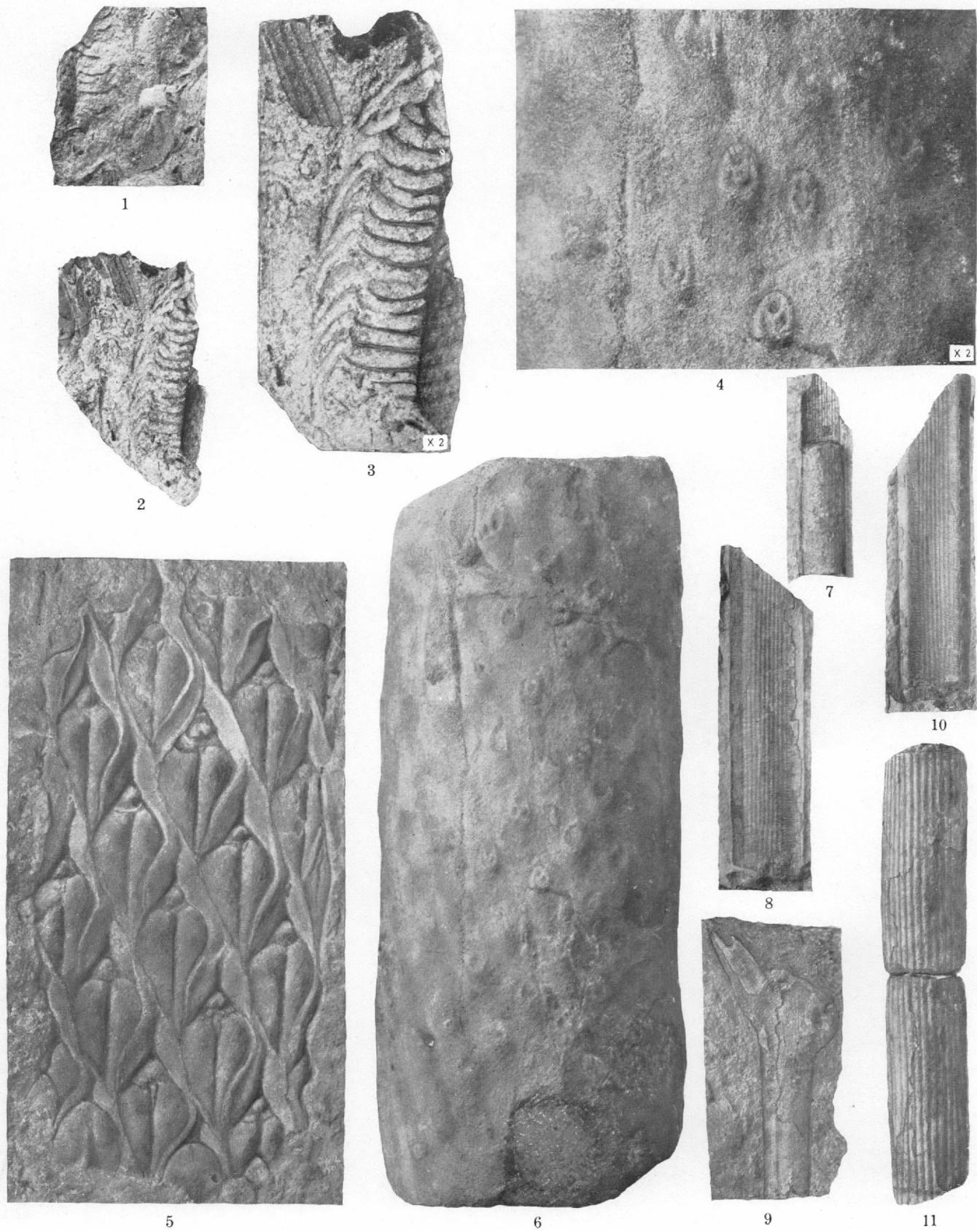


## PLANTS OF STANLEY SHALE AND JACKFORK SANDSTONE.

1, 13; 14; 15. *Calamites inopinatus* White, n. sp.  
2; 3; 8. *Rhynchogonium choctawense* White, n. sp.

4, 11; 5, 6; 7. *Rhabdocarpus secalicus* White, n. sp.  
9; 10. *Rhabdocarpus costatus* White, n. sp.

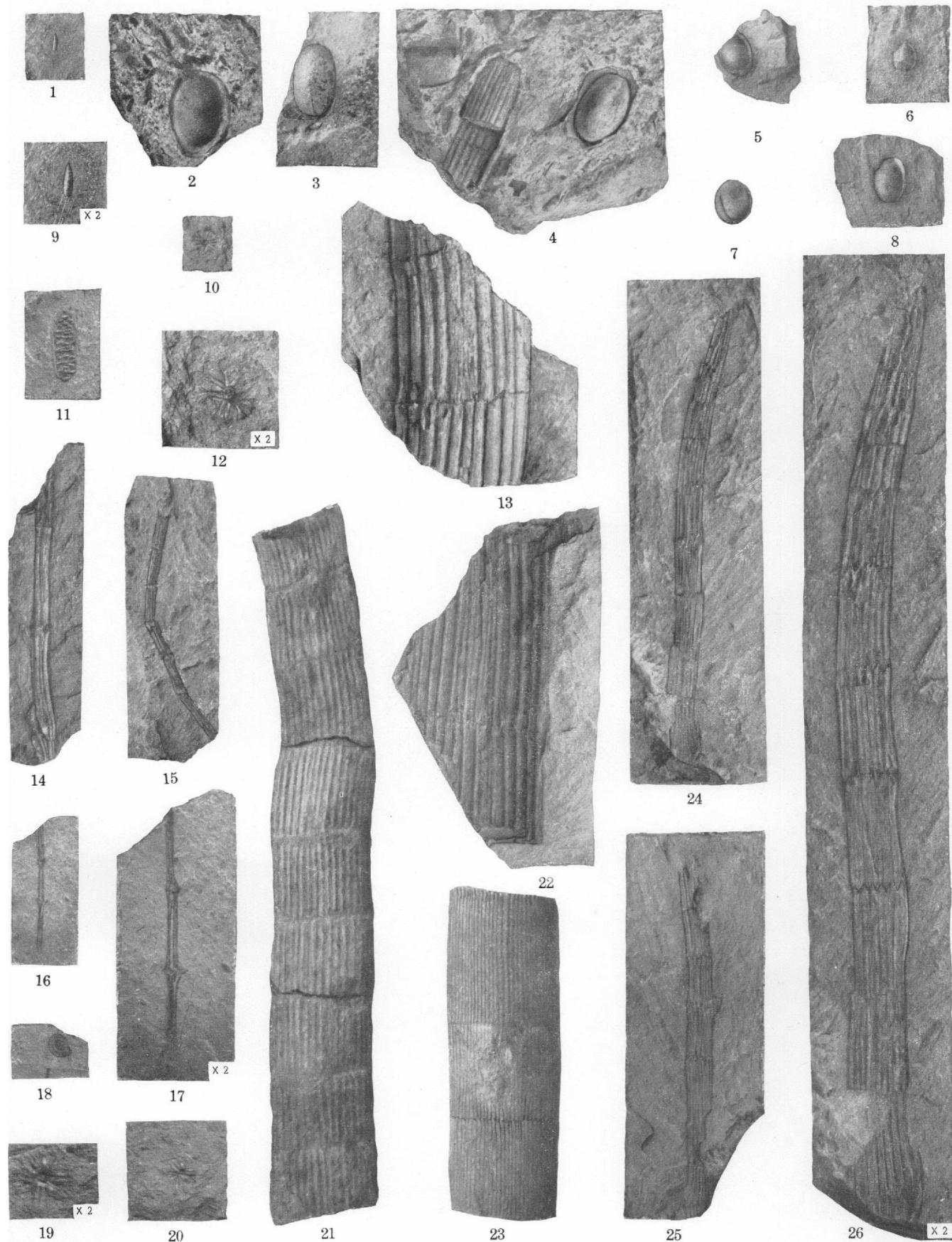
12. *Trigonocarpum gilhami* White, n. sp.  
16; 17. *Lepidodendron subclypeatum* White, n. sp.



PLANTS OF STANLEY SHALE AND JACKFORK SANDSTONE.

**1; 2; 3.** *Lepidostrobus peniculus* White, n. sp.  
**4, 6.** *Bothrodendron* sp.

**5.** *Lepidodendron subclypeatum* White, n. sp.  
**7; 8; 9; 10; 11.** *Archaeocalamites stanleyensis* White, n. sp.



## PLANTS OF STANLEY SHALE AND JACKFORK SANDSTONE.

1, 9. *Calymmatotheca* sp.  
2; 3; 4. *Trigonocarpum vallisjohanni* White, n. sp.  
5; 6; 7; 8. *Trigonocarpum gillhami* White, n. sp.  
10, 12; 14; 15; 19, 20. *Sphenophyllum arkansanum* White n. sp.  
11. *Heterangium?* sp.

13; 22; 24, 26; 25. *Calamites miser* White, n. sp.  
16, 17; 21. *Calamites menae* White, n. sp.  
18. *Stigmaria* sp.  
23. *Archaeocalamites coraloides* White, n. sp.



# SOME ORGANIC CONSTITUENTS OF A RECENT SEDIMENT FROM CHINCOTEAGUE BAY, VIRGINIA

By ROGER C. WELLS and E. THEODORE ERICKSON

## ABSTRACT

This paper is a development of a previous paper by the writers which called attention to the possible existence of calcium and magnesium salts of organic fatty acids as constituents of sediments and as possible source material in the formation of petroleum. Its main purpose, however, is to describe the methods of analysis and nature of the products or groups of products isolated from a recent sediment.

For the present study portions of sediment weighing nearly a kilogram were used for analysis. The material was collected under sea water in Chincoteague Bay, Va. This sediment contained about 0.7 percent of organic matter, from which a number of different substances were isolated by extraction with solvents, fractional precipitations, and other methods of analysis. The three principal reagents used were alcohol, ammonium hydroxide, and sodium hydroxide.

The organic substances or groups of substances found include chlorophyll, cholesterol, sulphur, "algin", wax, humic-acid material soluble in alcohol, humic-acid material insoluble in alcohol, fatty-acid material, pentosans, and acid-soluble organic matter. Different fractions of the waxlike material melted at 89° to 175° C. Different fractions of the free fatty acids eventually obtained ranged in their melting point from below 37° to 71° C. Several facts indicate that at least some of these fatty acids may be present in the sediments as calcium or magnesium salts. Among these facts are the tendency of the inorganic bases to accompany the fatty acids into the final fractions that were separated and the yield of precipitates from somewhat concentrated alcoholic solutions of several of the organic fractions when treated with sea water and with alcoholic calcium acetate solution.

As the organic content of the sample was only about 0.7 percent, the percentages of the different organic fractions obtained were correspondingly small. The main classes of substances found were algin, chlorophyll, sulphur, wax, humic-acid complex, fatty-acid material, and acid-soluble organic matter. These groups were further subdivided by melting-point and other tests. The analytical procedures and results are described in systematic detail.

## INTRODUCTION

The work of F. W. Clarke<sup>1</sup> called attention to certain relations among the inorganic constituents contributed to sediments by marine invertebrates, but in that study little or no attention was paid to the organic constituents. In fact, the samples were purposely ignited prior to analysis in order to destroy the organic matter. The organic contributions have long been of interest to economic geologists because of their bearing on the formation of coal and petroleum, and aside from

this feature they are of great interest to the geochemist on account of their variety and the chemical features involved in their progressive changes. Yet the organic constituents have been given relatively little study.

The organic constituents may include plant residues as well as animal remains, debris of microscopic algae, fatty material, the indefinite mixture termed "sapropel"—in short, a great variety of chemical compounds. These substances conceivably differ from one sediment to another, so that many sedimentary deposits should be examined and compared, but on account of the time required to make such studies, progress is necessarily slow, and hence the aim of the present paper is chiefly to describe in some detail what has been found about the nature of the organic matter in a single sediment.

In a recent paper by the writers<sup>2</sup> it was suggested that fatty acids may find their way into marine sediments in the form of insoluble calcium and magnesium salts. That viewpoint has been kept in mind in the present study. The experimental work here described is almost entirely that of the junior author, but responsibility for certain details of the investigation and for the conclusions is shared by the senior author.

Twenhofel<sup>3</sup> has summarized such information as is available on the more general chemical composition of sediments. The content of organic matter in sediments has also been rather fully studied by Trask, Hammar, and Wu,<sup>4</sup> but in attempting to cover a very large field they were obliged to limit their work for the most part to determinations of carbon and nitrogen, supplemented by the use of the customary solvents for organic matter. A beginning was made in studying the nature of the organic matter in some samples, but much remained to be done, and it seemed well worth while to the writers to make a more extended analysis of the organic matter in a single sediment. They are greatly indebted to Mr. Trask for helpful suggestions in the preparation of this paper.

<sup>1</sup> Clarke, F. W., and Wheeler, W. C., The inorganic constituents of marine invertebrates: U. S. Geol. Survey Prof. Paper 124, 1922.

<sup>2</sup> Wells, R. C., and Erickson, E. T., The analysis and composition of fatty material produced by the decomposition of herring in sea water: Am. Chem. Soc. Jour., vol. 55, pp. 338-341, 1933.

<sup>3</sup> Twenhofel, W. H., Treatise on sedimentation, 2d ed., ch. 1-4, Baltimore, Williams & Wilkins Co., 1932.

<sup>4</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., Origin and environment of source sediments of petroleum, Houston, Tex., Gulf Publishing Co., 1932.

David White<sup>5</sup> gives a concise summary of the present knowledge of the chemical changes in sediments. He points out that the carbonaceous material originally consists principally of the residues of plants or animals, more especially of plants. The early chemical changes are largely covered by the single word "decomposition", including biochemical decomposition, and the later changes are referred for the most part to those observable in the solid residues, the coals.

As a matter of fact, sapropel may also contain a high percentage of coprolitic matter, ejected or non-assimilable by both organisms and bacteria, which tends to accumulate because it is nonassimilable. Just what kinds of compounds may be so classed under marine conditions is not well known. Possibly wax-like substances, carbohydrates, fats, fatty acids, and soaps are the principal types. Anaerobic bacteria tend in the earlier stage of their activity to develop acidity, but where protein material is available the ammonia generated by its decomposition tends to produce an alkaline environment, at least temporarily, and sea water itself has an alkaline reaction. Some bacteria and lower organisms are poisoned by the higher fatty acids and soaps. Other bacteria convert different fatty acids into methane rather than into the expected higher hydrocarbons.<sup>6</sup> On the other hand, some bacteria and molds produce fats.<sup>7</sup> Hammar<sup>8</sup> concludes from an extensive survey of the literature that there is little or no evidence that hydrocarbons higher than methane are formed from other organic substances by bacteria.

These conflicting statements leave some doubt as to the fate of fatty acids from anaerobic bacterial attack, but in any case there will still remain the humus or residue. In this connection Waksman<sup>9</sup> says: "The marine humus, just as the soil humus, is formed by similar micro-organisms in a very similar manner", but certain differences in chemical nature from land humus are accounted for by the fact that marine residues, from which all or part of the humus is formed, are different in chemical composition from the land residues from which soil humus is formed. Thus, land vascular plants have a notable lignin content, which is lacking in algal material. For the problem here considered the principal differences in the marine environment are the alkaline reaction of the water and the presence of calcium and magnesium salts. The

<sup>5</sup> White, David, in Twenhofel, W. H., op. cit., p. 415; The origin of petroleum, in Petroleum investigation: 73d Cong. (recess), Hearings on H. Res. 441, pt. 2, pp. 898-906, 1934.

<sup>6</sup> Thayer, L. H., Bacterial genesis of hydrocarbons from fatty acids: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 441-453, 1931.

<sup>7</sup> Ward, G. E., Lockwood, L. B., and May, O. E., Production of fat from glucose by molds: Ind. and Eng. Chemistry, vol. 27, pp. 318-322, 1935.

<sup>8</sup> Hammar, H. E., Relation of micro-organisms to generation of petroleum: Problems of petroleum geology (Sidney Powers memorial volume), pp. 35-50, Am. Assoc. Petroleum Geologists, 1934.

<sup>9</sup> Waksman, S. A., The role of bacteria in the cycle of life in the sea: Sci. Monthly, vol. 38, pp. 35-49, 1934.

present study gives some indication of what kinds of organic matter may survive at an early stage of sedimentation.

#### SOURCE OF SEDIMENT STUDIED

The sample of sediment used in the present investigation was collected by E. T. Erickson in September 1932, at a locality in Chincoteague Bay, Va., about half a mile northwest of Killick Shoal Lighthouse, at the point marked "X" in plate 15. Here the bottom of the bay was approximately level and was just reached with an ordinary long-handled shovel from a small boat. The nearest land was the eastern member of a group of islands in Chincoteague Channel, about a mile south. Dr. Paul Bartsch, of the United States National Museum, to whom acknowledgment is gratefully made, suggested this locality on account of its marine life and convenient accessibility from Washington. Acknowledgment is also made to Mr. Archie Bradford, of Chincoteague Island, for assistance in collecting the sample and other materials studied. The water is essentially coastal sea water in a marginal lagoon or bay. The land nearby is covered with salt-marsh grass, and the shores are strewn with abundant masses of algae. In the water or on the bottom may be found fishes, sponges, and oysters. But K. E. Lohman, of the Geological Survey, found no Foraminifera or diatoms in the sample collected, which is mainly quartz sand with some mud. Dr. Bartsch suggests that the absence of diatoms may be due to their effective removal from the water by oysters, whose culture has increased in the bay in recent years.

The sample was dark gray when wet, lighter gray when dried. Its inorganic chemical composition is shown in table 1.

TABLE 1.—Analysis of sediment from Chincoteague Bay, Va.  
[E. T. Erickson, analyst]

|                                |       |                          |        |
|--------------------------------|-------|--------------------------|--------|
| SiO <sub>2</sub>               | 76.32 | NaCl                     | 0.88   |
| Fe <sub>2</sub> O <sub>3</sub> | 1.08  | MnO                      | .02    |
| Al <sub>2</sub> O <sub>3</sub> | 10.69 | SO <sub>3</sub>          | .31    |
| TiO <sub>2</sub>               | .46   | Loss at 105°             | 1.55   |
| P <sub>2</sub> O <sub>5</sub>  | .07   | Further loss on ignition |        |
| CaO                            | 1.46  |                          | 3.34   |
| MgO                            | .77   |                          |        |
| Na <sub>2</sub> O              | 1.65  | Total                    | 100.50 |
| K <sub>2</sub> O               | 1.90  |                          |        |

#### ORGANIC CONTENT OF THE SAMPLE

The organic content of the sample, other than carbonate, was small—approximately 0.7 percent, based on the total products extracted. The material dried on the steam bath gave 0.41 percent of carbon as the average of three determinations (0.38, 0.45, 0.40), and 0.0755 percent of nitrogen as the average of two determinations (0.076 and 0.075). Engler<sup>10</sup> has expressed the view that little nitrogen is to be expected in sedi-

<sup>10</sup> Engler, C., in Potonié, H., Zur Frage nach dem Ur-Materialien der Petrolea: K. preuss. geol. Landesanstalt Jahrb., Band 25, p. 342, 1904.

mentary sapropelic matter, as the nitrogen would be removed by biochemical processes before or during deposition. These are the first changes affecting the chemical composition of the sapropel. Nitrogenous compounds tend to move in a cycle rather than to become fixed in sediment, but according to Trask the nitrogen in most sediments ranges from one-seventh to one-eighteenth of the carbon.<sup>11</sup> In living matter the nitrogen-carbon ratio has a wide range, depending on the nature of the material.

The main organic substances or classes of substances separated from the sediment of Chincoteague Bay are as follows:

*Percentage of organic substances in sediment of Chincoteague Bay*

|   |       |
|---|-------|
| Algin-----  | 0.037 |
| Chlorophyll-----  | .003  |
| Sulphur-----  | .006  |
| Wax-----  | .023  |
| Humic-acid complex insoluble in alcohol<br>after isolation----- | .075  |
| Humic-acid complex soluble in alcohol after<br>isolation-----   | .116  |
| Fatty-acid material-----  | .034  |
| Acid-soluble organic matter-----                                | .448  |

It should not be thought that these substances necessarily exist as such in the free state in the sediments. There is clear evidence that some of them do not, although some may. One of the most difficult parts of the problem is to determine in what form they are actually present.

It seems clear that sulphur is present in the free state, though some may also be combined. Chlorophyll is probably present in the free state and in residues of plant tissue. The chemical formula of alpha-chlorophyll is  $C_{55}H_{72}O_5N_4Mg$ , with a carbon-nitrogen ratio of 11.8. This complex molecule is decomposed by treatment with either strong acids or alkalies and yields methyl alcohol and phytol alcohol,  $C_{20}H_{40}O$ , a primary unsaturated, monohydric alcohol, but it apparently dissolved directly without decomposition in the alcohol with which the organic matter was extracted from the sediment. The "algin" appears to be a colloidal complex of a hygroscopic nature. The writers believe that some of the "humic acids" and probably also some of the fatty acids are present as calcium and magnesium salts.

The waxes probably occur in the sediment in the free state; chemically these substances are salts or esters of the higher alcohols and acids. Krämer and Spilker<sup>12</sup> found that "sea-weed wax" obtained from algae appeared to consist of esters of alcohols containing 20 to 22 atoms of carbon united with arachidic, behenic, and lignoceric acids, and that it had a fairly low melting point. The wax from diatoms melted at 50° to 70°

C.<sup>13</sup> Waxes extracted from peat melt much higher.<sup>14</sup> Wax from the Chincoteague Bay sediment ranged in melting point from 25° to 90°, indicating a great variety of compounds. The survival of waxes in the sediments suggests that they are not assimilated by animals, though no direct evidence on this point is available. They may possibly even be built up by micro-organisms.

Extraction of the sediment with alcohol having removed "algin", chlorophyll, sulphur, wax, and some oily matter, the material was next treated either with ammonia or with dilute caustic soda solution. This procedure raises the question of the nature of the action of these reagents. It is well known that they bring a large proportion of organic matter into solution, but do they act simply as solvents and as hydrolyzing agents or by base exchange, forming salts with weak acids and compounds carrying exchangeable hydrogen? It seems likely that calcium and magnesium salts of organic acids may be present in the sediments rather than the free acids, and therefore the action of the alkalies is probably in part of the nature of a base exchange. If it is desired to minimize decomposition of the higher and complex molecules during the extraction, ammonia is preferable to the caustic alkalies on account of its milder action on the organic compounds.

Schreiner and Shorey<sup>15</sup> emphasize the fact that the organic matter of soils is reactive to the inorganic matter, and the same must be even more true of sediments deposited in sea water, which contain calcium and magnesium ions available to form insoluble compounds with such acids. In other words, the organic "acids" may be present in part as inorganic salts, besides existing as esters and adsorption complexes. Although this is not a new idea, it has received little emphasis heretofore.

At least two lines of evidence offer support for the idea. First, when the organic matter is extracted and concentrated in certain solvents, as described in the following pages, an inorganic part containing  $SiO_2$ ,  $R_2O_3$ ,  $MgO$ ,  $CaO$ , and a few other oxides tends to accompany the organic matter. Second, when the organic acids are set free with hydrochloric acid, extracted with benzene, then with alcohol after evaporating the benzene, the alcoholic solution gives a precipitate with sea water. A precipitate may also be obtained, if fatty acids are initially present, with an alcoholic solution of calcium acetate—a test proposed by Mr. Erickson. Such a solution is easily made by shaking at intervals during 15 minutes about 1 gram of calcium acetate with 55 milliliters of 95-percent alcohol and filtering, and it appears to be a convenient reagent for some purposes. That the reagent indicates

<sup>11</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., op. cit., p. 22.

<sup>12</sup> Krämer, G., and Spilker, A., Das Algenwachs und sein Zusammenhang mit dem Erdöl: Deutsche chem. Gesell. Ber., Jahrg. 32, Band 3, p. 2940, 1899.

<sup>13</sup> Lewkowitsch, J., Chemical technology and analysis of oils, fats, and waxes, 5th ed., vol. 3, p. 282, 1915.

<sup>14</sup> Schreiner, O., and Shorey, E. C., Chemical nature of soil organic matter: U. S. Bur. Soils Bull. 74, 1910.

the presence of fatty acids only has not been shown. The facts so far established are simply that "organic acids" are present in the sediment in small quantities and may be shown to give calcium precipitates with the reagent, or sea water, and among the acids so far identified are members of the paraffin series generally termed the "fatty acids."

Nitrogen was proved to be present in the humic-acid groups, though partly lost in the extraction. It is probably present largely as protein, but just what kind of protein has not yet been determined.

#### METHODS OF SEPARATING THE ORGANIC MATTER

The general scheme of analysis and separation of the different groups of constituents is shown in tables 2

and 5. In these tables the following abbreviations are used: R, residue; F, filtrate; P, precipitate; E, extract; S, solution. The figures in the tables refer to weights in grams of the different fractions obtained. The scheme is partly modeled on the work of Odén,<sup>16</sup> partly on that of Schreiner and Shorey<sup>17</sup> and on other work. These methods are the best so far developed for separating the organic matter into classes which can be tested for individual substances. The time has not yet arrived when some specific test can be made for each substance or even for each class of substances. The desired knowledge can be obtained only by successive approximations through a series of steps. The original samples were dried on the steam bath before weighing out portions for study.

TABLE 2.—Outline of method of analysis

| Extract with hot alcohol.   |   |  |  |  |  |  |   |
|---|---|--|--|--|--|--|---|
| R <sub>1</sub> . Heat with 600 ml of dilute NH <sub>4</sub> OH. Filter. |   |  |  | F <sub>1</sub> . Concentrate and filter off the insoluble inorganic salts. |  |  |   |
| F <sub>9</sub> . Evaporate slowly to 150 ml. Filter.                    |   |  |  | F <sub>5</sub> . Extract with petroleum ether.                             |  |  |   |
| R <sub>9</sub> . Repeat the extraction and finally discard residue.     | R <sub>10</sub> . "Reversed" precipitate, 0.8641. | F <sub>10</sub> . Add 25 ml of acetic acid and filter. | P <sub>4</sub> . Treat with hot alcohol. | F <sub>11</sub> . Treat with hot alcohol.                                  | S <sub>1</sub> . Residual solution. Extract with benzene.  | F <sub>6</sub> . Petroleum ether extract. Extract with alcohol, 0.333. | R <sub>4</sub> . Salts, 3.76.   |
|   | R <sub>11</sub> . Insoluble, 1.462.               | F <sub>12</sub> . Soluble, 0.390.                      | R <sub>12</sub> . Insoluble, 6.671.      | F <sub>13</sub> . Soluble, 1.531.  | R <sub>3</sub> . "Algin", 0.300. Extract with absolute alcohol.<br>R <sub>13</sub> , 0.026.<br>F <sub>14</sub> , 0.1509. | E <sub>2</sub> , 0.055.  | R <sub>6</sub> . See table 3. Wax, 0.190; sulphur, 0.051.<br>F <sub>7</sub> . Chlorophyll, etc., 0.024. Oily matter, 0.068. |

#### HOT ALCOHOL EXTRACT

A portion of the sample weighing 811 grams was extracted three times with 95 percent ethyl alcohol on the steam bath in a covered flask, using about 600 milliliters of alcohol each time. The duration of the heating varied from several days for the first extraction to overnight for the last one. While hot, each alcoholic solution was filtered. The first filtrate was noticeably green, the last practically colorless. This procedure left residue R<sub>1</sub>, which was reserved for further treatment.

The combined alcoholic extracts (F<sub>1</sub>) were evaporated to 50 milliliters and filtered. The insoluble material thus obtained was heated with successive small quantities of alcohol and filtered off until it was practically white and nearly free from organic matter; it then weighed 3.76 grams (R<sub>4</sub>).

The combined alcoholic filtrate (F<sub>5</sub>), evaporated to about 50 milliliters, was then placed in a separatory funnel and extracted several times with light petroleum ether. The first ether extract had a strong green color; the last was only slightly colored. Some green matter

also remained in the residual alcoholic solution, thus showing at least two kinds of green pigment. Ordinary chlorophyll is soluble in light petroleum ether. The total ether extract weighed 0.333 gram.

#### PETROLEUM ETHER EXTRACT

The ether extract (F<sub>6</sub>), after evaporation of the solvent, was treated with small quantities of alcohol until little coloring matter remained. Waxy matter tended to remain in the insoluble part (R<sub>6</sub>). The treatment was continued until from the soluble portion a final green viscous residue was obtained which would all dissolve in about 1 milliliter of alcohol (F<sub>7</sub>).

On treating the residue from evaporation of F<sub>7</sub> with still less alcohol the green portion was distinctly more soluble than the remainder. In this solution cholesterol was identified by the digitonin reaction,<sup>18</sup> but the

<sup>16</sup> Odén, Sven, Die Huminsäuren; chemische, physikalische und bodenkundliche Forschungen: Kolloid-chemische Beihefte, Band 11, pp. 76-260, 1919.

<sup>17</sup> Schreiner, O., and Shorey, E. C., op. cit.

<sup>18</sup> Holde, D., The examination of hydrocarbon oils and saponifiable fats and waxes, tr. by E. Mueller, p. 350, New York, John Wiley & Sons, 1922.

quantity was too small for determination or further study. Chlorophyll was definitely identified, aside from its color, by the copper acetate test.<sup>19</sup>

The rest of F<sub>7</sub> was then saponified with alcoholic potash solution. A little lead acetate solution was then added, which resulted in precipitation of the lead salts of the organic acids. The lead precipitate was filtered off, washed with hot water, dried, and decomposed with warm 20 percent hydrochloric acid, and the resulting mixture was extracted with benzene. The benzene solution, when separated in a separatory funnel, yielded 0.039 gram of oil-like matter on evaporation. This fraction may represent acids derived from algal oils. The remaining acid solution on evaporation to dryness and extraction with alcohol yielded 0.029 gram of brown amber-colored material that was fairly solid at

room temperature. These acids were not fully studied. The filtrate from the lead salts, which may have contained alcohols, was colorless. It was not studied further.

The residue of wax (R<sub>6</sub>) was fractionated with ether to separate sulphur. Repeated slow evaporations of the ether solution yielded small crystals of sulphur, which were picked out with a needle, with the aid of a hand lens, giving in all 0.051 gram of sulphur.

The wax was then subjected to a series of fractionations in different solvents, with tests of each fraction, as shown in table 3. The first fraction of wax represents the portion of R<sub>6</sub> that is relatively insoluble in alcohol but more soluble than in benzene, and similarly for the succeeding fractions.

TABLE 3.—*Results of fractionation of the waxlike material (R<sub>6</sub>) after separation from sulphur*

|  | Fraction<br>(gram) | Melting point (°C.)  | Lieberman's test   | Reactivity with alco-<br>holic lead acetate <sup>1</sup> | Properties   |
|--|--------------------|--|--|--|--|
| Insoluble in benzene but soluble in alcohol.         | 0.031              | —  | —  | —  | Mixture. Some crystalline material.  |
| Soluble in benzene but insoluble in warm ether.      | .021               | 89   | Slight reddish-brown color.  | Small  | Light-colored and waxlike.   |
| Soluble in warm ether but insoluble in cold ether.   | .016               | 79-81  | do   | do   | Do.  |
| Successively more soluble fractions from cold ether. | .026               | 70±  | do   | do   | Do.  |
| Do   | .011               | Softened below 100° C. but not clearly melted till 175° C. | do   | do   | Strong tendency to thread-like crystals. Practically white.                          |
| Do   | .008               | do   | do   | do   | Similar to above.  |
| Do   | .024               | 50-60  | do   | do   | Softer, waxlike. A little sulphur present.   |
| Residue  | .053               | Softer or sticky at 25° C.                                 | Fair or somewhat stronger color results. More reddish-greenish than reddish. | do   | Softer, waxlike, but contains some yellowish-green matter. A little sulphur present. |
| Total  | .190               |  |  |  |  |

<sup>1</sup> Test carried out in a similar way with palmitic acid gave a definite precipitate.

The various fractions of wax were tested for cholesterol by the Lieberman test<sup>20</sup> and for fatty acids with alcoholic lead acetate, but only small quantities were found. The results of these tests are shown in the fourth and fifth columns of table 3. A wide range of melting point of the waxes is shown. They were not individually identified.

#### Fractions found in petroleum ether extract

|  | Gram  | Percent of sample |
|--|-------|-------------------|
| R <sub>5</sub> . Waxlike material  | 0.190 | 0.023             |
| R <sub>6</sub> . Sulphur   | .051  | .006              |
| F <sub>7</sub> . Oil-like acids soluble in benzene                         | .039  | .005              |
| F <sub>7</sub> . Organic acids insoluble in benzene but soluble in alcohol | .029  | .004              |
| F <sub>7</sub> . Chlorophyll fraction (by difference)                      | .024  | .003              |
| Total  | .333  | .041              |

<sup>19</sup> Onslow, M. W., Practical plant biochemistry, p. 32, Cambridge Univ. Press, 1920.

<sup>20</sup> Holde, D., op. cit., p. 519.

#### RESIDUAL ALCOHOLIC SOLUTION

The alcoholic solution (S<sub>1</sub>) remaining in the separatory funnel after treatment with light petroleum ether still contained some green material. The mixture was extracted with benzene, yielding two layers; the benzene solution on evaporation left a green residue, E<sub>2</sub>, weighing 0.055 gram, which was partly crystalline. On account of its small weight this residue was not studied further.

On evaporating the remaining alcohol to a small volume, a further small quantity of inorganic salt was precipitated, which was added to R<sub>4</sub>. The remaining alcoholic solution, which contained considerable organic matter, was evaporated, and yielded approximately 0.30 gram of olive-gray organic matter (R<sub>3</sub>) that appeared either dry or moist according to the humidity of the air. This material was thought to be an inorganic salt of an "algin" component. It appeared to be a complex mixture of carbohydrates and other organic matter and some inorganic matter.

When heated directly in a test tube it yielded some volatile tarry or oily matter and left a carbonized residue. Similar material was later found in the alkali extracts. The dried residue was extracted with small volumes of absolute alcohol and yielded 0.0264 gram of insoluble material ( $R_{13}$ ) and 0.1509 gram of soluble material ( $F_{14}$ ). These two parts were studied as thoroughly as the rather small quantities would permit.

The insoluble part ( $R_{13}$ ) was too small to study very thoroughly, but as tests showed that considerable inorganic matter accompanied the organic, a partial analysis was made, with the following results:

*Results of partial analysis of inorganic matter in  $R_{13}$*

|                       | Percent of fraction | Percent of sediment |
|-----------------------|---------------------|---------------------|
| $SiO_2$ -----         | 3.7                 | 0.0001              |
| $R_2O_3$ -----        | 7.0                 | .0002               |
| $MgO$ -----           | 4.7                 | .0001               |
| $CaO$ -----           | 4.2                 | .0001               |
| $K_2O$ -----          | 1.9                 | .0001               |
| $Na_2O$ -----         | 11.4                | .0004               |
| $SO_3$ -----          | 17.9                | .0006               |
| Loss on ignition----- | 44.0                | .0014               |
| Total-----            | 94.8                | .0030               |

On digesting a portion with hydrochloric acid, evaporating, and extracting with benzene, a soft material resembling a fatty acid was obtained. This material, when dissolved in alcohol, gave a fairly definite precipitate with a solution of calcium acetate in alcohol. This precipitate appears to be one of the fractions in which part of the calcium and magnesium salts of the organic acids became concentrated.

The part soluble in absolute alcohol ( $F_{14}$ ), which weighed 0.1509 gram, gave the following results:

*Results of partial analysis of inorganic matter in  $F_{14}$*

|                       | Percent of fraction | Percent of sediment |
|-----------------------|---------------------|---------------------|
| $R_2O_3$ -----        | 5.4                 | 0.0010              |
| $MgO$ -----           | 1.3                 | .00024              |
| $CaO$ -----           | 2.7                 | .0005               |
| Loss on ignition----- | 83.3                | .0155               |
| Total-----            | 92.7                | .0194               |

This fraction was only slightly soluble in benzene, yielding a minute quantity of free sulphur and waxlike material. A small quantity of the dried material, on testing with dilute sodium hydroxide and iodine solution at room temperature, soon gave a persistent odor of iodoform, like that given by levulinic acid. It is thought that this acid or some analogous acid was present in this fraction. Similar material might possibly have been found in portions  $E_2$ ,  $R_6$ , and  $F_7$ , if tests had been made.

The same lot of the sediment was heated a fourth time with alcohol, and the alcohol was filtered off hot and evaporated, yielding a further small quantity of inorganic salts and some organic matter. It is unnecessary, however, to give details of these tests, as they yielded results essentially similar to those already described, except that the quantities of material obtained were smaller. Unfortunately lack of time has prevented the determination of the carbon-nitrogen ratios in the different fractions. Such determinations, as Mr. Trask has pointed out in conversation with the writers, would be very desirable for comparison with his results and would help to throw light on the nature of the organic material. Some nitrogen compounds were indeed obtained in the extractions with sodium hydroxide described later, but it was felt that this treatment also caused a partial loss of the nitrogen.

#### TEST OF THE SALTS FOR ORGANIC ACIDS

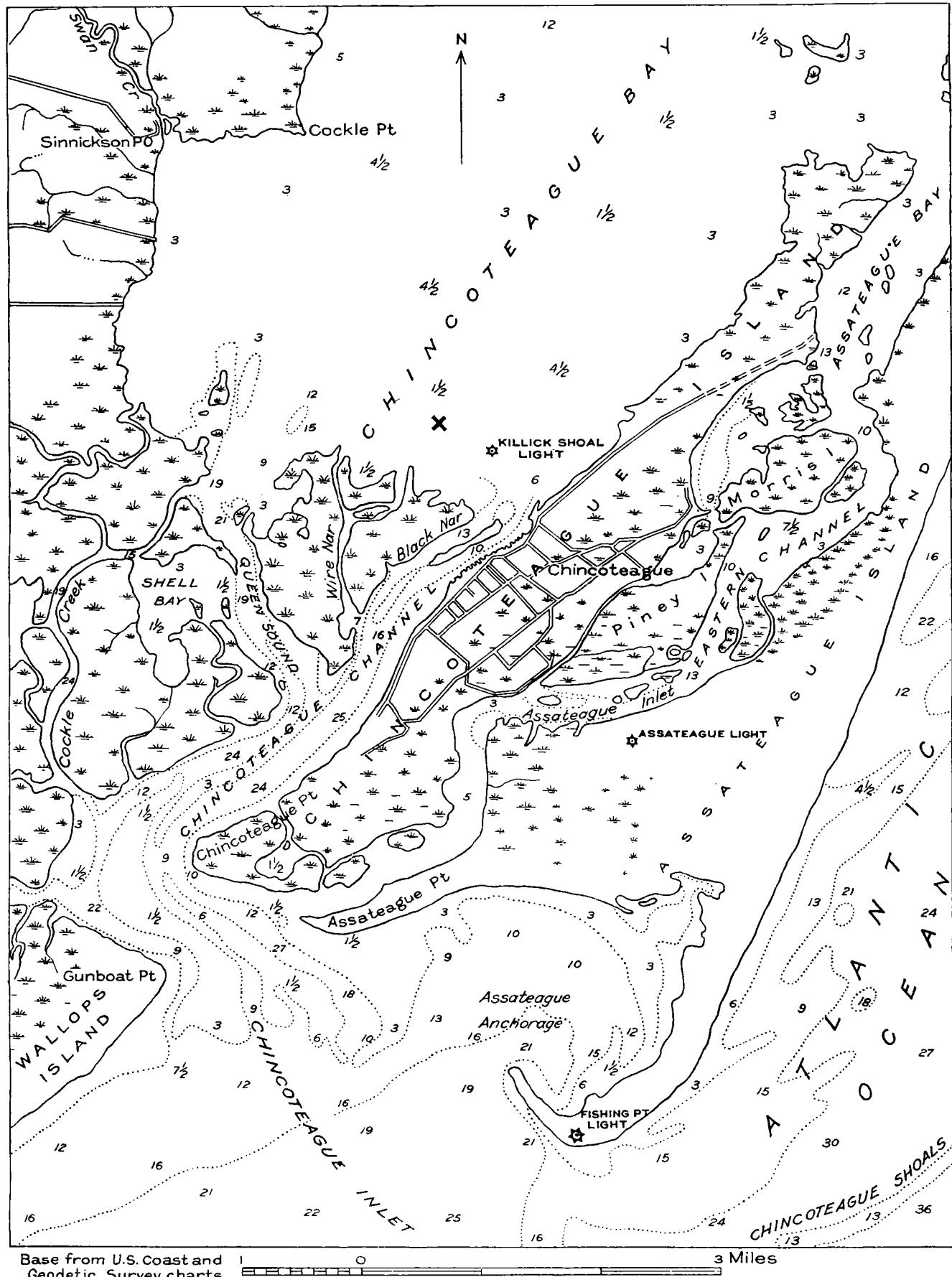
If calcium salts of the fatty acids, for example, were present in the sample, some of them would probably have been dissolved by the large volume of solvent alcohol used, but they would also probably have tended to reprecipitate along with the inorganic salts as the alcohol was evaporated, as the solubility of such salts is generally low. Few exact figures on their solubility are available. Beilstein<sup>21</sup> gives the solubility of calcium palmitate in alcohol at 20° C. as 0.0103 part per hundred. K. J. Murata, of the Geological Survey laboratory, in studies now in progress, finds 0.0074 part of calcium mucate ( $CaC_6H_5O_8 \cdot 4H_2O$ ) per hundred at 25° C.

Two grams of the inorganic salts ( $R_4$ ) separated by concentration of the original solvent alcohol was heated with 55 milliliters of 10 percent hydrochloric acid and, on cooling, extracted with benzene. Evaporation of the filtered benzene gave a somewhat colored waxlike residue weighing 0.0059 gram. This was treated with 2 milliliters of alcohol, and 0.2 milliliter of the calcium acetate reagent was added to the filtered solution. A precipitate resulted about equal in bulk to that obtained from 1 milligram of palmitic acid. Hence, the quantity of calcium soaps extracted by the alcohol was insignificant compared with the fatty acids found later on treatment with caustic soda ( $E_1$ ). The writers accordingly conclude that the calcium soaps are held in the sediment in an adsorption complex, from which they are not removed by such a solvent as alcohol but are easily brought into solution by metathesis with the strong alkali.

A recent paper by Duncan<sup>22</sup> calls attention to the fact that calcium and magnesium salts of certain sulphonated alcohol esters are easily or moderately soluble in water, and hence esters of this type may probably be excluded from consideration as constituents

<sup>21</sup> Beilstein, F., *Handbuch der organischen Chemie*, 3<sup>a</sup> Aufl., Band 1, p. 443, 1893.

<sup>22</sup> Duncan, R. A., *The new detergents: Ind. and Eng. Chemistry*, vol. 26, pp. 24-26, 1934.



Base from U.S. Coast and  
Geodetic Survey charts

MAP OF THE CHINCOTEAGUE BAY REGION, ACCOMAC COUNTY, VA.



of sediments formed in sea water, unless they also should be held in an adsorption complex.

#### TREATMENT WITH AMMONIA

The residue  $R_1$ , after extraction with alcohol as previously described, was treated five times at about 97° C. with dilute ammonia, in 600-milliliter portions in flasks immersed in a steam bath. Each portion after filtration was slowly evaporated to about 150 milliliters. This treatment resulted in a "reversal" or reprecipitation of dissolved material ( $R_{10}$ ). Absorption of carbon dioxide from the air may have helped to cause the reprecipitation. The total "reversed" precipitate amounted in all to 0.8641 gram, or 0.31 percent of the sample (811 grams).

The dark-brown ammoniacal filtrate was found to yield a precipitate with sea water. For example, 2 milliliters of the filtrate, on standing 10 days with an excess of sea water, lost its amber-brown color, and a flocculent precipitate appeared in the bottom of the solution.

Table 4 summarizes the results of the extractions with ammonia. The third column gives the weights of the "reversed" precipitate ( $R_{10}$ ). The next two columns give the material precipitated on neutralization with 25 milliliters of acetic acid, expressed as material insoluble and material soluble in hot alcohol. The last two columns give similar figures for the material remaining in the acetic-acid solution. Extracts 2 and 3 were combined to save time. The terms "1st" and "2d" under "reversed" precipitate refer to successive crops.

TABLE 4.—Results of extraction with ammonia (in grams)

| No.        | Strength of ammonia (percent) | "Reversed" precipitate ( $R_{10}$ ) | Precipitated by acetic acid ( $F_{11}$ ) |                                 | Remainder ( $F_{12}$ ) |
|------------|-------------------------------|-------------------------------------|--|---------------------------------|------------------------|
|            |                               |                                     | Insoluble in alcohol ( $R_{11}$ )        | Soluble in alcohol ( $F_{12}$ ) |                        |
| 1-----     | 10                            | { 0.5264 (1st)<br>.0378 (2d)}       | { 0.823                                  | 0.269                           | 5.082 1.011            |
| 2, 3-----  | 10                            | { .1583 (1st)<br>.0526 (2d)}        | .416                                     | .090                            | 1.001 .404             |
| 4-----     | 15                            | .0890                               | .223                                     | .031                            | .588 .116              |
| 5-----     | 125                           |                                     |  |                                 |                        |
| Total----- |                               | .8641                               | 1.462                                    | .390                            | 6.671 1.531            |

<sup>1</sup> The total extract of 0.6414 gram from the fifth treatment was not separated further.

All these fractions contained organic matter, ranging from perhaps 10 to 94 percent, but some also contained considerable inorganic matter. The inorganic matter appeared to be more than would be expected in products of ordinary solubility and must have included some organic compounds, or else the excessive solubility must have been due to the presence of organic matter. Silica was high in some of these extracts, also sulphate.

The two largest portions of the "reversed" precipitate noted in table 4 (0.6847 gram) were partially analyzed, with the following results:

#### Partial analysis of greater part of "reversed" precipitate

|  | Percent of fraction | Percent of sediment |
|--|---------------------|---------------------|
| SiO <sub>2</sub> -----   | 48.9                | 0.0413              |
| R <sub>2</sub> O <sub>3</sub> -----  | 4.4                 | .0037               |
| MgO-----   | .8                  | .0007               |
| CaO-----   | 4.0                 | .0034               |
| Loss on ignition-----  | 33.5                | .0282               |
| Total-----   | 91.6                | .0773               |
| Soluble in alcohol-----  | 3.2                 | .0027               |
| After warming with a little 5 percent HCl, evaporating, and extracting with alcohol----- | 24.8                | .0209               |
| Ammonia-soluble material in residue-----   | 8.3                 | .0070               |

The material soluble in alcohol after treatment with hydrochloric acid gave a slight precipitate with alcoholic calcium acetate solution. The results were somewhat better if the alcoholic extract was first concentrated to a smaller volume. Blank tests with reagents gave no precipitate.

Similar tests were made of the remainder of the "reversed" precipitate (0.1794 gram) with the following results:

#### Partial analysis of remainder of "reversed" precipitate

|  | Percent of fraction | Percent of sediment |
|--|---------------------|---------------------|
| SiO <sub>2</sub> -----   | 36.4                | 0.0080              |
| R <sub>2</sub> O <sub>3</sub> -----  | 14.6                | .0031               |
| MgO-----   | 5.4                 | .0012               |
| CaO-----   | 3.4                 | .0008               |
| Loss on ignition-----  | 39.4                | .0087               |
| Total-----   | 99.2                | .0218               |
| Soluble in alcohol-----  | 1.5                 | .0003               |
| After warming with a little 5 percent HCl, evaporating, and extracting with alcohol----- | 5.9                 | .0013               |
| Ammonia-soluble material in residue-----   | 18.6                | .0041               |

The calcium acetate test, when applied to the alcohol extracts, gave results similar to those obtained with the larger fractions. The alcoholic solutions evidently contained other organic matter, in addition to fatty acids. They gave brownish-white precipitates with alcoholic lead acetate. The final ammoniacal extracts noted above were dark, but were not studied further.

The fraction precipitated by acetic acid and insoluble in alcohol ( $R_{11}$ ) gave the following results:

#### Partial analysis of fraction $R_{11}$

|                                     | Percent of fraction | Percent of sediment |
|-------------------------------------|---------------------|---------------------|
| SiO <sub>2</sub> -----              | 1.2                 | 0.0022              |
| R <sub>2</sub> O <sub>3</sub> ----- | 1.2                 | .0022               |
| MgO-----                            | Trace               | .0000               |
| CaO-----                            | 0.4                 | .0007               |
| Loss on ignition-----               | 91.6                | .1650               |
| Total-----                          | 94.4                | .1701               |

When examined by the method of Tollens and others,<sup>23</sup> this material appeared to contain pentosans, as it yielded 2.6 percent of methyl pentose and 2.8 percent of pentose. It probably also contained so-called "humic acids."

The fraction precipitated by acetic acid and soluble in alcohol ( $F_{12}$ ) gave the following results:

*Partial analysis of fraction  $F_{12}$*

|                       | Percent of fraction | Percent of sediment |
|-----------------------|---------------------|---------------------|
| $R_2O_3$ -----        | 0.9                 | 0.0004              |
| MgO-----              | .3                  | .0001               |
| CaO-----              | 1.7                 | .0008               |
| Loss on ignition----- | 94.5                | .0456               |
| Total-----            | 97.4                | .0466               |

Fatty acids were definitely obtained from this material by the procedure previously described. The material was low in inorganic matter. It probably also contained pentosans and alcohol-soluble "humic acids."

The remainder of the acetic-acid solution gave 6.671 grams of material insoluble in alcohol ( $R_{12}$ ). It was analyzed with the following results:

*Analysis of fraction  $R_{12}$*

|                       | Percent of fraction | Percent of sediment |
|-----------------------|---------------------|---------------------|
| $SiO_2$ -----         | 0.5                 | 0.0042              |
| $R_2O_3$ -----        | .3                  | .0025               |
| $SO_3$ -----          | 22.2                | .1826               |
| Cl-----               | .5                  | .0042               |
| MgO-----              | .1                  | .0008               |
| CaO-----              | .1                  | .0008               |
| $Na_2O$ -----         | 19.0                | .1563               |
| $K_2O$ -----          | 3.3                 | .0271               |
| Loss on ignition----- | 51.0                | .4195               |
| Total-----            | 97.0                | .7980               |

Methyl pentose was estimated at 2.1 percent in this fraction and pentose at 4.2 percent. The fraction, though insoluble in alcohol, is soluble in water and is the dominant fraction of organic matter in the sediment. Some sodium sulphate appears to be present. Some marine algae gathered at the time the sediment was collected gave similarly from the dried material 5.9 percent of methyl pentose and 3.7 percent of pentose—a result which strongly suggests that marine algae are a prominent source of organic matter in the sediment. The material in fraction  $R_{12}$  forms a precipitate with sea water more slowly than the fraction precipitated by acetic acid ( $F_{12}$ ). In addition to the pentoses some acids are probably present, though they were not identified. In a similar fraction from

<sup>23</sup> Mayer, Willy, and Tollens, B., Ueber die Fukose und die Bestimmung der methyl Pentosane in Naturprodukten: Jour. Landwirtschaft, Band 55, pp. 261-271, 1907.

soil Shorey<sup>24</sup> found saccharic acid ((CHOH)<sub>4</sub>(COOH)<sub>2</sub>), acrylic acid (CH<sub>2</sub>:CHCOOH), and some amino acids.

The material of the last fraction ( $F_{13}$ ) was amber-colored and somewhat sirupy in appearance. That it contained some carbohydrate was shown by the Molisch alpha-naphthol test.

#### ACTION OF SODIUM HYDROXIDE

##### FIRST EXTRACTION

As an alternative to the treatment with ammonia use was also made of the more drastic reagent sodium hydroxide. The procedure is outlined in table 5. A separate portion of the original sample weighing 863 grams was extracted with alcohol, as previously described, but beginning with the residue R, this material was next heated for a week with about 750 milliliters of 2 percent sodium hydroxide solution in a flask immersed in a steam bath. The neck of the flask protruding from the steam bath was covered with a watch glass to prevent evaporation. The hot solution was filtered off, the residue was washed briefly with water, and the filtrate ( $F_2$ ), which was dark from organic matter, was made slightly acid with hydrochloric acid. The resulting flocculent precipitate ( $P_1$ ) was filtered off, washed briefly with water, and transferred while moist to 95 percent alcohol. This mixture was boiled and filtered, thus yielding Odén's "alcohol-insoluble" humic-acid complex ( $P_2$ ). This material was dried and weighed 0.312 gram. More was obtained from further treatments, as described below, and the weights given in table 5 represent the totals of four extractions (also summarized in table 6).

The alcoholic filtrate of considerable volume from  $P_2$  ( $F_4$ ), which was also dark from organic matter, was treated with an excess of alcoholic lead acetate, heated on the steam bath, and filtered, yielding the insoluble lead salts ( $P_3$ ) and a soluble portion ( $F_7$ ).

The lead salts insoluble in alcohol ( $P_3$ ) were digested with 20 percent hydrochloric acid, the acid slowly evaporated, and the residue extracted with alcohol. The alcoholic solution was transferred to a porcelain dish and evaporated; the first residue weighed 0.280 gram, and succeeding portions similarly treated gave a total yield of 1.007 grams ( $R_8$ ). This material, which was not very soluble in benzene, is the analytical equivalent of Odén's "hymetanelansäure", or alcohol-soluble humic acid.

The soluble portion ( $F_7$ ) was evaporated, digested with 20 percent hydrochloric acid, and extracted with benzene. This procedure left a residue ( $R_7$ ). The extract ( $E_1$ ) contained mainly solid fatty-acid material, the first yield weighing 0.0455 gram and the total 0.293 gram. Its treatment is described more fully below.

<sup>24</sup> Shorey, E. C., Some organic acid constituents: U. S. Dept. Agr., Bur. Soils, Bull. 88, p. 11, 1913.

TABLE 5.—*Scheme of analysis by using NaOH on residue ( $R_1$ ) extracted with alcohol (table 2)*  
 [Results in grams]

| Heat with NaOH 750-ml solution and filter. |                           |  |         |                                     |  |
|--|---------------------------|--|---------|-------------------------------------|--|
| $F_2$ . Add HCl. Filter.                   |                           |  |         |                                     |  |
| $F_1$ . Add to hot alcohol.                |                           |  |         |                                     |  |
| $R_2$ . Discard.                           | $P_2$ . Insoluble, 0.648. | $F_4$ . Treat with alcoholic $Pb(C_2H_3O_2)_2$ . <sup>1</sup>        |         |                                     | $F_3$ . Evaporate. Extract with alcohol. |
|  |                           | $F_3$ . Decompose with HCl and dissolve in alcohol.                  |         |                                     | $R_5$ . Salts. $E_2$ , 3.87.             |
|  |                           | $F_7$ . Evaporate alcohol, add dilute HCl, and extract with benzene. |         |                                     |  |
|  |                           | $R_8$ , 1.007.   | $R_7$ . | $E_1$ . Fatty-acid material, 0.293. |  |

<sup>1</sup> Control experiment: 1 gram of palmitic acid dissolved in 300 milliliters of 95-percent alcohol (heated on the steam bath) gave no indication of precipitation with an excess of alcoholic lead acetate solution. What applies to palmitic acid in this respect very likely applies to other common fatty acids.

The aqueous filtrate ( $F_3$ ) from the precipitate of humic material, produced on acidifying with hydrochloric acid, was evaporated and the residue extracted with alcohol a few times until the salts were white. The final material soluble in a little alcohol ( $E_2$ ) weighed 1.80 grams and the total 3.87 grams, as shown in table 6. Practically none of it was soluble in benzene. Its further treatment is also described below with that of the other portions.

#### ADDITIONAL EXTRACTIONS

The whole extraction with dilute alkali was repeated twice on the same material with 5 percent potassium hydroxide, and a fourth time with 10 percent potassium hydroxide. The yields of the separate fractions are shown in table 6.

TABLE 6.—*Yields of fractions extracted from 863 grams of sediment on successive treatments with caustic alkali solutions*

| Treatment         | Humic acid ( $P_2$ ) | "Soluble humic acid" ( $R_8$ ) | Fatty-acid material ( $E_1$ ) | Soluble organic matter ( $E_2$ ) |
|-------------------|----------------------|--------------------------------|-------------------------------|----------------------------------|
| 1. 2 percent NaOH | 0.312                | 0.280                          | 0.045                         | 1.80                             |
| 2. 5 percent KOH  | .307                 | .302                           | .097                          | 1.58                             |
| 3. 5 percent KOH  | .029                 | .131                           | .074                          | .38                              |
| 4. 10 percent KOH | Trace                | .294                           | .076                          | .11                              |
| Total-----        | .648                 | 1.007                          | .293                          | .387                             |

Probably a stronger alkali would have hastened the extraction somewhat. The final residue after four treatments was light gray when dry and contained very little remaining organic matter, as shown by the fact that on heating some of it in a test tube there was scarcely any detectable odor of organic matter, and no tarry or visible fumes of organic matter appeared.

The same observation was made with the residue remaining from the extractions with ammonia. During the course of the extractions the color of the residues lightened appreciably and the yields of organic matter successively decreased. From these facts it is concluded that practically all the organic matter was removed from the sample.

#### EXAMINATION OF THE FATTY-ACID MATERIAL ( $E_1$ )

Fraction  $E_1$  was examined by the Varrentrap method for the presence of unsaturated liquid and saturated solid fatty acids. The method is directly applicable to mixed free fatty acids.<sup>25</sup> The acid material was dissolved in about 25 milliliters of 95 percent alcohol and titrated to neutrality with tenth-normal sodium hydroxide, using phenolphthalein indicator. The alcohol was then largely evaporated, diluted to 50 milliliters with water, and heated, and an aqueous solution of lead acetate was added in excess, which precipitated practically all the fatty-acid material. After filtering, the evaporated filtrate gave a residue consisting of the excess of lead acetate reagent with practically no indication of organic matter. The filtered lead precipitate was carefully dried at low temperature and extracted with ether, which is supposed to dissolve the lead salts of the liquid fatty acids. This separation was apparently not complete, as only 0.0127 gram of liquid acids was obtained out of a total of 0.2925 gram.

Both portions were therefore again combined and then separated into different fractions by fractional precipitation of their magnesium salts with alcoholic magnesium acetate solution, according to the method

<sup>25</sup> Fryer, P. J., and Weston, F. E., Technical handbook of oils, fats, and waxes vol. 2, pp. 172-173, Cambridge, 1918.

of Heintz.<sup>26</sup> The alcoholic solution was concentrated until an appreciable fraction was precipitated. This was filtered off and the solution concentrated further, giving a second fraction, and so on until seven fractions had been obtained and a final mother liquor remained. Each fraction was then recrystallized from hot alcohol, the filtrate from each fraction being added to the solu-

tion of the next one. A freshly prepared solution of magnesium acetate was used. The several magnesium salts were eventually decomposed with a few milliliters of 20 percent hydrochloric acid, and the free acids were extracted with benzene. The observations made on these acids are given in table 7.

TABLE 7.—*Observations on organic acids fractionally precipitated as magnesium salts*

| Number of fraction | Percent of total fatty-acid material | Character   | Further fractionations  |
|--------------------|--------------------------------------|---|---|
| 1-----             | 4.7                                  | Solid, light color, melting above 50°-----  | 1. The fraction was dissolved in a little alcohol, leaving a small proportion of residue. This was dissolved in hot alcohol, precipitated with $Mg(OAc)_2$ , and the precipitate converted into free acid, which melted from 53° to 63°.<br>2. On adding $Mg(OAc)_2$ to the filtrate an acid was eventually obtained that melted from 68° to 71°.<br>3. The last filtrate was evaporated to dryness with an excess of $Mg(OAc)_2$ . When taken up in a little alcohol the insoluble part yielded an acid that melted from 62° to 64°. The part soluble in alcohol yielded an acid that melted over a wide range below 55°.  |
| 2-----             | 5.6                                  | -----do-----  | 1. The fraction was dissolved in a little alcohol, in which a slight insoluble precipitate that was not filtered remained.<br>2. A partial and direct precipitation with $Mg(OAc)_2$ yielded a light-colored precipitate from which was recovered a little soft free acid material that melted from about 53° to 63°.<br>3. From a further second precipitation with an excess of $Mg(OAc)_2$ was obtained free light-colored solid acid that melted from 63° to 67°.<br>4. Filtrate evaporated to dryness with excess of $Mg(OAc)_2$ and taken up with a little alcohol. The insoluble part yielded acid material that melted from 45° to 55°. The acid material from the soluble fraction was somewhat viscous at room temperature. |
| 3-----             | 7.8                                  | A little soft. Amber color becoming noticeable. Melted from 43° to 48°.                   | Nos. 3, 4, 5, and 6 dissolved together in a small volume of alcohol.  |
| 4-----             | 15.5                                 | Similar in appearance to no. 3. Melted from 44° to 48°.                                   | 1. A little insoluble material was filtered. This material was viscous at 33° and was light straw-colored. On dissolving in a small amount of heated alcohol, a precipitate formed with $Mg(OAc)_2$ .   |
| 5-----             | 15.1                                 | Increasing softness and color. Melted below 39°.  | 2. A first partial precipitation with $Mg(OAc)_2$ yielded light straw-colored acid material that melted from 45° to 48°.  |
| 6-----             | 23.2                                 | Somewhat soft at 33°. Darker amber color than no. 5.                                      | 3. A second partial precipitation with $Mg(OAc)_2$ yielded a little darker acid material that melted from 40° to 43°.<br>4. Further fractionation was obtained from filtrate 3 by evaporation to dryness with an excess of $Mg(OAc)_2$ and taking up with a little alcohol.   |
| 7-----             | 5.8                                  | Somewhat soft at room temperature. Amber-colored.   | 4a. The insoluble fraction yielded straw-colored acid material that melted below 37°.<br>4b. The soluble fraction yielded straw-colored acid material that was soft at ordinary temperature.<br>Dissolved in a small volume of alcohol. Direct precipitate with $Mg(OAc)_2$ slight. After evaporation with an excess of $Mg(OAc)_2$ to dryness, some insoluble material was obtained on taking up in a little alcohol. This yielded viscous acid material that melted below 35°. From the filtrate soft acid material was obtained in which needle markings flowed together.  |
| 8-----             | 22.3                                 | Amber oil-like at 33°. The oil readily flowed together after marking with a needle point. | Dissolved in a small volume of alcohol. Insoluble material slight. A small amount of precipitate formed directly with $Mg(OAc)_2$ , which yielded soft viscous acid material. The filtrate yielded liquid oil.  |

The range in melting point of the fatty acids was thus found to extend from below 37° to 71° and is typical of the fatty acids commonly found as esters in vegetable and mineral oils. Common saturated fatty acids and their melting points are: Stearic, 69.5°; palmitic, 63.5°; myristic, 57.5°; lauric, 47.5°; and

capric, 31.4°. The last two are found in vegetable oils. Although the oils in living matter are generally high in unsaturated constituents, the sediment examined was relatively low in such substances. Thus there seems to be no doubt that fatty acids were identified as such in the final tests and that they were present in the original organic matter in some form insoluble in hot alcohol. With the fatty-acid material there may

<sup>26</sup> Holde, D., The examination of hydrocarbon oils and saponifiable fats and waxes, tr. by E. Mueller, p. 378, New York, John Wiley & Sons, 1922.

have been some related acids, as indicated by the low melting points of the first subfractions of fractions 1 and 2 (table 7). Their magnesium salts were less soluble than those of the succeeding fractions of acids having higher melting points. Methods for the identification of such possible compounds, however, will have to await further research.

The portion E<sub>2</sub> was tested for carbohydrates by the Molisch reaction <sup>27</sup> with alpha-naphthol, and a distinct positive reaction obtained. The nature of the carbohydrate was revealed further by the aniline acetate test, which showed that some pentose and possibly a little hexose, such as fructose or sorbinose, was present.

A portion of E<sub>2</sub> weighing 0.4168 gram was dissolved in about 25 milliliters of water, 0.25 gram of sodium hydroxide added, and the solution evaporated to

dryness. The material was extracted several times with warm alcohol, which dissolved the remaining sodium hydroxide but very little organic matter. The brown residue, easily powdered, gave 6.3 percent of ash on ignition. Apparently a sodium salt of the material was formed which was insoluble in alcohol, although the material before conversion to the sodium salt was soluble.

Sodium hydroxide has long been used in extracting the organic matter of soils, and a considerable number of compounds have been thus isolated and identified.<sup>28</sup> For some constituents, portions weighing 50 pounds were necessary in order to obtain identifiable quantities of the organic compounds. Similar methods might well be applied to sediments.

<sup>27</sup> Mulliken, S. P., *The identification of organic substances*, vol. 1, p. 26, New York, John Wiley & Sons, 1904.

<sup>28</sup> Shorey, E. C., *Some organic soil constituents*: U. S. Dept. Agr., Bur. Soils, Bull. 88, 1918.



# THE FLORA OF THE NEW ALBANY SHALE

## PART 2. THE CALAMOPITYEAE AND THEIR RELATIONSHIPS

By CHARLES B. READ

### ABSTRACT

Material referable to *Calamopitys americana*, *Calamopitys foerstei*, *Stenomyelon muratum*, *Kalymma lirata*, *Kalymma resinosa*, and *Kalymma auriculata*, from the upper portion of the New Albany shale in central Kentucky, is described. All these species are based on the internal structure of stems and petioles. The suggestion is made that the genus *Stenomyelon* should be included in the family Calamopityeae rather than in a separate family. Relationships of the several species and genera belonging to the Calamopityeae are discussed, and it is recommended that the name *Calamopitys* be restricted to manoxylic forms (*C. saturni* Unger, etc.), that *Eristophyton* be used for the pycnoxylic species which have in the past been placed in *Calamopitys*, and that *Sphenoxylon* be adopted for the American species which has been called *Calamopitys eupunctata*. It is pointed out that the Calamopityeae may be divided, naturally, into two major groups—a manoxylic, protostelic group and a pycnoxylic, medullated group. *Stenomyelon* is probably in the lineage of the more primitive Calamopityeae, and *Endoxylon* is presumably the most advanced type now known.

### INTRODUCTION

In the first paper of this series the writer described in detail the morphology of a particularly interesting member of the Calamopityeae. The continued study of the New Albany shale and its flora, both in the field and in the laboratory, has resulted in the making of large collections of new or heretofore imperfectly known plants. The present report summarizes the results of the examination of the calamopityean forms and includes accounts of the species of *Calamopitys*, *Stenomyelon*, and *Kalymma*, all from the New Albany shale in the vicinity of Junction City, Ky.

The writer wishes to express his gratitude to Mr. Guy Campbell, of New Albany, Ind., with whom he spent several weeks in the field in 1934 and 1935, for his interest and aid in making the collections. The thin sections have been prepared by K. J. Murata, of the Geological Survey, and his interest, both in the preparation and in the study of the flora, is appreciated.

### SYSTEMATIC DESCRIPTIONS

#### CYCADOFILICALES

#### CALAMOPITYEAE

##### Genus CALAMOPITYS Unger 1856

1856. Unger, Franz, in Richter, Reinhard, and Unger, K. Akad. Wiss. Wien Denkschr., Band 11, p. 73 [159].

The genotype of *Calamopitys* is *C. saturni* Unger, from the *Cypridina* shales of uppermost Devonian or lowest Carboniferous age in the vicinity of Saalfeld,

Thuringia. This species is of the type designated *Eu-Calamopitys* by Scott.<sup>1</sup> It is similar to both *C. americana* and *C. annularis*, differing only in the more nearly centrally mesarch position of the protoxylem, in the apparent absence of medullary tracheids, and in the details of leaf-trace emission.

In the writer's opinion, the name *Calamopitys* should be restricted to the manoxylic species—that is, the eu-calamopityean forms—and the pycnoxylic species should, as suggested by Zalessky,<sup>2</sup> be segregated in the genus *Eristophyton*. This course is adopted in the present paper.

##### *Calamopitys americana* Scott and Jeffrey

Plate 16, figures 1, 2; plate 17, figures 1–4; plate 18, figures 1–4; plate 25, figure 1; plate 26, figures 2, 5

1914. Scott, D. H., and Jeffrey, E. C., Royal Soc. London Philos. Trans., ser. B, vol. 250, pp. 317–330, pl. 27, figs. 1–7; pl. 28, figs. 8–14; pl. 29, fig. 22; pl. 30, figs. 23–29; pl. 31, fig. 30; pl. 34, figs. 49–51; pl. 35, figs. 1–4; pl. 36, figs. 5–8.  
1918. Scott, D. H., Linnean Soc. London Jour., Botany, vol. 44, no. 297, pp. 206–209, 218, pl. 6, figs. 1–10.  
1923. Scott, D. H., Studies in fossil botany, 3d ed., pt. 2, pp. 109–116, figs. 49–51.  
1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, pp. 218–219, pl. 27, fig. 1.

According to Scott,<sup>3</sup> *Calamopitys americana* is characterized by

Primary xylem strands eccentrically mesarch, with the centrifugal portion smaller and smaller-celled than the centripetal. Strands united laterally to form an almost closed xylem-ring.

Pith "mixed", containing a varying proportion of medullary tracheids.

Leaf trace dividing into two as it passes through the secondary wood. Each leaf-trace bundle, where it leaves the wood, surrounded by a zone of secondary thickening.

Secondary wood with high, multiseriate medullary rays, not enlarged outward. Tracheids with several series of alternating bordered pits on the radial walls.

Leaf base with the structure of *Kalymma*, containing a number of mesarch bundles, each with from 2 to 5 protoxylem groups.

*Primary structure and pith.*—To go into more detail regarding the anatomy of *Calamopitys americana*, the pith, as has been stated, is "mixed", so that with only a slight departure from the commonly accepted defini-

<sup>1</sup> Scott, D. H., Studies in fossil botany, 3d ed., pt. 2, pp. 108–109, 1923.

<sup>2</sup> Zalessky, M. D., Étude sur l'anatomie du *Dadoxylon tchihatcheffi* Goepppert: Com. géol. [St.-Pétersbourg] Mém., nouv. sér., livr. 58, p. 27, 1911.

<sup>3</sup> Scott, D. H., Notes on *Calamopitys* Unger: Linnean Soc. London Jour., Botany, vol. 44, no. 297, p. 218, 1918.

tion the structure may be regarded as protostelic. Some idea of the situation may be grasped from an examination of plate 17, figures 1-4. The central area of the stem is at once seen to be occupied by a heterogeneous mass of tissue consisting of a groundmass of parenchyma containing isolated and connected groups or "nests" of few to many thick-walled cells, which have been identified as tracheids. Toward the periphery these aggregations of tracheids become more regularly disposed and finally form an almost continuous primary xylem. Figures 1-4, plate 18, illustrate a portion of this tissue more highly magnified, and it becomes evident that the primary structure is mesarch, the protoxylem being immersed but nearer the outer margin of the bundle than the inner.

*Secondary wood.*—Abutting this almost continuous ring of mesarch primary xylem on the exterior is a considerable thickness of secondary wood. This tissue is homogeneous, consisting of radially arranged tracheids except for the numerous multiseriate parenchymatous rays. The general aspect of the secondary wood in transverse section is shown in plate 18, figures 1 and 2, and in longitudinal section in plate 16, figure 2. The rays range in width from 1 to 11 cells and are, of course, widest close to the inner margin of the wood. They may be high, as is shown by the longitudinal tangential section.

It is impossible to demonstrate satisfactorily the pitting of the tracheids. It appears, both from the observations of Scott and Jeffrey and from those of the writer, that the pits are small, multiseriate, and alternate.

*Phloem and pericycle.*—Beyond the secondary wood there is a zone of more or less crushed and partly decomposed tissue, which is largely parenchymatous in nature. Its general appearance is shown in plate 18, figures 1 and 4. A similar tissue is commonly present in *Diichnia kentuckiensis*, where, as in the present species, it is interpreted as the remains of cambium, phloem, and pericycle.

*Cortex.*—The cortex of *Calamopitys americana* is a very broad zone of parenchymatous tissue. Its general aspect is shown in plate 16, figure 1. The cells are nearly isodiametric in transverse section and rather short. On the exterior is a zone of parenchyma in which are embedded radial plates of sclerenchyma to form a hypodermis of the familiar "*Sparganum*" type. The vascular bundles of the leaf traces that traverse the cortex are considered below.

*Leaf trace.*—The description up to this point has developed the fact that *Calamopitys* is a stem of modified protostelic type producing secondary wood and exhibiting a broad cortex. In these respects it resembles the stems of several species of *Heterangium*, and it is not until the leaf traces are examined that features are observed which serve to establish definitely the generic identity of *Calamopitys americana*.

The series of photographic illustrations in plate 17, figures 1-4, serve to show rather diagrammatically the stages in the origin and development of the leaf trace.

An early stage in the development of the foliar trace is shown in plate 17, figure 1. It will be recalled that the primary xylem is nearly continuous around the "mixed" pith. The first indication of a departing leaf trace is the formation of a prominent angle in the "mixed" pith at the point of emission (pl. 17, fig. 1). As this angle develops, the adjacent primary bundle moves outward and becomes radially elongated. The protoxylem, which at first lies as a single group near the outer margin of the bundle, begins to elongate radially (pl. 18, fig. 1) and finally separates into two radially aligned groups surrounded by metaxylem (pl. 18, fig. 2). The outer of these is the primary bundle of the leaf trace; the inner is known as a reparatory strand and remains in the stem as an integral part of the primary wood. As the angle of emission becomes more and more prominent and the subtending fan of secondary wood thins, the leaf-trace bundle becomes tangentially flattened and finally divides into two strands, each with its own protoxylem (pl. 18, figs. 3, 4). These strands remain close together at first but become more widely separated as they pass farther out. In the course of this passage a fan of secondary wood is seen on the outer side. As the double bundle emerges from the secondary wood of the stem a centripetal zone of secondary wood is developed, so that the leaf trace at this point has a concentric structure, which is, however, eccentric by reason of the position of the protoxylem and the smaller amount of centripetal secondary wood.

As the trace passes through the zone of phloem and pericycle the secondary xylem lessens in amount, and at the same time the two protoxylems become more widely separated, so that finally the two bundles are developed. As these pass into the inner cortex they diverge gradually and slowly lose all traces of secondary wood. As a result each bundle consists of primary xylem with an eccentrically mesarch protoxylem and is completely ensheathed by phloem and pericycle.

*Leaf base.*—In the collection made by the writer in 1932 there are several stems in which the cortex is well preserved. In view of the fact that Scott and Jeffrey apparently had only fragmentary material of the cortex showing leaf bases, an attempt is here made to record detailed observations on this feature.

As has already been indicated, the cortex is a rather homogeneous zone consisting of parenchyma except at the outer border, where a "*Sparganum*" hypodermis is present. The course of the leaf trace from its origin in the primary wood through the secondary wood, phloem, and pericycle has so far been followed, and it has been observed that the trace, originally single, divided into two bundles, which draw apart as the pericycle is traversed. As these bundles enter

the inner cortex the situation is that shown in plate 18, figure 4, and described in a previous paragraph.

These bundles gradually diverge as they continue outward and become radially elongate, with the development of two or more protoxylems. At the same time the last vestiges of secondary wood are lost, first on the inner side and later on the outer.

Soon, by a process of medial longitudinal constriction, each of these bundles divides into two. Successive divisions of these bundles finally result in a structure of the type illustrated in plate 16, figure 1. It will be noted that the bundles tend to be radially elongated, but where several protoxylems are present the long axis may be tangential.

*Affinities of Calamopitys americana.*—*Calamopitys americana* is a member of the group which has been designated by Scott<sup>4</sup> *Eu-Calamopitys*. This subgenus is characterized by the generally manoxylic secondary wood, large, uniform, mesarch primary xylem strands, and a marked tendency toward the development of a "mixed pith." In addition, all these forms give off *Kalymma*-like petioles.

Contrasted with *Eu-Calamopitys* is the group variously assigned to a genus or subgenus under the name *Eristophyton* Zalessky.<sup>5</sup> In this segregation the secondary wood is pycnoxylic, the primary bundles large and mesarch above, and small with a tendency to become endarch below. To the writer it appears that this group is a logical generic segregate, and he suggests that *Eristophyton* be regarded as a distinct genus. It then follows that *Eu-Calamopitys* may be discarded, because the whole of the group falling in the genus *Calamopitys* Unger likewise falls in *Eu-Calamopitys*. In other words, the generic recognition of *Eristophyton* establishes *Calamopitys* and *Eu-Calamopitys* as synonymous.

*Calamopitys americana* is very closely related to *Calamopitys annularis* Unger, if one may judge from Scott's recent account.<sup>6</sup> This species carries what appears to be a "mixed pith"—exarch-mesarch primary xylem strands, forming a nearly continuous ring, and manoxylic secondary wood. However, there are no details on record concerning the nodal morphology, which is of great importance in delimiting the species. In consequence, the two forms must remain separate for the present, although it is not improbable that they may be combined in time.

*Calamopitys americana* is quite distinct from the other known species of the genus. Comparisons are made in the general summation of the group elsewhere in this paper.

#### *Calamopitys foerstei* Read

##### Plate 19, figures 1-3

1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, p. 219, text fig. 6.

In the Junction City material there are several specimens of a species of *Calamopitys* which has been, with some hesitation, described as new. This species was named in honor of Dr. August Foerste, the eminent American geologist who named the Linietta clays, the basal part of which is the source of the material described in this paper.

As the material in hand consists of decorticated specimens, the following remarks are of necessity confined to the woody cylinder. A series of sections has been prepared, and these show the essential features of leaf-trace emission, a feature upon which this species is primarily based.

*General morphology.*—In plate 19, figure 1, a transverse section of a specimen of *Calamopitys foerstei* is shown at a low magnification. The more obvious features are the five-angled pith of rather large size and the woody cylinder traversed by multiseriate rays. Situated on the edge of the pith, but not usually in direct contact with the secondary wood, are numerous discrete bundles of mesarch primary xylem. Scattered through the pith are a few isolated or grouped tracheids. It is therefore evident that the central portion of the plant is a "mixed" pith comparable to that in *Dicroidium kentuckiensis* and *Calamopitys americana*. At one angle (pl. 19, fig. 1, rs) of this "mixed" pith it is evident that there is an interruption in the continuity of the tissues, owing to the departure of a leaf trace. At the other angles are to be seen other leaf traces in less advanced stages of emergence.

These traces, it is evident, are mesarch in structure and are developed in the fashion which is typical of the *Calamopitys*—that is, through the division of medullary xylem bundles into inner reparatory strands and outward-passing leaf-trace strands.

*Details of leaf-trace emergence.*—Owing to the insufficient and incomplete material available the nodal morphology can at present be only outlined in a general way. At an angle from which a leaf trace is to depart there is a gradual confluence of two strands of primary xylem lying on each side of the angle and embedded in the "mixed pith." These strands appear to remain separate while the protoxylem divides to form an outward-passing leaf-trace bundle from each and a continuing reparatory strand from each. The situation at this stage is seen in plate 19, figure 2, where the protoxylem groups of the reparatory and leaf-trace strands are separated, yet the metaxylem remains a continuous strand. An interesting feature here is that these two leaf-trace bundles, though

<sup>4</sup> Scott, D. H., Studies in fossil botany, 3d ed., pt. 2, p. 108, 1923.

<sup>5</sup> Zalessky, M. D., Étude sur l'anatomie du *Dadoxylon tchihatcheffi* Goeppert: Com. géol. Mém., nouv. sér., livr. 58, p. 23, 1911.

<sup>6</sup> Scott, D. H., Notes on *Calamopitys* Unger: Linnean Soc. London Jour., Botany, vol. 44, no. 207, pp. 210-215, 1918.

initially separate, tend to fuse so far as the metaxylem is concerned, thus forming a single leaf-trace bundle incorporating two protoxylems. As this bundle emerges through the secondary wood it carries with it a fan of secondary xylem, presumably into the cortex, so that the general aspect on the outer face of the stele is probably similar to that in *Calamopitys americana*, and as the reparatory strand is finally separated from the leaf trace a broadly inverted U-shaped strand is seen resting in the angle of the pith. At later stages this bundle, which still carries two protoxylems, one in each lobe, divides, and thus two distinct bundles are formed. These diverge slightly but remain adjacent to the prominent pith angle.

*Relationships of Calamopitys foerstei.*—*Calamopitys foerstei* is a rather unusual form apparently intermediate in many respects between *Diichnia kentuckiensis* and *Calamopitys americana*. In fact, it is questionable whether this species should be referred to *Diichnia* or *Calamopitys*. In view of the departure of the leaf trace as a single bundle with two protoxylems, the designation as *Calamopitys* seems preferable. As this species now stands it is rather unsatisfactory, however, and it is to be hoped that more complete material will be found illustrating morphologic features that are now unknown or imperfectly understood.

#### Genus *STENOMYELON* Kidston and Gwynne-Vaughan, 1912

1912. Kidston, Robert, and Gwynne-Vaughan, D. T., Royal Soc. Edinburgh Trans., vol. 48, pt. 2, pp. 263-271.

#### *Stenomyelon muratum* Read

Plate 20, figures 1-4; plate 21, figures 1-4; plate 22, figures 1-4; plate 23, figures 4, 5; plate 26, figures 1, 3, 6

1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, p. 220, pl. 29, fig. 1.

A single specimen collected in 1932 from Junction City is referable to the genus *Stenomyelon* Kidston.<sup>7</sup> A diagnosis of the type species, *Stenomyelon tuedianum* Kidston, is as follows:

Stem monostelic, primary xylem without xylem parenchyma, divided more or less distinctly into three lobes by as many radiating and interrupted bands of parenchyma. Primary tracheae porose on all walls. The protoxylems of the leaf trace decurrent as exarch strands on the extremities of the lobes. Secondary thickening occurs. Secondary tracheae with porose pits on the radial walls only. Medullary rays numerous. Stele closely invested by a zone of sclerotic periderm. Leaf traces depart successively from the extremities of the lobes and repeatedly divide in the cortex. Leaf-trace protoxylems become immersed. Outer cortex of the "Sparganum" type.<sup>8</sup>

With this diagnosis in mind, attention may now be turned to the new Kentucky material. In plate 23, figures 4, 5, thin sections of *Stenomyelon muratum* are

seen. Examination of these sections shows that the more obvious features are (1) a large triangular "pith", which in reality is a "mixed" pith or parenchymatous protostele; (2) a surrounding zone of secondary growth, marked by the occurrence of prominent rays; (3) a one-third phyllotaxy; (4) a broad, rather parenchymatous cortex; (5) leaf traces which originate from an angle of the "mixed" pith and which emerge slowly.

#### DETAILS OF MORPHOLOGY OF THE STEM

"Mixed" pith.—The features of the central column, or so-called pith, are well exhibited in plate 20, figures 1-4. Figure 1 shows that the triangular column is made up principally of sclerotic elements, which are beyond any doubt primary tracheids. Interspersed with this mass of xylem are scattered cells and groups of cells of parenchyma, and around the periphery, except at the angles, there is an almost continuous zone of parenchyma. One of the most marked features of this primary wood is the very slight differentiation of protoxylem except in the vicinity of emerging leaf traces, a feature which *Stenomyelon muratum* shows with *S. tuedianum* Kidston. In the latter species "there appear to be no protoxylem strands proper to the stem itself, but in the neighborhood of the departing leaf traces a pair of definite exarch protoxylem strands are usually to be seen."<sup>9</sup>

Secondary wood.—Most of the details of secondary-wood structure that are discernible in the material may be seen in plate 21, figures 1-4. It is of the manoxylic type, with rather large tracheids and numerous multi-seriate rays, which are broadest where they abut on the "mixed" pith. As is true of most of the Kentucky material, the preservation is such that few finer details of structure may be seen in longitudinal section. It appears, however, that the pitting is crowded on the walls of the cells and probably restricted to the radial surfaces.

Outer stelar tissues.—On the exterior of the secondary wood may be seen in some sections the fragmentary remains of probable cambium, phloem, and parenchyma. Examples of preservation of these tissues are seen in plate 21, figure 2, and plate 22, figures 1 and 2. These tissues are poorly preserved and somewhat crushed; they exhibit few features of more than casual interest.

Cortex.—The bulk of parenchymatous tissue that sheathes the woody cylinder is clearly referable to the cortex. This zone is for the most part a homogeneous one, consisting of large-lumened, more or less isodiametric cells. The walls are in places somewhat thickened, but this may be a function of preservation.

A well-differentiated and extensive hypoderma is present and consists of sinuous yet radiating strands of sclerenchyma, which frequently anastomose. The

<sup>7</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., On the Carboniferous flora of Berwickshire, pt. 1, *Stenomyelon tuedianum* Kidston: Royal Soc. Edinburgh Trans., vol. 48, pt. 2, pp. 263-271, pls. 1-4, 1912.

<sup>8</sup> Idem, p. 270.

<sup>9</sup> Idem, p. 265.

general aspect of this tissue is clearly shown in plate 22, figure 4.

*Leaf trace*.—In order to clarify the discussion of the leaf trace during the course of its development and emission, a series of photographs has been prepared from serial thin sections. These are shown in plate 20, figures 1-4; plate 21, figures 1-4; and plate 22, figures 1-2. The central column of admixed primary xylem and parenchyma is triangular in cross section and shows a development of protoxylem only at the three angles in connection with the emission of leaf traces. A very early stage in the development of the leaf-trace bundle is shown in plate 20, figure 3. An angle of the primary xylem has developed a slight bulge outward, and protoxylem has been differentiated. At this stage the bundle is mesarch. Somewhat later stages in the development of this trace are seen in plate 20, figure 4, and plate 21, figure 1, and as the bundle passes slowly outward (pl. 21, figs. 1-2) there is a gradual diminution in the amount of subtending secondary growth. It is obvious that the protoxylem, while it remains mesarch, is very eccentric (pl. 21, fig. 2), being just within the outer edge of the metaxylem.

In plate 21, figure 2, the protoxylem is evidently eccentrically mesarch and is enclosed in a large bundle of metaxylem, which has developed a centripetal constriction prior to its separation from the primary xylem of the main axis. The protoxylem is elongated tangentially, and the full significance of this feature is seen in plate 21, figure 3. At this stage the secondary cylinder has been completely broken by the leaf trace that has separated from the main mass of primary xylem. This trace has now assumed an oval outline, with the long axis tangential to the main axis. The protoxylem, which continues to lie near the outer edge of the bundle, has divided into two distinct groups.

As the trace passes upward and outward it assumes the appearance shown in plate 22, figure 1. The protoxylems have become more widely separate, and the bundle, now clearly double, becomes more elongate tangentially. It is now evident that the trace will divide into two bundles, as is shown in plate 22, figure 2. At this point the trace has emerged into the phloem and pericycle, and the two bundles have diverged considerably. The protoxylem occupies an immersed position near the outer edge of each bundle.

As these two strands pass into the cortex further division takes place, so that the leaf base is polydesmic. Owing to the fragmentary condition of the specimens at hand it is impossible to define accurately the bundle pattern of the petiole or leaf base. However, some observations of slight value have been made. The bundle structure remains eccentric by reason of the position of the protoxylem and is also concentric, consisting of an immersed protoxylem (one to several) near the outer edge of the wood, encased in metaxylem and

completely surrounded by tissues which are regarded as phloem and pericycle. This structure is shown in detail in plate 22, figure 3.

In the early stages of development the several bundles are arranged in a horseshoe outline and lie in the homogeneous cortex. The cross-sectional outline of the bundles in which only one protoxylem is present is nearly circular or only slightly oval. Where more than one protoxylem is present, these usually have a tangential alinement. In consequence the general aspect of the leaf base and of the individual bundles is somewhat different from that recorded for *Kalymma*, in which many of the bundles are elongated radially.

In the material at hand later stages of the leaf base are very imperfect. It appears, however, that numerous bundles exist, and that these are arranged in a ring.

The hypodermis, which is the outermost tissue preserved in the leaf base, is very characteristic. It consists of curving and frequently anastomosing strands of sclerenchyma and parenchyma and forms a zone of considerable width, as is shown in plate 22, figure 4.

*Affinities of Stenomyelon muratum*.—It has been shown in the preceding paragraphs that *Stenomyelon muratum* is characterized by (1) a mixed three-angled pith in which the protoxylem is imperfectly differentiated except in the advent of an emerging strand to supply the leaf; (2) a rather broad zone of secondary growth characterized by numerous multiseriate rays, some of which may be very broad; (3) a narrow zone of poorly preserved phloem and pericycle; (4) a broad zone of cortex; and (5) leaf traces passing outward from the angles of the mixed pith in a one-third divergence. A protoxylem develops at the angle, occupying an eccentrically mesarch position, and gaps the stele widely as it emerges. At the same time it divides into two bundles in the course of its passage through the secondary wood and further divides to form a polydesmic trace.

These facts immediately establish *Stenomyelon muratum* as a member of the Cycadofilicales, which were a dominant element of the Paleozoic floras. A comparative treatment of several of these with specimens in hand is now necessary to determine the affinities of the new form. In the writer's judgment the most valuable criteria in this comparison are data relating to the mixed pith, the morphology of the primary xylem, the leaf trace, and the leaf base. Of secondary importance is the structure of the secondary wood, phloem, pericycle, and cortex.

Although *Stenomyelon muratum* departs in certain features from the concept of the genus as it was defined by Kidston and Gwynne-Vaughan, nevertheless it seems to fit closely enough to make generic segregation unwise. The American form is characterized by a more parenchymatous central column, the "mixed pith", than the English *S. tuedianum* Kidston and *S. triparti-*

*tum* Kidston.<sup>10</sup> In both these English species there is simply a roughly tripartite division of the protostelic central column by narrow strands of parenchyma. However, this feature may be regarded as one that may vary considerably between species of the same genus.

The poorly characterized protoxylem, except in the vicinity of a leaf trace, is likewise a point in common, as is the method of leaf-trace emission. According to Kidston and Gwynne-Vaughan the leaf trace in *Stenomyelon tuedianum* "departs from the ends of the lobes of the primary xylem in a perfectly protostelic manner."<sup>11</sup> A comparison of Kidston and Gwynne-Vaughan's illustrations with those in this paper demonstrates a general similarity in the mode of leaf-trace departure. It is true that the leaf trace in the English material shows a more marked development of secondary xylem than that of *S. muratum*. Likewise the protoxylem is exarch, becoming immersed, in *S. tuedianum*, whereas in *S. muratum* the protoxylem is mesarch, tending slightly toward exarchy. Similar bundles are likewise developed in the petiole bases of both species, and these bases are polydesmic. Thus it would appear that although *Stenomyelon muratum* varies in detail from *S. tuedianum* and *S. tripartitum* Kidston it may be definitely assigned to the genus.

Probably the closest affinities of *Stenomyelon muratum* and, in consequence, of the other species of the genus are with the Calamopityeae, the family in which the writer suggests that *Stenomyelon* be placed. It would seem that except for the apparent absence of protoxylem in the caudine axis and, in consequence, of reparatory strands in connection with an emerging leaf trace, *Stenomyelon* might readily be admitted as an offshoot of the *Calamopitys* type in which secondary xylem is but slightly manifested in the leaf-trace bundles. Moreover, in view of the fact that there is some differentiation of protoxylem in *S. tripartitum* Kidston, it would appear that this feature is one of but doubtful value. The leaf base, both in the Calamopityeae and in *Stenomyelon*, is polydesmic, and the bundles are similar.

In summary, it is the writer's opinion that *Stenomyelon* is closely related to various calamopityean genera and should be assigned to the family Calamopityeae. It parallels some of the Lyginopterideae, but whether it has any direct relationship to that family is doubtful.

#### Genus KALYMMMA Unger

1856. Unger, Franz, K. Akad. Wiss. Wien, Math.-nat. Klasse, Denkschr., Band 11, p. 157.

The generic name *Kalymma* is used for detached petioles referable to *Calamopitys* and related genera. As defined by Unger and as now understood, it refers

particularly to petiolar organs characterized by a ring of polydesmic bundles, each bundle concentric in structure. This ring of bundles is embedded in a groundmass of parenchyma. Externally the petioles are characterized by a sheathing zone of alternating soft and sclerotic strands, the "Spanganum" cortex, and this is, of course, limited by the epidermis.

Unger originally described two species of *Kalymma*, *K. grandis* and *K. striata*. It is probable that these are identical, however. Scott and Jeffrey<sup>12</sup> in 1914 recognized *Kalymma grandis* Unger from the plant beds that yielded the material here under discussion. They likewise described *Calamopteris hippocrepis* from the same deposits, and, while admitting the relationship of this form and *Kalymma grandis*, they suggested generic segregation.

*Calamopteris* is a genus likewise established by Unger<sup>13</sup> and similar to *Kalymma* except for the tangential rather than radial elongation of the vascular bundles. It was suggested by Scott and Jeffrey<sup>14</sup> that these two genera might be grouped together, although they did not adopt that procedure. In this paper the writer suggests that the several species assigned to the two genera be placed in the genus *Kalymma*, which is preferable, owing to its more common usage.

The reasons for this generic synonymy are several:

1. A transition may be seen in a large series of specimens of *Kalymma* from the type defined as *Kalymma* with radially elongated bundles to the type defined as *Calamopteris* with tangentially elongated bundles.

2. The prominent invaginations mentioned by Scott and Jeffrey in the rim of bundles of *Calamopteris hippocrepis* and *C. debilis* Unger are characteristic of *Kalymma lirata* and cannot be taken as features of value in generic segregation. Such invaginations are common in other species in proximity to a dichotomy of the petiole.

3. The structure of the individual bundles appears to be identical in *Kalymma* and *Calamopteris*.

4. The parenchymatous groundmass and the "Spanganum" cortex are identical in both genera.

As regards the ramification of these petioles there is evidence at hand indicative of proximal dichotomy and distal lateral branching—that is, the fronds were probably bipartite. In the large specimens of *Kalymma* a deep groove marks both the abaxial and adaxial faces of the ring of vascular bundles. Certain fragments show these furrows strongly developed, with a tendency toward the formation of two equal rings of bundles. It is thus obvious that a dichotomy took place a short distance above.

<sup>10</sup> For a description of this form see Scott, D. H., Studies in fossil botany, 3d ed., pt. 2, pp. 141-143, 1923.

<sup>11</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., op. cit., p. 266.

<sup>12</sup> Scott, D. H., and Jeffrey E. C., On fossil plants showing structure from the base of the Waverly shale of Kentucky: Royal Soc. London Philos. Trans., ser. B, vol. 205, pp. 327-330, 1914.

<sup>13</sup> Unger, Franz, op. cit., p. 158.

<sup>14</sup> Scott, D. H., and Jeffrey, E. C., op. cit., pp. 334-335.

In a few small specimens there is clear evidence of lateral branching. Small arcuate traces involving several bundles in the parent axis are seen to emerge at an approximately right angle.

The descriptions and discussions which follow are based entirely on the writer's own collections, as he has been able to examine neither the Saalfeld material nor the early Kentucky collections reported by Scott and Jeffrey. *Kalymma grandis* Unger is recognized from Kentucky only on the basis of Scott and Jeffrey's account of fragmentary material. It is possible that their identification is incorrect, however, for the numerous specimens that have recently been examined appear to be referable to other species. These species, which are here described, include *Kalymma lirata* Read, *Kalymma resinosa* Read, and *Kalymma auriculata* Read.

#### *Kalymma lirata* Read

Plate 23, figures 1, 2; plate 24, figure 1; plate 25, figure 2; plate 26, figure 4

1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, p. 219, pl. 28, fig. 4.

In plate 23, figures 1 and 2, and plate 24, figure 1, are illustrated several specimens which are to be regarded as typical of this species. The specimen shown in plate 24, figure 1, may be considered the holotype. It is apparent that the petioles are characterized by a ring of vascular bundles and that this ring is marked by a depression or groove on both the abaxial and adaxial faces. This groove is more or less conspicuous, depending upon the proximity of the specimen to a dichotomy, but is invariably present. The ring of bundles is embedded in a groundmass of large cell parenchyma which is enclosed by a zone of "Spanganum" cortex. On the exterior of this hypodermal layer a fragmentary epidermis has been observed in a few specimens.

*Bundle structure.*—Some idea of the structure of the vascular bundles may be gained from an examination of plate 25, figure 2, and plate 26, figure 4. These figures show several bundles with the investing parenchyma. It is apparent that the xylem is entirely primary and that the general structure is concentric, one or more centrally mesarch protoxylems being situated in each bundle. The tracheids are scalariform.

Sheathing the xylem is a zone of poorly preserved tissue which undoubtedly constitutes the remains of phloem and possibly pericycle. On the exterior is the groundmass of parenchyma, which, in the illustration, appears thick-walled owing to the swelling of the cell walls.

*Hypodermis.*—On the exterior of the parenchymatous groundmass and in many specimens on the outermost tissue preserved there is a hypodermal zone consisting of radially aligned and alternating strands of sclerenchyma and parenchyma. This is shown in plate 23,

figure 2 and plate 24, figure 1, and is identical with the so-called "Spanganum" cortex or hypodermis of *Calamopitys americana* and *Dicroidium kentuckiensis*.

*Variations in the ring of vascular bundles.*—An idea of the variations to be seen in the ring of vascular bundles may be gained from plate 23, figures 1 and 2, and plate 24, figure 1. Plate 24, figure 1, illustrates a situation that may be regarded as most typical of *Kalymma lirata*. There is a ring of vascular bundles, each bundle radially elongated. At several points there are evidences of division of these bundles, and it is apparent that such division tends to produce a tangentially rather than radially elongated bundle.

The ring is bilaterally symmetrical, and it is apparent that the petiole has a well-defined dorsiventrality. Both the adaxial and abaxial surfaces are marked by grooves or invaginations, as is shown in the photograph, thus producing an outline similar to that in *Calamopteris hippocrepis* Scott and Jeffrey.

Plate 23, figure 2, shows another petiole that is placed in *Kalymma lirata*. Here the bundles are seen to be more commonly tangentially than radially elongated, although clearly there are several radially elongated bundles. It is probable that this feature of tangential elongation of the bundles is related to bundle branching or division below a dichotomy. The conspicuous furrows are evidence of proximity to such a ramification.

Plate 23, figure 1, shows a transverse section of *Kalymma lirata* in which the individual bundles are markedly elongated in a radial direction. Of interest is the U-shaped bundle forming the abaxial groove. Such a bundle is rather characteristic, as may be seen in the other figures.

It is thus apparent that there is marked variation in the general configuration of the individual bundles, but that the ring itself retains a rather characteristic form.

*Development of the petiole.*—The relationship of *Kalymma lirata* to *Calamopitys americana* is seen on examination of plate 25, figure 1, which is a portion of a transverse section of *C. americana*. It is apparent that at this point a petiole base has been cut. Furthermore, this leaf base consists of a series of vascular bundles arranged in a ring approximating in its outlines the ring characteristic of *Kalymma lirata*. The details of morphology of the bundles are likewise identical, as are the parenchymatous groundmass and the hypodermis.

It is apparent that such leaf bases are derived by repeated division of the vascular bundles from leaf traces similar to the one shown in plate 25, figure 1, emerging through the secondary xylem. To recapitulate, there is a branching of a single circummedullary, mesarch bundle, which is the first evidence of any emerging trace. The innermost of these branches remains in the "mixed" pith as a reparatory strand;

the outer one gradually traverses the secondary xylem, carrying with it a fan of secondary wood. In the secondary xylem there is a division of the protoxylem, and on the outer face of the secondary wood two concentric bundles may be seen, each sheathed in secondary growth. As these bundles traverse the cortex they branch and shortly lose their secondary growth. This branching of the vascular bundles results in a polydemic petiole of the type known as *Kalymma lirata*.

#### ***Kalymma resinosa* Read**

Plate 23, figure 3; plate 25, figures 3, 4.

1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, p. 219.

*Kalymma resinosa* is the name applied to petioles that are undoubtedly derived from the stems known as *Diichnia kentuckiensis* Read. These petioles are characterized by (1) a ring of concentric vascular bundles similar to that in *Kalymma lirata*; (2) a parenchymatous groundmass; (3) a "Spanganum" cortex; (4) secretory passages or sacs of lysigenous origin, situated in the parenchymatous groundmass.

Thus, in a general sense, it is apparent that *Kalymma resinosa* differs from *K. lirata* chiefly in the presence of secretory canals.

*Detailed morphology of the vascular bundles.*—Plate 25, figure 4, illustrates portions of two vascular bundles. These are concentric in structure—that is, with mesarch protoxylem and with a sheath of problematical phloem investing the whole bundle. The xylem is all primary, and the pitting, although not shown, is apparently scalariform. Generally there is but one protoxylem in each bundle, but where branching of the bundles occurs there may be several.

*Parenchymatous groundmass.*—Enclosing these bundles, as in *Kalymma lirata*, is a groundmass of parenchymatous tissue. The cells are large and isodiametric in transverse section but are rather elongate. Of considerable interest are the secretory ducts or sacs which occur in this groundmass. Several of these are shown in plate 25, figures 3 and 4, and plate 23, figure 3. These ducts, it appears, are lysigenous, being formed as a result of the disintegration of the cells. The occurrence of these secretory passages is one of the most characteristic features of *Kalymma resinosa*.

A hypodermis of radially directed alternating plates of parenchyma and sclerenchyma ("Spanganum" cortex) is present. The epidermis has not been observed.

*Ring of vascular bundles.*—The ring of vascular bundles in *Kalymma resinosa* contrasts sharply with that in *K. lirata*. In *K. lirata* marked abaxial and adaxial furrows occur. In *K. resinosa* such furrows are not observable; rather, the bundles are in the outline of a horseshoe with a marked adaxial gap and a less pronounced abaxial gap.

*Relationships.*—*Kalymma resinosa* is rather definitely the petiole of *Diichnia kentuckiensis* Read. In another paper<sup>15</sup> the writer has suggested that *Calamopteris hippocrepis* might be referable to that species, but it now appears that this statement was erroneous. The basis for inferring that *Kalymma resinosa* is the petiole of *Diichnia kentuckiensis* is the occurrence of lysigenous secretory sacs or ducts in the cortex in both organs. This is a rather unusual occurrence and affords ample basis for the correlation.

#### ***Kalymma auriculata* Read**

Plate 23, figure 6

1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, p. 220, text fig. 5.

A few petioles from the Junction City locality are referable to *Kalymma auriculata*, although this species is not so abundant as *Kalymma lirata* or *K. resinosa*. The general aspect of *Kalymma auriculata* is seen in plate 23, figure 6. It is apparent that these petioles are of the type conforming to the generic diagnosis, but in the characteristics of the ring of bundles there are points at variance with the known species. Abaxially there are two large bundles of irregular outline with prominent projections, hence the name *Kalymma auriculata*. Adaxially there are several smaller bundles constituting the ring. No sign of an invagination such as is characteristic of *Kalymma lirata* is seen. Instead the arrangement of bundles is that of a ring broken adaxially—that is, similar to *Kalymma resinosa*. However, the absence of secretory ducts precludes the possibility of referring such specimens to *K. resinosa*.

The detailed structure of the vascular strands is identical in both *Kalymma auriculata* and *K. lirata*. In other words, the xylem is mesarch with one to several protoxylems and is surrounded by tissues that are referable to phloem and pericycle.

The groundmass is parenchymatous and without any traces of secretory tissue. A "Spanganum" cortex limits this parenchyma externally. No traces of an epidermis have been seen.

It is apparent that petioles of this type are suggestive of the single specimen described in 1914 by Scott and Jeffrey<sup>16</sup> under the name *Calamopteris hippocrepis*. However, the marked abaxial and adaxial furrows in the ring of bundles in *C. hippocrepis* do not agree with the situation in *K. auriculata*. The differences between *K. auriculata* and *K. resinosa* have already been pointed out and need not be discussed further.

<sup>15</sup> Read, C. B., Flora of the New Albany shale, pt. 1, *Diichnia kentuckiensis*, a new representative of the Calamoptyeae: U. S. Geol. Survey Prof. Paper 185-H, pp. 153-155, 1936.

<sup>16</sup> Scott, D. H., and Jeffrey, E. C., On fossil plants, showing structure, from the base of the Waverly shale of Kentucky: Royal Soc. London Philos. Trans., ser. B, vol. 205, pp. 330-335, 1914.

**Kalymma hippocrepis (Scott and Jeffrey) Read**

1914. Scott, D. H., and Jeffrey, E. C., Royal Soc. London, Philos. Trans., ser. B, vol. 250, pp. 330-335.  
 1936. Read, C. B., Jour. Paleontology, vol. 10, no. 3, p. 220.

This species, which was described by Scott and Jeffrey, is known, to the writer's knowledge, only from the type specimen, which has not been available for study. In consequence, it is impossible to add further information concerning the form. According to the original description this species is characterized by

Vascular system of the petiole forming a horseshoe, with marked invagination at the bend.

Lateral bundles confluent, forming continuous bands.

Structure of the bundles collateral.

Xylem mesarch, with protoxylem groups near the morphologically outer surface.

Parenchyma uniform, short-celled.

Fibrous bands of the hypoderma crowded, with relatively little intervening parenchyma.

From this brief summary it will be seen that, except for the collateral structure of the vascular bundles, there is no great dissimilarity between *Calamopteris hippocrepis* and *Kalymma lirata*. However, this feature is sufficient basis for specific segregation.

There is no real reason, in the writer's opinion, for the continued use of the two genera *Kalymma* and *Calamopteris*. Specific separation is possible, but as it is shown in this paper that certain species combine the supposed generic characteristics of *Calamopteris* and *Kalymma*, it is apparent that the two genera must be consolidated. As has been previously indicated, the two names were both established by Unger in the same publication. *Kalymma* is in more common usage and hence is preferable. Thus it is suggested that *Kalymma hippocrepis* be substituted for the form previously known as *Calamopteris hippocrepis*.

**RELATIONSHIPS OF THE CALAMOPITYEAE**

The New Albany shale has now yielded four species assigned to the Calamopityeae on the basis of stem morphology. Several other forms that are referable to this family have been described from numerous other localities, both in America and in Europe. These are listed below.

*Calamopteris saturni* Unger—*Cypridina* shales, Thuringia.  
*Calamopteris annularis* (Unger) *Cypridina* shales, Thuringia.

Solms-Laubach.

*Calamopteris americana* Scott New Albany shale, Kentucky.  
 and Jeffrey.

*Calamopteris radiata* Scott—Calciferous sandstone, Scotland.  
*Calamopteris blayaci* Corsin—Lydites of Montagne Noire,  
 France.

*Calamopteris foerstei* Read—New Albany shale, Kentucky.  
*Stenomyelon tuedianum* Kidston and Gwynn-Vaughan.

*Stenomyelon tripartitum* (Kidston ms.) Scott—Calciferous sandstone, Scotland.

*Stenomyelon muratum* Read—New Albany shale, Kentucky.  
*Diichnia kentuckiensis* Read—New Albany shale, Kentucky.

*Bilignea solida* (Kidston ms.) Calciferous sandstone, Scotland.  
 Scott.

*Bilignea resinosa* Scott—Calciferous sandstone, Scotland.  
 "Calamopteris" eupunctata Portage shale, New York.

Thomas.

*Eristophyton fascicularis* Calciferous sandstone, England.  
 (Scott) Zalessky.

*Eristophyton beinertia nus* Lower Carboniferous limestone,  
 (Goeppert) Zalessky. Falkenberg, Silesia.

*Endoxylon zonatum* Scott—Carboniferous limestone, Scotland

An examination of this list indicates that, on the basis of stem morphology, there are known 16 species belonging to 6 genera of the Calamopityeae. The genus *Calamopteris* is the largest, with 6 or possibly 7 species. There are 3 species of *Stenomyelon* and 2 each of *Bilignea* and *Eristophyton*; *Diichnia* and *Endoxylon* are monotypic.

It appears to the writer that the family may be reasonably divided into two groups—one including the manoxylic and protostelic forms and the other the pycnoxylic and medullated forms. In the first such genera as *Calamopteris*, *Stenomyelon*, and *Diichnia* may be segregated; in the second, *Eristophyton* and *Endoxylon*. The genus *Bilignea* and "Calamopteris" *eupunctata* Thomas are puzzling, and their exact affinities are difficult to determine. (See fig. 1.)

*Stenomyelon* seems to be the most primitive known type. It must be borne in mind, however, that this does not imply descent of the other members of the family from *Stenomyelon*. Instead, the various forms here discussed may be considered iceloplasmic types.<sup>17</sup> *Stenomyelon* is a typical protostelic form. Owing to lack of differentiation between medullary and circum-medullary primary xylem the reparatory strands are indefinite, and the leaf-trace emission is typically protostelic. The protoxylem is mesarch in *S. muratum*, a primitive condition, in the writer's opinion. The leaf trace and petiole structure resemble those of *Calamopteris* and indicate the relationship. Further, *Stenomyelon* shows a marked resemblance to types that are apparently ancestral to the family. Thus *Stenomyelon* may be regarded as in the lineage of the more primitive Calamopityeae.

*Stenomyelon muratum* Read is apparently the most primitive member of the genus. The xylem is distinctly mesarch, whereas that of *S. tuedianum* and *S. tripartitum* tends to be exarch. These species are probably derived from some form comparable to *S. muratum*.

In the manoxylic Calamopityeae there is a trend toward medullation and toward a dilacunar leaf trace. The genus *Calamopteris* may thus be arranged next to *Stenomyelon*. This genus shows considerable diversification. So far as the leaf trace is concerned, *Calam-*

<sup>17</sup> Kirk, Edwin, The status of the genus *Mariocrinus* Hall: Am. Jour. Sci., 5th ser., vol. 18, p. 345, 1929. "In the working out of genetic relationships and the preparation of so-called phylogenetic series we must constantly realize that we may or may not be dealing with veritable ancestors and descendants. \* \* \* The forms chosen often may be terminal members of lateral offshoots and, so far as time relationship goes, may in fact be contemporaneous with descendant forms. \* \* \* For a suitable \* \* \* term I suggest that *iceloplasmic* might serve."

*mopitys saturni* Unger<sup>18</sup> appears to be the most primitive. The occurrence of a "mixed" pith has not yet been noted, although it may be present. In this species the leaf trace divided only after reaching the cortex. *Calamopitys annularis* (Unger) Solms-Laubach<sup>19</sup> and *C. americana* Scott and Jeffrey apparently rank next and are characterized by a well-defined protostele or "mixed" pith and by the leaf trace, which originates as a single bundle and divides into two as it emerges through the secondary xylem. *Calamopitys blayaci* Corsin<sup>20</sup> is closely related to both of these species.

To sum up this manoxylic group, their most logical arrangement is one from *Stenomyelon* through *Calamopitys* to *Diichnia*. Such a series indicates trends toward reduction of primary xylem, toward medullation, and toward a diarch leaf trace. Within *Stenomyelon* there is an offshoot in the direction of exarchy. In *Calamopitys* there is also a trend toward exarchy, but more prominent is that toward reduction of the primary xylem and toward the dilacunar trace. The culmination of this sequence, at least so far as known material is concerned, is seen in *Diichnia kentuckiensis*.

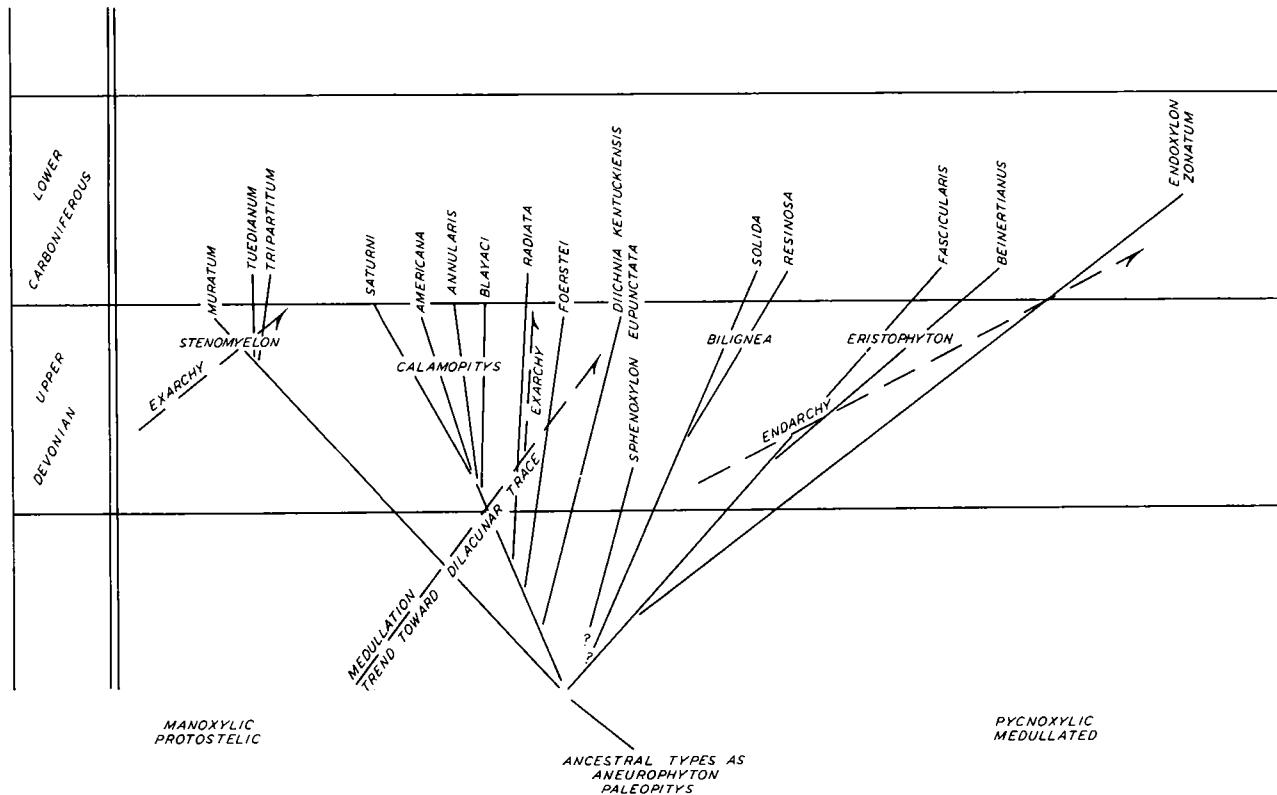


FIGURE 1.—Chart showing relationships of the Calamopityeae and general tendencies toward structural change within the family.

*Calamopitys foerstei* Read is obviously an advanced type, as is indicated by the reduction of primary xylem both in the "mixed" pith and in the number and continuity of the circummedullary strands. The mode of origin of the leaf trace is clearly an advancement in the direction of *Diichnia*.

*Calamopitys radiata* Scott<sup>21</sup> appears to be a blind specialization of the stock. It is remarkable in being exarch. No closely related species are known.

*Diichnia kentuckiensis* is clearly in the lineage of the calamopityean type just discussed, but in the dilacunar leaf trace and in the marked reduction of primary xylem it is clearly advanced beyond the limits of species that can properly be included in *Calamopitys*.

<sup>18</sup> Scott, D. H., Notes on *Calamopitys* Unger: Linnean Soc. London Jour., Botany, vol. 44, pp. 208-209, 1918.

<sup>19</sup> Idem, pp. 210-215.

<sup>20</sup> Corsin, Paul, in Böhm, Rodolphe, Étude sur la flore de l'horizon à lydiennes de la base du Carbonifère de la Montagne Noire, pp. 23-25, Montpellier, 1935.

<sup>21</sup> Scott, D. H., Fossil plants of the *Calamopitys* type from the Carboniferous rocks of Scotland: Royal Soc. Edinburgh Trans., vol. 53, pt. 3, pp. 569-596, 1925.

The pycnoxylic Calamopityeae appear to fall into two minor groups, the medullated and nonmedullated. The medullated group includes *Eristophyton fasciculare*, *E. beinertianus*, and *Endoxylon zonatum*; the nonmedullated group includes *Bilinea solidia*, *B. resinosa*, and "*Calamopitys*" *eupunctata* Thomas.<sup>22</sup>

The affinities of the protostelic-pycnoxylic forms within the Calamopityeae are vague. They appear to be, in the opinion of competent observers, calamopityean and so may best be regarded as blind offshoots of specialized types. Presumably they stand near the line that may be drawn between the manoxylic and pycnoxylic forms, yet they are clearly not in the direct sequence. The account of "*Calamopitys*" *eupunctata* is very complete so far as the material goes, but it seems better, in view of the restriction of *Calamopitys* to the multiseriate-rayed, manoxylic types, to use a different

<sup>22</sup> Thomas, D. E., A new species of *Calamopitys* from the American Devonian Bot. Gazette, vol. 97, pp. 334-345, 1935.

generic assignment. For this form, characterized by a stellate protostele and with the remarkable fans of secondary growth, the writer suggests the new generic name *Sphenoxylon*, with *S. eupunctata* as the genotype. *Sphenoxylon eupunctata* is provisionally grouped with *Bilignea solida* and *B. resinosa*, although the relationship is not close, and the grouping may be artificial.

The three species *Eristophyton fascicularis* (Scott) Zalessky,<sup>23</sup> *E. beinertianus* (Goeppert) Zalessky,<sup>23</sup> and *Eudoxylon zonatum* Scott<sup>24</sup> form a closely defined sequence indicating the transition from mesarch to endarch stelar types. As representatives of this group are unknown in the New Albany shale, and as they stand apart from the manoxylic types, they will not be further considered in this paper.

<sup>23</sup> Scott, D. H., Notes on *Calamopitys* Unger: Linnean Soc. London Jour., Botany, vol. 44, pp. 218-221, 1918.

<sup>24</sup> Scott, D. H., Fossil plants of the *Calamopitys* type from the Carboniferous rocks of Scotland: Royal Soc. Edinburgh Trans., vol. 43, pt. 3, p. 579, 1924.

Concerning the origin of the Calamopityeae it is apparent that any statement that might be made would necessarily be based on conjecture. However, the similarities in stelar make-up between such early types as *Aneurophyton germanicum* Krause and Weyland<sup>25</sup> and *Palaeopitys milleri* McNab,<sup>26</sup> on the one hand, and *Stenomyelon*, on the other, suggest in a striking fashion that the ancestral Calamopityeae may have been simple prostostelic types with only slight differentiation between stem and leaf.

The relationships of the Calamopityeae with other early families of Cycadofilices are likewise conjectural. There are obvious similarities with the *Heterangium-Lyginopteris* series, but as Scott has pointed out these are analogies. To the writer it appears that the family probably became extinct in the lower Carboniferous. At any rate, no derivative groups are known.

<sup>25</sup> Krause, R., and Weyland, H., Beiträge zur Kenntnis der Devonflora, pt. 1: Senckenbergiana, Wiss. Mitt., vol. 5, p. 178, 1923.

<sup>26</sup> Kidston, Robert, and Lang, W. G., On *Palaeopitys milleri* McNab: Royal Soc. Edinburgh Trans., vol. 53, pp. 409-417, 1923.



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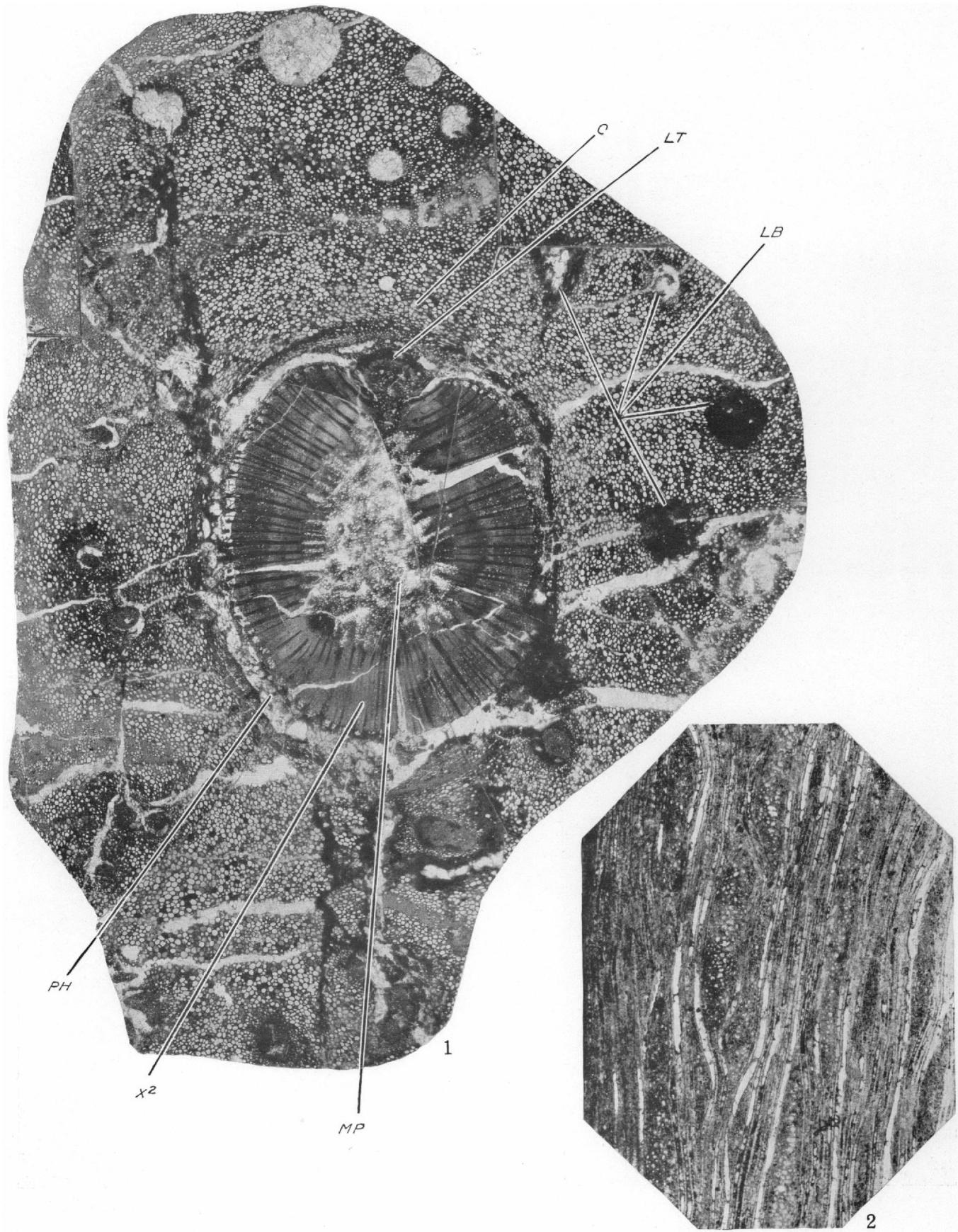
**PLATES 16-26**

## PLATE 16

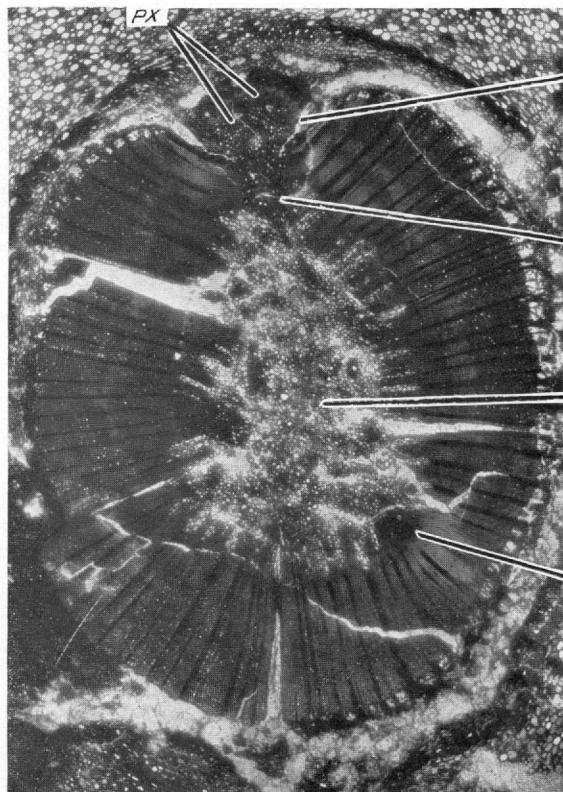
### *Calamopitys americana* Scott and Jeffrey

FIGURE 1. A mosaic of photographs of a transverse section of *Calamopitys americana* Scott and Jeffrey. The central portion of the stem is occupied by a "mixed" pith (MP), or parenchymatous protostele. Mesarch bundles of primary xylem form a nearly continuous ring around this column. A cylinder of secondary xylem is seen at X<sup>2</sup>, and at PH the zone occupied by phloem and pericycle. The cortex (C) consists largely of parenchyma. The remains of vascular strands making up the leaf bases are seen at LT (trace emerging from the stele) and at LB (leaf base). Enlarged 7 diameters.

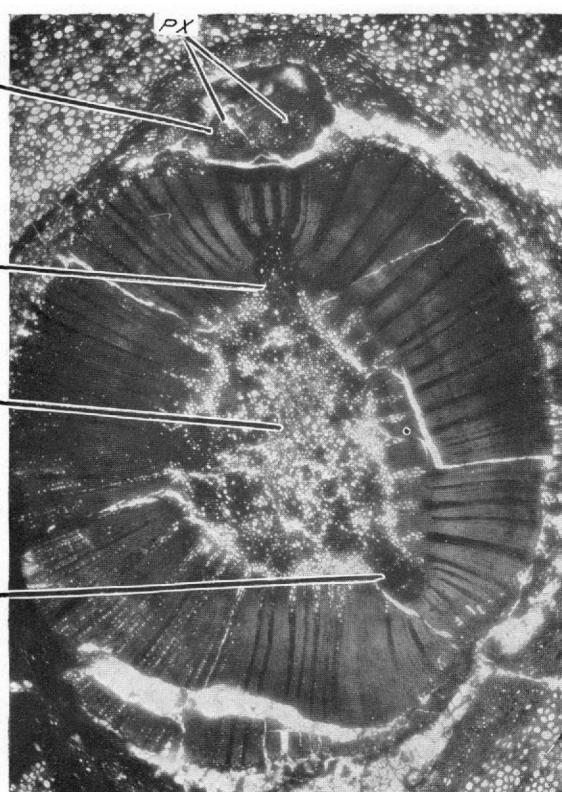
FIGURE 2. A photograph of a tangential section of the secondary xylem of *Calamopitys americana* showing the multiseriate rays. Enlarged 25 diameters.



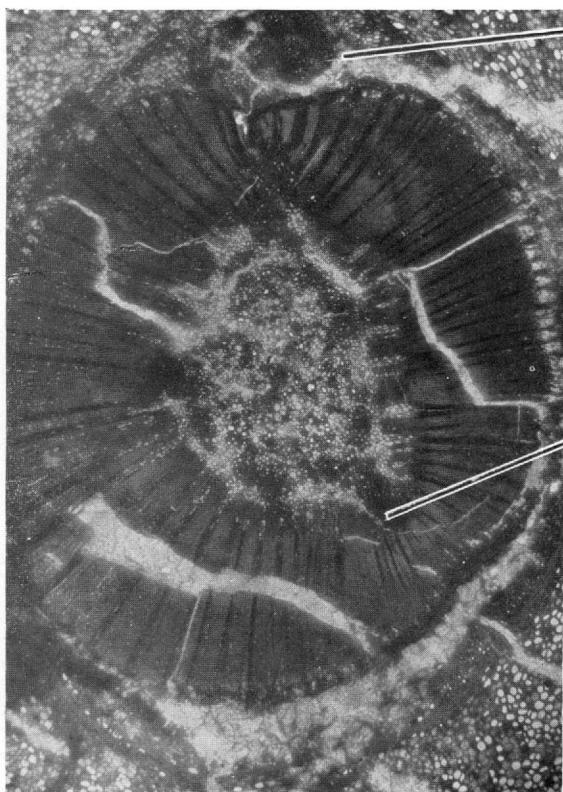
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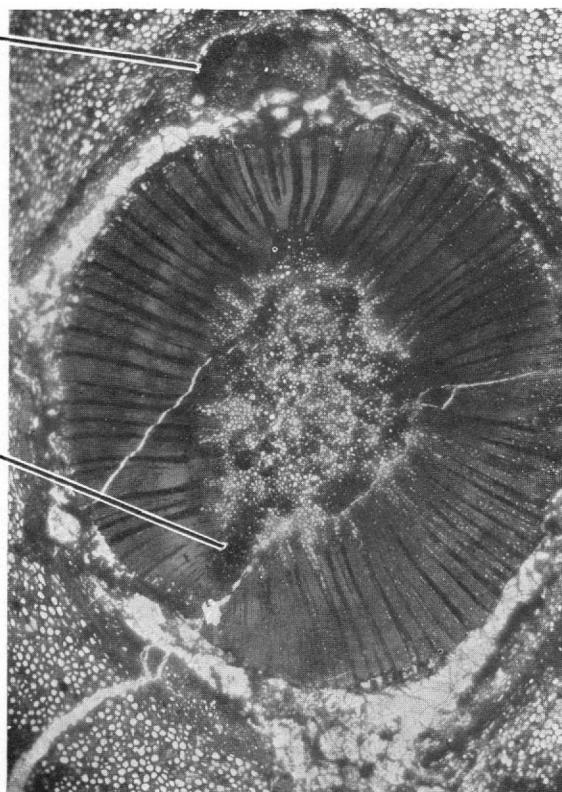
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CALAMOPITYEAE OF THE NEW ALBANY SHALE.

## PLATE 17

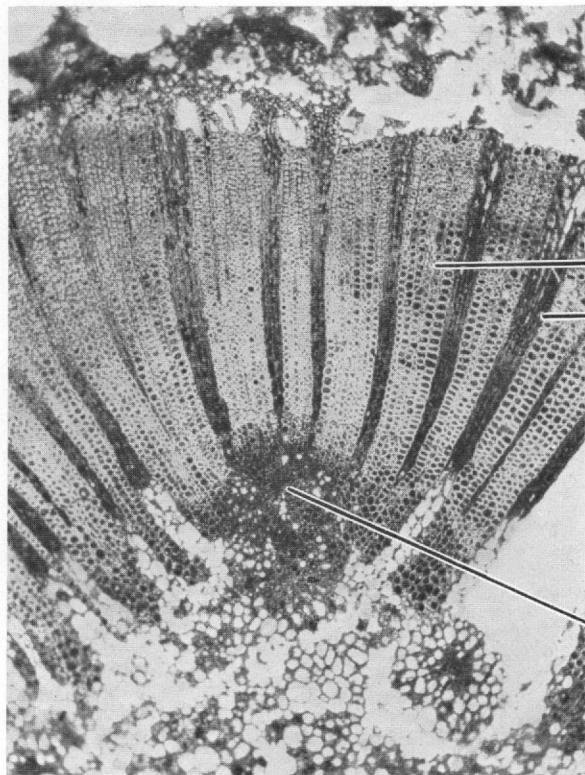
### *Calamopitys americana* Scott and Jeffrey

FIGURES 1-4. A series of transverse serial sections of the stele illustrating the emission of leaf traces. Two leaf traces ( $LT^1$  and  $LT^2$ ) are shown in all photographs. The letters RS and MP refer to reparatory strand and "mixed" pith. PX refers to protoxylem. The complete sequence of changes accompanying the giving off of a leaf trace may be followed by tracing  $LT^1$  from figure 1 to figure 4 and then by tracing  $LT^2$  from figure 1 to figure 4. It will be seen that the leaf trace originates as a result of the division of a single vascular strand into an outer leaf-trace bundle and an inner reparatory bundle. As the trace emerges it divides into two bundles which are completely separated in the outer tissues of the stele, as is seen in  $LT^2$ , figure 4. Enlarged 9 diameters.

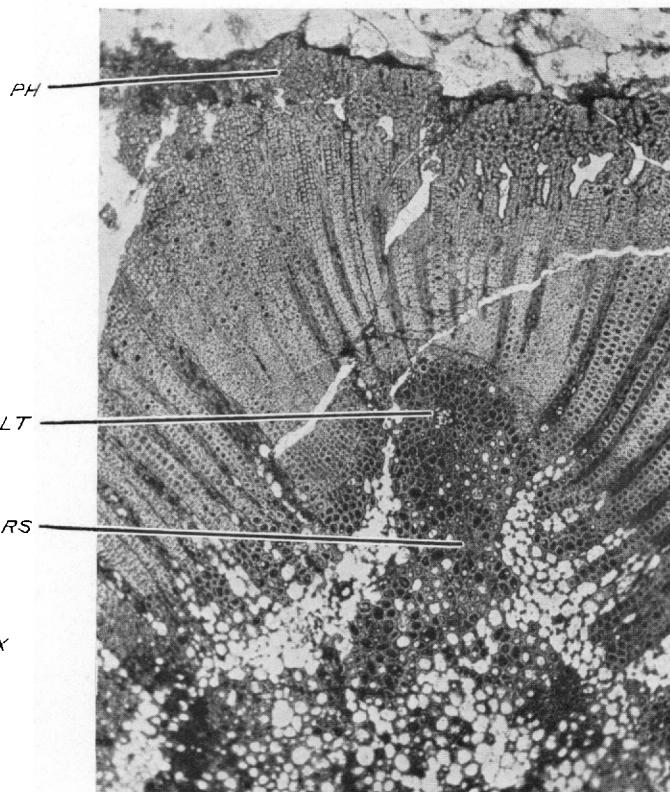
## PLATE 18

### *Calamopitys americana* Scott and Jeffrey

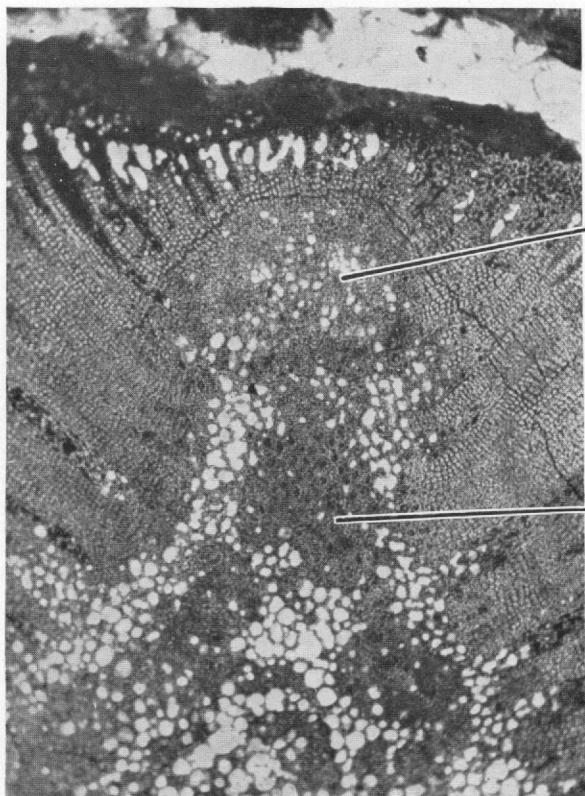
FIGURES 1-4. A series of photographs illustrating the emission of the leaf trace. In figure 1 the mesarch bundle of primary xylem is seen at the inner edge of the secondary wood. In figure 2 the protoxylem has divided into two, and the leaf trace is emerging through the secondary growth. The leaf trace and reparatory strand are more widely separated in figure 3, and the leaf-trace protoxylem has divided into two as it passes through the secondary xylem. Figure 4 shows the leaf trace on the outer face of the woody cylinder, where it has divided into two bundles. The letters used on the photographs refer to the protoxylem (PX), reparatory strand (RS), leaf trace (LT), ray (R), secondary xylem ( $X^2$ ), and outer stelar tissues (PH). Enlarged 25 diameters.



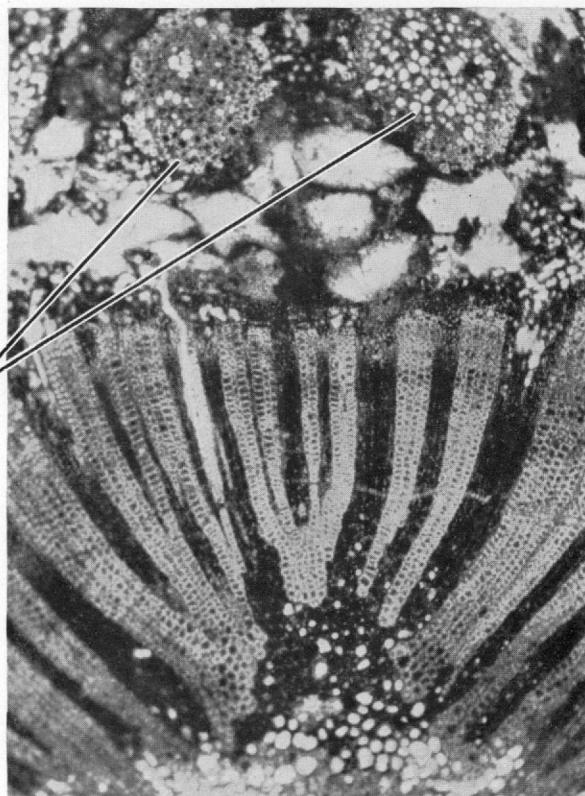
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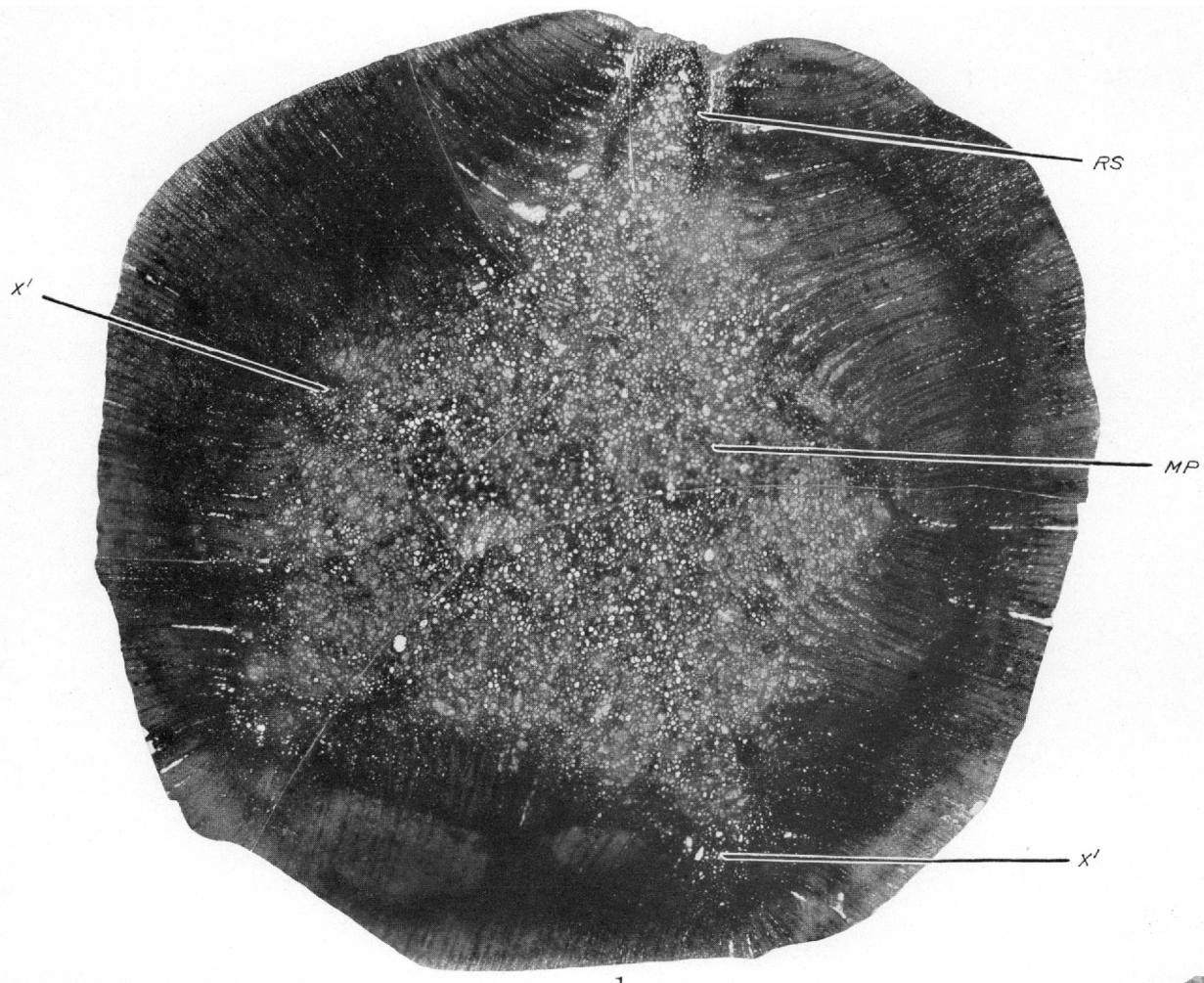


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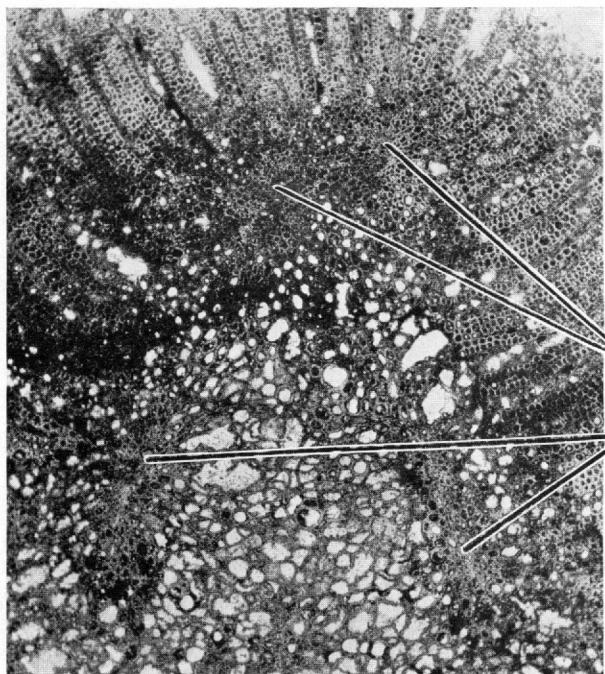


4

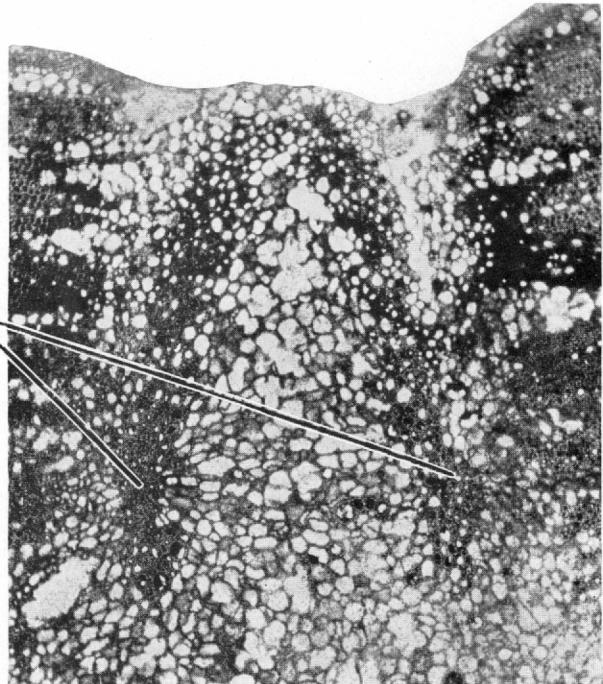
CALAMOPITYEAE OF THE NEW ALBANY SHALE.



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CALAMOPITYEAE OF THE NEW ALBANY SHALE.

PLATE 19

*Calamopitys foerstei* Read

FIGURE 1. A mosaic of photographs of a transverse section of the stem showing the "mixed" pith (MP), the primary bundles (X<sup>1</sup>), and a reparatory strand (RS). Enlarged 7 diameters.

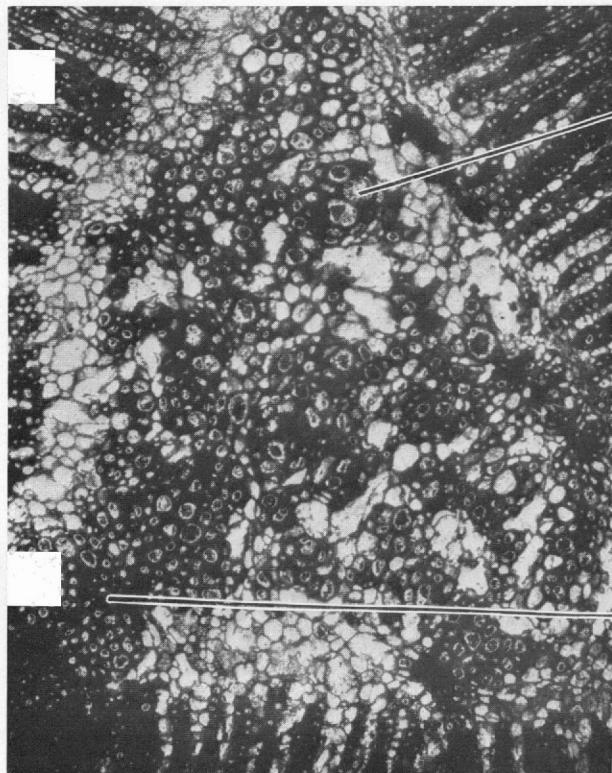
FIGURE 2. A more detailed view of one angle of the "mixed" pith showing the two bundles involved in leaf-trace emission (RS), and the single leaf-trace bundle with two protoxylem groups which results (PX). Enlarged 24 diameters.

FIGURE 3. A more detailed view of another angle of the "mixed" pith showing the double reparatory strand with protoxylem at PX. Enlarged 24 diameters.

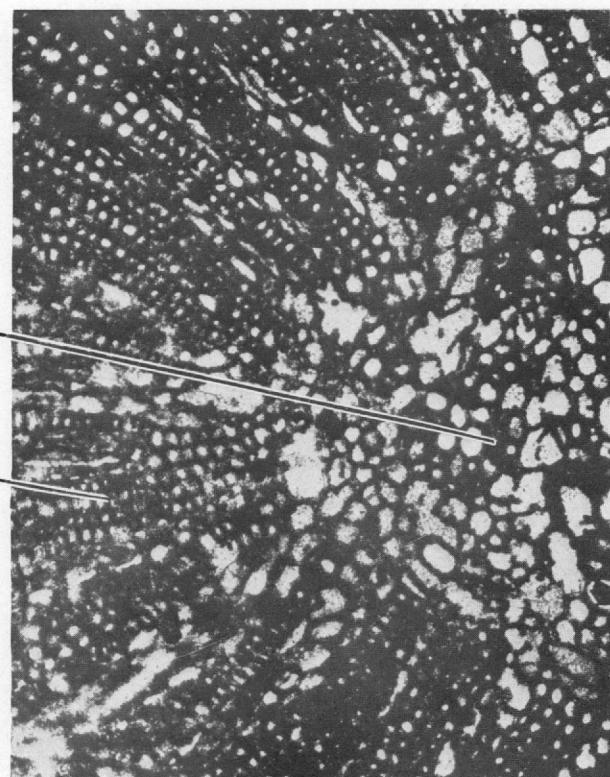
PLATE 20

*Stenomyelon muratum* Read

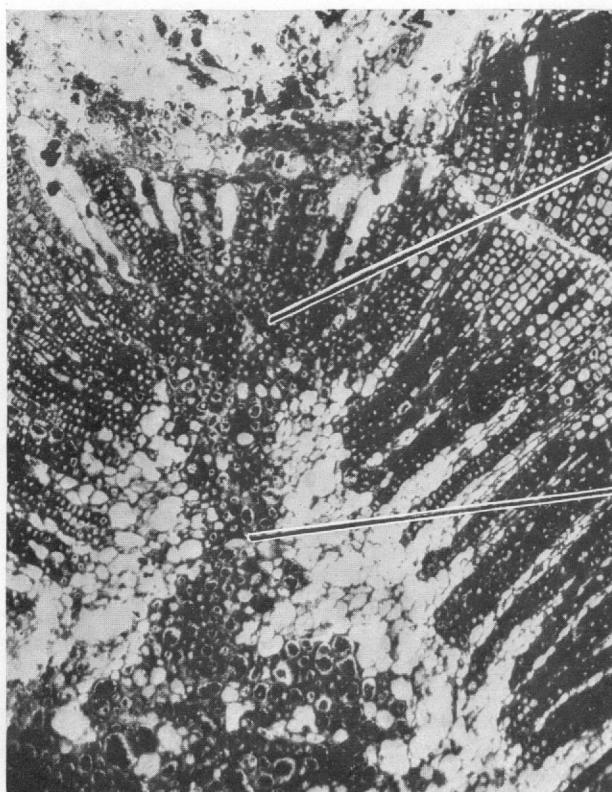
- FIGURE 1. A photograph showing a transverse section of the protostele or so-called "mixed" pith. Note the admixture of parenchyna. The protoxylem of an emerging leaf trace is seen at PX. Enlarged 24 diameters.
- FIGURE 2. A photograph of a portion of the "mixed" pith and adjacent secondary xylem. Note the absence of a definite protoxylem. X<sup>1</sup>, Primary xylem; X<sup>2</sup>, secondary xylem. Enlarged 50 diameters.
- FIGURE 3. A photograph of a transverse section of the stem showing an early stage in leaf-trace emission. A protoxylem has been differentiated, and the leaf trace is passing outward through the secondary xylem. X<sup>1</sup>, Primary xylem; LT, leaf-trace protoxylem. Enlarged 24 diameters.
- FIGURE 4. A photograph of a slightly later stage in the emission of a leaf trace. The protoxylem is apparently dividing. MP, "Mixed" pith; PX, protoxylem; LT, leaf trace. Enlarged 24 diameters.



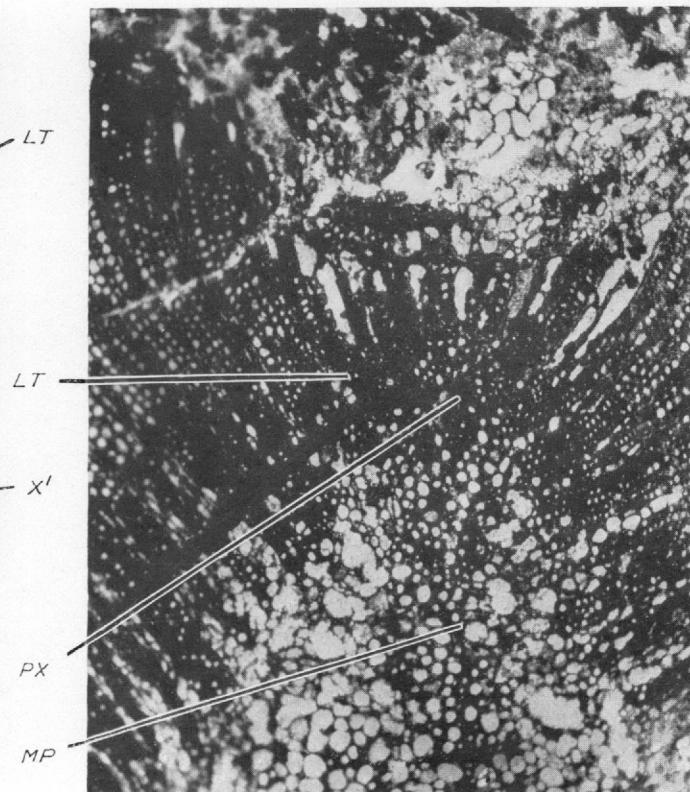
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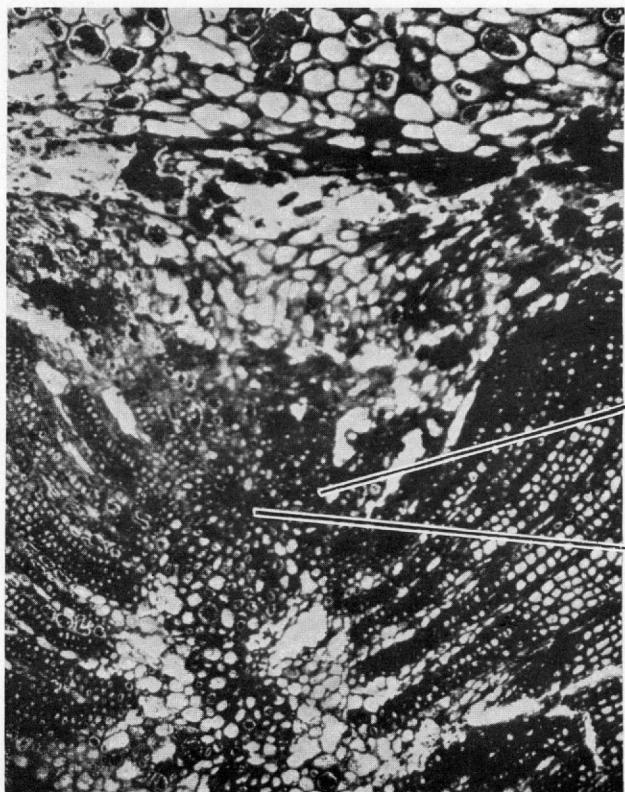


3

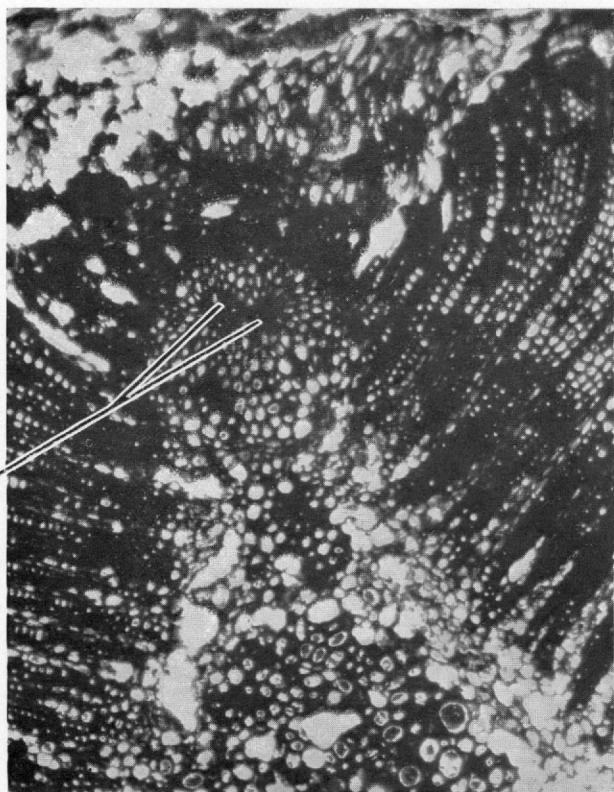


4

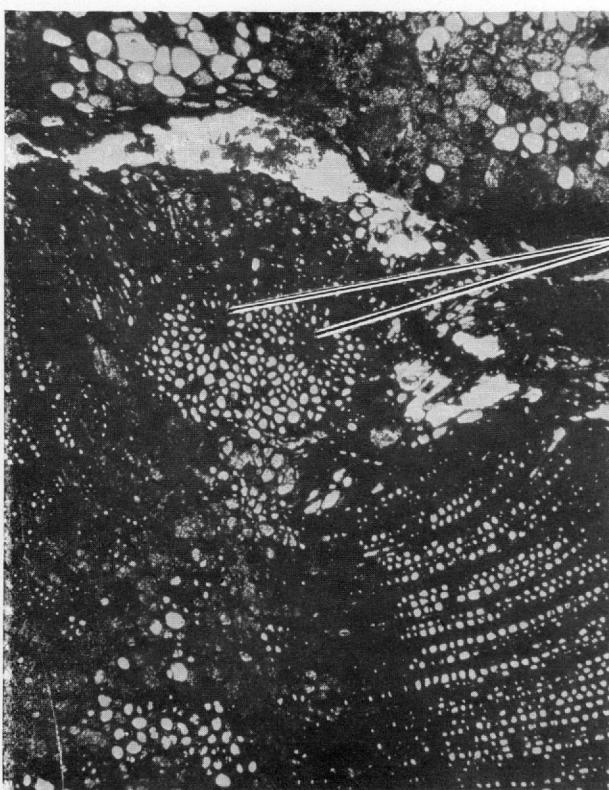
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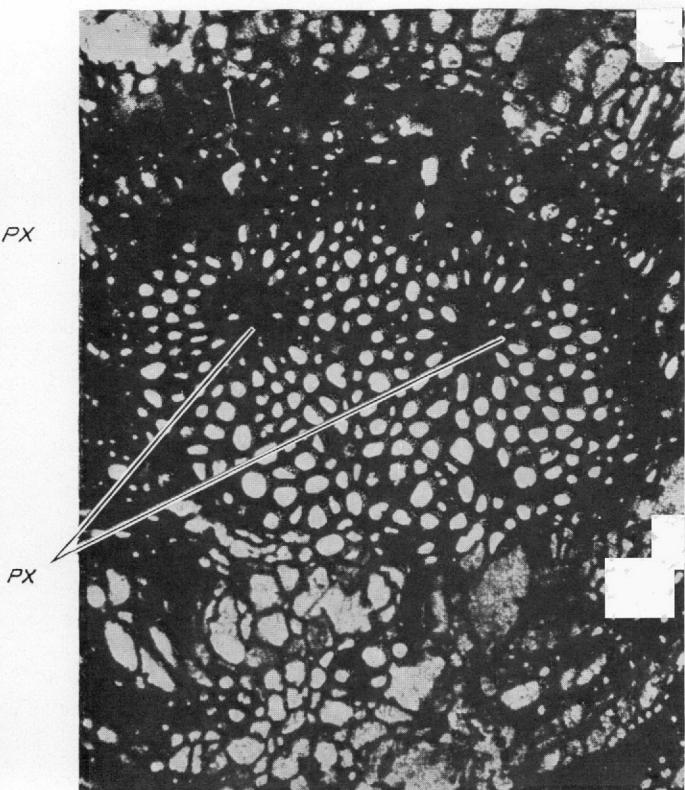
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CALAMOPITYYEAE OF THE NEW ALBANY SHALE.

PLATE 21

*Stenomyelon muratum* Read

- FIGURE 1. Photograph of a transverse section of *Stenomyelon muratum* showing an early stage in the emission of the leaf trace. It will be noted that the protoxylem is divided into two. LT, Leaf trace; PX, protoxylem. Enlarged 24 diameters.
- FIGURE 2. A photograph of a stage slightly later than figure 1, showing leaf-trace emission. Note that the protoxylems are separated. Enlarged 24 diameters.
- FIGURE 3. A still later stage in leaf-trace emission. The trace here shows two definite protoxylems and is tangentially elongate. Enlarged 24 diameters.
- FIGURE 4. A photograph at a higher magnification of the leaf trace shown in figure 3. Note the two mesarch protoxylems. Enlarged 50 diameters.

PLATE 22

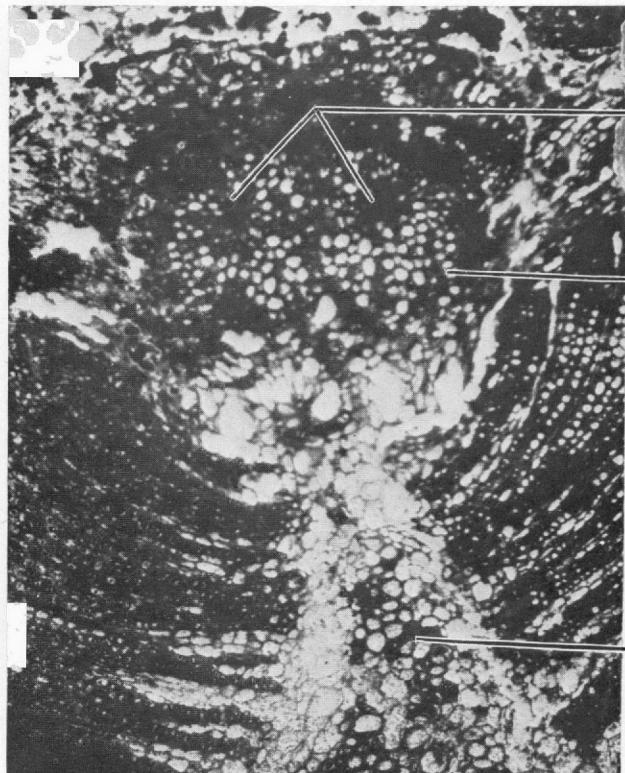
*Stenomyelon muratum* Read

FIGURE 1. A transverse section of the stem showing the bilobed leaf trace in the outer stelar tissues. PX, Protoxylem; LT, leaf trace; X<sup>1</sup>, primary xylem. Enlarged 24 diameters.

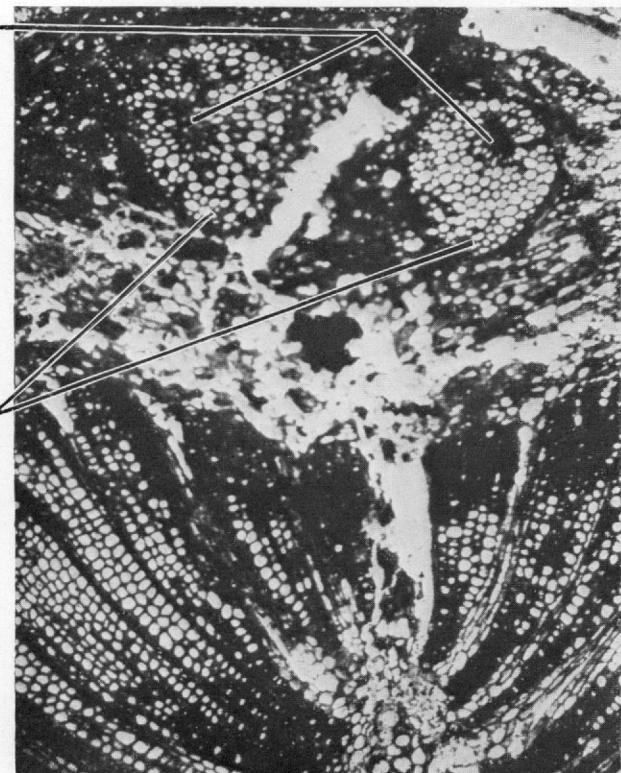
FIGURE 2. A somewhat later stage than figure 1, showing the two bundles of the leaf trace in the inner cortex. These are the result of division of the single strand shown in figure 1. Continued division results in the formation of a polydesmic petiole of the *Kalymma* type. Enlarged 30 diameters.

FIGURE 3. A portion of the cortex of the stem showing two vascular bundles of a polydesmic leaf base. Note the mesarch protoxylem. Enlarged 50 diameters.

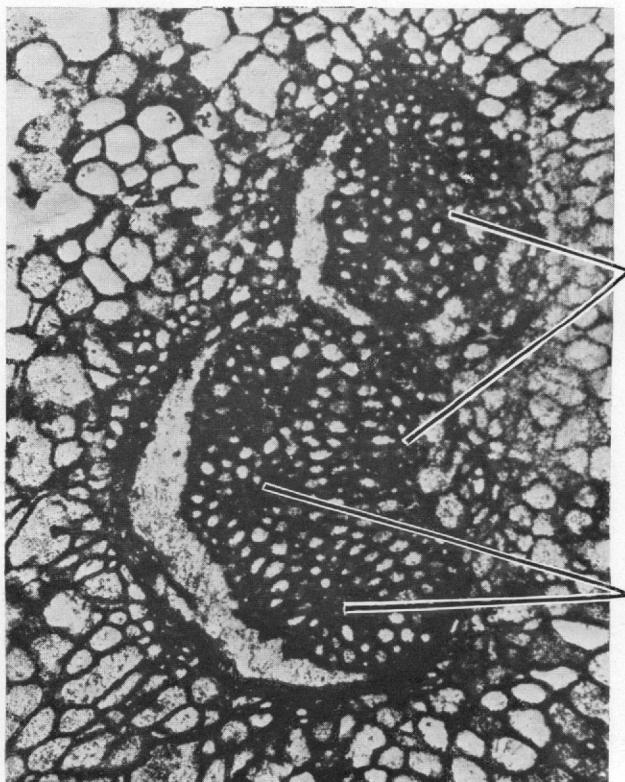
FIGURE 4. A photograph illustrating the hypodermal strands in the outer cortex. Above a partly decomposed vascular bundle is seen. H, Sclerotic strands of the hypodermis. Enlarged 24 diameters.



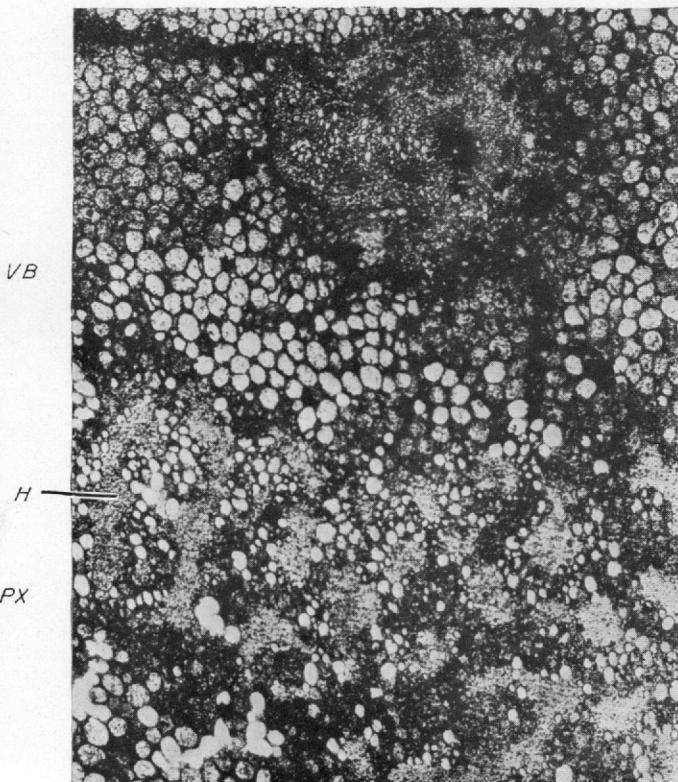
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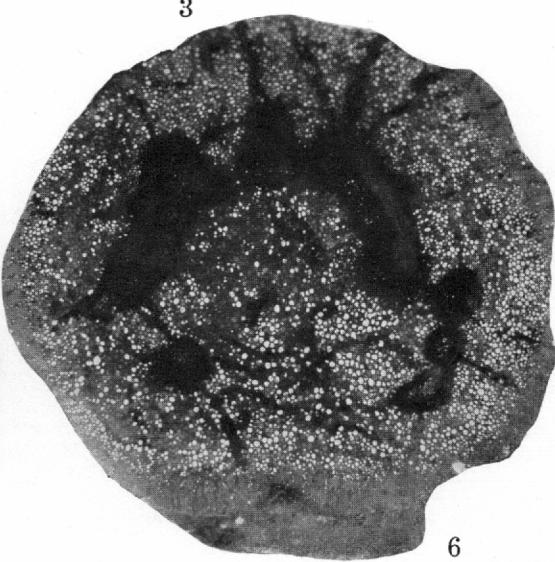
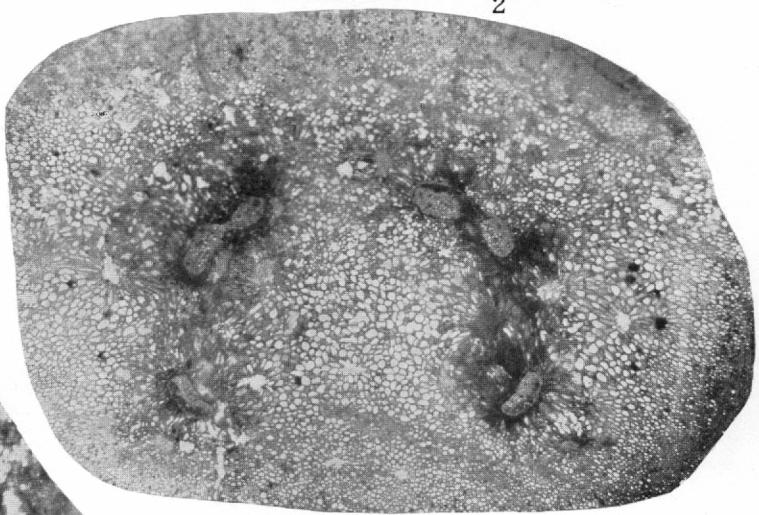


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CALAMOPITYEAE OF THE NEW ALBANY SHALE.



CALAMOPITYEAE OF THE NEW ALBANY SHALE.

## PLATE 23

### *Kalymma lirata* Read

FIGURE 1. A photograph of a portion of the petiole, showing the prominent abaxial and adaxial furrows in the ring of vascular bundles. Enlarged 6 diameters.

FIGURE 2. A petiole of the *Kalymma lirata* type cut a short distance below a dichotomy, showing the ring of vascular bundles, the very pronounced furrows, and a fragment of the "Sparganum" cortex. Enlarged 6 diameters.

### *Kalymma resinosa* Read

FIGURE 3. A petiole showing the vascular bundles forming an open U and the lysigenous secretory ducts. Enlarged 6 diameters.

### *Stenomyelon muratum* Read

FIGURES 4, 5. Photographs of two transverse sections showing the general aspect of the stem at a low magnification. Enlarged 6 diameters.

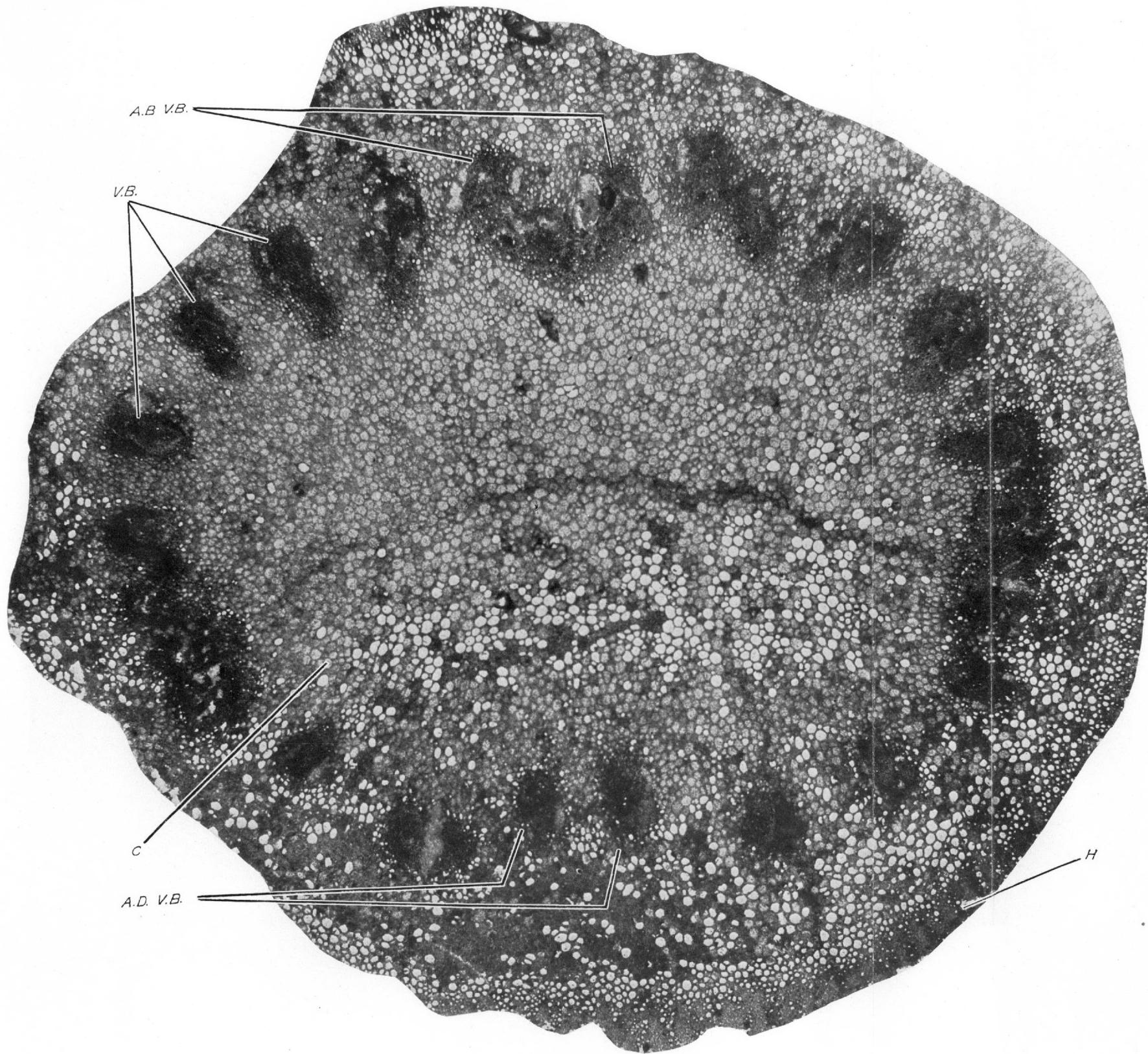
### *Kalymma auriculata* Read

FIGURE 6. A photograph of a transverse section showing the general aspects. Note the prominent abaxial projections of the vascular bundles. Enlarged 6 diameters.

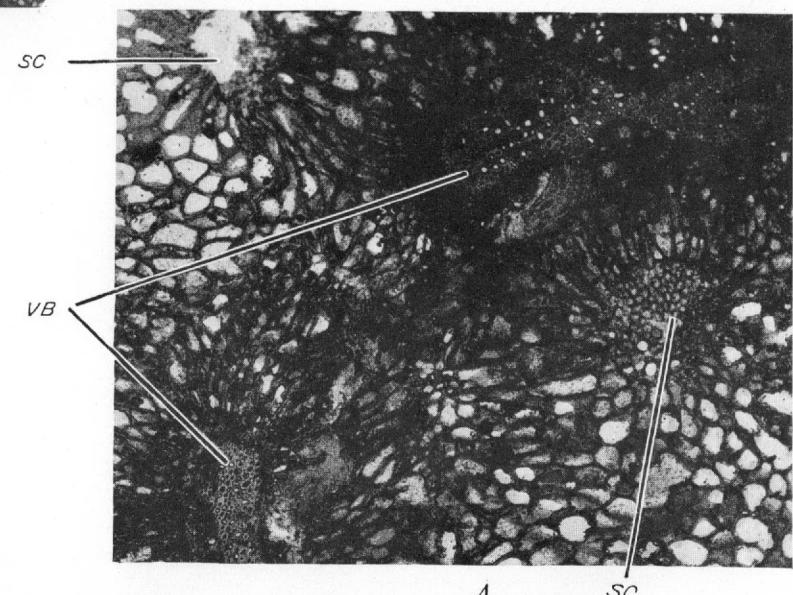
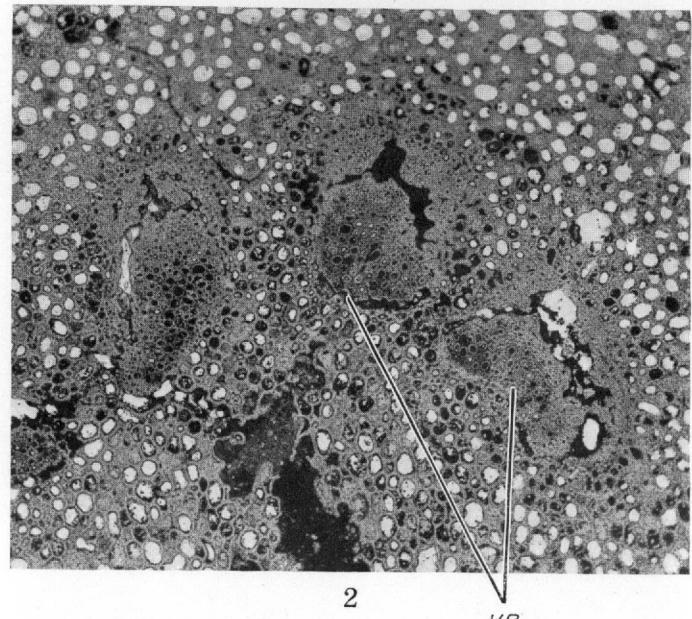
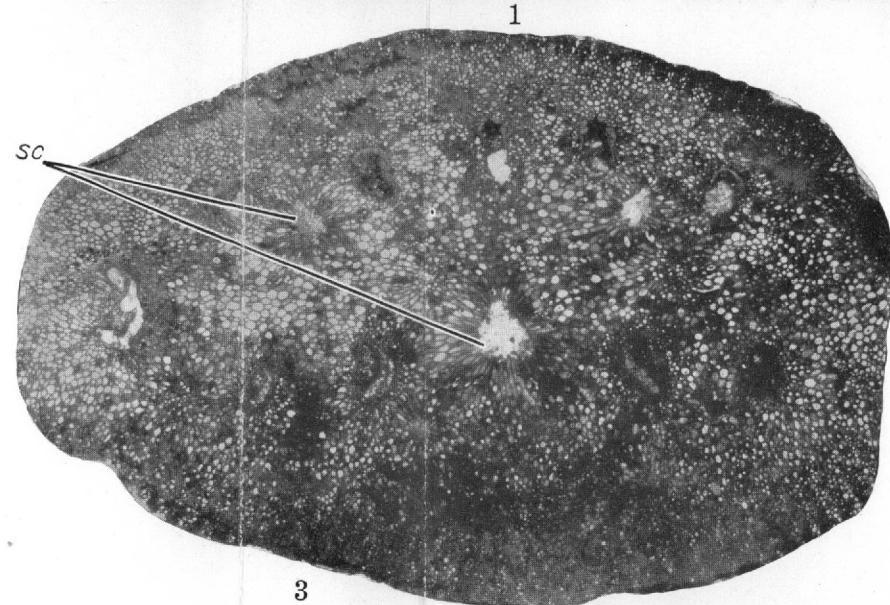
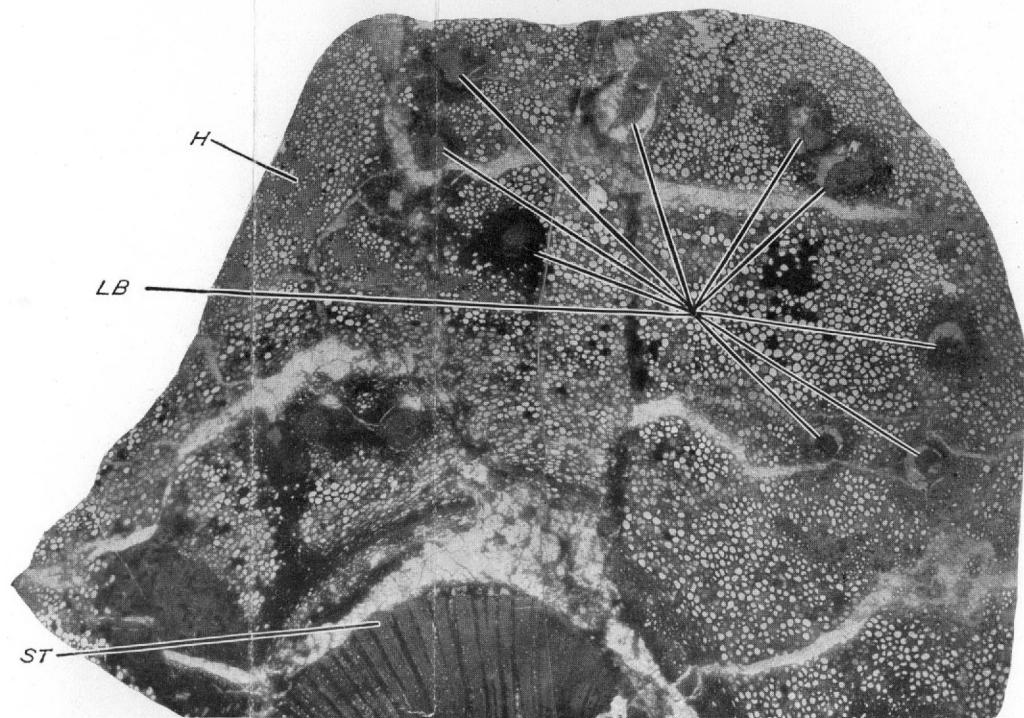
PLATE 24

*Kalymma lirata* Read

FIGURE 1. A photograph of a transverse section showing the ring of vascular bundles (VB), the abaxial (ABVB) and adaxial (ADVB) furrows in the ring, the parenchymatous groundmass (C), and the "Sparganum" hypodermis (H). Enlarged 15 diameters.



CALAMOPITYEAE OF THE NEW ALBANY SHALE.



CALAMOPITYEAE OF THE NEW ALBANY SHALE.

## PLATE 25

### *Kalymma lirata* Read

FIGURE 1. A leaf base of the *Kalymma lirata* type (LB) shown attached to the stem of *Calamopitys americana* Scott and Jeffrey. ST, Stele of *C. americana*; H, "Sparganum" hypodermis. Enlarged 7 diameters.

FIGURE 2. A photograph of a portion of a section of *Kalymma lirata* showing the vascular bundles (VB), embedded in the parenchymatous groundmass. Enlarged 15 diameters.

### *Kalymma resinosa* Read

FIGURE 3. A transverse section of *Kalymma resinosa* showing the vascular bundles, the secretory canals (SC), and portions of the "Sparganum" cortex. Enlarged 6 diameters.

FIGURE 4. A portion of a transverse section of *Kalymma resinosa* illustrating the secretory canals (SC) and the vascular bundles (VB). Enlarged 24 diameters.

PLATE 26

*Stenomyelon muratum* Read

FIGURE 1. A portion of the "mixed" pith and adjacent secondary xylem in a somewhat tangentially cut longitudinal section. Note the admixture of parenchyma and tracheids in the "mixed" pith. Enlarged 25 diameters.

FIGURE 3. A more detailed view of a portion of the photograph shown in figure 1. Enlarged 40 diameters.

FIGURE 6. A tangential longitudinal section showing two sclerotic strands in the cortex. Enlarged 30 diameters.

*Calamopitys americana* Scott and Jeffrey

FIGURE 2. A leaf trace as seen on the outer face of the stele. Note the bilobed trace and the fan of secondary xylem, which is quickly lost as the trace passes through the cortex. Enlarged 20 diameters.

*Kalymma lirata* Read

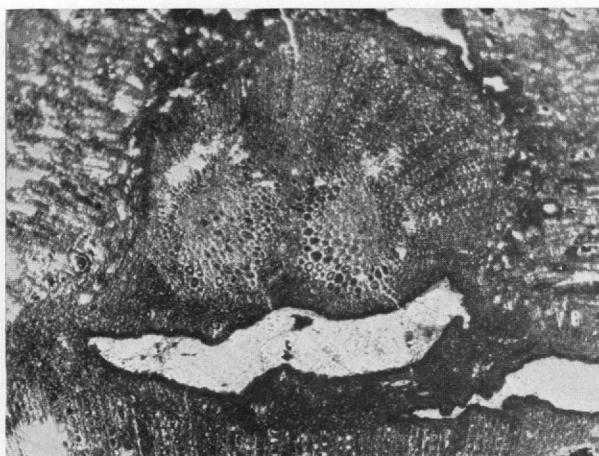
FIGURE 4. A single vascular bundle showing the concentric structure. Enlarged 24 diameters.

*Calamopitys americana* Scott and Jeffrey

FIGURE 5. A portion of the "mixed" pith as seen in longitudinal section. Enlarged 30 diameters.



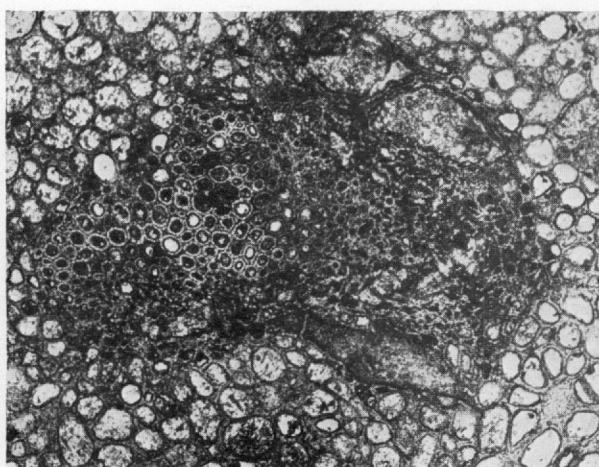
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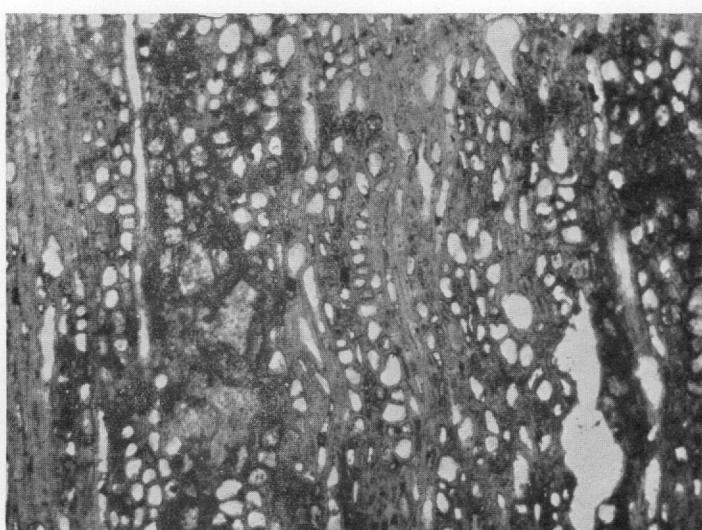
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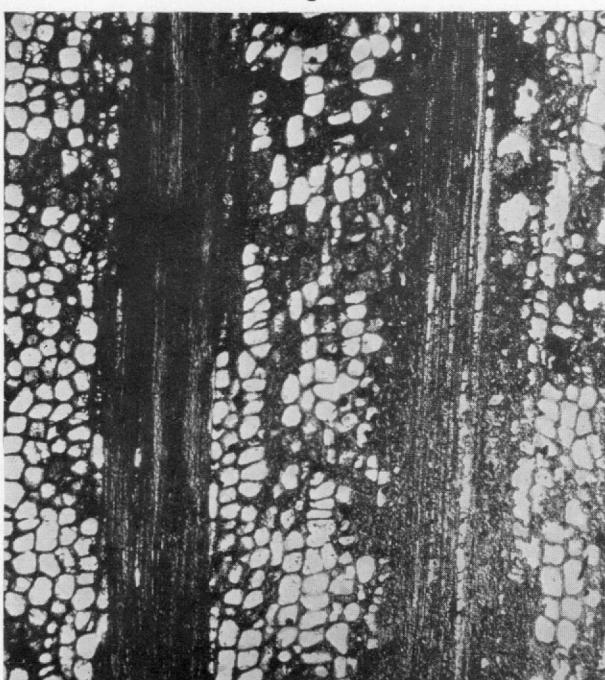
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CALAMOPITYAE OF THE NEW ALBANY SHALE.



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Harold L. Ickes, Secretary

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W. C. Mendenhall, Director

Professional Paper 186-F

AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA

BY

CHARLES B. READ AND ROLAND W. BROWN

Shorter contributions to general geology, 1936

(Pages 105-131)



UNITED STATES  
GOVERNMENT PRINTING OFFICE  
WASHINGTON : 1937

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## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA

By CHARLES B. READ and ROLAND W. BROWN

### ABSTRACT

The Tempskyas are a group of ferns, known at present from remains of stems, leaf bases, and roots found in rocks of Cretaceous age in Europe and North America. They were first recorded in 1824 by Stokes and Webb under the name *Endogenites*. In 1845 Corda, after examination of similar material from Bohemia, established *Tempskya* as a genus, and some years later the identity of Stokes and Webb's specimens became known. During the later part of the nineteenth century several investigators, among them Feistmantel, Velenovsky, and Seward, had occasion to deal with the genus. Owing to the very poor preservation of most of the specimens the investigators were not able to recognize the true nature of the materials, although they were admitted to be fern stems. The prevalent opinion was that the structure was similar to that of *Protopteris*.

In 1911 Kidston and Gwynne-Vaughan published a study of a well-preserved *Tempskya* from the Ural Mountains and definitely established the fact that in *Tempskya* the large trunklike mass that is commonly preserved consists of an aggregate of stems bound together by a thick mat of roots into a false trunk.

In America the first record of *Tempskya* was made in 1911, when Berry described *Tempskya whitei* from the Patapsco formation (Lower Cretaceous) of Maryland. In 1924 Seward published an account of a very well preserved specimen from what is now known to be the Colorado shale (Upper Cretaceous) near Harlowton, Mont. In that contribution considerable space was devoted to an analysis of habit and affinities, and the conclusion was reached that the false trunk was subterranean, obliquely ascending, and that the plant was of schizaeaceous affinities.

The present paper sets forth the generic characters and, after presenting a summary of *Tempskya knowltoni* Seward, describes *Tempskya grandis*, *Tempskya minor*, and *Tempskya* sp. from strata of Upper Cretaceous age in western Wyoming and adjacent portions of Idaho and Utah. A few observations are made on *Tempskya whitei* Berry. All these species conform to the generic diagnosis based on *Tempskya rossica* as regards the dorsiventral stems, the siphonosteles, the two-ranked leaves, and the diarch roots. All have developed the false-trunk habit. It is shown that this false trunk may be dorsiventral or radial in its symmetry and that this symmetry appears to be constant within a species. It is suggested that the radially arranged false trunks must have stood upright and that the dorsiventral false trunk may have been characteristic of lianalike or cliff-climbing ferns, or even of partial epiphytes. False trunks of a similar type are not known among either modern ferns or other groups of fossil ferns.

The problem of the exact affinities of *Tempskya* is not solved. *Tempskya* is unquestionably one of the Leptosporangiatae and may be related to any one of several families. A temporary family, the Tempskyaceae, is erected for the genus.

The stratigraphic range of the genus appears to be from lowermost Lower Cretaceous to Senonian. In western America it is apparently restricted to the Colorado group.

### INTRODUCTION

In the annals of paleobotany the genus *Tempskya* has long occupied a very speculative position. It was reported under the name *Endogenites* as early as 1824 and elevated to its present status as the genus *Tempskya* in 1845, but its true nature was not realized until 1911. Since then there has been some progress by way of occasional contributions tending to show the diversification of the genus. However, several important issues remain to be decided. There are conflicting points of view concerning the habit and taxonomic position of *Tempskya* among the ferns.

It is the purpose of the writers of this paper to review the genus and the various opinions that have been expressed concerning it. New material from the western United States is described, some of which has a significant bearing on the habits of the genus. *Tempskya knowltoni* Seward has been redescribed, not because of any fault in Seward's account but because of the desirability of emphasizing the distinctive characters of this fossil by way of contrast in making the specific differentiation of the other materials. Little attempt has been made in the past to discuss the stratigraphic range of *Tempskya*. The writers have essayed to compile the facts concerning its occurrence in an effort to estimate the value of the several species as age indexes.

The assistance and encouragement of the officials of the United States Geological Survey in the preparation of this report is acknowledged with pleasure. J. B. Reeside, Jr., has been especially interested in the work and has given many valuable suggestions. The late Dr. David White likewise cheerfully contributed advice and constructive criticism. G. R. Mansfield, W. W. Rubey, and J. S. Williams, of the Geological Survey, Prof. G. R. Wieland, of Yale University, and Prof. S. H. Knight, of the University of Wyoming, have collected most of the new material during the course of various geologic investigations in southeastern Idaho and adjacent parts of Wyoming. Dr. R. S. Bassler has generously permitted the preparation of several unusually large thin sections in the laboratories of the United States National Museum, and K. J. Murata has prepared most of the excellent sections of the new material here illustrated.

## HISTORICAL ACCOUNT

The earliest record of *Tempskya* that the writers have been able to find is an account of *Endogenites erosa* given by Stokes and Webb<sup>1</sup> in 1824 in their report on plant material collected in Tilgate Forest by Mantell. As the generic name indicates, the silicified remains were regarded as monocotyledonous forms, possibly palms. In 1832 Cotta<sup>2</sup> referred similar material to *Porosus marginatus* and differed with Stokes and Webb in pronouncing the material to be portions of a large fern stem. In the following year this same opinion was expressed by Mantell<sup>3</sup> after a careful examination of the specimens that he had collected about 10 years before. In 1836 Fitton gave an account of similar materials found near Hastings and referred them to *Endogenites erosa*.

In 1845 a noteworthy contribution was made by Unger,<sup>4</sup> who inclined to the opinion that *Endogenites erosa* was simply a mode of preservation of *Protopteris* and introduced evidence in support of this idea.

In the same year Corda<sup>5</sup> published the results of his observations on large collections of petrifications and erected in honor of Tempsky a new genus, *Tempskya*, for four specimens of silicified material from as many localities, presumably in Bohemia and adjacent regions. The generic diagnosis is as follows:

Truncus \* \* \* Rhachis rotundata, plicata vel alata; cortice crassiuscula, fasciculis vasorum ternatis, majori clauso vel lunulato et supra incurvo, minoribus oppositis lunulatis. Radices minutae numerosissimae; fasciculo vasorum centrali unico.

*Tempskya* was placed in the Phthoropterides, and the interpretation of the silicified masses was that they were branched petioles sheathed in a thick mat of roots. Four species—*Tempskya pulchra*, *T. macrocaula*, *T. microrrhiza*, and *T. schimperi*—were described on rather questionable grounds. As the preservation is very poor, this historically important material does not furnish many data of value in the study of other specimens. Corda was apparently unaware of the occurrence of similar fossils in England, for no mention is made of *Endogenites erosa*.

The first intimation that *Tempskya* is other than the outer or perhaps distal portion of a tree-fern axis is found in a paper by Schenk.<sup>6</sup> In his opinion *Tempskya* was a complete stem of possibly marattiaceous affinities, with numerous vascular bundles sheathed in a parenchymatous and sclerenchymatous groundmass.

<sup>1</sup> Stokes, Charles, and Webb, P. B., Description of some fossil vegetables of the Tilgate Forest in Sussex: Geol. Soc. London Trans., ser. 2, vol. 1, pp. 421-424, pls. 45-47, 1824.

<sup>2</sup> Cotta, C. B., Die Dendrolithen, p. 41, pl. 8, figs. 4, 5, 1832.

<sup>3</sup> Mantell, G. A., The geology of the Southeast of England, p. 236, pl. 1, figs. 4, 5, 7, 1833.

<sup>4</sup> Unger, Franz, Synopsis plantarum fossilium, p. 107, 1845.

<sup>5</sup> Corda, A. J., Flora protogaea; Beiträge zur Flora der Vorwelt, p. 81, 1845.

<sup>6</sup> Schenk, August, Beiträge zur Flora der Vorwelt; IV, Die fossile Flora der nordwestdeutschen Wealdenformation: Palaeontographica, vol. 9, pp. 203-266, pls. 42-43, 1871.

In 1872 Feistmantel<sup>7</sup> suggested that *Tempskya* was not a genus but rather a mode of preservation of several distinct types of fern stems. *Protopteris sternbergii* Corda was suggested as one species that might be correlated with tempskyoid preservation. This opinion is very interesting and seems to have made a profound impression on contemporary investigators, for several papers were soon published in support of this theory. Velenovsky<sup>8</sup> accepted this view and produced new evidence which seemed to corroborate this interpretation.

A very valuable account of the literature on *Tempskya* is given by Seward in his catalog of Wealden plants.<sup>9</sup> Feistmantel's ideas were questioned but not definitely discarded. Seward's general conclusions are as follows:

In *Tempskya schimperi* we have masses of branched diarch fern roots associated with petiole axes, which occasionally afford evidence of branching; probably some forms of *Tempskya* and *Protopteris* are very closely related, if not identical plants; but, so far as English specimens are concerned, there is an absence of any direct proof of such organic connection between the two fossils, as Feistmantel and Velenovsky have previously suggested.

In 1897 Stenzel<sup>10</sup> discussed the question at length and decided that the morphologic make-up of the fossils did not entirely justify any conclusion so far reached as to their exact nature. He offered several possible explanations:

1. Lateral organs of a tree fern growing downward and encased in downward-growing roots. (This hypothesis is similar to that suggested by Corda, although not identical with it.)
2. Independent stems climbing upward between roots.
3. Upward-growing and branching fern stems encased in their own downward-growing roots.

Of these explanations Stenzel inclined toward the last, although he preferred to leave the question open and did not finally commit himself.

It remained for Kidston and Gwynne-Vaughan to determine definitely the exact nature of *Tempskya*, which they did in an excellent account<sup>11</sup> of *Tempskya rossica*, a new species described from the basin of the Karaganda River in Russia. Unfortunately the geologic age of the material is uncertain, because it seems to have been reworked from older strata into a conglomerate of Tertiary age. It must be borne in mind that before the discovery of *T. rossica* all the specimens known were poorly preserved and did not permit detailed examination of the tissues. In the type of *T. rossica* the preservation is excellent, and as a result

<sup>7</sup> Feistmantel, Ottokar, Über Baumfarrenreste der böhmischen Steinkohlen-Perm- und Kreideformation: K. böhm. Gesell. Wiss. Abh., Folge 6, Band 6, p. 22, 1872.

<sup>8</sup> Velenovsky, Josef, Die Farne der böhmischen Kreideformation: K. böhm. Gesell. Wiss. Abh., Folge 7, Band 2, Nr. 8, p. 25, 1888.

<sup>9</sup> Seward, A. C., The Wealden flora, part 1; Catalogue of the Mesozoic plants in the Department of Geology, British Museum (Natural History), pp. 148-159, 1894.

<sup>10</sup> Stenzel, K. G., Verkieselte Farne von Kamenz in Sachsen: K. min. Mus. Dresden Mitt., Heft 13, p. 3, 1897.

<sup>11</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., On a new species of *Tempskya* from Russia: Russ. k. min. Gesell. Verh., Band 48, pp. 1-20, pls. 1-3, 1911.

the investigators were able to clear up many unsettled points. They finally concluded that the siliceous masses were false stems—that is, composed of a single dichotomously branching stem system encased in a thick mat of adventitious roots. The stems were highly sclerenchymatous, solenostelic, and dorsiventral. The roots were diarch. As regards the habit, the false stems were suspected of having stood erect to a height of several feet and of having produced a crown of leaves. The affinities of *Tempskya* were left unsettled, although it was held that they were with the Leptosporangiatae.

In the same year Berry<sup>12</sup> described an American species, *Tempskya whitei*, from the Patapsco (Lower Cretaceous) deposits of the Atlantic Coastal Plain. The preservation is poor, however, and no additions to the anatomical knowledge of the genus were made.

Stopes,<sup>13</sup> in her discussion of the Lower Greensand plants of Great Britain, presented a summary of the progress in the study of *Tempskya* and redescribed *Tempskya erosa* Stokes, Webb, and Mantell. A reconstruction of the probable aspect of *Tempskya rossica* Kidston and Gwynne-Vaughan was included and shows a massive erect false stem bearing a terminal cluster of leaves.

In 1924<sup>14</sup> Seward described a very well preserved *Tempskya* from Montana. This fossil had been collected by A. C. Silberling in 1908 in the Musselshell Valley and had been in the collections of the United States Geological Survey for a number of years. Dr. Knowlton's activities had been so intensively directed in other fields that he had never been able to investigate it and finally transmitted the complete specimen to Seward. The species was named *Tempskya knowltoni* and is of Colorado age. It presents several interesting features, among which is an apparent dorsiventrality of the entire false stem. This caused Seward to conclude that *T. knowltoni* was "a root-encircled bundle of stems, obconical and tapering, lying obliquely in the soil, a few of the stem branches bearing crowded fronds near the ground level." The affinities of *Tempskya* were held to be with the Schizaeaceae, in view of the stelar similarities, the similarity of certain spores found by Boodle in an English specimen to those of schizaeaceous ferns, and finally the alleged similarity of certain sporangia found in the root mat of *T. knowltoni* to the type of sporangia characteristic of the Schizaeaceae.

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<sup>13</sup> Stopes, M. C., The Cretaceous flora, part 2, Lower Greensand (Aptian) plants of Britain: Catalogue of Mesozoic plants in the British Museum (Natural History), pp. 9-21, text figs. 2-5, 1915.

<sup>14</sup> Seward, A. C., On a new species of *Tempskya* from Montana, *Tempskya knowltoni*, sp. nov.: Annals of Botany, vol. 38, no. 151, pp. 485-507, text figs. 1-3, pls. 16, 17, 1924.

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#### SYSTEMATIC DESCRIPTIONS

##### TEMPSKYACEAE<sup>15</sup>

###### Genus TEMPSKYA Corda (emend.)

1845. Corda, A. J., Flora protogaea; Beiträge zur Flora der Vorwelt, p. 81.
1911. Kidston, Robert, and Gwynne-Vaughan, D. T., On a new species of *Tempskya* from Russia: Russ. k. min. Gesell. Verh., Band 48, pp. 1-20, pls. 1-3.

The generic diagnosis given by Kidston and Gwynne-Vaughan is as follows:

Stems of small diameter, erect, dichotomous, and embedded in a felted mass of their own adventitious roots. Dorsiventral, with the leaves in two rows on one side of the stem and roots alone on the opposite side. Vascular system of stem a solenostele. Leaf trace departs as a single strand. Roots diarch.<sup>16</sup>

In Corda's account<sup>17</sup> of *Tempskya* four species—*Tempskya pulchra*, *T. macrocaula*, *T. microrrhiza*, and *T. schimperi*—are described in the order named. According to strict botanic nomenclature one of these, preferably the first, should be designated as the genotype. The writers, although they heartily approve of the several codes of rules followed by systematists, think it is desirable here to depart from their general practice and recommend that *Tempskya rossica* Kidston and Gwynne-Vaughan be admitted as the type of the genus. The reasons are several. In the first place, *T. pulchra*, the first species named by Corda, is very imperfectly known and has not been carefully investigated, to the writers' knowledge, since Corda's publication. The same is true of his other three species. Furthermore, the preservation of the material, if several later accounts are correct, is very mediocre, so that many of the details are lost and specific differentiation is questionable. On the other hand, *T. rossica* is a beautifully preserved fossil and has been carefully studied by two very distinguished investigators of plant morphology. In consequence a wealth of detail has been recorded. Therefore, *T. pulchra* Corda at best

can be recognized as no more than a nominal genotype, and *T. rossica* must be taken as the "working" type.

*Gross aspect of Tempskya*.—As viewed with the naked eye or under a low-power hand lens, specimens of

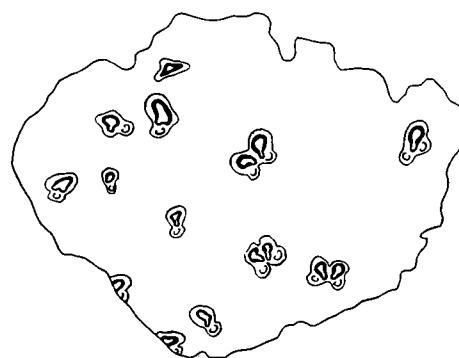


FIGURE 2.—Sketch of a transverse section of *Tempskya knowltoni* Seward showing the dorsiventral orientation of the stems in the root mass.

*Tempskya* bear a striking similarity to fragments of palm stem. Plate 28, figures 1 and 2, and plate 29,

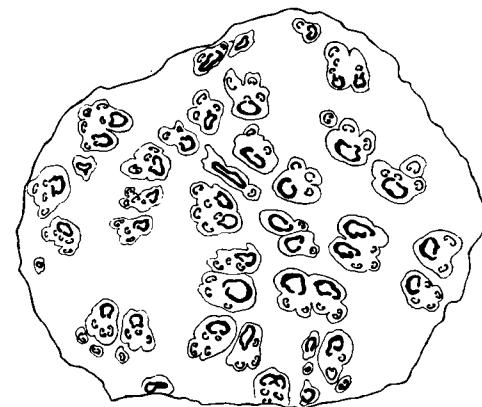


FIGURE 3.—Sketch of a transversely cut face of *Tempskya grandis* Read and Brown, n. sp., showing the radial orientation of the dorsiventral stems in the false trunk. U. S. Nat. Mus. 39267. Half natural size.

figures 1 and 2, convey some idea of the general aspect of transverse faces of the "false stem" with a magni-

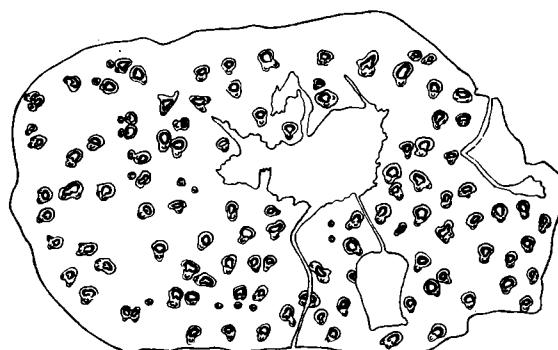


FIGURE 4.—Sketch of *Tempskya minor* Read and Brown, n. sp., showing the predominantly dorsiventral orientation of the stems in the false trunk. U. S. Nat. Mus. 39259. Half natural size.

fication of a few diameters. There is a groundmass of small organs, round or elliptic in cross section that suggest the scattered collateral vascular bundles of a palm trunk, and embedded in this mass are a few

<sup>15</sup> See p. 122.

<sup>16</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., op. cit., p. 13, 1911.

<sup>17</sup> Corda, A. J., op. cit., pp. 81-82, 1845.

larger and more irregularly shaped organs that suggest the adventitious roots so commonly found in the outer region of the basal portion of the stem of an arborescent monocotyledon. The former are adventitious diarch roots; the latter are stems embedded in this felted root mass, and the whole forms what is termed a false stem.

which is sketched from a section of *Tempskya knowltoni* Seward, indicates that there is apparently a strong dorsiventrality in the false stem—that is, the stems are so oriented that their leaf traces pass off in approximately the same direction throughout the false stem. Another diagram of the arrangement of stems within

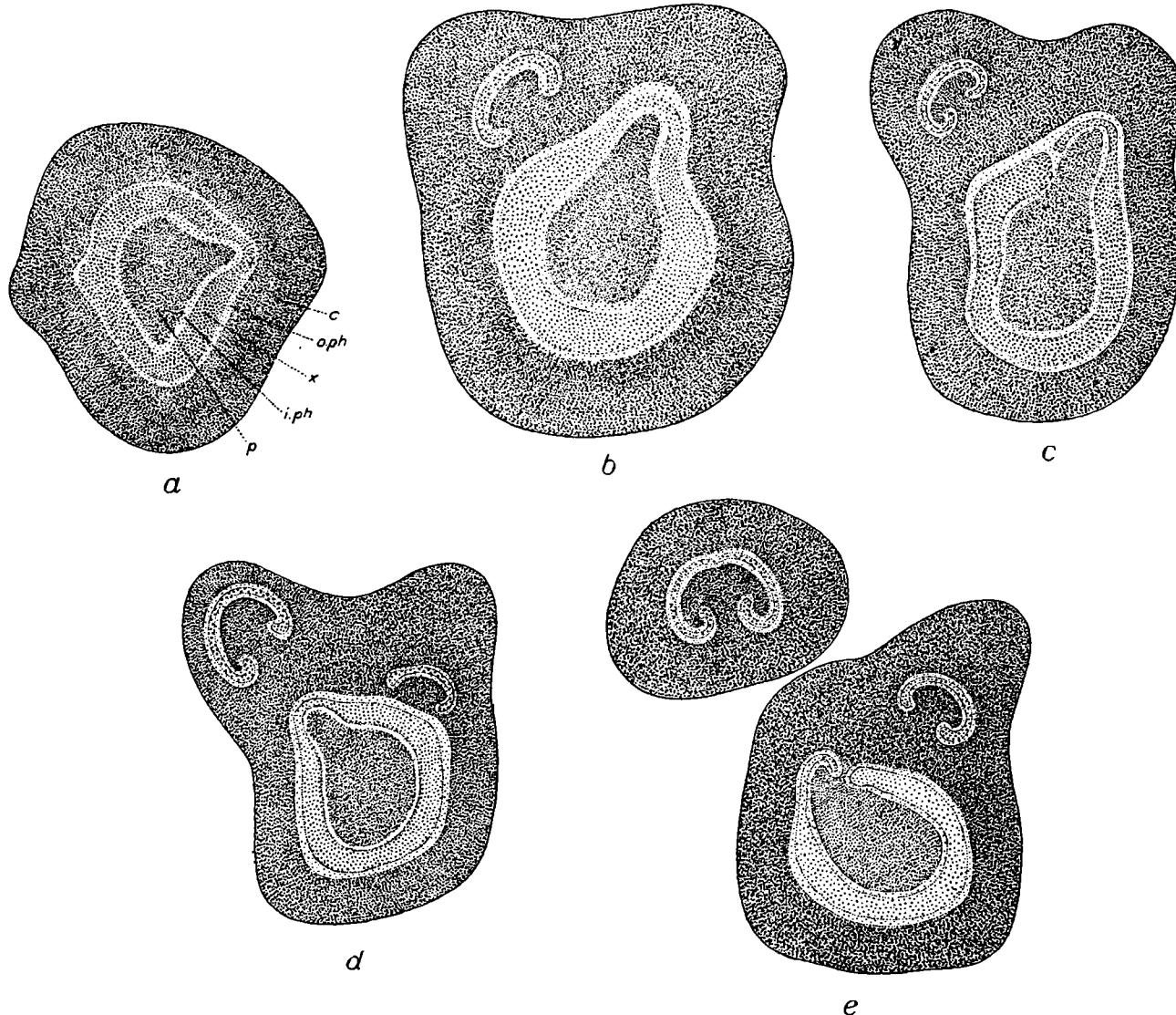


FIGURE 5.—Sketches showing in diagrammatic fashion the development of the leaf trace in *Tempskya*. *a*, A stem just prior to the gapping by an emerging leaf trace, which is shown in the upper right portion of the stele (*p*, pith; *i. ph*, internal phloem, pericycle, and endodermis; *x*, xylem; *o. ph*, external phloem, pericycle, and endodermis; *c*, cortex). *b*, Leaf trace forming a distinct bulge outward from the main axis. To the left is another trace in the cortex. *c*, Gap of right trace just

forming and terminal portions of left trace showing a tendency to recurve. *d*, Right trace has just passed into the inner cortex, the gap having closed behind it, and left trace has become still more recurved. *e*, Left trace has passed into the base of the phyllopodium, whereas the right trace is gradually emerging in the cortex. Enlarged about 10 diameters.

The stems, as has been previously demonstrated<sup>18</sup> and as is again shown in this paper, are dorsiventral and appear to be a much-branched axial system of a single plant rather than a number of individuals of gregarious disposition. It follows, therefore, that a survey of the orientation of the individual stems may furnish information of great value for the determination of the habit of the plant. Text figures 2 to 4 have been prepared to demonstrate this plainly. Text figure 2,

the groundmass of roots is seen in text figure 4, which is drawn from the specimen that is described on page 117 as *T. minor*, a new species. A similar dorsiventral arrangement is at once manifest. Figure 3 shows the condition in *T. grandis*, another new species. A striking lack of similarity to *T. knowltoni*, so far as the orientation of the stems is concerned, is at once apparent. The symmetry of the dorsiventral stems is radial within the false stem—that is to say, the leaf traces are regularly directed toward the nearest point

<sup>18</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., op. cit., 1911.

on the periphery. *T. rossica* Kidston and Gwynne-Vaughan shows symmetry perhaps intermediate between radial and dorsiventral.

In conclusion, two conditions prevail in the genus *Tempskya*, so far as the orientation of the dorsiventral stems within the false stem is concerned—an apparently well-established dorsiventral arrangement in some species and an apparent radial arrangement in other species. Transitional forms may occur as well. The bearing of these facts on the probable habit of *Tempskya* is discussed elsewhere (pp. 122-124).

*Branching of the stem.*—The numerous thin sections that have been prepared from the several species of *Tempskya* show that frequent dichotomy of the stem is characteristic of the genus as a whole. That the forks of this dichotomy are equal in size is obvious from plate 29, figure 3. No suggestion of lateral branching has been observed. The writers attempted to determine the distance between these successive bifurcations by cutting a block several inches long into serial sections, but they found that this character is so variable that it has little value either for morphologic or for taxonomic considerations.

*Disposition of the tissues in the stem.*—The stem of *Tempskya* is characterized by a siphonostele, as is clearly shown in plate 30, figure 1, and plate 31, figures 1 and 2. The periphery of the stem is a layer a few cells thick of only slightly modified parenchyma and constitutes what may be termed the outer cortex. The epidermis, in the individuals that the writers have observed, is in a very poor state of preservation and rarely furnishes information relative to emergences which might be of systematic value. Beneath this thin outer cortex is a rather thick zone of highly sclerenchymatous tissue, which in many specimens makes up the bulk of the cortex. This tissue is here referred to as the middle or sclerenchymatous cortex. The cells that make up this tissue are isodiametric in cross section, their lumens are minute and commonly appear to have been congested with some gummy material, and when viewed in longitudinal section they are elongate. They are typical fibrous elements similar to those which may be observed in the mechanical tissue of the bracken fern or in the so-called "bast" of the higher plants.

Within the zone of sclerenchyma there is a variable but generally thin zone of inner parenchymatous cortex. In *Tempskya rossica*, *T. knowltoni*, and *T. minor* this layer is so homogeneous that it does not merit a detailed description. In *T. grandis*, however, the inner cortex is more complex. There the zone is rather broad, sometimes rivaling the sclerenchymatous sheath in breadth. The bulk of the tissue is large-celled parenchyma, but near the inner margin there is an irregular layer of sclerotic tissue (pl. 34, fig. 4). Isolated strands of this tissue also occur. Within is a narrow zone of parenchyma bordering the endodermis.

The width of this inner cortex is a character of considerable value in taxonomic work on the genus, and obviously the varying complexity, as typified on the one hand by *Tempskya knowltoni* and on the other by *T. grandis*, is of specific worth.

The cortical tissues are limited internally by an endodermis, which is seldom distinctly seen for any considerable distance, perhaps because of faulty preservation. In *Tempskya knowltoni* Seward it is not usually observed, but in one species that is described in this paper it is a fairly definite layer and is of the type found in the leptosporangiate Filicales.

The pericycle, which is developed below the endodermis, is a tissue of parenchymatous nature and variable thickness. It is usually thin (only two or three cells in thickness), although in some individuals it seems to be slightly thicker. Its inner limit cannot be determined exactly, for in many specimens it cannot be definitely delimited from the phloem. Plate 34, figure 3, illustrates this feature fairly well.

The phloem is rather indefinite so far as its limits are concerned. Its morphologic identity cannot always be determined with exactitude, but one of the writers has observed the remains of poorly preserved sieve plates, so there seems to be no doubt that it actually exists as a well-organized tissue. There appears to be a thin zone of larger parenchymatous cells on the inner face of the phloem, which may possibly be regarded as ground parenchyma occupying a position between the phloem and xylem. This has not finally been determined but is quite within the range of probability.

The xylem ring, which is the most conspicuous feature of the stele, is from 5 to about 15 cells in thickness. For the sake of convenience, the xylem may be divided into an outer limiting region of very small elements and an inner region of larger elements. The outer limiting region of the xylem may be best described as problematical protoxylem. It may form a rather continuous layer, as is seen in plate 30, figure 1, or it may be somewhat scattered, as in plate 34, figure 4. In the writers' opinion this zone must be regarded as an exarch protoxylem, and in *Tempskya grandis* the protoxylem may vary from exarch to slightly mesarch. They are unable, however, to produce any evidence of spiral or annular thickenings on the walls of the elements. Such a condition is not without parallel in the Leptosporangiateae—the Schizaeaceae, for instance, being without any typical protoxylem. Also it is stressed that the siliceous constitution of all of the material seems to be unfavorable to the preservation of such delicate structures as the thickenings on the walls of the protoxylem, even though they were originally present.

The inner region of the xylem presents nothing out of the ordinary. The tracheids are of the scalariform type so common in the Filicales. One feature of note, which the writers stress in the specific differentiation

attempted in another part of this paper, is the variation in the amount of parenchyma diffused through the xylem. In *Tempskya knowltoni* Seward there is very little xylem parenchyma, but in one of the species collected from the Aspen shale of Wyoming parenchyma is abundant. This variation is seen at once by comparing plate 31, figures 1 and 2, with plate 34, figures 3 and 4.

The xylem ring is continuous except in the region immediately subtended by a departing leaf trace and varies little in thickness except at such points. A discussion of the origin of these lateral organs is given below.

Internal to the xylem there is present a thin layer of parenchymatous tissue limited by an inner endodermis. This parenchyma includes both phloem, pericycle, and the layer of thin-walled cells between the xylem and phloem and is in all respects similar to the comparable tissues that enclose the xylem.

The pith is sclerotic in all specimens. Just below the endodermis there may be in some places a narrow zone of parenchymatous tissue, but by far the greater portion of the central area is occupied by sclerenchymatous tissue quite similar to that found in the middle cortex.

*Leaf trace.*—The stelar ring is, except in the region where leaf traces are given off, rather regular in thickness. On the upper side of the stem there are, however, in almost every section, indications of departure or preparation for departure of one or more traces to the lateral appendages. The situation that exists at the point of origin of a trace is, first of all, a thinning of the xylem ring in the immediate vicinity of the portion that is destined to pass out. At the same time this portion of the stele tends to arch outward, approaching gradually the state shown in text figure 5, *a*, and in plate 31, figure 1. The xylem and other stelar tissues thin still more and at the same time bulge outward (text fig. 5, *b*). It must be borne in mind that the leaves are two-ranked on the upper surface, and a plane of bilateral symmetry lies between the two rows of appendages. Gradually the stele is broken, first on the side nearest this plane of bilateral symmetry, as is shown in text figure 5, *c*, and also in plate 31, figure 2. Immediately the internal and external phloem as well as the other tissues enclosed by the endodermis pass around the free ends of the xylem and become continuous. At the same time there is established a connection between the sclerotic and parenchymatous tissues of the middle and inner cortex and the similar tissues of the pith. This is well shown in plate 31, figure 2, as well as in text figure 5, *e*. The hook-shaped xylem rapidly becomes more highly arched and finally detached inferiorly to assume a curved form similar to that shown in text figure 5, *d*. This trace consists of an inner and outer phloem, pericycle, and endodermis with a centrally disposed band of xylem. At first the

trace is rather broadly U-shaped with the extremities facing directly inward. Gradually as the trace traverses the cortex on its obliquely ascending course these extremities fold inward until the very characteristic form of the free petiole or phyllopodium is assumed. This is shown in plate 42, figures 1–3 and 5, and in text figure 5, *d* and *e*. The gap formed by the leaf trace is very short, closing up almost immediately after the superior terminus of the trace becomes free from the main stele. The course of the traces, as has been previously suggested, is nearly parallel to that of the stem, so that a section cut transversely across the stem is very nearly a transverse section of the leaf trace. In the outer portion of the cortex and in the free and nearly free petioles such sections indicate that the vascular strand flexes to pass outward more rapidly.

The course of the protoxylem is very difficult to follow because it is not well differentiated. According to the writers' understanding, the leaf bundle is triarch-endarch. A careful study of numerous leaf traces has shown that on the inner (concave) side of each lateral termination of the leaf trace there is a cluster of small cells which has all the aspects of protoxylem. A third lies at the bottom of the concavity.

The length of the internode varies considerably within the genus. Plate 29, figure 3, and plate 32, figures 2–5, convey some idea of the extremes.

*Phylloodium.*—The term "phylloodium" as here used refers to the axial system of those lateral appendages of the stem commonly referred to as leaves—that is, it applies to the petiole and rachis and the branches of those organs. In all except one of the species that have been studied only the bases of the phylloodia are commonly present. This fact is rather noteworthy, and its full significance is discussed in the descriptions of species. Here it is sufficient to point out that usually an abscission layer was early developed and resulted in the occurrence of attached leaves only at the apex of the false stem. The exception is *Tempskya minor*, where rachides are common in the groundmass of the false stem. Serial sections of several specimens have shown that these are attached to the axes. Some of these stems have been penetrated by adventitious roots, an indication of old age. It therefore seems most likely that in this species the leaves were persistent for a considerable time.

The vascular system at the base of the phylloodium is similar to that of the leaf trace. There is a progressive thinning and at the same time a lengthening of the xylem strand, so that at its actual emergence from the stem it is but one to three tracheids wide except at the swollen terminals and includes a rather large area of sclerotic cells within the arch. (See pl. 42, fig. 1.) The most striking feature, however, is the decidedly involute position of the terminal portions of the strand as seen in plate 42, figure 1. There is a tendency for these points to curl inward as the leaf trace approaches

the periphery of the stem. At the base of the phyllo-podium this is very marked and simulates the completely closed, pseudoaxial stele of the petiole of *Gleichenia pectinata*.

The problematical parenchyma sheath, phloem, pericycle, and endodermis completely encircle the xylem. These tissues are similar to those that enclose the xylem in the main axis and so do not merit further discussion except to point out that they diminish in areal extent in the phyllo-podium so as to retain appropriate proportions with the xylem.

Within the C-shaped stelar mass there is a parenchymatous sheath of slight extent bordering the endodermis and flanked inwardly by a mass of sclerenchyma similar to that observed in the pith of the stem. Both the parenchymatous sheath and the sclerenchymatous tissue are in direct connection with similar areas external to the vascular strand—that is, there is a similar zone of thin-celled tissue on the adaxial side of the stele in direct connection around the extremities of the vascular bundle, and external to this there is a hypodermal layer of considerable extent of sclerotic tissue also in connection with the similar tissue within the C. The whole mass is enclosed by a narrow zone of parenchyma, usually showing poor preservation and limited by an epidermis equally poor in preservation.

Dermal emergences are occasionally preserved in the species described as *Tempskya minor*. These are unbranched hairs several cells long and but one cell wide. They are particularly abundant in the younger parts of the stems, as is shown in plate 39, figures 1 and 2. Similar appendages are seen in transverse section in plate 38, figure 1. Apparently these dermal hairs are soon lost, as sections cut through mature stems show little indication of such organs. Of course, the remains of these hairs may become quickly obliterated because of their small size. Furthermore, a search for them is particularly difficult on account of the great quantity of heterogeneous materials that compose the false stem.

**Root.**—The adventitious roots that form the closely felted mat around the stems are without exception diarch. As seen in plate 29, figure 3, they vary considerably in size, probably in part because of their distance from the point of origin and in part because of the branching. The stele is rather large and consists of two to four centrally disposed large tracheids grouped in an irregular line at right angles to the plane of the protoxylem. Laterally the tracheids very rapidly decrease in size to the first-formed elements, which consist of two to three cells located at the poles. A thin zone of sheathing parenchyma encircles the xylem, becoming continuous with the pericycle at the protoxylem points. The protophloem is located principally in a plane at right angles to the protoxylem and is as poorly differentiated as similar tissue in the stems. The pericycle is well developed and shows no note-

worthy differences from that in the stems. A well-defined endodermis delimits the stele, showing at some points poorly preserved Caspary bands on the radial walls.

The cortex consists of a parenchymatous inner layer followed by a thick zone of sclerenchyma. On the exterior of this zone there is seen, in well-preserved specimens, a layer of large-celled parenchyma. Usually this zone shows a marked tendency to become lacunar through the breaking down of some of the tissue. The situation is illustrated in plate 40. Sheathing this lacunar layer are smaller, thicker-walled cells of the subepidermis and epidermis. Not uncommonly in well-preserved masses of roots there may be observed remarkably well preserved root hairs, which are, like those of modern plants, simple outgrowths from the epidermis. They are remarkable in *Tempskya* only because of the perfection of preservation of these delicate structures. They may, in fact, be taken as evidence of extremely rapid silicification of the material.

As regards the origin of the root, the first indication of the development of such an organ is reflected in a slight outward bulge in the pericycle. The vascular elements appear to grow out at a variable angle until they reach the middle cortex, where the root flexes directly outward. At the same time there is developed on the xylem ring of the stem a small protuberance of tracheids which appear to unite gradually with those of the root.

#### *Tempskya knowltoni* Seward

Plate 28, figures 1–3; plate 29, figure 3; plate 30, figures 1, 2; plate 31, figures 1, 2; plate 32, figure 1; plate 42, figure 4; plate 43, figures 2, 3.

1924. *Tempskya knowltoni* Seward, Annals of Botany, vol. 38, no. 151, pp. 485–507, pls. 16, 17.

**Gross aspect.**—The type specimen of *Tempskya knowltoni*, which has been reported by Seward, is a slightly curved tapering specimen about 33 centimeters long. In cross section the false stem is oval, as shown in plate 28, figures 1 and 2, owing possibly to compression. At the larger and presumably distal end the greater diameter is about 6 centimeters; at the smaller and proximal end, 2 centimeters. The surface is considerably weathered and gives to the specimen a rather nondescript appearance not unlike that of a half-decayed fragment of a palm stem, inasmuch as the numerous roots simulate the scattered bundles of a monocotyledon. Thin slices cut from the specimen show a very excellent preservation. Plate 28, figures 1 and 2, show the general aspect of *T. knowltoni* in transverse section. The stems, which are numerous, are sheathed in a dense felt of their own adventitious roots. It will be noted that several stems are cut at stages of dichotomy, which in this species was apparently equal.

Photographs of portions of thin sections of *Tempskya knowltoni* taken at a somewhat higher magnification

are shown in plate 28, figure 3, and plate 29, figure 3. The occurrence of the stems in the groundmass of roots is well shown. Most of the roots roughly parallel the stems in their course, but some of them deviate to run obliquely. One very characteristic feature of the siphonostelic stems is well brought out in these photographs—the very dense and thick sclerotic cortex. In both figures numerous roots invade the stelar tissues. This likewise is rather significant and is carefully considered on page 123.

*Anatomy of the stem.*—Plate 31, figure 1, illustrates the general aspect of the stem at a magnification of about 40 diameters. The division of the cortex into three distinct regions is clearly shown. On the outside is seen a large-celled parenchymatous tissue that shows a tendency to slough and shred. This zone is only a few cells thick. Within is a very thick zone of sclerenchyma that shows a dense black on the photograph. This region of fibrous tissue is exceptionally developed in *Tempskya knowltoni* and furnishes one criterion for its specific separation. The inner cortex is rarely well preserved in this species. It is, however, shown at points and is parenchymatous and from 6 to 11 cells in thickness.

The endodermis is poorly defined in the species, owing possibly to faulty preservation. At any rate it can be recognized at only a few points but is probably a layer a single cell in thickness bounding the cortex. Within lie the pericycle, phloem, and sheathing parenchyma, all poorly preserved but definite at various points on most stems.

The xylem ring, as is shown in plate 30, figure 1, and plate 31, figures 1 and 2, is from 4 to 15 cells in thickness. It is composed almost entirely of scalariform tracheids with almost no xylem parenchyma. On the exterior of the ring there is an almost continuous layer of very small lumened tracheids. Superficially these suggest protoxylem and in fact are probably best regarded as such, despite the fact that they are scalariform rather than spiral. It may be assumed, temporarily at least, that the protoxylem is exarch and not well differentiated. Such a condition is not without parallel in extant ferns, among which the Schizaeaceae and some other Leptosporangiatae show a similar structure.

Within the xylem ring there is a repetition on a slightly smaller scale of the sheathing parenchyma, phloem, and pericycle investing the cylinder. This zone is bounded by an internal endodermis also vaguely marked.

The central area of the stem consists of an outer thin-walled zone, already described and similar to the inner cortex in general appearance and extent, which encloses an area of very thick-walled, small-lumened sclerenchymatous tissue.

*Leaf trace.*—The numerous sections of stems of *Tempskya knowltoni* furnish a very complete series of

stages bearing on the origin and development of the leaf trace. The first indication of an emerging strand destined to pass into a phyllopodium is a thinning of the whole stele in a small area in the upper half of the stem. The position of this point is usually to the side of the medial plane. Accompanying this decrease of a part of the stele there is a flexing outward of the area, as seen in plate 31, figure 1. This protrusion rapidly increases until first the xylem strand and finally the phloem, pericycle, and endodermis are interrupted on the upper side of the bulge, as is shown in the stem to the left in plate 31, figure 2. The outer and inner phloem, pericycle, and endodermis immediately close around this interruption both on the side of the leaf trace and of the parent stele. The figures show that a portion of the pith passes outward within the inverted U-shaped meristele. Shortly after the parting of the termination of the trace on the upper side—that is, the one proximal to the median plane—the lower termination separates in a similar manner. The result is the formation of a broad and shallow U-shaped trace with the two ends facing inward toward the foliar gap (pl. 31, fig. 2). This trace consists of a thin strand of xylem thickening toward the extremities, where the protoxylem appears to lie on the inner side. Phloem, pericycle, and endodermis completely enclose the xylem but form a thicker zone on the convex side of the U than in the concavity. The mass of sclerenchymatous pith that followed the leaf trace out and occupied the space within the U becomes continuous with the similar tissue of the cortex as soon as the trace penetrates this tissue.

The course of the trace through the cortex is nearly parallel to the parent stele. During this gradual emergence there is a curving inward of the edges of the strand, as is shown in plate 30, figure 2. The xylem on the upper side of the trace thins to one or two tracheids in thickness, and the identity of the internal sclerenchyma is lost by reason of its similarity to that of the cortex, with which it is in direct connection.

*Phyllopodium.*—Very rarely are free leaf bases—phyllopodia—observed in the sections of *Tempskya knowltoni* Seward. Where they are present they are usually in an advanced stage of decomposition and disintegration, as attested by the clogging of lumens with dark gumlike deposits, maceration of cells, and dislocation of tissues. As a result, though the series of stages leading up to the phyllopodium is complete, the sum total of knowledge of the mature organ is very small. It is certain, however, that the single vascular strand of the leaf trace persists and is modified into the highly convoluted meristele described for the genus as a whole.

*Roots.*—The mass of the specimen is, as in other species, a mat of branching roots, which differs little within the genus. The xylem is diarch, with two or

three centrally located tracheids of unusually large diameter. The phloem and pericycle are well developed, and the stele is limited by an endodermal sheath. The cortex is similar to that of other species.

*Comparison.*—The only species of *Tempskya* previously described that is well enough preserved to permit accurate comparison is *Tempskya rossica* Kidston and Gwynne-Vaughan.<sup>19</sup> It has been suggested that these species may be identical, the apparent differences being due to the derivation of the specimens from proximal and distal portions of the false trunk, respectively.<sup>20</sup> In the writers' opinion these two species are distinct, although they admit that considerable variation may be expected in different parts of the same axis and between different individuals of the same species. The most obvious differences are as follows:

1. The size of the individual stems. According to the account given by Kidston and Gwynne-Vaughan, the stems of their species are much larger than those of *Tempskya knowltoni*.

2. The symmetry of the false stem. In *Tempskya rossica* the stems are arranged roughly according to a plan of radial symmetry. *T. knowltoni* shows a distinct dorsiventrality. This variation in the plan of symmetry is, in the writers' opinion, a character of some value.

3. The length of the internodes. In *Tempskya knowltoni* the internodes are of such length that only rarely does a trace remain in the cortex of the axis at the third node above the point where it originated. The figures of *T. rossica* indicate that the internodes were somewhat shorter in that species.

4. The nature of the xylem. The xylem of *Tempskya knowltoni* is homogeneous, but in *T. rossica* a considerable quantity of parenchyma is present.

*Tempskya knowltoni* Seward is quite distinct from the species described as new in this paper. Comparisons are presented elsewhere (pp. 116, 118).

Occurrence: Colorado shale (Upper Cretaceous), about 500 feet above base, about 10 miles southeast of Harlowton, Mont., in sec. 36, T. 7 N., R. 16 E. Collected in 1908 by A. C. Silberling.

Holotype: U. S. Nat. Mus. 39266.

#### *Tempskya grandis* Read and Brown, n. sp.

Plate 29, figure 2; plate 32, figures 2-5; plate 33, figures 1-4; plate 34, figures 1-4; plate 35, figures 1-4; plate 41, figure 4; plate 42, figures 1-3; plate 43, figures 1, 4-7

The collections of *Tempskya* made by W. W. Rubey and J. S. Williams in the Aspen shale of the Wyoming Range of western Wyoming include two very distinct species—one a small-stemmed form with long internodes and the other a large-stemmed form with crowded nodes. This large-stemmed form the writers propose to call *Tempskya grandis*.

<sup>19</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., On a new species of *Tempskya* from Russia: Russ. k. min. Gesell. Verh., Band 48, pp. 1-20, pls. 1-3, 1911.

<sup>20</sup> Seward, A. C., Annals of Botany, vol. 38, no. 151, p. 498, 1924.

*Gross aspect.*—The type specimen of *Tempskya grandis* is a columnar fragment of a false stem about 8 centimeters in diameter and 20 centimeters long. The shape in cross section is oval, as is common in the false stems that have been examined. The weathered surface is quite like that of *T. knowltoni* Seward.

Plate 29, figure 2, illustrates the general aspect in cross section of *Tempskya grandis* at a low magnification. The stems are large as compared with *T. knowltoni* Seward and differ in several notable respects, as shown below. Text figure 3 (p. 108) is a carefully traced drawing of the false stem and the small stems included. The fact that these stems are dorsiventral shows clearly that there is a radial arrangement throughout so far as the orientation of these organs is concerned. Without exception the leaf traces that are sketched as U-shaped lines face toward the nearest point on the periphery of the mass. This arrangement of dorsiventral stems to simulate and probably to function in many respects as a single radially symmetrical axis is a very remarkable adaptation. The full significance of this feature is discussed on page 123.

*Anatomy of the stem.*—Plate 32, figures 2-5, illustrates the general appearance of typical stems of *Tempskya grandis* when slightly enlarged. The vascular cylinder is, of course, a siphonostele. Numerous leaf traces at various stages of development are visible.

The epidermis of the stem is rarely well enough preserved to be studied. Ordinarily the outermost tissue is a thin layer of parenchyma, indicated in plate 34, figure 4. This tissue is what the writers have called the outer cortex. Commonly it is deeply stained with some dark gummy substance. Immediately beneath the outer parenchymatous cortex is a region of sclerenchyma that constitutes the middle cortex. This feature is also indicated in plate 34, figure 4. This tissue is clearly very similar in histology to the comparable tissue in *Tempskya knowltoni* Seward but differs in its extent. A comparison of plate 31, figure 2 (*T. knowltoni*), with plate 34, figure 4 (*T. grandis*), immediately indicates that in *T. grandis* the amount of middle cortex is much less in proportion to the size of the stem than in *T. knowltoni*.

Beneath the tissue just described is a very well developed inner cortex, shown in plate 34, figure 4. In *Tempskya knowltoni* the parenchymatous inner cortex is a tissue of slight extent and presents no especially noteworthy features. In *T. grandis*, however, a somewhat different and significant condition is manifested. Plate 34, figures 2 and 4, shows that not only is this zone very well developed and fully as wide as that of the middle cortex but in addition there is an irregular band and commonly isolated nests of gummy sclerenchyma near the inner margin. Plate 34, figures 1 and 4, illustrates a portion of the inner cortex at a medium magnification and gives a good

idea of the histology. The writers are inclined to accept this differentiation of the inner cortex as a character of specific value.

The endodermis in *Tempskya grandis* is usually rather definite. Beneath it lies a thin layer of pericycle, then phloem, and finally the sheathing parenchyma of the xylem. (See pl. 34, fig. 3.)

The cylinder of xylem is well developed and prominent. In detail it differs somewhat from that of *Tempskya knowltoni* Seward. Plate 33, figure 3, shows that the zone of small-lumened elements, which is so prominent in *T. knowltoni* on the periphery of the ring, is not so conspicuous in *T. grandis*. The writers examined over 100 cross sections of steles and in none of them found this region so well developed. The position of the protoxylem is problematic. It appears, however, that this may be exarch or very slightly immersed (see pl. 34, fig. 3) and limited to a very small amount. Another point of difference between *T. knowltoni* and *T. grandis* is the abundance of xylem parenchyma in *T. grandis*. Plate 31, figures 1 and 2, and plate 34, figures 3 and 4, show that abundant thin-walled elements are interspersed with the tracheids. These cells have all the outward aspects of parenchyma, and the writers can only interpret them as such. Similar xylem parenchyma occurs in most of the families of the Filicales.

In *Tempskya grandis*, as in *T. knowltoni* Seward, an inner phloem, pericycle, and endodermis are present, although these tissues do not form so extensive a zone as those on the exterior of the xylem.

The outermost tissues of the pith are extremely interesting for several reasons. Plate 34, figure 2, indicates that there exists just within the endodermis a zone of large-celled parenchyma containing nests of sclerenchyma, and these are particularly abundant in the vicinity of a leaf gap. As a comparable zone exists in the cortex just outside of the outer endodermis the two may have a common origin. The writers do not propose to enter into the highly controversial discussion of the origin of the pith in the Filicales, because the several theories that have been advanced are subjects foreign to the purpose of this paper. Nevertheless, regardless of the origin of the tissues, they seem to furnish very reliable criteria for specific differentiation.

The central portion of the pith is an area of sclerenchymatous tissue similar to that found in *Tempskya knowltoni* Seward. Plate 34, figure 2, illustrates the general aspect of this region.

*Leaf trace.*—The illustrations of *Tempskya grandis* show that every section contains several leaf traces at various stages of development. A comparison of plate 32, figures 2–5, with plate 29, figure 3, shows clearly that the traces in *T. grandis* are more numerous in any given portion of the stem than in *T. knowltoni*. Consequently it may be inferred that in the former the inter-

node was much shorter than in the latter, as the writers believe, or else the traces passed outward at a more acute angle. This abundance of leaf traces has enabled the writers to make a very detailed study of the origin and development of the vascular strands that lead to the lateral organs.

A very early stage in the origin of a trace is shown in plate 35, figure 4 (on the left). At this point only a slight protrusion of the xylem strand and a narrowing in width are material evidence that the stele is about to be interrupted. A somewhat later stage is shown in plate 32, figure 3. The protrusion seen in plate 35, figure 4, has become plainly marked, and the stele is about to part at the point of formation of the upper termination of the trace. In plate 35, figures 3 and 4, this gap has appeared, and a very decided xylem loop has formed. Also a constriction of the stele at the point destined to be the lower termination of the trace is evident. These illustrations clearly show that a portion of the parenchymatous and sclerotic pith fills the concavity of the trace.

Plate 35, figures 3 and 4, shows the leaf trace shortly after the formation of a complete foliar gap. The trace consists of a narrow inverted U-shaped xylem strand, which is slightly swollen at the terminations and invested by phloem, pericycle, and endodermis. The concavity facing toward the parent stele contains a tissue that is histologically identical with the pith. An interesting feature is the development of a large amount of parenchymatous tissue containing nests and irregular patches of sclerenchyma in the region of the foliar gap. As previously stated, this tissue is characteristic both of the inner cortex and of the outer pith. There is a connection between these two usually separate units at the gap, and nests of sclerenchyma actually lie in the opening.

In plate 32, figure 5, the trace is shown in the sclerenchymatous cortex. Its general configuration is similar to that just described, but the terminations tend to curve inward. The investing tissues are very interesting. The characteristic parenchymatous and sclerotic tissue that sheathes the parent siphonostele both within and without occurs as a comparable sheath to the trace.

Plate 32, figure 3, illustrates a somewhat later stage in development of the trace. The ends are recurved, and it may be assumed that there is a progressive tendency toward this curvature, which has its extreme development at the base of the phyllospodium.

A very significant point, which the writers wish to emphasize, is the apparently short length of the internodes in *Tempskya grandis* as compared with *T. knowltoni* Seward. The numerous foliar traces that occur in every transverse section of a stem are highly indicative of such a condition. Likewise it is worth noting that almost invariably the sections of the central steles show foliar gaps. In contrast, *T. knowltoni* Seward shows not uncommonly a completely closed

stellar cylinder, and likewise the traces are never so numerous in any one section.

*Phyllopodium*.—In plate 42, figure 1, a phyllopodium of *Tempskya grandis* is shown in transverse section. The xylem strand is a modified, inverted U with the terminations swollen and strongly incurved. The dorsal convexity is flattened and tends to flex downward medially. Except for the terminations the xylem is rarely over two tracheids in thickness and commonly only one. The protoxylem, as in the solenostele, is problematical, for no spiral or annular elements have been observed. From the size of the tracheids, however, it appears that there are three groups of endarch protoxylem, one occupying the ventral surface of each of the swollen terminations and the third at the point of flattening of the medial portion of the strand. An endodermis completely encases the stele, following the contour of the xylem. A considerable amount of phloem exists externally but is clearly reduced internally.

The extrastelar tissues are extremely interesting. The exterior of the phyllopodium consists of a poorly preserved epidermis beneath which is a small amount of parenchyma. In some specimens this tissue is clearly reduced to isolated areas that contain only a few cells. The bulk of the outer mass consists of a thick zone of sclerenchymatous tissue, apparently homologous with the middle cortex of the stem. Within this sheath lies a broad tract of large-celled parenchyma containing an irregular zone and isolated patches of sclerenchyma. This tissue is similar to and probably histologically identical with the inner cortex of the stem. As shown in the illustration, the area is continuous with the similar area on the inside of the bay of the meristele. The central portion of the bay is occupied by a mass of sclerenchyma.

*Root*.—The root varies so little in the several species of *Tempskya* examined that the generic description may be taken as a general account. The stele is diarch and is limited by a readily distinguishable endodermis, and the cortex is almost entirely sclerenchymatous.

The roots branch freely and occur in a variety of sizes. So far as the writers have been able to ascertain they are essentially parallel to the course of the stems, although they may locally deviate considerably from the course.

*Comparison*.—*Tempskya grandis* stands so distinctly apart from the several other species of the genus which have been described that there can be no question of its validity. Probably its nearest relative, if the details of vegetative anatomy may be taken as a guide, is *T. rossica* Kidston and Gwynne-Vaughan,<sup>21</sup> from a Tertiary conglomerate in the Karaganda River Basin

of Russia. However, the specimen appears to have been reworked from older, probably Cretaceous rocks. According to Kidston and Gwynne-Vaughan this species is characterized by

stems 6–7 millimeters in diameter. Leaves very closely inserted, indications of two leaf traces being present in each transverse section of the stem. Vascular system a solenostele. Xylem parenchymatous, tracheae scalariform, rarely multiseriate, without definite protoxylem groups. Petiole about 5 millimeters in greatest diameter. Leaf trace in petiole horseshoe-shaped with median abaxial depression and incurved, slightly enlarged extremities.<sup>22</sup>

According to this diagnosis *Tempskya rossica* approaches *T. grandis* in size of the stems and in the parenchymatous condition of the xylem. In fact, the writers were inclined during their preliminary studies to identify the species here described as new with the Russian specimen. A number of differences have manifested themselves, however, upon careful study. The internodes are much shorter in *T. grandis*, as is indicated both by the serial sections and by the numerous leaf traces (commonly five or six) found in every cross section of a stem. This, of course, cannot be taken as a criterion of high specific value but coupled with other evidence may be accepted with slight reservation. More significant is the matter of the inner cortex. Kidston and Gwynne-Vaughan found that in *T. rossica*

the cortex consists of two distinct zones; that next the stele is composed of fairly large cells with comparatively thin walls, probably parenchyma. Then comes a zone of thick-walled sclerenchyma about half as wide as the inner cortex, and outside this there may be a few layers of thin-walled cells.<sup>23</sup>

No mention is made of the occurrence of an irregular zone of sclerenchyma near the inner border of the inner cortex, and their figures do not indicate such a tissue. Such a zone, however, is invariably present in *T. grandis* and may be taken as a character of considerable systematic value. The similar outer pith found in *T. grandis* is also different from that in *T. rossica*, where "there is a zone of thin-walled parenchyma next the endodermis, while the whole of the central region of the stem is occupied by a mass of sclerotic cells."<sup>24</sup> The outer pith and inner cortex of the phyllopodium, which are histologically identical with comparable regions of the stem, differ in the same manner in *T. grandis* and *T. rossica*.

Numerous differences between *Tempskya grandis* and *T. knowltoni* Seward have already been pointed out. The longer internodes, the narrow zones of inner cortex and outer pith, which are entirely parenchymatous, the absence of any appreciable quantity of xylem parenchyma, and the flattened meristele of the phyllopodium in *T. knowltoni* Seward are characters that serve as accurate indices to its segregation.

<sup>21</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., On a new species of *Tempskya* from Russia: Russ. k. min. Gesell. Verh., Band 48, pp. 1–20, pls. 1–3, 1911.

<sup>22</sup> Idem, pp. 13–14.

<sup>23</sup> Idem, p. 9.

<sup>24</sup> Idem, p. 10.

Also, if the single specimen of *Tempskya knowltoni* can be accepted as typical and entire, the dorsiventral symmetry of the false stem as contrasted with the radial symmetry of the aggregation in *T. grandis* may likewise furnish grounds for distinction. The writers are inclined to place some emphasis on this character in systematic work.

**Occurrence:** Material collected by W. W. Rubey and J. S. Williams in porcelainlike beds of Aspen shale (Upper Cretaceous) about 400 feet above the Bear River formation (Upper Cretaceous) at a locality in sec. 17, T. 35 N., R. 115 W., in the Afton quadrangle, Wyo. In addition one specimen was collected by S. H. Knight, of the University of Wyoming, from the Aspen shale in sec. 14, T. 31 N., R. 115 W., Lincoln County, Wyo., and transmitted to the writers by G. R. Wieland, of Yale University.

**Cotypes:** U. S. Nat. Mus. 39267, 39164.

**Tempskya minor Read and Brown, n. sp.**

Plate 29, figure 1; plate 36, figures 1-4; plate 37, figures 1-4; plate 38, figures 1-4; plate 39, figures 1-4; plate 40, figures 1-4; plate 41, figures 1-3; plate 42, figure 5.

In addition to *Tempskya grandis* the collections made by Rubey and Williams in the Aspen shale (Upper Cretaceous) contain a small-stemmed species of the same genus. Similar specimens are included in the small lot obtained from the Wayan formation of southeastern Idaho by Mansfield in 1930 and by Mansfield, Rubey, and Williams in 1931 and S. H. Knight from the Aspen shale in sec. 14, T. 31 N., R. 115 W., Lincoln County, Wyo. This species is of the same general stock as *Tempskya knowltoni* Seward; in fact, the relationship seems to be very close. The writers believe, however, that *Tempskya minor* is distinct and can, with care, be separated from *T. knowltoni*. Certain minor morphologic differences exist, and these appear to be constant. This separation may seem to some students to be of doubtful validity, but a careful study of the numerous figures should convince the observer that specific differences exist.

**Gross aspect.**—A sketch of a large transverse section of an entire false stem is shown in text figure 4 (p. 108). Only the outlines of the stems, leaf bases, and the steles of these organs have been drawn. A comparison with the sketch of *Tempskya grandis* shown in text figure 3 (p. 108) immediately indicates significant differences. With very few exceptions the stems are so oriented that their leaf bases face in one direction. In other words, the symmetry tends to be dorsiventral. Whether this is apparent or real it is impossible to say. Most of the specimens of this species are large and do not suggest mere segments of a much larger false stem. At present the writers prefer to regard the symmetry as real, although they admit the possibility that the dorsiventrality is only apparent.

In this respect *Tempskya minor* is similar to *T. knowltoni*. If the symmetry of *T. minor* and *T. knowltoni* is actually dorsiventral then there is a strong

suggestion of two groups of Tempskyas—one typified by *T. minor* and the other by the radially symmetrical *T. grandis*. These problematic subgeneric groups are discussed more fully on page 122.

**Anatomy of the stem.**—The general appearance of the stem of *Tempskya minor* is shown in plate 29, figure 1, and in plate 36, figures 1-4. The species conforms very well to the generic characters. The vascular tissues are arranged in a dorsiventral siphonoste. The leaf gaps are short, and the traces are inverted U-shaped. The cortex and pith contain prominent areas of sclerenchyma. A thick mass of adventitious roots sheathes each stem and binds the whole system into a false stem.

Plate 38, figure 3, illustrates outer tissues of a stem. The exterior is rarely well preserved but appears to consist of a few layers of large, thin-walled elements beneath the epidermis.

The middle cortex is an extensive area of sclerotic elements. In general this tissue is similar to that described in the cortex of *Tempskya knowltoni* Seward and *T. grandis*. However, it is not so highly sclerotized as in the other two species and does not form so thick a ring as in *T. knowltoni*.

The inner cortex is well developed. In proportion to the size of the stem the area occupied by this tissue is fully as broad as in *Tempskya grandis*. The elements are large and thin walled. The occurrence of nests or even isolated cells of sclerenchyma was not noted, in contrast with their universal occurrence in *T. grandis*, which was collected in the same beds.

The cortical tissues are limited by a distinct endodermis, which, however, is well preserved in only a few specimens. An inner as well as an outer endodermis is present. As in the other species described these become continuous at each foliar gap, closing around the free ends of the interrupted vascular cylinder.

In plate 41, figure 3, the details of the morphology of the stele are shown. The amount of tissue that can be identified with certainty as pericyclic is slight, much less than in either *Tempskya knowltoni* or *T. grandis*. Likewise the phloem and the sheathing parenchyma are reduced in amount, on both the exterior and the interior of the xylem.

The xylem ring is similar to that described for *Tempskya knowltoni*. In plate 39, figures 2 and 3, the details of structure of this tissue are shown at a rather high magnification. The nearly continuous peripheral zone of small elements that has been tentatively regarded as protoxylem in *T. knowltoni* is represented by a discontinuous zone in *T. minor*. Likewise the ring is somewhat narrower in *T. minor*. The xylem appears to be wholly without parenchyma, another point of difference from *T. knowltoni*; in which xylem parenchyma occurs in very small quantity, though it is present in most sections.

Within the inner endodermis there is a narrow zone of large-celled parenchyma enclosing a mass of sclerenchyma that extends to the center.

*Leaf trace.*—The stems of *Tempskya minor* are characterized by long internodes in comparison with the other species of *Tempskya* that have been studied. In consequence it is by no means uncommon to find transverse sections that show a continuous vascular cylinder and no sign of foliar interruption. (See pl. 41, fig. 3.)

The first indication of the emission of a trace is a thinning of the xylem in the portion of the cylinder that is destined to pass into the rachis. At the same time there is a protrusion of the entire stele, which continues until a gap is formed on the upper side of the trace. The shape of the foliar strand then is that of a narrow, inverted U. Immediately afterward the lower termination of the strand is detached. The phloem, pericycle, and endodermis are continuous around the ends of the xylem, both in the parent stele and in the leaf trace. The gap is rather short and closes very soon after the departure of the trace.

In plate 37, figure 2, the aspect of the trace is shown shortly after its departure from the cylinder. It is a broad, shallow arch, obliquely ascending, with the xylem only 1 to 3 tracheids in thickness except at the swollen ends. Completely surrounding it is a thin layer of phloem, pericycle, and endodermis. Within this horseshoe-shaped mass is a narrow zone of parenchyma that partly encloses the sclerotic tissue, which is in connection with the sclerenchyma of the pith and unquestionably falls in the same morphologic category.

As the trace passes out through the cortex it becomes sheathed on its abaxial surface first with parenchyma and then with sclerenchyma from the middle cortex. Plate 37, figures 1-4, shows a series of stages in the development of the trace within the cortex. The stele is at first a broad, shallow U with slightly enlarged ends, which becomes progressively more and more recurved as the trace passes out. At the same time a slight depression develops on the abaxial surface.

The protoxylem groups are as problematical in the foliar trace as in the central cylinder. Groups of small tracheids that are tentatively regarded as protoxylem occur at the inner surface of the enlarged terminations and at the centrally located depression of the stele. Though no indication of spiral or annular thickenings has been observed, it seems safe to assume that the traces are triarch-endarch.

*Phyllopodium.*—In plate 36, figure 1, the appearance of the rachis in transverse section shortly before it becomes completely detached is shown. The stele is a broad, flat arch with recurved and enlarged terminations. Near the center there is the prominent abaxial depression that has already been mentioned. The protoxylem is apparently triarch and endarch. Completely enclosing the xylem strand is a zone of phloem,

pericycle, and endodermis, which follows the configuration of the xylem very exactly. Within the arch there is a thin layer of parenchyma, which is continuous with a smaller tissue on the outer surface of the stele. The center is a mass of sclerotic tissue likewise in connection with the similar layer on the exterior, which makes up the bulk of the rachis, as is clearly shown in the figure.

Numerous remains of rachides are found in the groundmass of roots. These are scarcely well enough preserved to warrant description. Generally the stele is decayed or reduced to an unidentifiable mass and commonly displaced. Two of these masses are illustrated in plate 42, figure 5. This common occurrence of rachides in the root felt of *Tempskya minor* is in decided contrast with the condition in *T. knowltoni*, where such organs are very rare.

*Root.*—No essential difference in root structure between *Tempskya minor* and *T. knowltoni* and *T. grandis* was observed. Therefore the details of structure of these organs need not be considered. In fact, the generic description suffices for all the species that are considered in this report.

*Comparison.*—The foregoing description clearly indicates that *Tempskya minor* is very distinct from its associate in the Aspen shale, *T. grandis*. To recapitulate: *T. grandis* is a large-stemmed species with very short internodes. The axis is characterized by a xylem containing abundant parenchyma and by an inner parenchymatous cortex of considerable extent containing an irregular zone of sclerotic cells. A similar tissue exists in the outer pith. The rachis contains a deep, highly recurved stelar arch surrounded by tissues similar to those in the stem. On the other hand, *T. minor* is a small-stemmed form with a homogeneous xylem and without fibrous masses in the inner cortex. The foliar meristele is a flat arch, not nearly so recurved at the ends. The internodes are very long. The false stem of *T. grandis* is radially symmetrical; that of *T. minor* is approximately dorsiventral. The differences are so numerous and so constant that there is little danger of confusing the two.

The distinction of *Tempskya minor* from *T. knowltoni* is much more finely drawn, yet the writers believe that the two species can be accurately separated if sufficient care is taken. The more noteworthy differences are the larger size of *T. minor*, the more compact xylem with groups of problematic protoxylem instead of a nearly continuous layer, the broader zone of inner cortex, the less sclerotic outer cortex, and the broader, flatter arch of the meristele in the base of the rachis. In *T. knowltoni* the xylem contains some parenchyma; in *T. minor* such cells have not been observed. Likewise it appears that in *T. minor* the leaves, as indicated by the common occurrence of rachides, were more persistent than in *T. knowltoni*, where such organs are very rare.

Of the European species *Tempskya rossica* is the only one well enough known to justify comparison.

This species, however, is closely related to *T. grandis* and in consequence should not be confused with the plant here described. According to the original report,<sup>25</sup> *T. rossica* is characterized by short internodes and in consequence numerous foliar traces in cross section and by xylem parenchyma. The stems are very nearly the size of the larger ones in *T. minor*. However, microscopic examination should make the separation rather simple, for *T. minor* contains no xylem parenchyma.

Occurrence: 1. Porcelainlike beds of Aspen shale about 400 feet above the Bear River formation in sec. 17, T. 35 N., R. 115 W., Wyo. Collected in 1931 by W. W. Rubey and J. S. Williams.

2. Aspen shale in sec. 14, T. 31 N., R. 115 W., Lincoln County, Wyo. Collected by S. H. Knight and transmitted by G. R. Wieland.

3. Aspen shale on divide between middle and east forks of Hoback Creek near head, in sec. 18, T. 35 N., R. 115 W., Wyo. Collected in 1931 by W. W. Rubey and J. S. Williams. Another collection from this same locality was made by W. W. Rubey in 1933.

4. Terrace gravel in valley of Twin Creek near Fossil, Wyo. Collected by R. W. Brown in 1930.

5. Upper part of Wayan formation in secs. 17 and 19, T. 5 S., R. 44 E., Idaho. Collected by G. R. Mansfield.

Cotypes: U. S. Nat. Mus. 39253, 39259, 39260; paratypes: U. S. Nat. Mus. 39163, 39254, 39255, 39256, 39257, 39258, 39261, 39262.

#### *Tempskya whitei* Berry

1911. Berry, E. W., Maryland Geol. Survey, Lower Cretaceous, pp. 295-299, pls. 37, 38.

The specimens designated *Tempskya whitei* by Berry in his report on the Lower Cretaceous floras of Maryland have considerable historic interest. They represent the first record of the genus in America and also the only one from the Atlantic Coastal Plain. In consequence the writers have devoted much more time to the study of the prepared sections than the very poor preservation would really warrant. The results have been rather unsatisfactory, as will be seen below.

*Tempskya whitei* Berry is a large-stemmed form with relatively short internodes, as is indicated by the numerous leaf bases. In most specimens it has been impossible to observe the details of the xylem ring, but in a few of the best-preserved stems it appears to be from 7 to 12 tracheids in thickness and very sparingly parenchymatous. The protoxylem is in its usual position on the exterior of the cylinder. The cortex and "pith" are so poorly preserved in all the sections that their detailed structure cannot be determined. The leaf traces are apparently similar in form to those of the other species described in this paper.

The above remarks are intended to justify the writers' opinion as to the validity of the generic determination of this material. The very poor state of preservation makes it impossible to formulate a specific diagnosis at this time.

<sup>25</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., op. cit., 1911.

Occurrence: Patapsco formation (Lower Cretaceous). The specimens examined by the writers came from Stony Run and Deep Run near Severn, Anne Arundel County, Md.

Plesiotype: U. S. Nat. Mus. 39264.

#### *Tempskya* sp.

A small fragment of a large false trunk of *Tempskya* from the La Sal Mountains of Utah has come to the writers through the kindness of Frank L. Hess, of the United States Bureau of Mines. This specimen is, unfortunately, a mass of diarch roots without any recognizable stems. In consequence it is impossible to assign the material to any species, as the roots do not afford any specific criteria. The record is of value only in that it further outlines the geographic and stratigraphic distribution of the genus.

Occurrence: Collected by F. L. Hess in the La Sal Mountains, Utah, on the divide southwest of Winburn's ranch, near the head and northwest of Pack Creek; probably from the Upper Cretaceous Dakota (?) sandstone.

Holotype: U. S. Nat. Mus. 39265.

#### SYNOPSIS

The writers have prepared a concise synopsis of the chief characters that serve to segregate the several better-known species of *Tempskya*. This synopsis may be of value not only for general reference but also for aid in identification.

1. Individual stems of false stem large, with very short internodes as indicated by the numerous leaf bases present in transverse sections. Xylem exarch or possibly slightly immersed in some specimens. False stem chiefly radially symmetrical. Xylem ring containing much parenchyma:<sup>26</sup>
  - A. Inner cortex a broad zone of parenchyma containing near its inner margin an irregular but continuous tract of sclerenchyma. Outer layer of "pith" a similar zone of parenchyma containing sclerenchyma, especially in the vicinity of the nodes. *Tempskya grandis*.
  - B. Inner cortex a narrow zone of large-celled parenchyma. Presence of an inner sclerotic layer not recorded. *Tempskya rossica*.
2. Individual stems of false stem small, internodes of such length as to permit only a little overlapping (2-3) of leaf bases. Xylem exarch. False stem dorsiventral. Xylem ring containing little if any parenchyma:<sup>27</sup>
  - A. Xylem very compact; protoxylem commonly segregated into definite groups. Inner cortex broad, parenchymatous. Petioles common in false stems, indicating persistence of leaves; xylem arch fairly flat. Stems averaging larger than those in the next group. *Tempskya minor*.
  - B. Xylem compact but with parenchyma in places interspersed with the tracheids. Inner cortex usually narrow, parenchymatous. Petioles rare in false stem; xylem arch rounded. *Tempskya knowltoni*.

<sup>26</sup> Under 1 may probably be included such indifferently preserved and poorly known species as *Tempskya whitei*, *T. erosa* (some forms), *T. pulchra*, *T. macrocaula*, *T. micorrhiza*, and *T. schimperi*.

<sup>27</sup> Some forms of *Tempskya erosa* belong in this group.

TAXONOMIC POSITION  
AFFINITIES OF TEMPSKYA

In their admirable discussion of *Tempskya rossica* Kidston and Gwynne-Vaughan stated that

The affinities of the Tempskyas appear to lie with the leptosporangiate ferns, but beyond this their systematic position must at present be left uncertain. \* \* \* For instance, stems with a solenostelic vascular system are known to occur in the Schizaeaceae, Gleicheniaceae, the *Dipteris-Matonia* series, in *Loxsoma*, the Cyatheae, the Dennstaedtineae, and in certain series of the Polypodiaceae.<sup>28</sup>

Even with the discovery of abundant new material these statements, though conservative, must still be accepted as expressive of the somewhat nebulous ideas concerning the affinities of *Tempskya*.

The writers have made a careful survey of the literature dealing with the vascular anatomy of the ferns in the hope that it would be possible to establish the systematic position of the genus. The results, though not so satisfactory as might be wished, narrow down the probable affinities somewhat and are therefore recorded.

The Eusporangiatae, as already stated, may at once be eliminated. The stems of the representatives of this group, both living and fossil so far as they are known, are quite distinct in their vascular make-up from those of *Tempskya*. Likewise there is the circumstantial evidence of the occurrence of sporangia of the leptosporangiate type entangled in the adventitious roots of *Tempskya knowltoni*.<sup>29</sup>

Although within the Leptosporangiatae siphonostelic axes occur in groups that appear to be widely separated, yet there are certain characteristic features of *Tempskya* that immediately tend to eliminate several possibilities. The probable absence of spiral protoxylem, the exarch or very slightly immersed position of the protoxylem, the shape of the leaf trace and its mode of origin, and the outline of the vascular system of the petiole are criteria of great value in narrowing down the affinities. Without going into detail regarding the morphologic discrepancies that have permitted this elimination, it may be stated that certain members of the Schizaeaceae, Loxsomaceae, and Gleicheniaceae are anatomically more harmonious with *Tempskya* than any other ferns of which the writers have seen accounts. These families present features, however, that apparently do not conform with those observed in *Tempskya*.

The Schizaeaceae are a family that includes four living genera—*Schizaea*, *Lygodium*, *Aneimia*, and *Mohria*. Except for the last-named, all the genera include numerous species. The distribution is widespread but chiefly tropical. In habit there is a pronounced tendency toward dorsiventrality, although the radial con-

dition persists in some species of *Schizaea* and *Mohria* and in most species of *Aneimia*. Repeated dichotomy of the stem characterizes all the dorsiventral representatives.

In the internal structure of the axis there is considerable diversity in the family, ranging from protostely to siphonostely and dictyostely. Among the siphonostelic members are encountered features that indicate an affinity with *Tempskya*.

The section *Aneimiiorrhiza* of *Aneimia* forms a natural group of at least seven species, all having siphonostelic stems. Boodle<sup>30</sup> has published an authoritative treatise on the anatomical features of these species and of *Aneimia mexicana* in particular. The stems are highly sclerotic and show a thin ring of xylem bounded without and within by phloem, pericycle, and endodermis. The protoxylem is usually scalariform and appears diffuse exarch, although this point is not made clear. In some species, however, the spiral elements of the protoxylem in the leaf trace may continue downward into the central axis for a short distance. The petiole of this species has not been studied in detail, but in the related *Aneimia aurita* an inverted narrowly U-shaped leaf trace passes out in a manner similar to that in *Tempskya*. A median and two lateral areas of protoxylems are present. The phloem and endodermis conform to the outline of the xylem but are absent in the deeper portions of the concavity. The protoxylem is confined to the inner surface. A hypodermal layer of sclerenchyma is present, but the petiole is not prevailingly sclerotic.

The xylem presents certain features that militate somewhat against a very close comparison with *Tempskya*. According to Boodle, parenchyma intermingled with the tracheids is rare. If comparisons were being drawn only between this family and species of the type of *Tempskya knowltoni* Seward the point might be made that the occurrence of parenchyma is too sporadic to be worthy of serious consideration. However, its abundance in *Tempskya rossica* Kidston and Gwynne-Vaughan and in *Tempskya grandis* makes the difference worthy of note. Another feature upon which Boodle lays particular stress is the occurrence of sclerosed sieve tubes in the phloem of representatives of all the genera except *Mohria*. Such fibers have not been observed by the writers in *Tempskya*, nor has any record of such an occurrence been brought to their attention.

Another character that may be of some value in discussing the affinities of *Tempskya* is the prevalence of diarch roots in the Schizaeaceae similar to those characteristic of the fossil.

The Gleicheniaceae include two genera—the monotypic *Stromatopteris* and *Gleichenia*—with about 80

<sup>28</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., On a new species of *Tempskya* from Russia: Russ. k. min. Gesell. Verh., Band 48, pp. 16-17, 1911.

<sup>29</sup> Seward, A. C. Annals of Botany, vol. 38, no. 151, p. 466, pl. 16, figs. 5, 8, 1924.

<sup>30</sup> Boodle, L. A., Comparative anatomy of the Hymenophyllaceae, Schizaeaceae, and Gleicheniaceae; II, On the anatomy of the Schizaeaceae: Annals of Botany, vol. 15, pp. 359-421, pls. 19-21, 1901.

species. Their distribution is chiefly tropical and south temperate. *Gleichenia* has been divided into three subgenera—*Mertensia*, *Eu-Gleichenia*, and *Platysoma*. In species of *Mertensia* characters are seen that suggest a comparison with *Tempskya*. In most species of the genus a protostele characterizes the vascular axis, but in *Gleichenia pectinata* of the subgenus *Mertensia* there is a very interesting solenostele of a type highly suggestive of that in *Tempskya*.

In *Gleichenia pectinata* the stem is sclerotic. The solenostele carries numerous groups of slightly immersed protoxylem. Outer and inner phloem, pericycle, and endodermis are present. The central area is occupied by sclerenchyma. The stem is markedly dorsiventral, giving off leaves above and roots below. At the node a band of tissue destined to pass into the leaf begins to separate from the xylem ring, the outer portion contributing more than the inner, in such a manner that the central sclerotic mass has a two-armed upward and lateral extension filling the concavity of the trace. The strand then splits off and gradually assumes an inverted U-shape with strongly recurved and somewhat swollen ends. The stele is left open for a time after the departure of the trace, so that there is free communication between central and cortical tissues.

In the petiole there is a prominent protoxylem group at each of the terminal hooks, and between lie an indeterminate number of groups derived from a centrally located protoxylem in the early stages of the leaf trace. A considerable amount of sclerenchyma is included in the convexity of the petiole, and the phloem and endodermis are continuous within as well as without the xylem.

In this plant there are several points of disagreement with the observed facts of structure in *Tempskya*, chief among which are the definite and slightly mesarch protoxylem, which is spiral, and the mode of origin of the leaf trace.

Evidence of spiral protoxylem has not been noted in *Tempskya*, and its presence in slightly mesarch groups in *Gleichenia pectinata* is a significant point of difference. However, such protoxylem may exist in *Tempskya* but may have been obliterated during the course of silicification. This feature is in the writers' opinion an indecisive one.

The origin of the leaf trace plainly presents considerable differences between *Gleichenia pectinata* and *Tempskya* species. However, some question may be raised as to the systematic value of this feature.

Certain characters of the xylem necessitate the careful consideration of the Gleicheniaceae in this discussion. In its parenchymatous nature the ring is strongly suggestive of the stele of *Tempskyas* of the group of *Tempskya rossica*. Likewise the outline of the petiolar bundle and the distribution of the tissues in general in *Gleichenia pectinata* as well as in other species of the genus is strongly suggestive of *Tempskya*.

The Loxsomaceae, a family of ferns of the Tropics and the Southern Hemisphere, include two genera—*Loxsoma* and *Loxsomopsis*, the former being monotypic. The anatomy of *Loxsoma cunninghami* has been fully investigated by Gwynne-Vaughan,<sup>31</sup> and it is therefore possible to draw a rather careful comparison with *Tempskya*. The stem is a typical solenostele, a complete ring of xylem being invested on both sides by phloem, pericycle, and endodermis. The groundmass of the stem is chiefly sclerenchyma, although a thin layer of parenchyma adjacent to the inner and outer endodermis is similar to the feature that the writers have called the inner cortex. Scattered "islets" of parenchyma occur in sclerotic tissue of the groundmass, being abundant in the vicinity of the stele and disappearing farther away. The xylem is only a few cells thick and may be parenchymatous. "The protoxylem \* \* \* consists of narrow scalariform tracheids evenly distributed around the external periphery of the xylem ring."<sup>32</sup>

The closed stele is interrupted periodically along the upper side by the departure of leaves. At each node a portion of the ring separates and passes slowly outward as an inverted U-shaped meristele. Through the gap thus formed in the central cylinder there is free communication of medullary and cortical tissues. This gap may continue for some distance but never overlaps the succeeding one.

The vascular strand in the petiole thus developed is horseshoe- or inverted U-shaped, with the extremities enlarged and incurved. The protoxylem lies in several groups on the adaxial surface of the thin strand, one group occupying the bay of each of the incurved hooks and an indeterminate number being situated along the dorsal curve. The phloem, pericycle, and endodermis follow closely the contour of the xylem, although they may thin along the convex surface. The groundmass of the petiole is sclerenchymatous in the proximal portions but becomes more parenchymatous higher up. The roots are diarch and similar to those in *Tempskya*.

*Loxsoma cunninghami* presents a number of features that suggest comparison with *Tempskya*. The exarch siphonostele with scalariform protoxylem, the sclerotic cortex, the dorsiventrality of the stem, the modified triarch, endarch leaf traces, and the diarch roots are all characters that are shared with *Tempskya*. However, the leaves are very nearly one-ranked, instead of two-ranked as in *Tempskya*, and the leaf trace is broader and flatter in outline. In *Loxsoma* islets of parenchyma related to the inner cortex are scattered in the sclerotic tissue for some distance from the stele, whereas in *Tempskya grandis* there are numerous islets and in fact an irregular sheet of sclerenchyma near the inner margin of the inner cortex. This feature may

<sup>31</sup> Gwynne-Vaughan, D. T., Observations on the anatomy of solenostelic ferns; I. *Loxsoma*: Annals of Botany, vol. 15, pp. 71-98, pl. 3, 1901.

<sup>32</sup> Idem, p. 79.

be taken as evidence of a trend toward sclerification of the parenchymatous cortex, with the possibility not remote of isolation of the softer tissue as islands. It is, of course, impossible to say how far this sclerification proceeded.

The above discussion shows that the writers are at a loss regarding the exact affinities of *Tempskya*. Professor Seward has urged that the genus be referred to the Schizaeaceae and has drawn a close comparison with *Aneimia*.<sup>33</sup> The writers admit that there is much to be said in favor of this reference, including the circumstantial occurrence of spores and sporangia in the root felt, but on the other hand there are several serious discrepancies. Therefore it is proposed to erect, temporarily at least, a group designation for *Tempskya* and related fossil forms. For this group the family name Tempskyaceae is suggested. The limits of this family must for the present remain in doubt, and it may be temporarily regarded as unigenetic.

To recapitulate, the Tempskyaceae are a family of Mesozoic ferns including one genus, *Tempskya*. Several species are known. The affinities of the group lie with the leptosporangiate ferns, and trends are seen that suggest relation with the Schizaeaceae and the Loxsomaceae on the one hand and the Gleicheniaceae on the other. The limits of the family cannot be determined at present.

#### INTERRELATIONSHIPS OF THE SPECIES

The problem of the relationships of the species of any genus is invariably difficult—in fact, several solutions can usually be found that will be in harmony with the apparent trends of phylesis. The writers' views presented here are merely suggestions and are by no means intended to be dogmatic.

In the more formal systematic portions of this paper evidence has been presented which clearly shows that the genus *Tempskya* can be divided into two natural groups. *Tempskya knowltoni* Seward may be taken as the type example of one group. It is a small-stemmed form with relatively long internodes, thick sclerotic cortex, and xylem that is homogeneous. *T. grandis* may be taken as the type of the other group. It is a large-stemmed type with very short internodes, parenchymatous xylem, and a cortex differentiated into several layers.

To the first group the writers assign *Tempskya minor* in addition to *T. knowltoni*. To the second are referred *T. grandis*, *T. rossica* Kidston and Gwynne-Vaughan, *T. whitei* Berry, some specimens of *T. erosa* Mantell, and probably the several species described by Corda.

The relative primitiveness of the two groups is of great interest. Unfortunately, as at present known their stratigraphic ranges are approximately the same. It appears that the group of *Tempskya knowltoni* is

more primitive so far as the morphology of the axis is concerned, and at the same time *T. grandis* presents several features that point to high specialization. The facts concerning this alleged primitiveness of *T. knowltoni* Seward may be summarized as follows:

The small stems with fairly long internodes seem more nearly typical of the solenostelic condition than the large stems with very short internodes that are exhibited in *Tempskya grandis*. In *T. grandis* it is at once evident that there is an approach to polystely and ventilation brought about by shortening of the internodal length, and as polystely, or any approach to it from the typical solenostele, is a distinct anatomical advance in the ferns it must be assumed that *T. grandis* is a more specialized representative of the genus.

The homogeneity of the xylem in *Tempskya knowltoni* may be taken as primitive, whereas the presence of abundant xylem parenchyma intermingled with the tracheids in *T. grandis* is some proof of advancement.

The cortex of *Tempskya knowltoni* is nearly homogeneous, consisting below the thin subepidermal zone of a broad belt of sclerotic tissue with only a few cells of parenchyma lying next to the endodermis. On the other hand, *T. grandis* has a cortex clearly divisible, below the subepidermal layers, into two zones—an outer sclerotic and a broad inner layer of parenchyma containing an irregular belt of sclerenchyma near its inner margin. It may be that the condition in *T. knowltoni* is primitive, or possibly it is a derivative of the condition in *T. grandis*.

There is indication that *Tempskya knowltoni* and others of the group present a dorsiventral symmetry in the false stem. *T. grandis* shows a distinct radial arrangement. It is reasonable to suppose that this dorsiventral condition preceded the radial one. This point is discussed above.

#### PROBABLE HABIT OF TEMPSKYA

The false stem, which is so characteristic of *Tempskya*, has been a subject of some discussion among paleobotanists because it brings up the very interesting problem of habit. A number of opinions on this point have already been considered in this paper, but for the sake of clarity it is necessary to restate briefly the conclusions of Kidston and Gwynne-Vaughan and of Seward.

The aggregate of axes with their root packing must have stood upright. If they had grown horizontally the roots would not have run parallel with the stems, and again the leaf-bearing sides of all the stems would have pointed in the same direction—that is, away from the soil. The whole aggregate of axes and roots undoubtedly reached a very considerable height and size, for Fitton describes specimens of the fossil measuring as much as 9 feet long, 1 foot wide, and 4 inches thick.<sup>34</sup>

An examination of the American material leads me to express an opinion different from that of Kidston and Gwynne-Vaughan. \* \* \* The general though not invariable tendency of the

<sup>33</sup> Seward, A. C., Annals of Botany, vol. 38, no. 151, p. 499, 1924.

<sup>34</sup> Kidston, Robert, and Gwynne-Vaughan, D. T., On a new species of *Tempskya* from Russia: Russ. k. min. Gesell. Verh., Band 48, p. 14, 1911.

roots to follow a vertical course does not \* \* \* justify the assumption of an erect position. The mass of compact roots seen in the fossil was probably covered during life by a much looser felt of roots which grew into the soil \* \* \*. Moreover, hydrotropism as well as geotropism must be taken into account. \* \* \*

I believe that the available evidence supports the conclusion that the false stem of *Tempskya*, or at least of *T. knowltoni*, may best be compared with the obliquely ascending and for the most part subterranean stem of such a fern as *Dryopteris filix-mas*.<sup>35</sup>

The new material which the writers have examined introduces some evidence that may help in the solution of the point at issue. Text figure 3 (p. 108) is a carefully prepared sketch of a cross section of an entire false stem of *Tempskya grandis*.

An interesting feature is the orientation of the true stems. Almost without exception they face directly toward the nearest point on the periphery of the mass—that is, there is a definitely organized radial arrangement in the false stem. The roots take a course parallel or very slightly divergent to that of the subparallel stems. Any deviations of great magnitude can be explained by the crowding and are purely local.

The most reasonable interpretation of this feature is, in the writers' opinion, that *Tempskya grandis* was an upright-growing plant, possibly with an axis of considerable length. It is difficult to harmonize any idea of a subterranean, oblique, or horizontal rootstock with the evidence. The height to which such a fascicle might rise with any degree of erectness is a matter for academic discussion. The mat of roots might prop the mass up to a considerable height, although such an arrangement is not so mechanically sound as a single stem of the same size. Probably the false stem tapered upward—that is, was conical—notwithstanding the evidence of *Tempskya knowltoni* Seward to the contrary. Though the base may have contained only a single stem it must be admitted that the mass of roots might be enlarged there and taper upward to the apex of the stems, where little other than the actual stems would be present. It is, of course, probable that most of the roots were produced only a short distance below the growing points. However, they probably elongated slowly, so that they could not attain such length as to increase noticeably the bulk of the false stem until they were some distance below the apex of the false stem. A significant feature pointing toward the formation of a swollen base and conical shape of the false stem is found in the fact that whereas roots are numerous root origins are relatively rare. This may be indicative of great length and profuse branching of the organs.

The condition in *Tempskya knowltoni* Seward is quite different. Text figure 2 (p. 108) illustrates the orientation of leaf bases in the false stem. Instead of a radial symmetry there is a very pronounced dorsi-

ventral arrangement, which has led Seward<sup>36</sup> to the guarded assumption that the plant was horizontal or obliquely ascending and probably subterranean. Much can be said in favor of this assumption. The occurrence of coniferous roots in the false stem is cited as proof of the subterranean position of the mass. The exact category in which these so-called roots are to be placed, however, is in the writers' opinion uncertain. Possibly they are crushed portions of small stems. If *T. knowltoni* was obliquely ascending it is strange that the roots should so nearly parallel the stems, and it is begging the question to call in the influence of hydrotropism.

Several possibilities have been overlooked in previous discussions of the habit of *Tempskya knowltoni* Seward and similar dorsiventral types. The writers suggest that such forms may have been inclined or oblique in accordance with Seward's views but aerial and clambering over very steep hillsides, or they may have been climbers, either on cliffs or steep rock surfaces, or else lianlike and climbing on arborescent plants. Although there is no evidence at present of nearby land with any considerable relief, it must be borne in mind that material of *Tempskya* is well adapted to transportation and might have been brought in by currents from more distant rugged areas. These ideas are no more than suggestions made reasonable by the following facts:

The dorsiventrality of the false stem is as satisfactorily explained by the assumption of a climbing or clambering habit as by a subterranean one.

The roots might be expected to serve efficiently as holdfasts.

The false stem, if it is regarded as a mechanical unit, should be quite efficient in a cliff climber or liana, inasmuch as the demands for the utmost strength and at the same time extreme flexibility are fulfilled. The very sclerotic nature of the stems and roots is ample evidence of strength, and the aggregation of roots and stems into a ropy mass without cohesion of the elements would seem to permit flexibility.

The decay of the older portions of the stems may be cited as a possible adaptation toward the perching of a plant in crevices or possibly on some other plant or else on its own dead false stem. The loss of the older portions of the false stem through disintegration would relieve the strain on the plant and would permit its more efficient function as a liana or clamberer.

The situation in *Tempskya minor* is exactly comparable to that in *T. knowltoni*. The false stem shows a marked dorsiventrality, and in this species some of the masses are rather large, containing more than 50 stems. It is most probable, in some species at least, that dorsiventrality was the condition during the entire life of the plant and did not change to a radial symmetry as maturity was approached.

<sup>35</sup> Seward, A. C., On a new species of *Tempskya* from Montana, *Tempskya knowltoni* sp. nov.: Annals of Botany, vol. 38, pp. 498-499, 1924.

<sup>36</sup> Seward, A. C., op. cit., p. 505.

To summarize, there appears to have been considerable diversity of habit in the genus. *Tempskya rossica* Kidston and Gwynne-Vaughan and *T. grandis* certainly show a radial symmetry that may be linked with an upright habit. The exact height to which a false stem might rise is, of course, uncertain, but it could not have been very efficient. The basal portions were probably much enlarged by the concentration of roots, so that the mass tapered upward. Of course, there must have been a downward taper also in the extreme basal region. In *T. knowltoni* Seward and *T. minor* dorsiventrality is very pronounced. The explanation may lie in the fact that the plant was subterranean and obliquely ascending. There is much evidence in favor of this assumption, but it is difficult to explain the course of the roots parallel to the stems if this is true. The writers offer as an alternative the suggestion that the plant was a liana but do not urge it, because it may present some fundamental difficulties.

The false-stemmed or "tempskyoid" condition is by no means peculiar to *Tempskya*. Several examples are known, both living and fossil, and Sahni,<sup>37</sup> in a recent paper, has summarized the facts concerning them.

The best-known living ferns that possess false stems are *Todea barbara* Moore and *Hemitelia crenulata* Mettenius. In *Todea barbara* the trunk is rather massive but low. The individual stems are radially constructed and arise both through repeated bifurcation and by lateral branching. In *H. crenulata* the stems are entirely the result of lateral branching of a central axis. These branches grow horizontally at first but turn upward on reaching the surface. The size attained is considerable.

In Sahni's paper there is described a very interesting zygopterid fern, *Clepsydropsis australis* Sahni, of Westphalian age, from localities in New South Wales. Sahni has clearly shown that this plant produced a false stem

of numerous repeatedly forked leaf-forming axes and relatively stout, erect petioles, the stems and petioles being all bound together by and embedded in a packing of adventitious roots and aphyllae.<sup>38</sup>

The false stem shows a distinct radial organization both in the individual stems and the composite mass. It is likewise suggested that *Clepsydropsis antiqua* and *C. kingisica* may have had false stems, although this has not yet been demonstrated.

These comparisons cannot be carried very far, for a number of reasons. In the first place, even though the systematic position of *Tempskya* is not definitely established, yet it is certainly quite distinct from any members of the Osmundaceae, Cyatheaceae, or Coenopteridaceae. The false stem of *Tempskya* is therefore the result of independent development and can be

expected to differ in many significant respects from those developed in only distantly related families. Secondly, it is the only genus at present known to produce a false stem in which the individual axes are dorsiventral. Thirdly, it differs from other genera in that the aggregate is one of roots and stems with only a few petioles. In the other forms cited the petioles are notable constituents of the false stems.

#### STRATIGRAPHIC SIGNIFICANCE OF THE TEMP SKYACEAE

The recognition of specific differences among the specimens of American Tempskyas reported in this paper raises the question whether the species so differentiated are of any value in stratigraphic segregation. To answer this question the writers have tabulated stratigraphic sections from the localities where the specimens were collected or nearby areas and have attempted thus to show the relation between these sections and also, in a general way, to show the age relation of the American to the European occurrences. (See pl. 27.) This tabulation gives some sections in rather complete detail; others are somewhat meager because fuller information was not available. The fossil fern flora associated with the *Tempskya* species is given in a column to the right of that giving the stratigraphic names of the beds. The floral lists are confined to the ferns because the Tempskyas were ferns and because a list of the total flora for each locality would make such a table unwieldy and would probably serve no useful purpose in this connection. The lists therefore invite comparison and supply material for conjecture as to the probable reference of foliage to *Tempskya*. The following comments apply to the localities and the sections in which Tempskyas occur. The distribution of the Tempskyas within the United States is shown in figure 6.

*Maryland*.—The first American *Tempskya* to be described was *Tempskya whitei* Berry. The type specimen and others were collected in the valleys of Stony Run and Deep Run, north of Severn, Anne Arundel County, Md. The specimens were exposed by erosion of the Patapsco formation, which, in the Maryland Geological Survey's volume on the Lower Cretaceous,<sup>39</sup> is classed as the uppermost formation of the Potomac group (Lower Cretaceous). E. W. Berry, in discussing the age of the relatively large flora of the Patapsco formation, says:<sup>40</sup>

Moreover, the latter flora [Albian of Portugal] closely parallels the Patapsco, in that both mark the first abundant appearance of undoubted dicotyledons and a persistence of a considerable number of the earlier Cretaceous types, which survive in both the Patapsco flora and that of the Albian of Portugal.

On the basis of this close similarity between these two floras on opposite sides of the Atlantic, and the fact that both mark the first abundant appearance of Dicotyledonae, and the further

<sup>37</sup> Sahni, Berbal, On *Clepsydropsis australis*, a zygopterid tree fern with a *Tempskya*-like false stem, from the Carboniferous rocks of Australia: Royal Soc. London Philos. Trans., ser. B, vol. 217, pp. 1-37 (especially pp. 27-29), pls. 1-6, 1928.

<sup>38</sup> Idem, p. 19.

<sup>39</sup> Clark, W. B., Bibbins, A. B., and Berry, E. W., The Lower Cretaceous deposits of Maryland: Maryland Geol. Survey, Lower Cretaceous, 1911.

<sup>40</sup> Idem, p. 160.

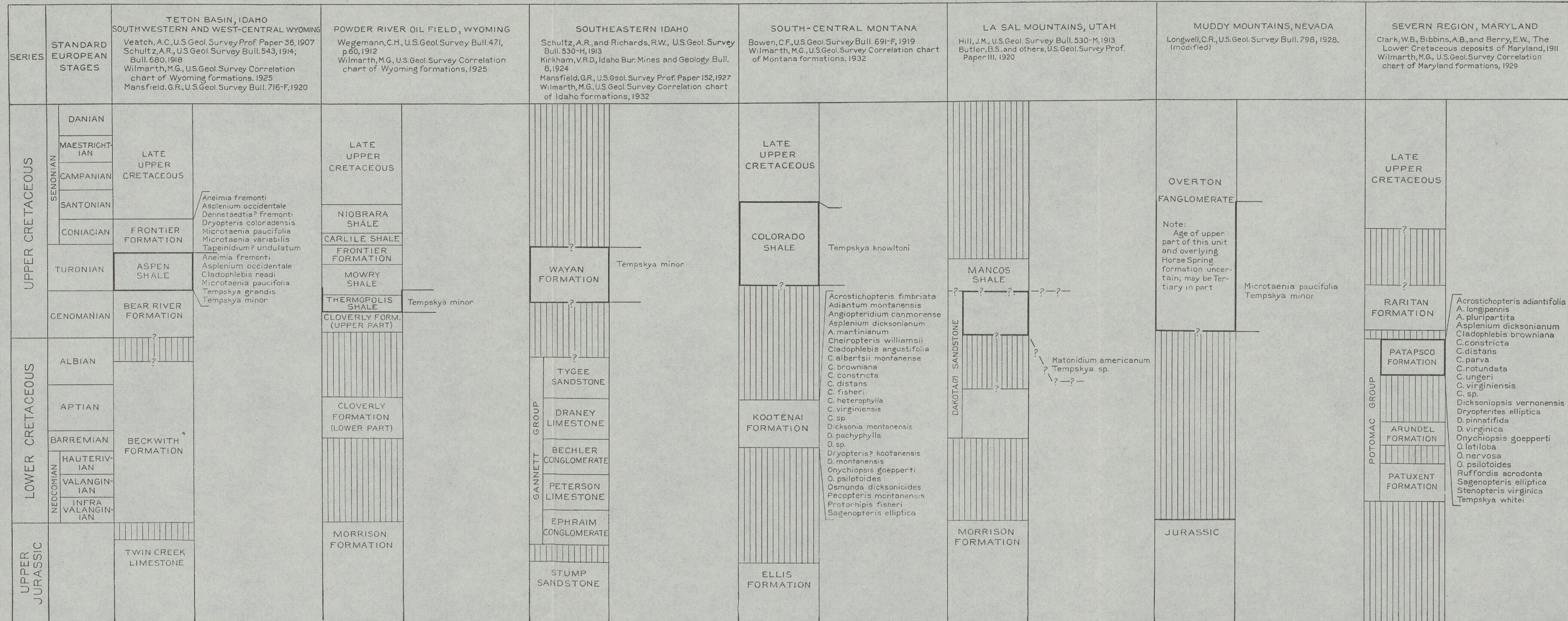


CHART SHOWING OCCURRENCE OF TEMPSKYA.



fact that the Patapsco formation is overlain unconformably by the Raritan formation, carrying an abundant and unmistakably Cenomanian flora, the Patapsco formation is considered of Albian age. The unconformity which separates the Patapsco formation from the underlying Potomac beds is believed to represent all or nearly all of the time interval represented by the Aptian stage of European geology.

*Montana*.—*Tempskya knowltoni* Seward was the next *Tempskya* to be described. This specimen, according to the locality labels and as reported by Seward, was

collected in 1908 by A. C. Silberling in the Musselshell Valley at a point about 10 miles southeast of Harlowton, Mont. This information seemed rather indefinite to the writers, and accordingly after careful search they were fortunate in finding two letters by Silberling to F. H. Knowlton which gave the exact information required. The specimen was found in sec. 36, T. 7 N., R. 16 E., at a stratigraphic horizon "about 700 feet above the unconformity separating the Jurassic red

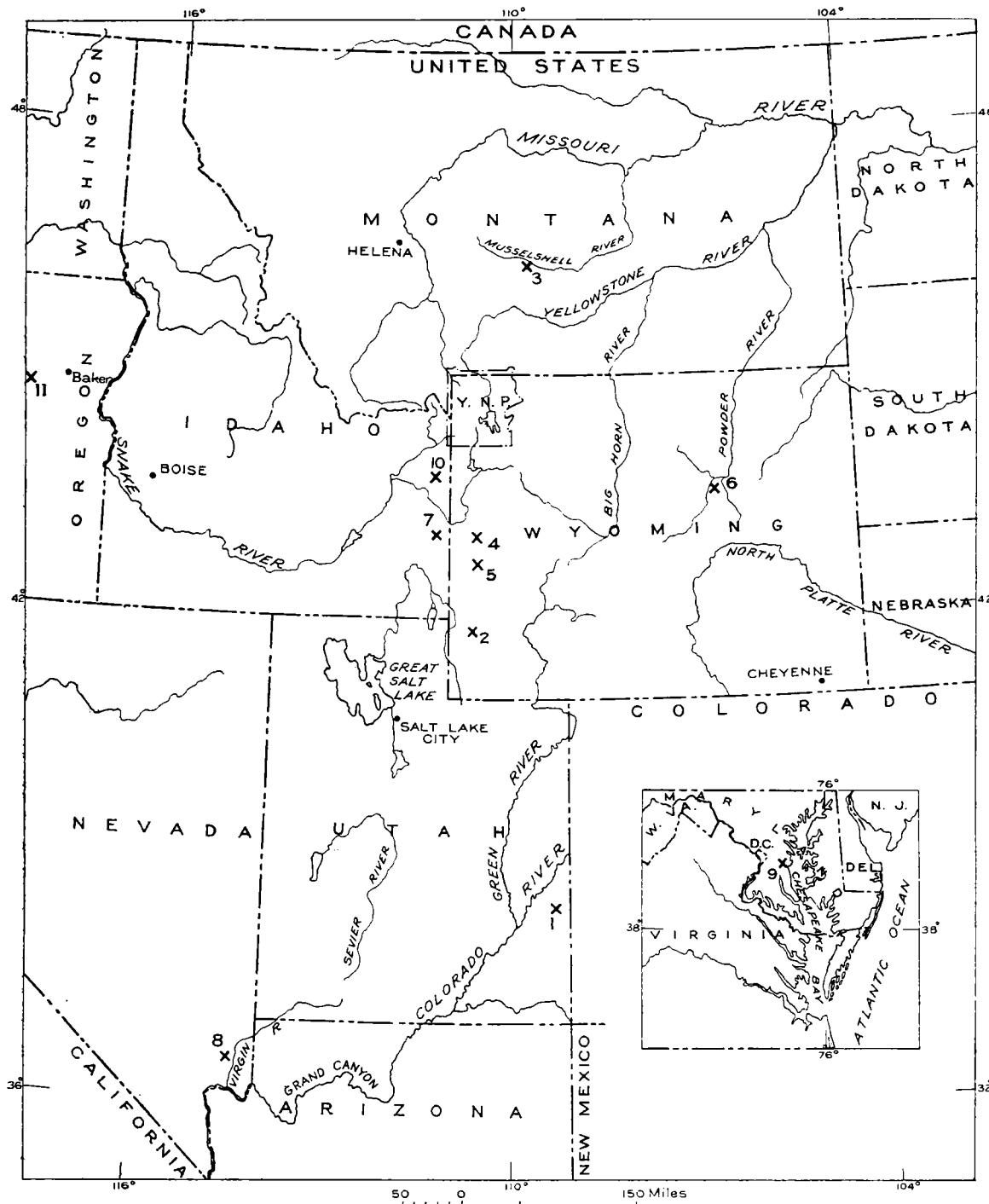


FIGURE 6.—Map showing *Tempskya* localities in the United States. 1, Head of Pack Creek, La Sal Mountains, Utah; 2, gravel terrace in T. 21 N., R. 117 W., Wyo.; 3, sec. 36, T. 7 N., R. 16 E., Mont.; 4, secs. 17 and 18, T. 35 N., R. 115 W., Wyo.; 5, sec. 14, T. 31 N., R. 115 W., Wyo.; 6, sec. 28, T. 41 N., R. 81 W., Wyo.;

7, secs. 17 and 19, T. 5 S., R. 44 E., Idaho; 8, half a mile east of White Butte, 6 miles southwest of Kaolin, Clark County, Nev.; 9, mouth of Severn River, Anne Arundel County, Md.; 10, sec. 19, T. 5 N., R. 44 E., Idaho; 11, Lightning Creek, 1 mile north of Greenhorn, sec. 9, T. 10 S., R. 35 E., Oregon.

beds from the Comanche and about 500 feet below the heavy Dakota sandstones." By superimposing this information on that acquired by later work the facts and terminology used by Silberling become clear. Plate 25 of Bowen's bulletin<sup>41</sup> shows that the sec. 36 indicated by Silberling lies on the structural feature called East dome of the Shawmut anticline and that all the rocks that crop out within the section are of Upper Cretaceous Colorado age. The "Jurassic red beds" mentioned by Silberling are the maroon beds of the Kootenai formation (Lower Cretaceous). The Comanche of Silberling is the undifferentiated Colorado shale, and the "heavy Dakota sandstones" are the Big Elk sandstone member of the Colorado shale. The area in which the Kootenai crops out in the section next to the west, in Middle dome, is both topographically and stratigraphically lower, thereby making it improbable that the *Tempskya* specimen could reasonably have come from the Kootenai formation by the usual natural means of transportation of geologic materials. The writers are convinced that the specimen was derived from the lower sediments of Colorado age and very likely from the undifferentiated zone below the Big Elk sandstone member. This zone probably represents the stratigraphic equivalent of the Mowry shale or Aspen shale and the Frontier formation of adjacent areas.

*Wyoming and Teton Basin, Idaho.*—The new *Tempskya*s more particularly described in this paper—*Tempskya grandis* and *Tempskya minor*—were collected by W. W. Rubey and J. S. Williams in the folded Cretaceous area north of Kemmerer, in west-central Wyoming, and by Rubey in the Teton Basin, Idaho. The horizon is in the porcelainlike beds of the Aspen shale, about 400 feet above the Bear River formation; an excellent exposure is presented in the northeast corner of the Afton quadrangle, in sec. 17, T. 35 N., R. 115 W. The generalized section given below is supplied by Rubey, who writes:

The section is taken along part of the Green River-Snake River divide between Lookout Peak (southern end of the Hoback Range) and Deadman Mountain (northern end of the Wyoming Range). The beds that yield specimens of *Tempskya* are exposed at the head of Horse Creek.

#### Section of Cretaceous beds in west-central Wyoming

Feet

Lower part of Frontier formation: Alternating soft dark-gray sandy shale and brown thin-bedded calcareous medium- to coarse-grained sandstone, with conglomeratic lenses, some thick beds of unconsolidated sand, and poor coal near the base. Basal portion contains [coniferous] petrified wood and fragmentary [coniferous and dicotyledonous] leaves. Marine invertebrates at several localities in upper part of unit----- 1,000±

<sup>41</sup> Bowen, C. F., Anticlines in a part of the Musselshell Valley, Musselshell, Meagher, and Sweetgrass Counties, Mont.: U. S. Geol. Survey Bull. 691-F, pp. 185-209, pl. 25, 1919.

#### Section of Cretaceous beds in west-central Wyoming—Continued

Feet

|  |      |
|--|------|
| Aspen shale (harder and lighter gray than overlying and underlying units):   |      |
| Gray shale, thin beds of sandstone, and tuffaceous shales-----   | 200± |
| Gray shale, thin beds of light-gray tuffaceous sandstone, dark-green siliceous shale, and silvery-gray dense cherty argillite. Specimens of <i>Tempskya</i> locally abundant-----  | 600± |
| Gray shale and thin beds of sandstone-----   | 400± |
| Bear River formation (shale unit): Black and dark greenish-gray shale and mudstone with thin ferruginous layers in some places; contains the typical Bear River fauna-----   | 250± |
| Bear River formation (olive-brown quartzite unit, mapped as lower part of Bear River formation by A. R. Schultz): Very hard fine-grained olive-brown sandstone in 10- to 50-foot beds alternating with thicker beds of very dark gray shale-----                 | 150± |
| Alternation of dense gray limestone, shale, and purplish, pink, and gray calcareous shale. Mapped as upper part of Beckwith formation by A. R. Schultz. Corresponds to Peterson limestone, Bechler conglomerate, and Draney limestone of southeastern Idaho----- | 400± |

Westward these units thicken notably and undergo great lateral lithologic changes, making correlation difficult. The upper units are lost within a short distance, but the successively lower ones can be traced farther and farther westward. To judge merely by stratigraphic position and the general thickening, the Wayan formation of Idaho seems to occupy approximately the position of the upper part of the Bear River, the Aspen, and possibly the lower part of the Frontier of adjacent areas in Wyoming. This correlation is further suggested by the similar lithologic character of portions of the Aspen and Wayan units, and especially by the more coarsely granular tuffaceous beds in the middle member of the Aspen, which resemble strikingly in both their field and microscopic characteristics the tuffaceous beds in the upper part of the Wayan.

The Aspen deposits that yield *Tempskya* are regarded as near-shore marine with some lagoonal and coastal swamp facies. In the Wyoming Range and eastward and southeastward, particularly on the Meridian anticline southeast of Kemmerer, there are beds that carry marine fossils.<sup>42</sup>

One specimen of *Tempskya grandis* and one of *Tempskya minor* were collected by S. H. Knight, of the University of Wyoming, in sec. 14, T. 31 N., R. 115 W. As that section, according to A. R. Schultz's map,<sup>43</sup> shows Bear River deposits in the eastern half and Aspen deposits in the western half, and as neither is well exposed, Knight is uncertain as to the exact horizon from which the specimens were

<sup>42</sup> Reeside, J. B., Jr., and Weymouth, A. A., Mollusks from the Aspen shale (Cretaceous) of southwestern Wyoming: U. S. Nat. Mus. Proc., vol. 78, art. 17, pp. 1-24, pls. 1-4, 1931.

<sup>43</sup> Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pl. 1, 1914.

collected but thinks that they probably came from beds near the top of the Bear River deposits. At any rate the material is not far from the lower limits of the Colorado group.

One small water-worn specimen of *Tempskya minor* was collected by R. W. Brown in June 1930 from a gravel terrace in the valley of the westward-flowing Twin Creek near the town of Fossil, in T. 21 N., R. 117 W., Wyo., the regional geology of which is described by Veatch.<sup>44</sup> The debris of this gravel terrace includes, besides other rocks, some pebbles of igneous rock, no outcrop of which occurs within the present drainage basin of Twin Creek. The gravel has therefore not been derived entirely from the Tertiary bedrock on which it lies, but a portion must have come from some exterior source. The specimen of *Tempskya*, if the diagnosis of the stratigraphic significance of the species is correct, came from Upper Cretaceous deposits of Colorado age. The nearest area of outcrop of such deposits to the point where the specimen was found is across the low divide and in the townships next to the east, where Bear River, Aspen, and Frontier beds occur just east of Kemmerer. The inference that the specimen came from this area seems reasonable, but it involves the necessity of explaining some changes in drainage which the writers believe have taken place but the elucidation of which they deem not within their present undertaking.

A small collection of fossil plants made in the Powder River oil field, Wyo., by C. H. Wegemann in 1910 has likewise yielded *Tempskya minor*. The specimen comes from a locality near the center of sec. 28, T. 41 N., R. 81 W., at the horizon of a coal 25 feet below the base of the Mowry shale. Consequently it is from strata that are now called Thermopolis. Accordingly, the Thermopolis and the Mowry, which is conformable upon it, are considered to be correlated with the Aspen of western Wyoming—an idea that is well supported by other evidence.

*Idaho, exclusive of the Teton Basin.*—Several specimens of *Tempskya minor* were collected by G. R. Mansfield, W. W. Rubey, and J. S. Williams in the Lanes Creek quadrangle, southeast of Grays Lake and 40 miles west of the Horse Creek area, in Idaho. These specimens were found loose on the surface in secs. 17 and 19, T. 5 S., R. 44 E., in an extensive outcrop of the Wayan formation. Other specimens, according to Mansfield, were seen but not collected in the region northwest of Grays Lake. All these specimens were most probably derived from the uppermost beds of the Wayan formation, as these beds occupy the axial region of a broad syncline, and the course of the axis to the northwest in the region of Grays Lake Outlet marks the general line along which the specimens were found. The writers believe that

the finding of *Tempskya minor* in the Wayan formation only 40 miles distant from the Aspen localities in Wyoming, in a region of relatively similar lithology, indicates a fairly close correlation in age, and that the Wayan formation, or a portion of it, may reasonably be regarded as of Colorado age and the time equivalent of the Aspen shale of Wyoming. This conclusion was also independently reached by W. W. Rubey in his field studies of the stratigraphy and lithology of these beds.

*Utah.*—Frank L. Hess, of the United States Bureau of Mines, during an investigation of the carnotite deposits in the region of the La Sal Mountains, Utah, found a specimen of *Tempskya* lying in the soil on deposits overlying the Upper Jurassic Morrison formation (†McElmo<sup>45</sup> of some reports). The locality is on the divide southwest of Winburn's ranch, near the head and on the northwest side of Pack Creek, just west of Mount Peale in the La Sal Mountains. As the specimen came from deposits above the Morrison, its source must lie between the Upper Cretaceous Dakota (?) sandstone and the Mancos shale. The Mancos shale is a dark marine shale deposit and is not likely to have contained the *Tempskya*. There remains the relatively thin deposit of light-colored Dakota (?) sandstone (about 40 feet), which, however, Hess did not distinguish as a separate unit in the section at the time of his visit. The outcrop of the Dakota (?) thickens and thins considerably in this area because its top was greatly eroded before the first deposits of the Mancos were laid down. It appears probable, therefore, that the Dakota (?) was the source of the *Tempskya* collected by Hess.

*Nevada.*—In 1934 fragments of *Tempskya* identified as *T. minor* were submitted to the writers by Eugene Callaghan and W. W. Rubey from the Overton conglomerate, near Kaolin, Clark County, Nev. According to Rubey the fossils were obtained from the gray clays about 100 feet thick that constitute the basal member of the Overton. These beds have been reported as Tertiary.<sup>46</sup> There is apparently no possibility that the material has been reworked from older deposits (Colorado Cretaceous). In consequence, at least the basal beds of the Overton, which are correlative with the *Tempskya*-bearing beds, must be regarded as Colorado in age. Additional evidence in support of this opinion is found in the occurrence of a specimen of *Microtaenia paucifolia* (Hall) Knowlton, which is a fern indigenous to the Frontier and Aspen formations of Wyoming.

*Oregon.*—Two well-preserved specimens of *Tempskya* having the appearance of jasper were collected in 1914 by J. T. Pardee from a placer pit on Lightning Creek

<sup>44</sup> A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

<sup>45</sup> Longwell, C. R., Geology of the Muddy Mountains, Nev.: U. S. Geol. Survey Bull. 798, pp. 68-74, 1928.

in the NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 9, T. 10 S., R. 35 E., 1 mile north of Greenhorn, in the Sumpter quadrangle, Oregon. The age of the placer deposit has not been established but appears to be pre-Mascall. At any rate it is fairly certain that some of the material was derived from a Cretaceous source.

*England*.—Sussex, in southeast England, is crossed by a northwest-southeast anticlinal axis, which passes through Horsham and Tilgate Forest (St. Leonards) and emerges on the coast about 5 miles east of Hastings. This arch in the strata raises and exposes in the cliffs the Lower Cretaceous Wealden deposits known as the Hastings sands. This member of Wealden is commonly regarded as having three divisions, the lowest of which, the Ashdown sands, is, according to Evans,<sup>47</sup> the source of specimens of *Tempskya erosa*. Dixon,<sup>48</sup> however, gives a section in which he refers the *T. erosa* bands to either the upper part of the Ashdown sands or the lower part of the Wadhurst clays, but on page 144 he ascribes the *T. erosa* bands to the Wadhurst clays. The specimens weather out of the cliffs and accumulate on the beach near Ecclesbourne. Inland in Tilgate Forest presumably the same beds yielded the original specimens first reported by G. A. Mantell as "arborescent ferns" and later as *Endogenites erosa*. Tempskyas have also been collected from the Wealden of the Isle of Wight.

The occurrence of *Tempskya erosa* in the Lower Greensand (Aptian) at Potton, near Woburn, in Bedford, is discussed by Stopes<sup>49</sup> as follows:

Regarding the distribution of *Tempskya* in the English Lower Greensand, so far as I can discover, the only specimens of the genus occur in the Potton sands. The beds at Potton are peculiar in containing a number of fossils which are certainly derived, it may be from the preceding Wealden deposits. These fossils generally show a richly colored, rolled, and often highly glazed surface, by which they can at once be distinguished by anyone well acquainted with the plants of the horizon. Of the specimens in the Museum, V. 13081 lacks the most noticeable characters of the derived fossils and might reasonably be regarded as a true Lower Greensand fossil. There is also one very fragmentary specimen from Ireland.

*France*.—*Tempskya schimperi* was collected by Carpentier<sup>50</sup> from two localities in the Wealden of northern France—one near Glageon, the other near Fourmies, about 3 kilometers distant. The Wealden deposits in this area overlie unconformably the calcareous Givetian and Frasnian beds of the Devonian and the Bathonian beds of the Jurassic. Overlying the Wealden are sands and clays that resemble the Lower Greensand and Gault, and, in spots like the Bois de Montfaucon, immediately west of Glageon, the Cretaceous elements are capped by Eocene sands and clays. The Wealden of this region is confidently correlated by Carpentier with that of England on the basis of no less

than 22 species of fossil plants in common and with the Wealden of north Germany on the basis of 19 species of fossil plants in common.

*Germany*.—*Tempskya schimperi* (originally *Endogenites erosa*) was reported by Wilhelm Dunker from the Hils beds (Hastings sands) at Neundorf, near Hannover. *T. cretacea*, a species regarded by Hosius and Von der Marck as different from *T. schimperi*, was collected in the Senonian near Haltern, in Westphalia.

*Bohemia (Czechoslovakia)*.—From the Peručer beds of the Cenomanian of Rynholec, near Lana, 35 kilometers west of Prague, Joseph Velenovsky described *Tempskya varians*. The section showing the horizon where this species was collected is pictured by Frič and Bayer.<sup>51</sup> The Peručer beds of Bohemia have yielded 127 species of fossil plants.

The specimens of the four Tempskyas—*Tempskya pulchra*, *T. macrocaula*, *T. microrrhiza*, and *T. schimperi*—described by A. J. Corda in 1845 were sent to him by three different persons and were thought by him to have come from the gravel along the Elbe River east of Neupaka, in Bohemia. It is particularly unfortunate that the exact source of the nominal type species, *T. pulchra*, of the now well-characterized genus *Tempskya* should be unknown.

*Russia*.—The specimen described by Kidston and Gwynne-Vaughan as *Tempskya rossica* was collected (according to the locality citation given by them) in the basin of the Karaganda River, on the west flank of the Mugodjar Mountains. The locality is about 15 kilometers south-southeast of the Ber-Chogur station on the Tashkent Railway. That station is about 450 kilometers east of Orenburg and about 75 kilometers west of Chelkar. The specimen apparently came from a Tertiary conglomerate that includes pebbles of crystalline rock and Devonian and Carboniferous limestone and sandstone. According to the more recent work of Prigorovsky<sup>52</sup> the Mugodjar Mountains, which are the southern extension of the Urals, heading toward the Ust-Urt Plateau between the Caspian and Aral Seas, are composed of igneous rocks—granite, diabase, gabbro, and porphyry—and of local disturbed or metamorphosed Devonian and Carboniferous sedimentary beds either covering the igneous rocks or being penetrated by them. On the west flank of the Mugodjars the upper drainage basin of the Emba River, of which the Karaganda is a tributary, is a region of Upper Cretaceous (Senonian) deposits that lie horizontally or almost horizontally but unconformably upon the older Paleozoic beds. Prigorovsky's map (his pl. 35a) shows Tertiary deposits bordering those of the Upper Cretaceous in the Emba Valley, but this map, doubtless on

<sup>47</sup> Evans, J. W., Geology of the British Isles, p. 248, 1918.

<sup>48</sup> Dixon, Frederick, Geology of Sussex, pp. 142, 144, 1878.

<sup>49</sup> Stopes, M. C., The Cretaceous flora, part 2, Lower Greensand (Aptian) plants of Britain; Catalogue of the Mesozoic plants in the British Museum (Natural History), p. 19, 1915.

<sup>50</sup> Carpentier, Alfred, La flore wealdienne de Féron-Glageon (Nord): Soc. géol. Nord Mém., vol. 10, p. 48, pl. 11, figs. 3-10, 1927.

<sup>51</sup> Frič, Anton, and Bayer, Edvin, Studien im Gebiete der böhmischen Kreideformation; Palaeontologische Untersuchungen der einzelnen Schichten; Peručer Schichten: Archiv naturwiss. Landesd. Böhmen, p. 39, fig. 20, 1900.

<sup>52</sup> Prigorovsky, M., Esquisse géologique des monts Mougodjars et des parties voisines des steppes de Tourgai et de l'Oural: Com. géol. [St.-Pétersbourg] Bull., vol. 33, pt. 2, pp. 889-928, pl. 35a, 1914.

account of its small scale and reconnaissance character, shows only Upper Cretaceous deposits at the locality where *T. rossica* is said to have been found. That unmapped Tertiary terrace materials exist there seems reasonable and that the *T. rossica* specimen was derived from the surrounding Upper Cretaceous sediments and was deposited in the Tertiary gravel is the conclusion which, in the opinion of the writers, seems to fit this situation most satisfactorily.

*Conclusions concerning stratigraphic range.*—The range of the genus *Tempskya*, as so far revealed, thus appears to have been from lowermost Lower Cretaceous time to Senonian time in the Upper Cretaceous. In America the record shows a range from the uppermost Lower Cretaceous to a point well up in the earlier portion of the Upper Cretaceous. The fact that the European specimens, with the exception of *T. rossica*, are so poorly preserved makes identification and correlation difficult or even impossible on the basis of similarity or dissimilarity of species.

The American Upper Cretaceous *Tempskyas*, as shown in the discussion of their anatomical structure, fall into two fairly well defined groups—the *Tempskya grandis* group and the *Tempskya knowltoni* and *T. minor* group. The Lower Cretaceous *T. whitei* appears to belong to the latter group, but its preservation, like that of the European specimens, is disappointing, and no definite statement can therefore be made in regard to its classification. The *T. grandis* group, to which also apparently belongs the Russian *T. rossica*, is regarded as anatomically more highly specialized than the *T. knowltoni* group. The *T. knowltoni* group would therefore indicate a somewhat earlier development, which is compatible with the geologic record if *T. whitei* and the European Lower Cretaceous species can ever be proved to belong to the *T. knowltoni* group.

#### CONCLUSIONS

As a result of the investigation of a considerable quantity of material of *Tempskya* from various sources in western America the writers reach the following conclusions:

1. The genus *Tempskya* is characterized by a freely dichotomizing, dorsiventral, siphonostelic stem system sheathed in a thick and dense felt of diarch adventitious roots in such a manner that a false trunk is developed. The leaves are two-ranked on the upper surface of the stems and are marked by the emission of simple inverted U-shaped triarch traces, which continue into the base of the phyllopodium with but slight modification. The characters of the species are not summarized here but are given in connection with the taxonomic details on pages 108–119.

2. The symmetry of the false trunk is either dorsiventral, as in *Tempskya knowltoni*, or radial, as in *T. grandis*. This feature of false-trunk symmetry is suspected to be constant within the species.

3. The affinities of *Tempskya* are with the leptosporangiate ferns. There is evidence to indicate close proximity to the Schizaeaceae, but this is not conclusive. Certain features likewise indicate connections with the Loxsomaceae and the Gleicheniaceae. In view of this obscure relationship, a provisional family, the Tempskyaceae, is erected for the temporary inclusion of the genus.

4. The species that have been reported appear to fall into two natural subgeneric groups. The first is typified by *Tempskya grandis* and is characterized by large stems with short internodes, abundantly parenchymatous xylem, and a radial arrangement of the stems in the false trunk. The second group, the type example of which is *T. knowltoni*, is characterized by small stems with long internodes, a more homogeneous xylem, and a marked dorsiventrality of the false stem.

5. Of these two groups the one typified by *Tempskya knowltoni* is regarded as more primitive. The small stems with comparatively long internodes exhibit a more primitive solenostelic condition than those in the group of *T. grandis*, where, through a shortening of the internodal length, there is an approach toward polystely. The homogeneous xylem of *T. knowltoni* is taken to be less specialized than the parenchymatous xylem of *T. grandis*. The complex cortex of *T. grandis* is obviously an advanced character, although this is perhaps not a character of the whole subgeneric group. The radial symmetry of the false stem in *T. grandis* is regarded as probably derived from the dorsiventral stage represented by *T. knowltoni*.

6. As regards the habit, the stems of *Tempskya grandis* must have been upright. The radial symmetry of the false stem and the parallelism of the roots and stems is considered weighty evidence pointing in that direction. In the *T. knowltoni* group several possibilities are suggested. The symmetry of the false stem is dorsiventral, which may indicate a prone or obliquely ascending habit. The roots, however, run parallel to the stems, and this fact argues against such an explanation. As an alternative the suggestion is made that the plants may have been lianlike in habit or even epiphytic.

7. The few examples of false stems known in modern ferns are not comparable to the situation exhibited in *Tempskya*. Likewise the false-stemmed condition in other fossil ferns is somewhat different.

8. The occurrences of *Tempskya*, which have been reviewed, indicate that the stratigraphic range of the genus is from lowermost Lower Cretaceous to Senonian (late Upper Cretaceous). In western North America the genus is at present known definitely only from the lower part of the Colorado group, from the lower part of the Wayan formation, from the basal part of the Overton fanglomerate, and from beds that belong to either the top of the Bear River formation or the base of the overlying Colorado group.

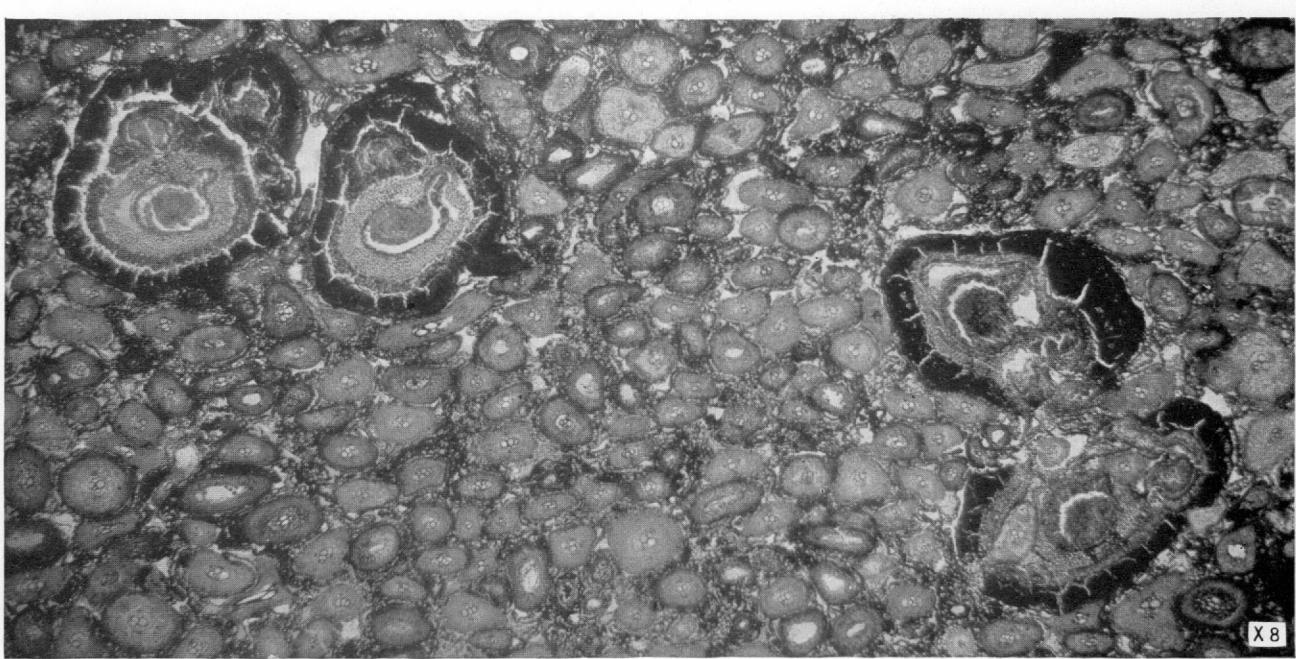
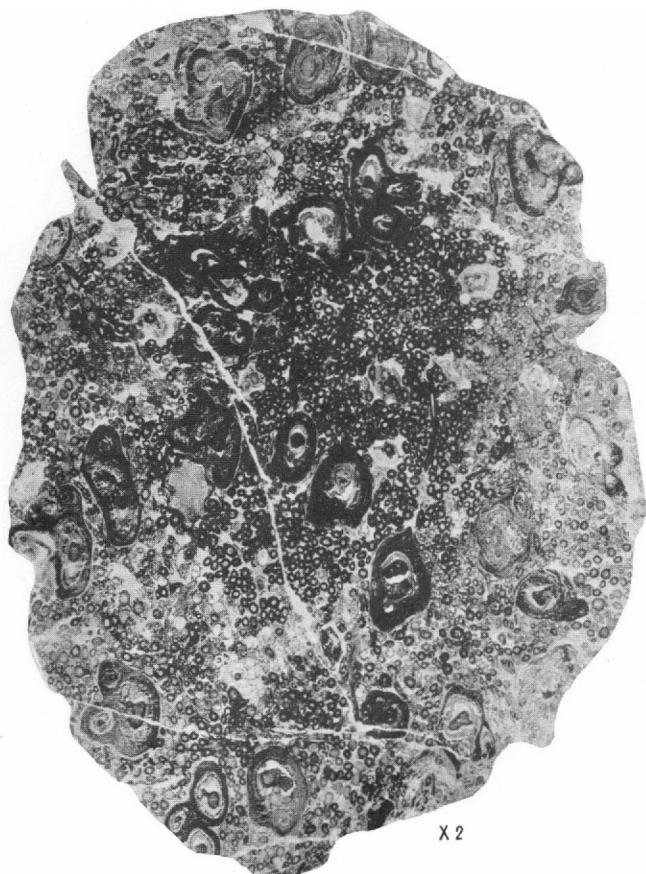


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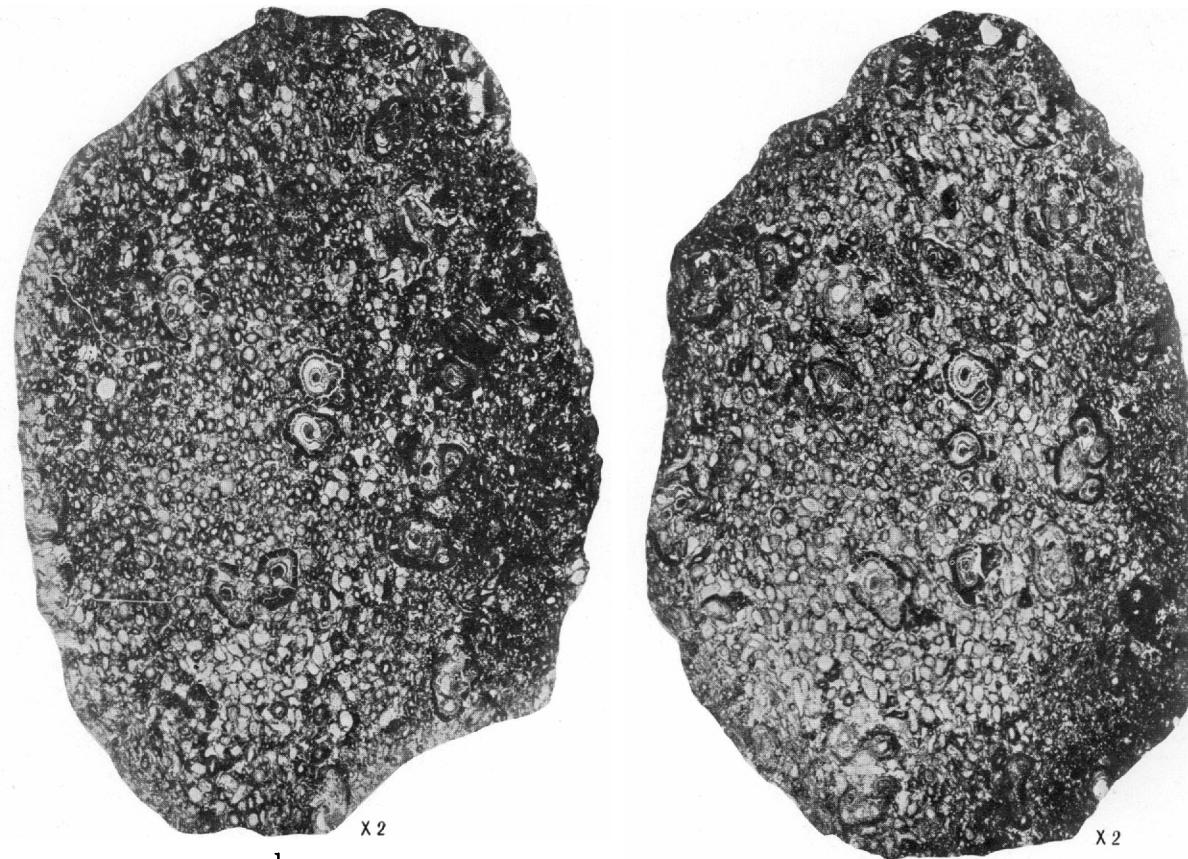
**PLATES 28-43**





## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

- 1, 2. Transverse sections of *Tempskya knowltoni* showing general aspect of false stem.
3. Portion of slide shown in figure 2 enlarged to show relations of roots and stems in more detail.

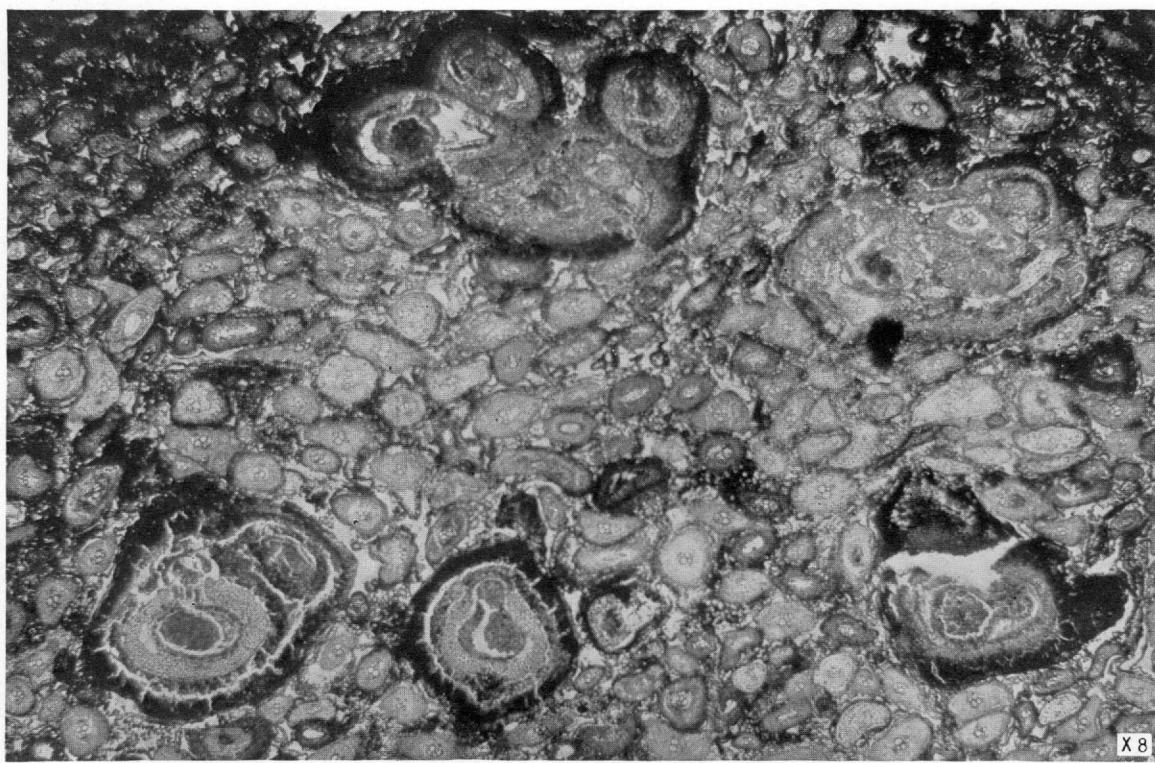


X 2

1

X 2

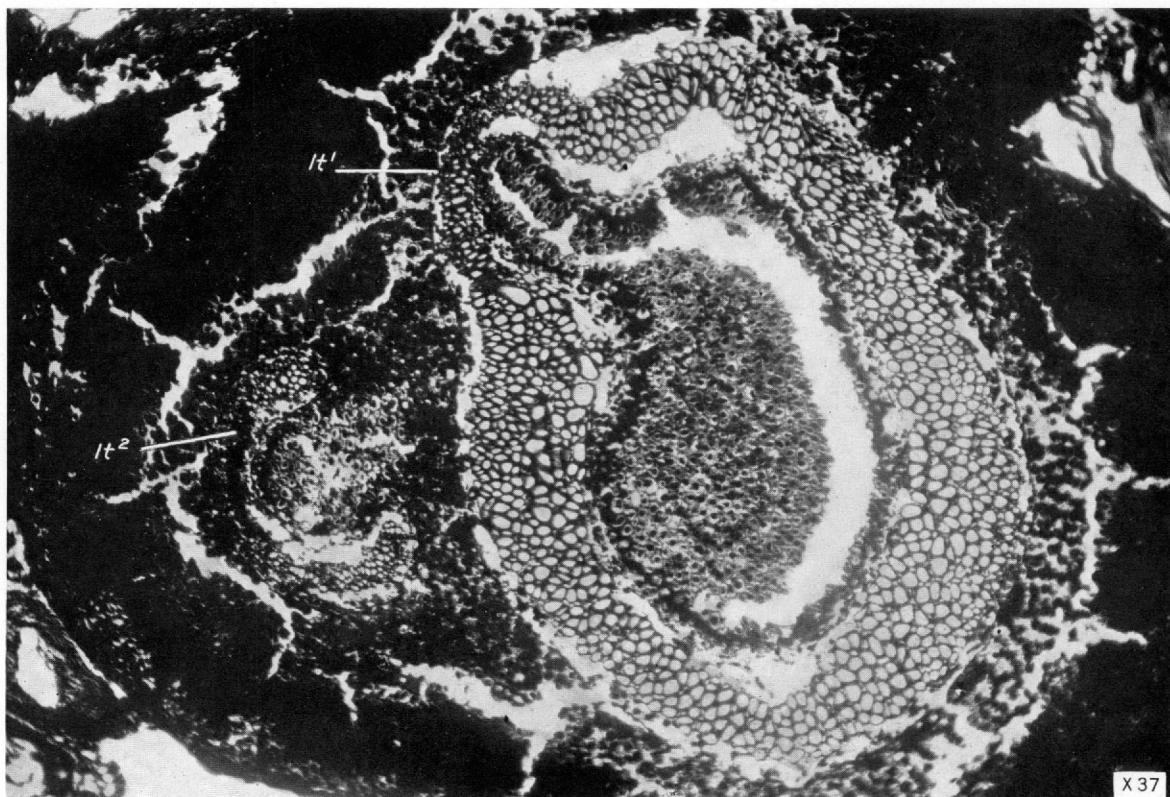
2



3

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Transverse section of *Tempskya minor*.
2. Transverse section of *Tempskya grandis*.
3. Portion of section of *Tempskya knowltoni* shown in plate 28, figure 1, enlarged to show more detail.



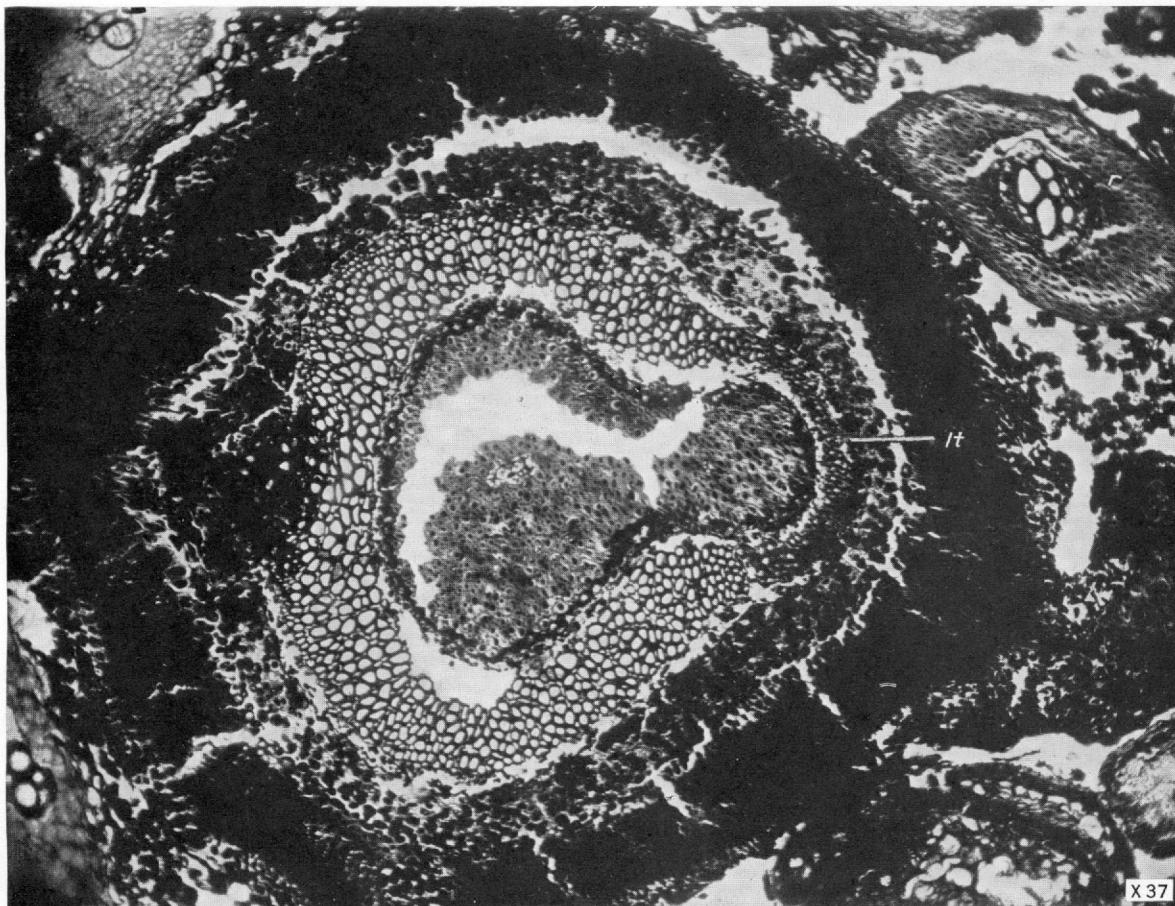
1



2

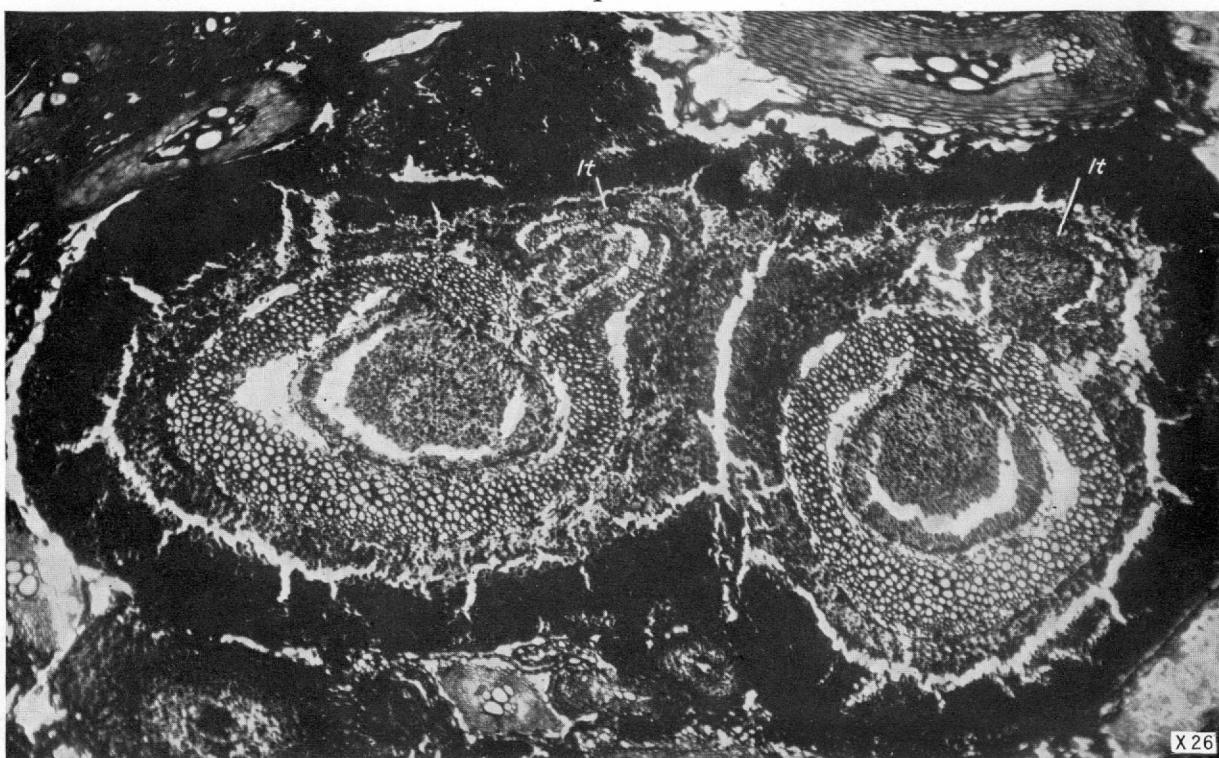
## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Transverse section of a stem of *Tempskya knowltoni* showing the characteristic solenostele. Note the leaf traces, *lt<sup>1</sup>* and *lt<sup>2</sup>*.
2. Transverse section of a decayed stem of *Tempskya knowltoni*. Note the penetrating roots, *r*.



1

X 37

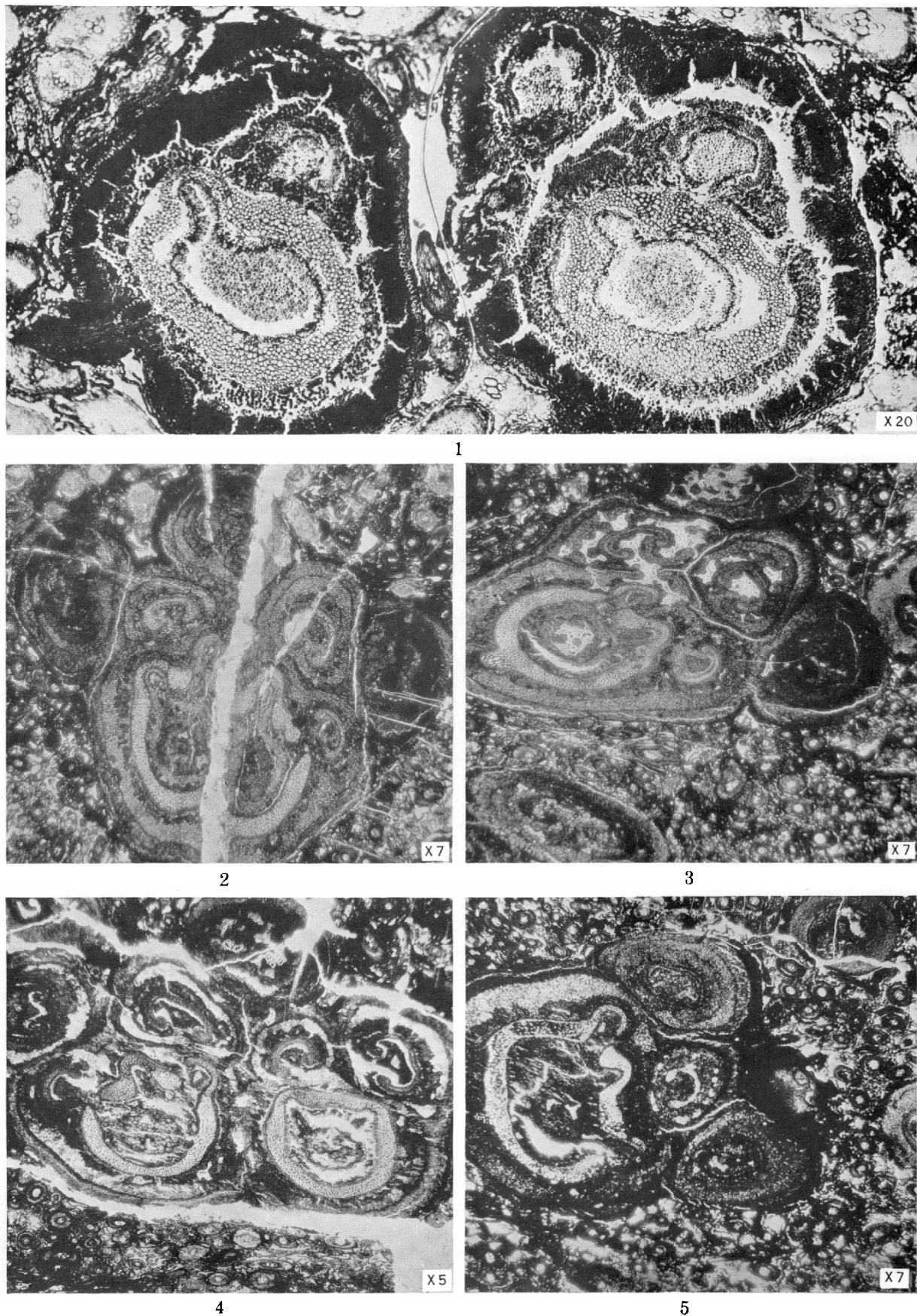


2

X 26

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Transverse section of a stem of *Tempskya knowltoni* showing an early stage in the emergence of a leaf trace (*lt*).
2. Dichotomously branching stem of *Tempskya knowltoni* (leaf traces, *lt*).



## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Transverse section of a portion of a false stem of *Tempskya knudtzenii* showing two stems just above a dichotomy.
- 2-5. Transverse sections of stems of *Tempskya grandis* showing general aspects. Note the dichotomy in figure 4.



1



2



3



4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1-4. Transverse sections of stems of *Tempskya grandis* illustrating general characteristics. Note the sclerotic layers shown in the cortex and pith of the stem shown in figure 2. Likewise note the suggestion of short internodes indicated by the numerous leaf traces in any one section. In figure 4 two nearly free petioles are to be seen.



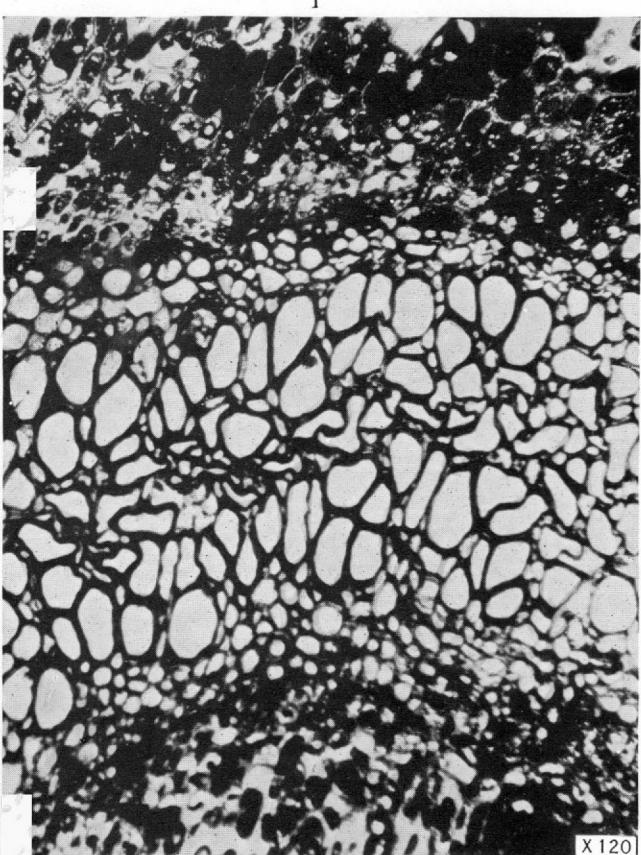
X 35

1



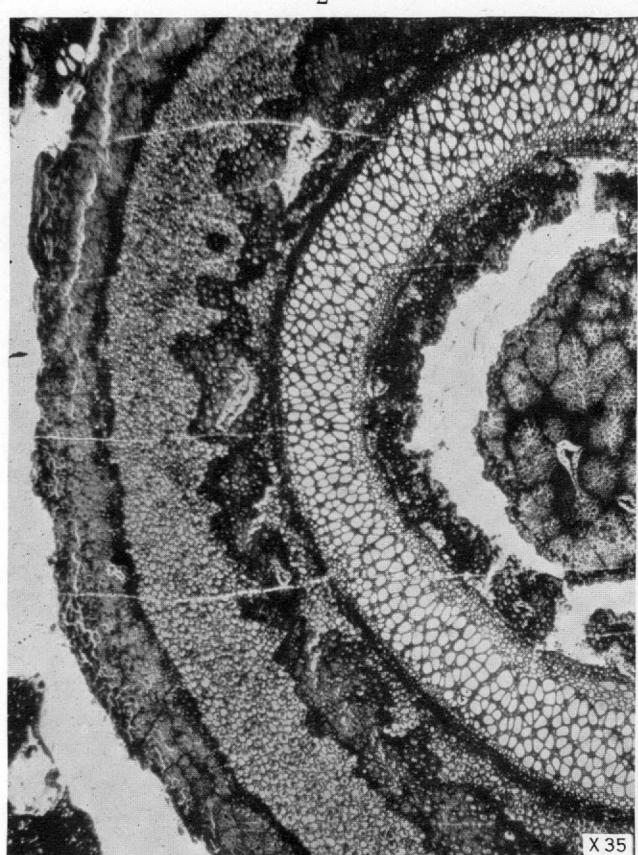
X 20

2



X 120

3



X 35

4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Portion of a stem of *Tempskya grandis* showing an emerging leaf trace.
2. Transverse section of a stem of *Tempskya grandis* showing emerging leaf traces (lt).
3. Portion of the stem xylem and adjacent tissues of *Tempskya grandis*. Note the occurrence of xylem parenchyma.
4. Transverse section of a portion of a stem of *Tempskya grandis* showing in particular the sclerotic tissue of the cortex.



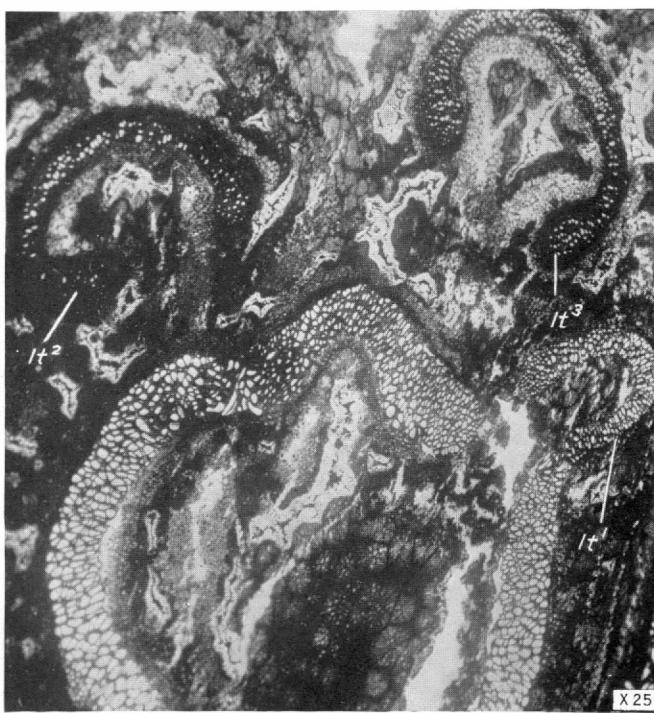
1



2



3



4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

**1, 2.** Transverse sections of stems of *Tempskya grandis* illustrating emission of leaf traces. Note the petiole at *lb*, figure 2.

**3, 4.** Higher magnification of stems shown in figures 1 and 2, showing successive stages in development of leaf traces (*lt<sup>1</sup>*, *lt<sup>2</sup>*, *lt<sup>3</sup>*, *lt<sup>4</sup>*).



1



2



3



4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

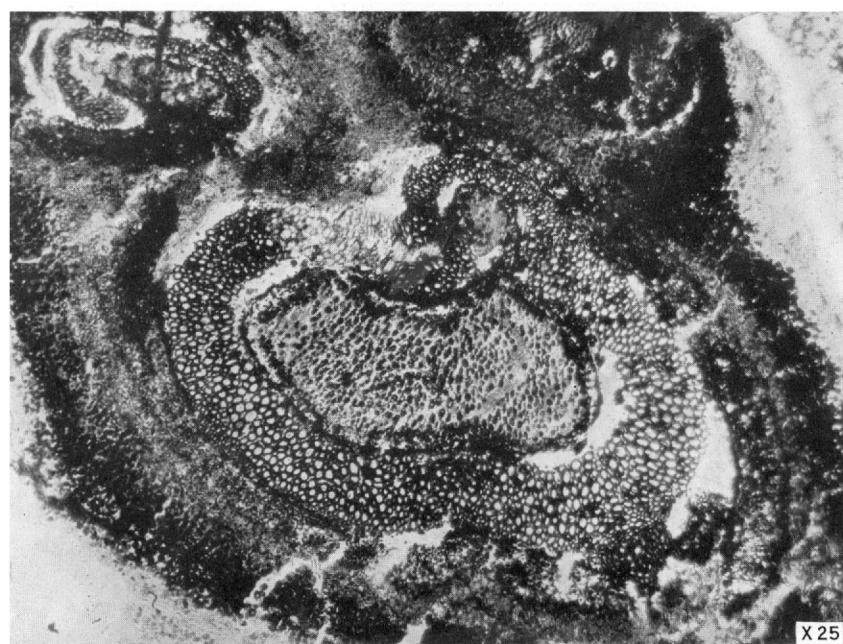
1-4. Transverse sections of *Tempskya minor* illustrating their general aspect. Note the dermal emergences (simple hairs) shown in figures 2 and 4.  
*p*, Leaf base; *r*, root insertion.



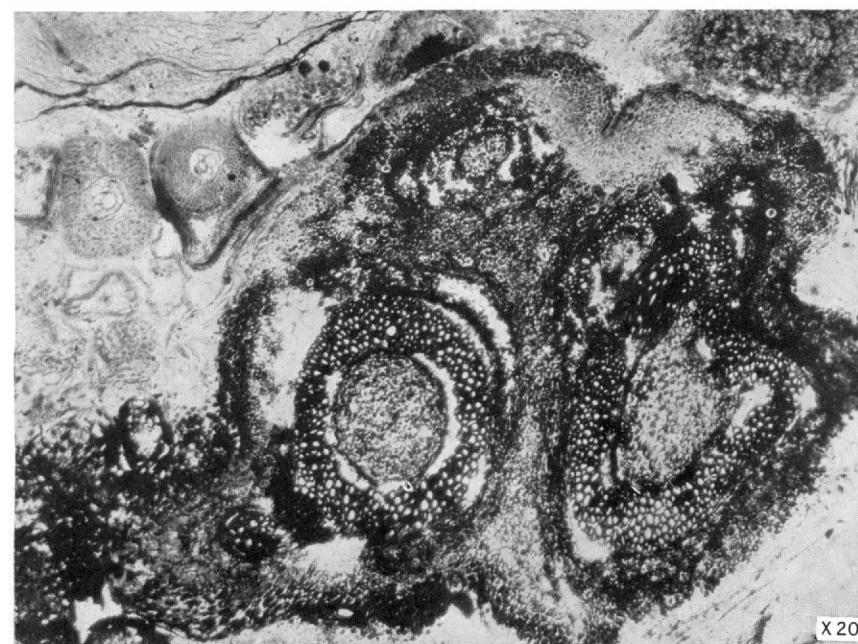
1



2



3



4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1-4. Transverse sections of *Tempskya minor* illustrating general characteristics. Note the dichotomy of the stems and the occurrence of dermal hairs.



1



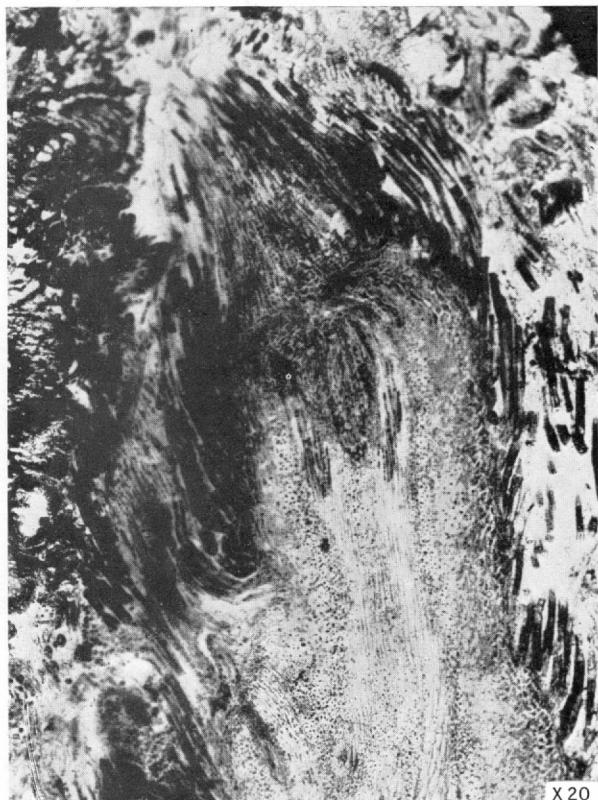
2



3

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Section of the stem of *Tempskya minor* showing the abundant epidermal hairs, apparently most numerous on the upper surface of the stem in the vicinity of the leaf bases.
2. Section of the stem of *Tempskya minor* showing the uninterrupted xylem cylinder at an internode.
3. Higher magnification of the stem shown in figure 1. Note the epidermal emergences or hairs at h.



X 20

1



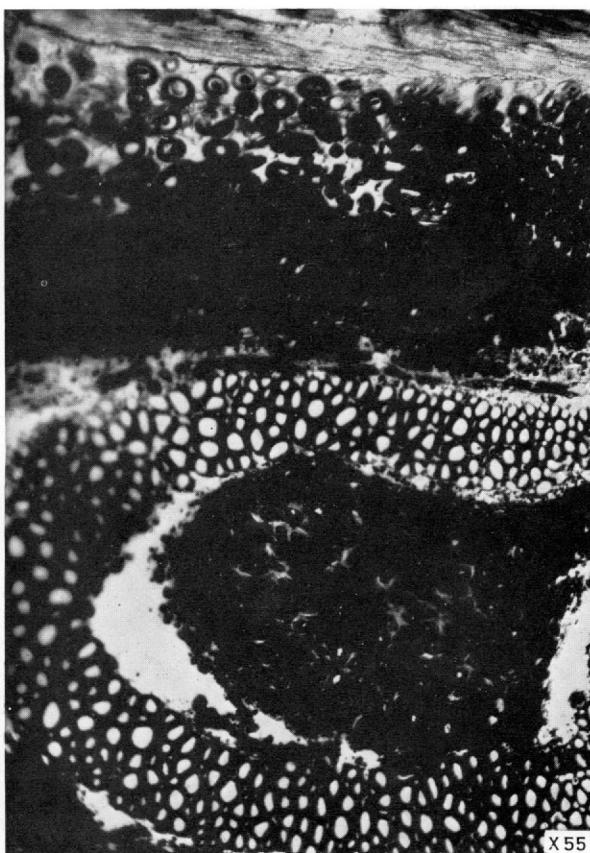
X 55

2



X 55

3

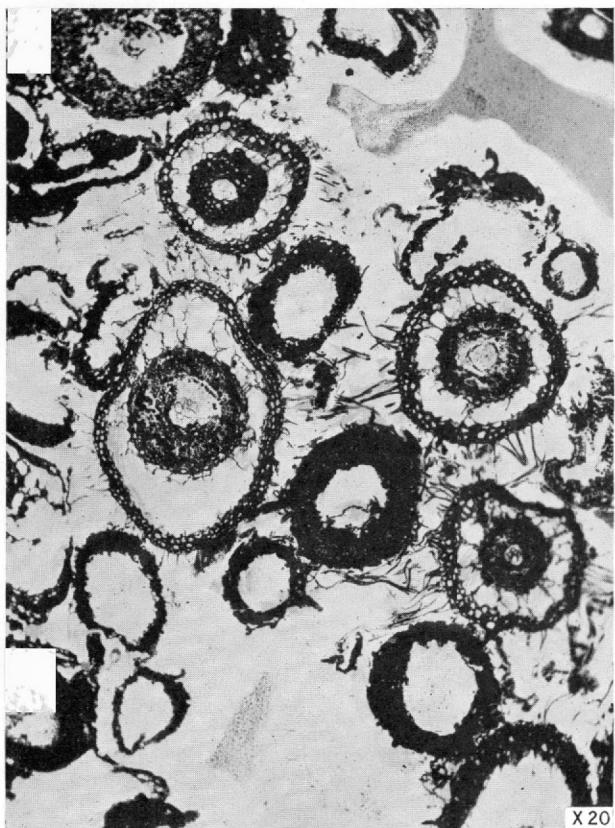


X 55

4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Longitudinal section of a stem of *Tempskya minor* cut near the apex, showing the investing epidermal hairs.
2. Portion of the section shown in figure 1 taken at a higher magnification to show details of the hairs.
- 3, 4. Transverse sections of stem of *Tempskya minor* showing the epidermal emergences.



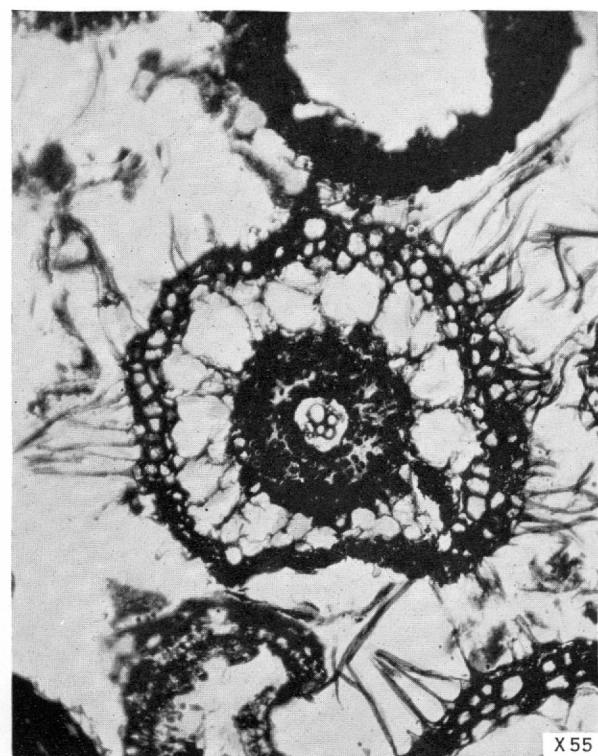
X 20

1



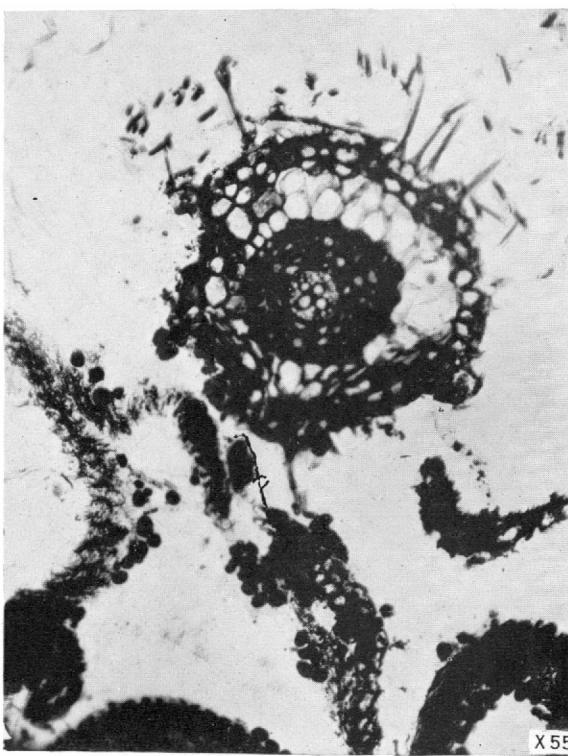
X 20

2



X 55

3

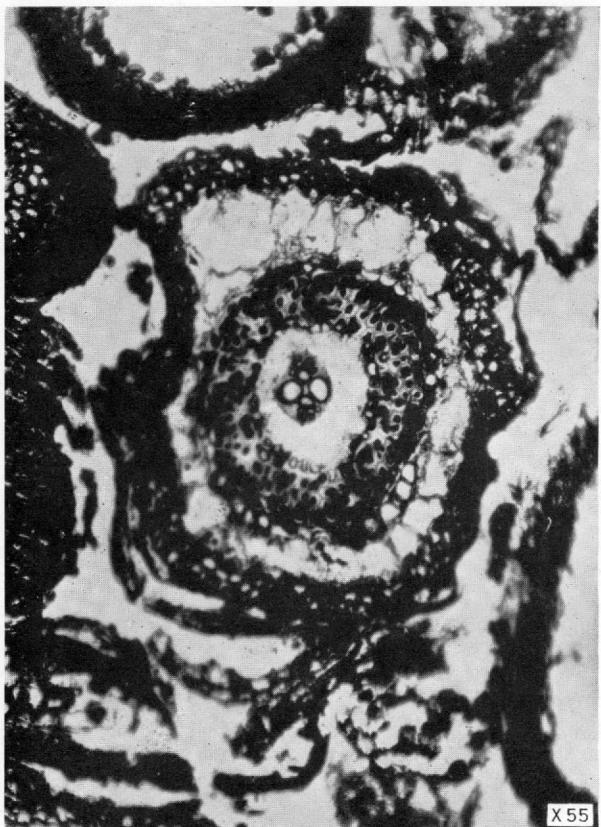


X 55

4

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

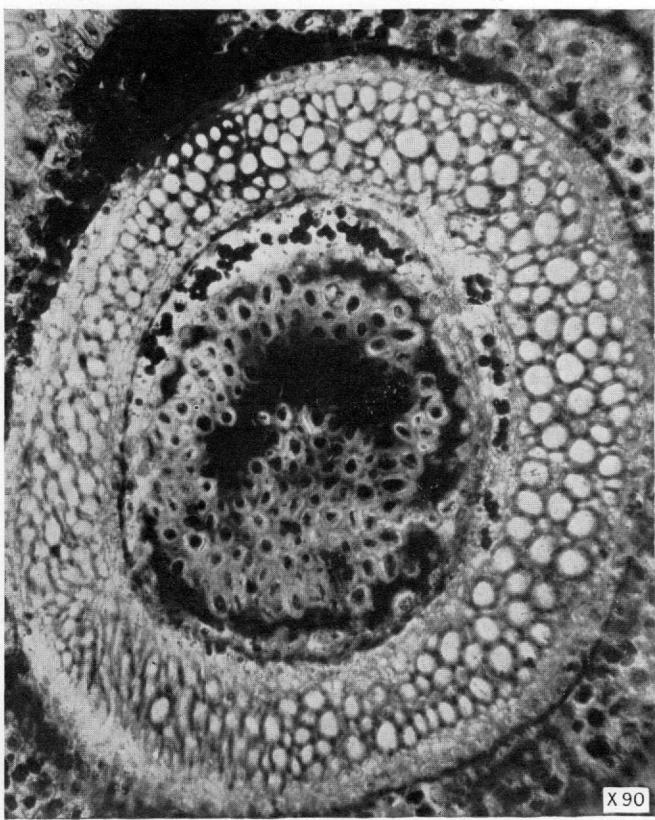
1. Transverse sections of roots with attached root hairs in *Tempskya minor*. Note the lacunar zone in the outer cortex.
2. Longitudinal section of roots with attached root hairs.
- 3, 4. Transverse sections of roots showing details of structure and attachment of root hairs.



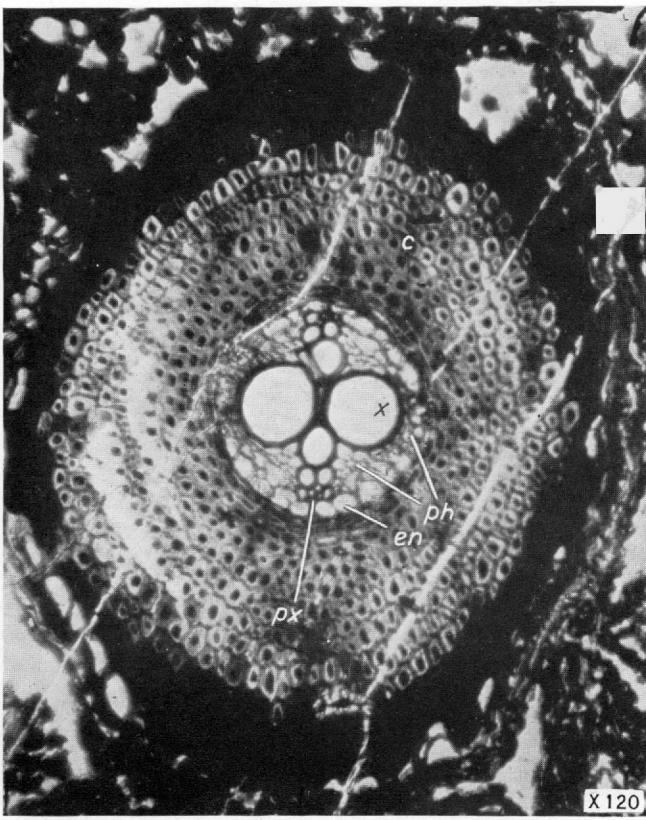
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2



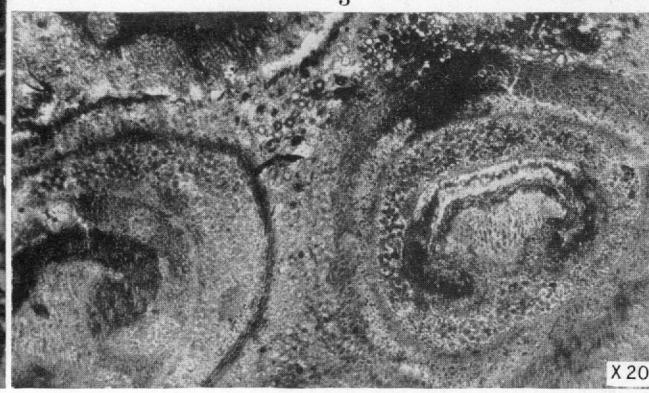
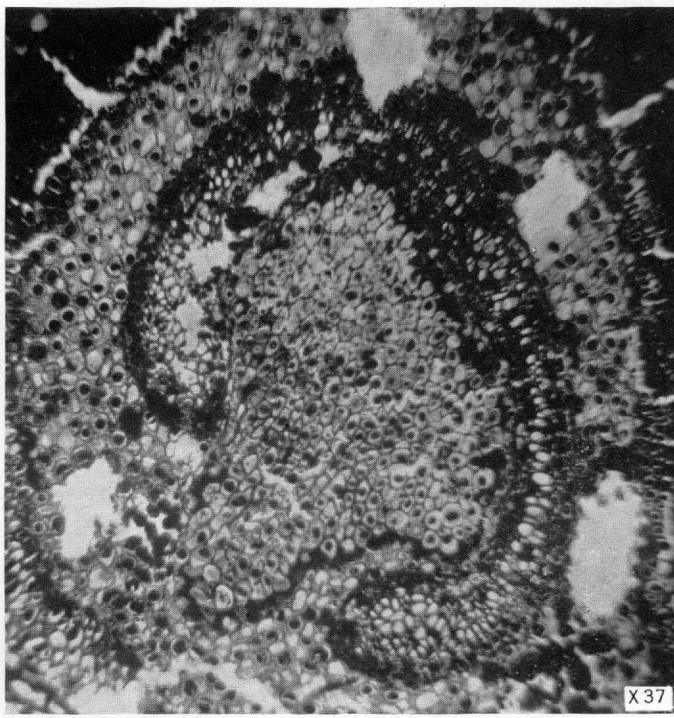
3



4

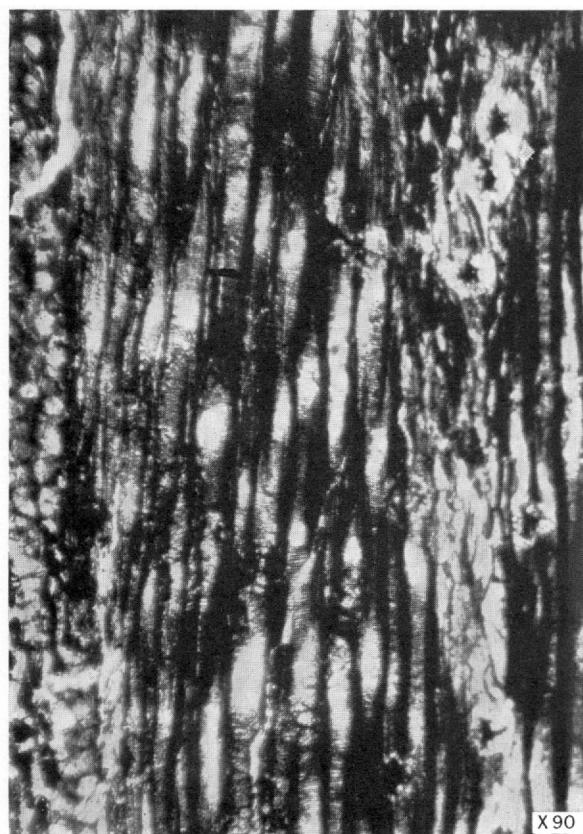
## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Root of *Tempskya minor* showing lacunar cortex.
2. Stem of *Tempskya minor* showing leaf traces,  $lt^1$ ,  $lt^2$ ,  $lt^3$ .
3. Transverse section of the vascular cylinder of *Tempskya minor* showing details of structure. Note the suggestion of a long internode indicated by the absence of any leaf gap in the internodal area.
4. Transverse section of a root of *Tempskya grandis* showing details of morphology. *px*, Protoxylem; *x*, xylem; *ph*, phloem; *en*, endodermis; *c*, cortex.

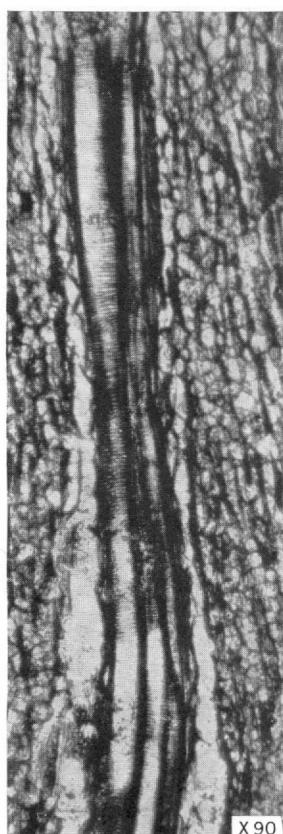


## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

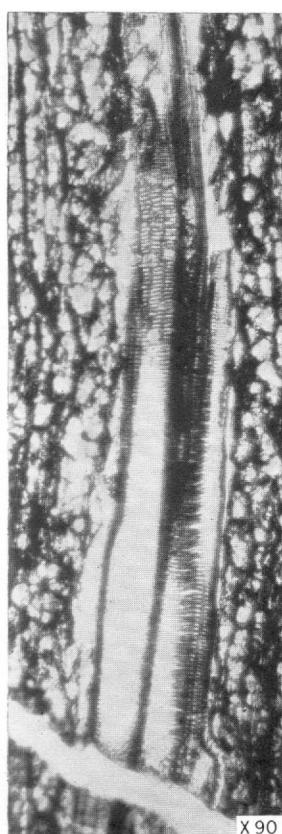
- 1-3. Leaf bases of *Tempskya grandis* showing characteristic morphology. *x*, Xylem.
4. Leaf trace of *Tempskya knowltoni* showing details of morphology.
5. Leaf bases of *Tempskya minor* showing general features. Note the investing hairs.



1



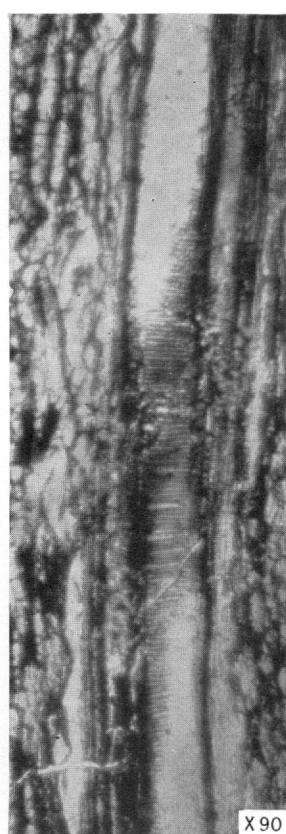
2



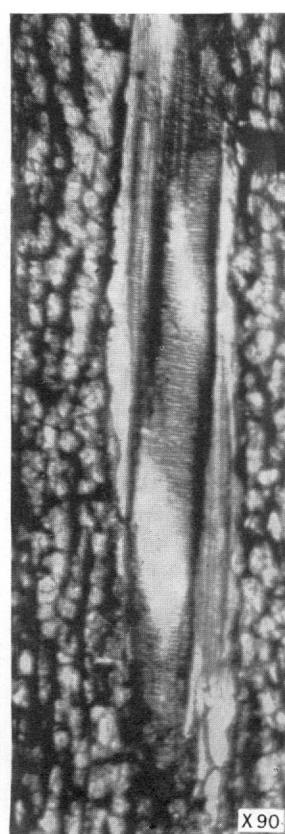
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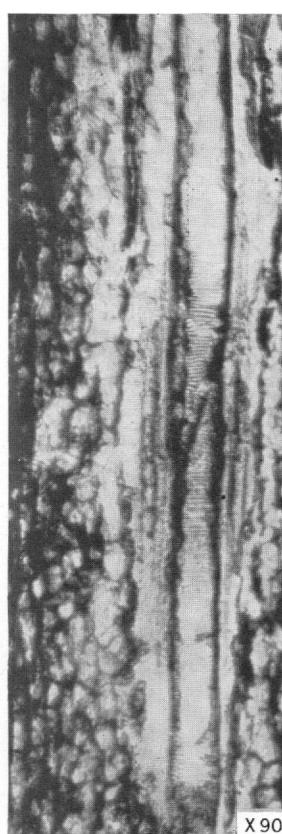
4



5



6



7

## AMERICAN CRETACEOUS FERNS OF THE GENUS TEMPSKYA.

1. Longitudinal section of the stem of *Tempskya grandis* showing the scalariform tracheids.
2. Longitudinal section of the stem of *Tempskya knowltoni* cut through an emerging leaf trace and showing the scalariform tracheids.
- 3-7. Longitudinal sections of roots of *Tempskya knowltoni* (fig. 3) and *Tempskya grandis* (figs. 4-7) showing xylem and adjacent tissues.



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# STRATIGRAPHIC RELATIONS OF THE AUSTIN, TAYLOR, AND EQUIVALENT FORMATIONS IN TEXAS

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## ABSTRACT

The relation of faunal zones in the upper part of the Austin chalk to the top of the chalk indicates the presence of an unconformity of regional extent separating the Austin and beds of Austin age from the overlying Taylor marl and beds of Taylor age. The time value of this unconformity varies greatly from place to place along the strike, owing in part to unequal erosion at the top of the Austin and in part to differential warping in early Taylor time.

The maximum erosion at the top of the Austin is found in the vicinity of Waco, where the Taylor rests directly on the *Inoceramus undulato-plicatus* zone, and the minimum erosion is found in Fannin and Lamar Counties, where the top of the Gober tongue of the Austin chalk is estimated to be on the order of 400 feet above the same zone.

Differential warping caused the deposition of the Taylor sediments to begin earlier in the Waco area than elsewhere; there the thickness of lower Taylor sediments below the Pecan Gap chalk member is 900 feet; the minimum thickness or complete absence of lower Taylor sediments beneath beds of Pecan Gap age is between New Braunfels and San Antonio.

The Austin-Taylor unconformity is marked at most places by a thin phosphatic bed that forms the base of the Taylor marl. In northeastern Texas this bed is traceable from Lamar County, where it immediately overlies the Gober tongue of the Austin chalk, eastward to eastern Red River County, where it forms the basal bed of the Annona chalk immediately overlying the Brownstown marl.

The field relations of the traceable beds in Red River and Lamar Counties indicate that the Annona chalk as a whole is the time equivalent of the lower part of the Taylor marl, the Wolfe City sand member, and the typical Pecan Gap chalk.

The macrofauna in the Annona chalk and in the underlying Ozan formation in southeastern Arkansas and the unconformity at the base of the Ozan suggest that these two formations together are the time equivalents of the Annona chalk of Red River County, Tex. The Brownstown marl of Arkansas appears to be correctly correlated with the marl to which the same name has been applied in Texas.

A zone of concretions near the top of the Blossom sand in Red River County, Tex., which carries many shells of *Ostrea elegantula* White, is correlated with a marine sand carrying the same species, near Hatcheechubbee, Russell County, Ala.; this sand is a facies corresponding in age to the lower part of the Selma chalk farther west in Alabama.

As both the Annona chalk and the Anacacho limestone include several hundred feet of beds older than the typical Pecan Gap chalk, and as these older beds are of the age of the Taylor marl (lower), which underlies the typical Pecan Gap chalk, the supplanting of the names "Annona" and "Anacacho" by "Pecan Gap" is not justified.

## INTRODUCTION

In early accounts of the Upper Cretaceous formations of Texas, by Hill,<sup>1</sup> Vaughan,<sup>2</sup> and other pioneer geologists, the Taylor marl is interpreted as resting conformably on the Austin chalk, the implication being that the top of the Austin and the base of the Taylor are of about the same age throughout their geographic extent.

In 1929 the writer<sup>3</sup> presented evidence that an unconformity separates the Austin and Taylor, at least from Travis County to the northern part of Ellis County. Evidence collected since 1929, particularly during the autumn of 1935, indicates that the two formations are separated by an unconformity of regional extent, that both the top of the Austin and the base of the Taylor differ in their stratigraphic positions from place to place, and that the maximum interval, measured in thickness of strata, approximates 900 feet.

The data given on the following pages are selected from a large amount of detailed information, as having a critical bearing on the stratigraphic relations of the Austin and Taylor sediments.

## SECTION IN TRAVIS COUNTY

In its type area in Travis County the Austin chalk has an estimated thickness of 420 feet. The formation consists of interbedded layers of hard chalk, softer chalk, and chalky marl; some of the marly layers are rather strongly argillaceous, as in the upper part that Adkins<sup>4</sup> has called the Burditt marl, though this part of the formation is no more marly than other lower parts of the formation elsewhere in Texas.

The formation is capable of subdivision into faunal zones, and several zones recognized in its upper one-fourth in Travis County have been traced for considerable distances away from that area both toward the north and toward the south. These zones in ascending order are the *Inoceramus undulato-plicatus* zone,

<sup>1</sup> Hill, R. T., Geography and geology of the Black and Grand Prairies, Tex.: U. S. Geol. Survey 21st Ann. Rept., pt. 7, p. 330, 1901.

<sup>2</sup> Hill, R. T., and Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Austin folio (no. 76), p. 5, 1902.

<sup>3</sup> Stephenson, L. W., Unconformities in Upper Cretaceous series of Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1328-1330, pl. 13, 1929.

<sup>4</sup> Adkins, W. S., Texas Univ. Bull. 3232, pp. 449-451, 1932.

*Gryphaea wratheri* zone, *Exogyra tigrina* zone, *Ostrea centerensis* zone, and *Ostrea travisana* zone.

The lowest and most persistent of the zones has been designated the "*Inoceramus undulato-plicatus* zone", because of the occurrence of great numbers of this large and easily recognized bivalve in the zone. This species was first described by Roemer,<sup>5</sup> who found it at the classic exposure of the Austin chalk on the Guadalupe River, called by him the "Wasserfalle der Guadalupe", about 2 miles below the highway bridge at New Braunfels, in Guadalupe County. In Travis County the species is contained in a hard, massive facies of the chalk exposed in the bed and banks of Little Walnut Creek upstream for 1,000 feet or more from a fault that crosses the creek 300 feet above the iron Sprinkle road bridge, now abandoned. Because of the faulting it is not possible to determine the exact position of the *undulato-plicatus* zone with respect to the Austin-Taylor contact, but the zone is obviously 100 feet or more stratigraphically below the contact; the observed thickness of the massive chalk above the bed of the creek at this locality is 15 or 20 feet.

A few shells of the species *Gryphaea wratheri* Stephenson were observed in the upper part of the massive chalk at the locality just described, indicating that the *G. wratheri* zone<sup>6</sup> closely overlies the *Inoceramus undulato-plicatus* zone; this is the normal relation of these two zones, as shown by other sections in Texas that will be described on subsequent pages.

The fault above mentioned crosses the creek obliquely, striking approximately north and dipping 70°-75° E.; the beds are downthrown on the downstream side, and although the amount of the throw is unknown the massive chalk that appears on the upthrown side is dropped from sight below the stream bed. The section exposed in the bluffs and upper slopes of the creek in the immediate vicinity of the old bridge and for 1,000 feet or so downstream therefrom comprises about 70 feet of chalk and chalky marl as described below.

Section on left bank of Little Walnut Creek, in the vicinity of the old Sprinkle road bridge (abandoned), Travis County

|  | Feet |
|--|------|
| Taylor marl: Marly clay, poorly exposed in upper slope..   | 10   |
| Unconformity (not clearly exposed here).   |      |
| Austin chalk:  |      |
| Alternating layers of massive marly chalk and harder chalk; contains <i>Ostrea travisana</i> Stephenson about 10 feet below top, <i>Exogyra ponderosa</i> var. <i>erraticostata</i> Stephenson, and toward the base <i>Gryphaea aucella</i> Roemer and <i>Exogyra</i> aff. <i>E. laeviuscula</i> Roemer. | 20±  |
| Grainy chalk, irregularly indurated  | 3    |
| Chalky marl, slightly shaly  | 5    |
| Chalky marl containing many shells of <i>Ostrea centerensis</i> Stephenson   | 1    |

<sup>5</sup> Roemer, Ferdinand, Die Kreidebildungen von Texas, p. 12, Bonn, 1852.

<sup>6</sup> Stephenson, L. W., New Upper Cretaceous Ostreidae from the Gulf region: U. S. Geol. Survey Prof. Paper 186-A, pp. 1-12, 1936.

|   | Feet            |
|---|-----------------|
| Austin chalk—Continued.   |                 |
| Chalky marl, slightly shaly, glauconitic in lower 2 or 3 feet; J. A. Cushman identified characteristic Austin Foraminifera in a sample taken 5 feet above base.   | $8\frac{1}{2}$  |
| Rather hard, grainy chalk, containing incompletely phosphatized internal molds of <i>Cucullaea</i> and other mollusks and many shells of <i>Exogyra tigrina</i> Stephenson (type locality).                             | 1               |
| Hard chalk containing many shells of a small smooth <i>Exogyra</i> related to <i>E. laeviuscula</i> Roemer and other larger Exogyras which have not been described; this resistant layer forms a bench along the bluff. | 3               |
| Hard, massive chalk with thinner intervening layers of relatively softer chalk; contains widely scattered shells of <i>Exogyra ponderosa</i> Roemer.  | 23              |
| Hard chalk containing vast numbers of <i>Gryphaea aucella</i> Roemer and a few shells of <i>Exogyra laeviuscula</i> Roemer and <i>Exogyra ponderosa</i> ; to water's edge.  | 7               |
|   | $79\frac{1}{2}$ |

The 7-foot bed of chalk at the base of this section is conspicuous for the great number of the small shells of *Gryphaea aucella* Roemer that it contains. This species is not confined in its range to this bed but has been observed rarely at lower levels in the Austin chalk and is common at higher levels, particularly in a thin bed 15 or 20 feet below the top of the chalk in this section.

The hard chalk 23 to 26 feet above the *Gryphaea aucella* layer, which contains great numbers of a small, smooth *Exogyra* related to *E. laeviuscula* Roemer and other medium to large shells of *Exogyra*, probably belonging to two or more species, is resistant enough to produce a distinct bench along the bluff. The 1-foot layer of glauconitic chalk immediately above the hard bed is designated the "*Exogyra tigrina* zone"<sup>7</sup> because of the abundance of the shells of this *Exogyra*, which is notable for the preservation of its color markings. Although Adkins did not designate this bed as the lower limit of his Burditt marl, it is at the base of the marly portion of the section and should probably be so regarded. The 1-foot bed of chalky marl  $8\frac{1}{2}$  feet above the *Exogyra tigrina* zone is appropriately called the "*Ostrea centerensis* zone."<sup>8</sup> The holotype and one paratype of *Ostrea travisana* Stephenson<sup>9</sup> were found in a chalk layer about 15 feet above the *O. centerensis* zone and about 10 feet below the top of the Austin chalk. Although *O. travisana* does not seem to form a continuous zone with a uniform distribution of individual shells, the species has been found at several more or less widely separated localities near the top of the Austin chalk, and for the purposes of this paper it is convenient to refer to this part of the section as the *Ostrea travisana* zone.

<sup>7</sup> Stephenson, L. W., U. S. Nat. Mus. Proc., vol. 76, art. 18, pp. 4, 5, pl. 3, 1929.

<sup>8</sup> Idem, pp. 2-4, pls. 1, 2.

<sup>9</sup> Stephenson, L. W., New Upper Cretaceous Ostreidae from the Gulf region: U. S. Geol. Survey Prof. Paper 186-A, pp. 4-5, 1936.

In a bluff on the right side of Little Walnut Creek, three-quarters of a mile downstream from the old Sprinkle road crossing, a sample of marly chalk taken 22 feet above the *Ostrea centerensis* zone yielded characteristic Austin Foraminifera (determined by Cushman).

The zones indicated above are important in determining the stratigraphic relation of the Austin chalk to the Taylor marl in central Texas, for in places some of the zones have been cut out by the erosion recorded in the unconformity that separates the two formations, allowing the marl to rest on successively lower beds of the chalk at least down to the top of the *Inoceramus undulato-plicatus* zone.

As shown beyond, the base of the Taylor marl is marked at most places by a bed of strongly phosphatic chalk or marl, which at some localities has the characteristics of a thin basal conglomerate and is interpreted to indicate an unconformity. The Austin-Taylor contact is not clearly exposed in the section on Little Walnut Creek at the old Sprinkle road bridge, but good exposures are afforded by the banks and bluffs of the same creek both above and below the crossing of the Austin-Manor road (State Highway 20). The section given below is made up from outcrops extending from the bridge downstream for a quarter of a mile. The beds dip downstream, so that the lowest beds in the section appear under the bridge, and the Austin-Taylor contact passes beneath the stream bed about 0.2 mile below the bridge. The beds are broken here and there by minor faults.

*Section on Little Walnut Creek from the crossing of the Manor road downstream for a quarter of a mile*

|   | Feet |
|---|------|
| Pleistocene alluvium: Mainly calcareous loam  | 9    |
| Unconformity.   |      |
| Taylor marl:  |      |
| Gray, slightly shaly, relatively soft calcareous clay or marl; contains imprints of large <i>Inoceramus</i> and Taylor Foraminifera (identified by Cushman)   | 23   |
| Gray argillaceous chalk, slightly nodular, showing traces of filled borings and containing scattered phosphatic nodules and internal molds of mollusks; this rock is rather tough and much harder than the marl above and is not so brittle as typical chalk                  | 1    |
| Unconformity (contact irregular in minor detail).   |      |
| Austin chalk: Interbedded layers of medium- to thick-bedded hard chalk and thinner, softer marly chalk; an upper massive 2-foot layer of chalk is perforated with borings filled with material like the matrix of the phosphatic bed at the base of the overlying Taylor marl | 14   |
|   | 47   |

From the Manor road crossing upstream to the old Sprinkle road bridge, an air-line distance of 1.8 miles, the outcrops along Little Walnut Creek reveal either the upper beds of the Austin chalk or the lower beds of the Taylor marl, or both. There is a general but

gentle dip of the beds downstream, but the regularity of this monoclonal structure is interrupted by faults, mostly of minor displacement, which locally drop the Austin-Taylor contact below the level of the creek; at a big bend about three-quarters of a mile upstream from the Manor road bridge, 40 or 50 feet of the gray marl of the Taylor appears above water level in the left bank. At a point about 2,300 feet from the Manor road bridge the Austin-Taylor contact is well exposed a few feet above the creek bed on the upthrown side of a fault; it is essentially like the contact in the section below the bridge.

An exposure in the right bank 1,100 feet upstream from the Manor road bridge on the upthrown side of a normal fault reveals 20 feet of massive-bedded chalk with subordinate interbedded layers of softer marly chalk; this section shows that at least the upper 20 feet of the Burditt marl of Adkins is chalk comparable in all respects with the more typical chalk of the Austin.

East of Austin the width of the belt of outcrop of that part of the Taylor marl which lies between the top of the Austin chalk and the base of the Pecan Gap member is only 2 or 3 miles, and its thickness is probably less than 300 feet. In comparison

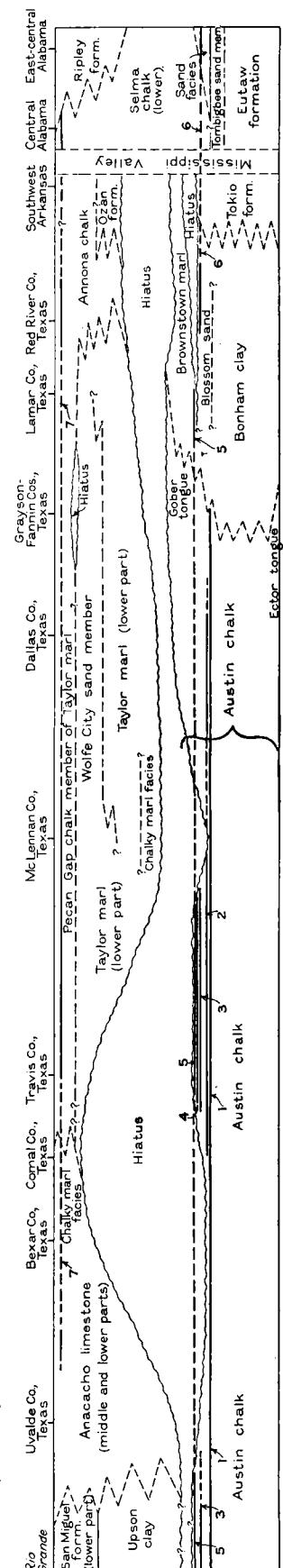


FIGURE 7.—Correlation of the exposed sediments of Austin and lower Taylor age in the Gulf Coastal Plain.

the width of the belt of outcrop of the lower Taylor, including the Wolfe City sand member, east of Waco, in McLennan County, exceeds 15 miles, and well logs show that its thickness below the Pecan Gap member is over 900 feet; the lower Taylor is therefore thinner by 600 feet or more in Travis County than it is in McLennan County. The thinning of this part of the Taylor section was recorded in 1934 in a valuable contribution by Ellisor and Teagle,<sup>10</sup> who found that the zone carrying a Pecan Gap microfauna progressively approaches the top of the Austin chalk from north to south and southwest.

#### SECTIONS ALONG BELT OF OUTCROP TO THE SOUTH AND TO THE NORTH OF TRAVIS COUNTY

*Vicinity of New Braunfels.*—The lower part of the Taylor becomes still thinner toward the southwest than in Travis County, for at New Braunfels 50 or 60 feet of chalky marl that was correlated by Ellisor and Teagle<sup>11</sup> with the Pecan Gap chalk is separated from the Austin chalk below by 50 feet or less of marl.

Before the power dam was constructed on the Guadalupe River just east of New Braunfels, the right bank of the river about 400 feet upstream from the International-Great Northern Railroad bridge afforded a clean-cut exposure of the Austin-Taylor contact, which is now concealed by the impounded water; this is the classic "Furt der Guadalupe" of Roemer. The section here, as observed in 1911, is described below:

*Section on right bank of Guadalupe River 400 feet upstream from International-Great Northern Railroad bridge, New Braunfels*

|   |       |
|---|-------|
| Pleistocene terrace deposit:  | Feet  |
| Brown pebbly loam-----  | 10    |
| Irregularly bedded sand and gravel-----   | 6-15  |
| Unconformity.   |       |
| Taylor marl:  |       |
| Dark clay marl-----   | 0-10  |
| Sandy limestone containing phosphatic nodules-----  | 0-0.6 |
| Unconformity.   |       |
| Austin chalk: Hard chalky limestone containing <i>Gryphaea aucella</i> Roemer (very abundant in layer 4 or 5 feet below top), <i>Exogyra ponderosa</i> Roemer, and other fossils----- | 0-13  |

The beds of the Austin and Taylor in this section dip perceptibly to the northwest; they are involved in block faulting that has tilted the Upper Cretaceous formations in the vicinity of New Braunfels toward a major fault of the Balcones fault zone, the scarp of which passes in a northeasterly direction just north of New Braunfels.

*North and west of San Antonio.*—Between New Braunfels and San Antonio the lower marl of the Taylor seems to pinch out entirely, for in the vicinity

<sup>10</sup> Ellisor, A. C., and Teagle, John, Correlation of the Pecan Gap chalk in Texas: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1506-1536, 1934.

<sup>11</sup> Idem, pp. 1522-1523.

of San Antonio the Austin chalk is immediately overlain by soft marly chalk which, on the basis of its contained Foraminifera, was classed by Ellisor and Teagle<sup>12</sup> as Pecan Gap chalk; in the opinion of the present writer this chalk, although approximately of Pecan Gap age, should be regarded as an eastward-thinning wedge of the Anacacho limestone. A section observed in 1933 in the main pit of the cement plant at Cementville, 4.7 miles north of the Alamo at San Antonio, is described below:

*Section in pit of cement plant at Cementville, north of San Antonio*

|   |      |
|---|------|
| Anacacho limestone: White brittle marly chalk, glauconitic in the lower 6 inches, with a phosphatic conglomerate 2 to 3 inches thick at the base; the phosphate is in the form of irregular nodules an inch or more in maximum length; the chalk contains the imprints of <i>Inoceramus</i> , <i>Scaphites</i> , <i>Baculites</i> , <i>Placenticeras?</i> , <i>Parapachydiscus?</i> , <i>Hamites</i> , and other fossils----- | Feet |
| Unconformity (contact sharp and gently undulating).   |      |
| Austin chalk: Hard, tough, massive chalk with layers containing many shells of <i>Gryphaea aucella</i> Roemer and a few of <i>Exogyra laeviuscula</i> Roemer; one 2-foot layer full of <i>G. aucella</i> lies 3 feet below the top-----   | 45+  |
|   | 50   |

The 95 feet of strata described are not seen in one continuous vertical section; as observed in 1933, the Austin-Anacacho contact was 50 feet above the floor of the pit toward the north end of the excavation, where the face of the pit was 60 feet high; near the middle of the pit the contact was dropped to a level within 15 feet of the floor by a normal fault, thus revealing about 45 feet of Anacacho above the contact; and at the south end another normal fault carried the contact below the floor.

The Anacacho limestone in the vicinity of San Antonio is estimated by A. N. Sayre<sup>13</sup> to be 200 or 250 feet thick. As indicated in the section at the cement plant, the Anacacho rests unconformably on the Austin chalk, the unconformity representing a large part of the lower Taylor beds. From San Antonio westward the Anacacho thickens rapidly in its lower part, and the marl becomes interbedded with the more typical impure limestones of the formation. The place nearest to San Antonio at which the impure limestone of the Anacacho was observed is in the bed and banks of Leon Creek from about 1.6 to 4 miles upstream from the Castroville road crossing.

*Hondo and Seco Creeks, Medina County.*—In Medina County impure limestone becomes the dominant rock of the Anacacho, though its full thickness cannot be determined from surface outcrops, owing to fault displacements. Some good exposures are afforded by the bed and banks of Hondo Creek, 2½ to 4 miles north by west of Hondo. The well-known section at King's

<sup>12</sup> Ellisor, A. C., and Teagle, John, op. cit., pp. 1533-1536.

<sup>13</sup> Oral communication.

Water Hole, which Liddle<sup>14</sup> incorrectly referred to the Escondido formation, is a typical example of Anacacho limestone.

The Anacacho in the longitude of D'Hanis is estimated by A. N. Sayre<sup>15</sup> to be 400 feet thick above the Austin chalk.

A fine section several hundred yards long in a northward-facing bluff on Seco Creek on the Rothe ranch, about 3 miles north of D'Hanis, exposes the upper part of the Anacacho and reveals its relation to the overlying Escondido formation.

*Section on Seco Creek about 3 miles north of D'Hanis, Medina County*

Escondido formation (marl facies):

Cream-colored glauconitic sandy marl, irregularly indurated and weathering to a roughened surface but showing fairly definite stratification lines-----

Feet

30

Light-gray laminated clay and sand with thin interbedded layers of ocherlike clay-----

4

Unconformity (sharp contact).

Anacacho limestone:

Soft to medium-hard sandy marl; contains great numbers of *Terebratulina* cf. *T. filosa* Conrad, a few *Diploschiza cretacea minor* Stephenson,<sup>15</sup> and a few other shells-----

1

Relatively hard cream-colored sandy, rather tough limestone, which is, however, easily cut with a sharp tool; contains scattered tests of the large echinoid *Echinocorys texana* (Cragin) and a few shells of *Gryphaea mutabilis* Morton; to creek bed-----

5

Upstream from the place where the preceding section was examined a normal fault, with downthrow to the north, drops the Anacacho limestone below the stream bed; here the beds are in gentle reverse dip upstream. Near the fault the lower 25 or 30 feet of the section is sandy marl of the Escondido formation, like that in the uppermost division in the preceding section, and the marl is conformably overlain by 20 feet or more of shaly clay, sandy clay, and interbedded hard calcareous platy sandstone, typical of the Escondido formation. Upstream from this locality the beds continue for some distance in reverse dip, beyond which they first flatten out and then bend up again to their normal southward dip. The Anacacho reappears from beneath the Escondido half a mile or so upstream from the fault and is the country rock in a belt 3 miles wide north of the Rothe ranch locality; this belt is paralleled on the north by the outcrop of the Austin chalk.

*Travis County to Falls County.*—The faunal zones recognized in the upper part of the Austin chalk in Travis County (see pp. 133—136) are all present in the section from this county northward as far as Bell County, although one or more of them may be locally concealed by normal faults, downthrown to the east, which have dropped them below the surface. The

*Ostrea travisana* zone, the highest of the zones, has not been observed farther north than southern Bell County. The *Ostrea centerensis* zone has been observed as far north as a point on a small branch 5 miles south of Temple. The *Ostrea tigrina* zone has been traced to Little Elm Creek 2.7 miles north-northeast of Temple; Foraminifera obtained in this zone at the Little Elm Creek locality were identified by J. A. Cushman as Austin species.

On a branch of Deer Creek 2 miles southeast of Eddy, Falls County, a phosphatic bed (see p. 135), believed to be the one at the base of the Taylor marl, lies only 5½ feet above a hard bed of chalk containing many shells of *Gryphaea aucella*, and this in turn is only a few feet above the top of the *Gryphaea wratheri* zone. The phosphate bed is overlain by chalky marl of undetermined thickness, presumably a facies of the Taylor marl; this appears to indicate that the phosphate bed, which from Travis County to Bell County lies above the *Ostrea travisana* zone, has here descended to a stratigraphic position a little above the *Gryphaea wratheri* zone.

The phosphate bed was again seen in the right bank of a small branch west of the Mooresville road 1.6 miles east-southeast of Eddy. Here a bed of hard Austin chalk containing *Gryphaea aucella* Roemer forms the bed of the branch and is overlain by 8 feet of marly thin-bedded chalk having the conglomeratic phosphate bed, 1 to 4 inches thick, at its base. An absence of Austin species was noted by Cushman in a sample taken 2½ feet above the base of the phosphate bed, and the marly chalk is believed to be basal Taylor marl.

*Waco and vicinity.*—The relation between the Austin chalk and overlying chalky marl believed to be the base of the Taylor marl in this area is revealed by exposures in the banks and valley slopes of several of the southeastward-flowing creeks between the southern boundary of McLennan County and Waco. In a steep northeastward-facing slope of South Cow Bayou Valley, in a road leading to the northeast, 1.4 miles northeast of Bruceville, 60 feet of Austin chalk is exposed in the road ditches. Near the top of the section is a layer containing *Gryphaea aucella* Roemer, and *Gryphaea wratheri* occurs in considerable numbers 15 to 30 feet below the *G. aucella* layer. The lower 30 feet of the section was not very well exposed at the time it was examined.

In going down South Cow Bayou from the crossing of the road just mentioned many exposures of Austin chalk were observed, and the imprints of *Inoceramus undulato-plicatus* Roemer were noted here and there in the chalk; several good imprints of this species were seen in the right bank at the mouth of Prather Creek, 0.2 mile below the bridge. A bluff along the left bank about 0.85 mile below the bridge revealed 12 feet of massive chalk containing many shells of *Gryphaea wratheri*, and associated with this species were several large

<sup>14</sup> Oral communication.

<sup>15</sup> Liddle, R. A., The geology and mineral resources of Medina County: Texas Univ. Bull. 1860, pp. 64–65, 1918.

<sup>16</sup> Stephenson, L. W., The genus *Diploschiza* from the Upper Cretaceous of Alabama and Texas: Jour. Paleontology, vol. 8, pp. 279–280, 1934.

imprints of *Inoceramus undulato-plicatus* Roemer. The last place at which the Austin chalk was seen was a low exposure in the right bank about 1.2 miles below the bridge. Here the top of the chalk slopes downstream from 3 feet above water level at the upper end of a 100-foot stretch to water level at its lower end; the chalk is overlain by chalky marl, which is concealed by vegetation except at its lower end, where 6 inches of the marl is sharply separated from the chalk and has at its base a thin phosphatic conglomerate. A short distance farther downstream characteristic chalky marl rises 10 feet above water level in a steep bluff.

The phosphatic bed at the base of the chalky marl, resting unconformably upon the much harder Austin chalk, was observed at several places in the bed and low banks of North Cow Bayou 1.3 to 1.7 miles below the crossing of the old U. S. Highway 81. Here the chalk is broken by numerous minor faults.

On Bullhide Creek about 0.6 mile below the crossing of a public road leading to the northeast, 2½ miles northeast of Lorena, the following section was examined near the east edge of a fault block tilted to the west:

*Section on Bullhide Creek 2½ miles northeast of Lorena, McLennan County*

|  | Feet                          |
|--|-------------------------------|
| Pleistocene terrace deposit: Silty loam with a gravel bed at base-----   | 8                             |
| Unconformity.  |                               |
| Taylor marl:   |                               |
| Gray chalky marl, weathering into angular, irregular fragments-----  | 10                            |
| Conglomerate composed of many phosphatic nodules and internal molds of mollusks and containing a few shells of <i>Gryphaea wratheri</i> mechanically included from the underlying chalk----- | $\frac{1}{4}$ - $\frac{1}{2}$ |
| Unconformity (contact sharp).  |                               |
| Austin chalk: Hard massive-bedded chalk containing shells of <i>Gryphaea wratheri</i> -----  | 1-5                           |

On account of the westward dip the Austin-Taylor contact rises downstream, and within a few hundred feet 10 feet of chalk is exposed above water level; imprints of *Inoceramus undulato-plicatus* Roemer were seen in the lower part of the chalk exposure. A short distance still farther downstream, at the eastern edge of the fault block, the chalky marl has been brought down against the Austin chalk. About 0.4 mile upstream from the place where the preceding section was observed the west edge of the fault block is marked by a major fault, which brings the chalky marl down against the Austin chalk.

Adkins<sup>16</sup> has suggested that the chalky marl just described may represent his Burditt marl; opposed to this suggestion is the fact that none of the characteristic macrofossils of his Burditt have been found in the marl, although the conditions appear to have been favorable for their existence, and the field relations

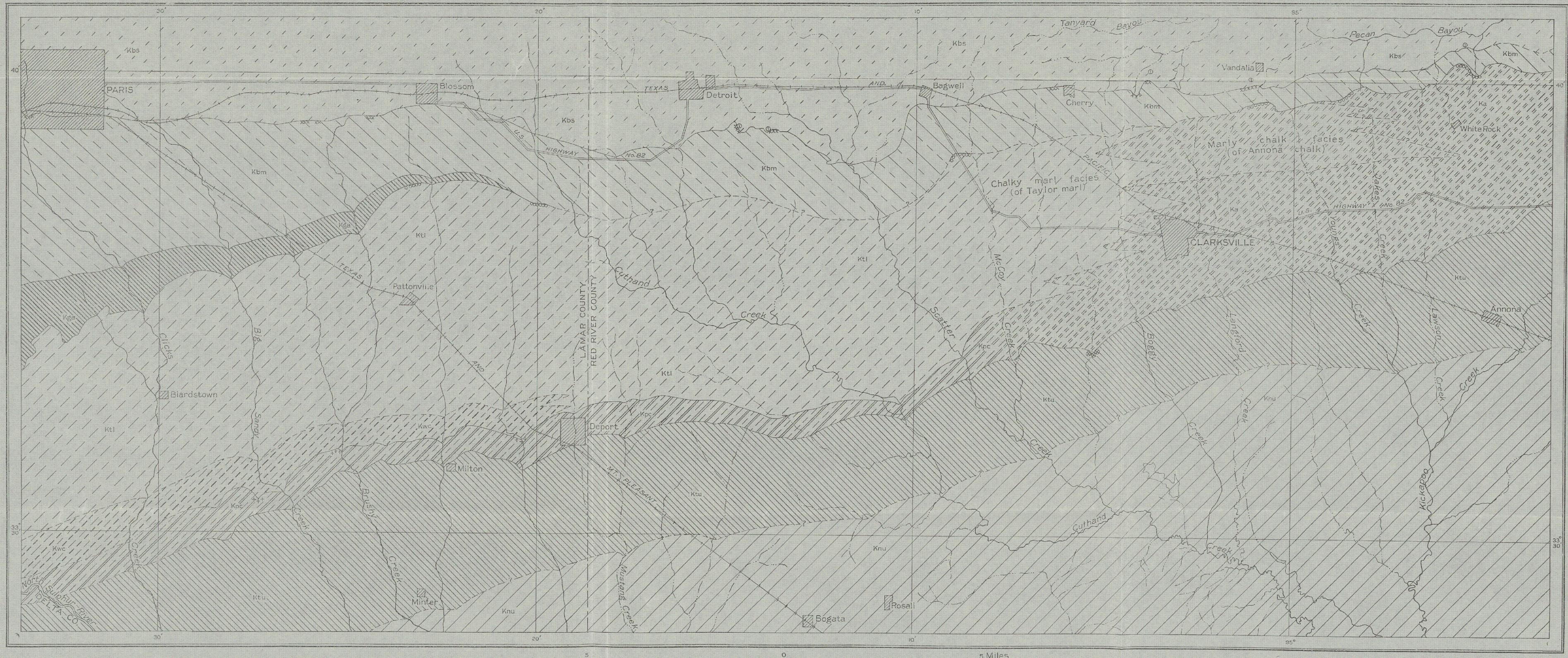
suggest that the phosphate bed is the northward continuation of the one at the base of the Taylor on Little Walnut Creek, in Travis County. Confirmatory evidence is afforded by Foraminifera obtained near the base of the chalky marl 1½ miles southwest of Lorena, which were identified by J. A. Cushman as of Taylor age. Cushman also identified Taylor Foraminifera from a sample taken in the upper part of the chalky marl in a road ditch on the northward-facing slope of Bullhide Creek, 5½ miles east by south of Lorena.

On North Flat Creek 5 miles south of Waco the phosphate bed has descended still lower and rests directly upon the *Inoceramus undulato-plicatus* zone with an abundance of the imprints of this characteristic species. The best exposure noted was in a low bank of the creek, 1,500 feet upstream from the crossing of the new U. S. Highway 81. Cushman noted an absence of characteristic Austin species in a sample of chalky marl taken 2 feet above the phosphate bed, and Austin species were wanting in a similar sample of chalky marl taken 350 feet downstream from the highway bridge.

*McLennan County to Dallas County.*—Northwest of Elm Mott, in McLennan County, the Austin chalk is completely cut out by a major normal fault, trending north-northeast, that drops the Taylor marl against the Eagle Ford shale; toward the north the throw of this fault decreases, and the chalk reappears on the upthrown side of the displacement. The first place north of McLennan County at which the Austin-Taylor contact was observed is on a small branch, 2½ miles east-southeast of Bynum, Hill County; here the two formations are separated by an obvious unconformity marked by a thin phosphatic layer at the base, but the zonal position of the top of the chalk was not determined. Good exposures of a conglomeratic phosphate bed were observed at the base of the Taylor at several localities between Bynum and the northern part of Ellis County; the one farthest north is on Bear Creek, 6½ miles east-northeast of Sterrett. Inasmuch as the *Gryphaea wratheri* zone is exposed to its maximum observed thickness of 35 feet at a point 1 mile north of Sterrett, 5.7 miles west by south of the Bear Creek locality, it appears that the phosphatic bed rises stratigraphically toward the north.

*Dallas and vicinity.*—In Dallas County the *Inoceramus undulato-plicatus* zone of the Austin chalk is well exposed just below the dam of White Rock Lake, at the northeastern outskirts of Dallas, and the overlying *Gryphaea wratheri* zone may be seen in a cut on Gaston Avenue near the intersection of West Shore Drive, less than a mile west of the dam. From 40 to 50 feet of shaly chalk with several interbedded harder, more chalky layers is exposed in gullies in the northward-facing slope and in the banks of a small branch draining into White Rock Lake 1.6 miles northeast of the dam; the section is stratigraphically somewhat higher

<sup>16</sup> Adkins, W. S., The geology of Texas, pt. 2, The Mesozoic systems in Texas: Texas Univ. Bull. 3232, pp. 449-451, 1933.

EXPLANATION  
UPPER CRETACEOUS

|                                    |                          |                                       |                                       |   |                              |                 |              |
|------------------------------------|--------------------------|---------------------------------------|---------------------------------------|---|------------------------------|-----------------|--------------|
| Navarro group (undifferentiated)   | Taylor marl (upper part) | Pecan Gap chalk member of Taylor marl | Wolfe City sand member of Taylor marl | Taylor marl (lower part)                                | Gober tongue of Austin chalk | Brownstown marl | Blossom sand |
| Localities of basal phosphate beds |                          |                                       |                                       |   |                              |                 |              |
|                                    |                          |                                       |                                       |   |                              |                 |              |
| Taylor marl (upper)                | Pecan Gap chalk          | Annona chalk and Taylor marl (lower)  | Brownstown marl                       | Ostrea elegantula White (in upper part of Blossom sand) |                              |                 |              |

RECONNAISSANCE GEOLOGIC MAP OF PARTS OF LAMAR AND RED RIVER COUNTIES, TEX.



than the *Inoceramus undulato-plicatus* zone at the dam. The presence of the *Gryphaea wratheri* zone is indicated by a few shells of that species in the banks of the branch low in the section, and *Gryphaea aucella* occurs in abundance in a 1-foot layer 20 or 25 feet higher in the section, about 20 feet below the level of U. S. Highway 67.

The Austin-Taylor contact is fully 4 miles east of the Gaston Avenue locality and must be at a considerably higher stratigraphic position than the *Gryphaea wratheri* zone—perhaps as much as 200 or 250 feet. The upper 50 or 60 feet of the Austin in Dallas County consists of interbedded layers of chalk, marly chalk, and chalky marl.

No phosphatic material was observed at the Austin-Taylor contact in Dallas County, but the contact is marked by a bed of limestone ranging in thickness from less than 1 inch to 6 inches, which lies at the base of the Taylor; this limestone is granular in texture and contains scattered shells of *Diploschiza* n. sp. and fragments of the shells of *Inoceramus* and ostracids. Although at most places this limestone is nearly parallel to the bedding of the underlying chalk, at one locality on Prairie Creek, 1,000 feet upstream from an east-west road, 1½ miles northeast of Pleasant Grove, a marked angular discordance was observed between the limestone and the chalk; in a horizontal distance of 100 feet the limestone bed rises from a stratigraphic position 2 feet above a traceable layer of chalk to 9 feet above it, thus apparently indicating an unconformity. Localities in Dallas County, in addition to the one on Prairie Creek, at which this limestone with its characteristic *Diploschiza* shells have been observed are in a gully on the bank of Cottonwood Creek, 200 feet east of the Southern Pacific Railroad bridge north of Wilmer; on a branch of Prairie Creek just above a public-road bridge 1.15 miles east of Pleasant Grove; and at the heads of gullies in the northward-facing slope of a small branch of Rowlett Creek, south of U. S. Highway 67, 1.3 miles east of the public square at Garland.

The sediments immediately above the thin limestone consist of soft gray marl weathering yellow, typical of the Taylor and lacking chalky layers. The limestone is interpreted to be the basal bed of the Taylor marl, resting with unconformable relations upon the Austin chalk, and this conclusion is supported by the microfaunal evidence; on the authority of J. A. Cushman, a sample taken 1 foot below the limestone contained Austin Foraminifera, and one taken 1 foot above the limestone yielded Taylor Foraminifera.

*Collin County*.—North of Dallas County the first place at which the exact contact between the Austin chalk and Taylor marl was seen was in a crooked east-west second-class road 0.85 mile east of Lucas and 6.2 miles east by south of Allen, Collin County. The ditch at the side of the road exposed about 1 foot of the chalk, overlain by 2 or 3 feet of soft yellowish marl;

the contact is sharp, and a few phosphatic nodules are present along the base of the marl. In a chalk quarry just south of State Highway 24, 3 miles east of McKinney, Collin County, shells of *Gryphaea aucella* Roemer occur in abundance in a layer 10 feet above the bed of the quarry; as the Austin-Taylor contact, though not well exposed, is 2 miles east of this quarry, the regional eastward dip of the beds would indicate that the shell bed is stratigraphically considerably below the top of the chalk—perhaps as much as 100 or 150 feet.

A good exposure of the Austin-Taylor contact is afforded by a small quarry just south of an east-west road 2.9 miles north by west of Blue Ridge, Collin County. The contact is marked by a well-developed phosphatic layer, with many of the usual nodules and internal molds of mollusks, among which *Baculites* is conspicuous. The stratigraphic position of the top of the chalk in the quarry could not be directly determined, but the field relations suggest a high position with respect to the faunal zones of the upper part of the Austin.

*Grayson, Fannin, and Lamar Counties*.—The next place at which the chalk and the overlying Taylor marl were seen in a good exposure was in a small wash in the westward-facing slope of a creek valley 0.55 mile south of State Highway 78 and 5.8 miles west by south of Leonard, Fannin County. Here the contact is sharp and lies 20 feet above the creek bed; it is marked by a thin line of phosphatic nodules and internal molds of mollusks.

A section having a significant bearing on the relation of the Gober tongue of the Austin chalk to the main body of the Austin is exposed in a low bluff on the right side of an eastward-flowing headwater branch of Bois d'Arc Creek, 150 feet upstream from the crossing of U. S. Highway 69 and 0.7 mile northwest of the business center of Whitewright, in eastern Grayson County. The section is as follows:

*Section 0.7 mile northwest of Whitewright, Grayson County*

| Austin chalk:  | Feet     |
|--|----------|
| Marly chalk, breaking in irregular fragments; contains Foraminifera of Austin age (identified by J. A. Cushman)-----   | 10       |
| Bentonite containing a sprinkling of fine biotite mica.-----   | 3        |
| Hard, massive, brittle chalk containing a few large imprints of <i>Inoceramus undulato-plicatus</i> Roemer and Foraminifera of Austin age (identified by J. A. Cushman)----- | 1-2      |
|  | <hr/> 15 |

This locality is 11 miles north by west of the place west of Leonard, described above, at which the contact of the chalk with the overlying Taylor marl was seen. The area between the Whitewright and Leonard localities appears to be continuously underlain by chalk, as shown by many outcrops along roads and in stream

banks. The chalk in this area may be regarded as the root of the Gober tongue. If the southward dip of the strata amounts to as much as 50 feet to the mile, the thickness of the chalk in the interval of 11 miles would be 500 feet or more. If the conservative figure of 40 feet to the mile is assumed, the thickness would be at least 400 feet. The evidence therefore appears to indicate that the Austin-Taylor contact rises stratigraphically from a position immediately above the *Inoceramus undulato-plicatus* zone in McLennan County, south of Waco, to a position at least 400 feet above that zone in Fannin County, west of Leonard.

North and northeast of Whitewright the lower beds of the Austin chalk merge eastward along the strike into the facies unit to which the name "Bonham clay" has been given. In east-central Fannin County the upper part of the Bonham merges eastward into the Blossom sand and perhaps also into the lower part of the overlying Brownstown marl; however, the stratigraphic relations of the formations in this area have not been determined in detail.

From the Whitewright-Leonard area the belt of outcrop of the Gober tongue of the Austin chalk extends first northeastward and then eastward through Fannin and Lamar Counties; the tongue becomes progressively thinner in that direction and finally pinches out, as such, a little less than 4 miles northeast of Pattonville, before reaching the Red River County line. As the upper part of the Gober, which consists of 10 feet or less of cream-colored tough, soft chalk or limestone, suitable for building stone, has been traced continuously from the vicinity of Bailey, in Fannin County, to the eastern terminus of this tongue, it appears that the top of the tongue is at one stratigraphic position throughout this distance; the tongue thins therefore at the expense of its lower portion, successively higher beds of which probably merge toward the east into the Brownstown marl facies.

A foraminiferal sample taken in an eastward-facing slope in a public road just east of its junction with U. S. Highway 69, 1 mile east of Trenton, Fannin County, was determined by J. A. Cushman to contain an Austin fauna; this locality is estimated to be approximately in the middle of the Gober tongue as it is developed in this area. Another sample of chalk taken near the top of the Gober tongue in a small branch about a quarter of a mile southeast of Bailey, Fannin County, yielded Foraminifera which Cushman referred to the Austin.

The top of the Gober tongue crops out on State Highway 24, 4.3 miles south of the Texas & Pacific Railway at Paris, and the width of the belt of outcrop of this tongue along the highway is only about 1½ miles. Between this belt and the railroad at Paris the country is underlain by Brownstown marl. In a small creek at the southwest edge of Paris shells of *Ostrea travisana* are present in a phosphatic, glauconitic

marl that forms the base of the Brownstown. At a southward dip of 50 feet to the mile, the thickness of the strata between the base of the Brownstown marl and the top of the Gober tongue more than 4 miles to the south would be at least 200 feet. If *Ostrea travisana* is a reliable index fossil marking the upper part of the Austin chalk in central Texas, as it is believed to be, its presence in the base of the Brownstown marl near Paris indicates that the containing bed there corresponds to the uppermost part of the Austin chalk in Travis County. It follows, therefore, that in Fannin and Lamar Counties the top of the Gober tongue lies stratigraphically 200 feet or more higher than the top of the typical Austin chalk in Travis County. The Gober tongue at its thick end in southwestern Fannin County would necessarily include representatives of the Burditt marl of Adkins.

To return to consideration of the contact between the Austin chalk (Gober tongue) and the Taylor marl, examination of a large quarry in the building-stone facies at the northwestern edge of the village of Gober showed that this rock is overlain by several feet of typical Taylor marl, and the sharp contact between the Gober and the Taylor is marked by a thin line of phosphatic nodules and internal molds of mollusks. No attempt was made to determine the presence or absence of phosphate at the top of the Gober tongue between Gober and eastern Lamar County, but at a small quarry a quarter of a mile west of a north-south road 3 miles north of Pattonville (pl. 44), phosphatic material of the usual type was observed in great abundance at the top of the Gober tongue. This locality is near the eastern tip of the Gober tongue, for within the next 3 or 4 miles to the east the chalk disappears as such and is replaced by marl.

The phosphatic bed seen at the locality last mentioned does not come to an end with the pinching out of the chalk but continues eastward and was seen well developed in fields on each side of a north-south road about 4 miles northeast of Pattonville and 1½ miles west of the Red River County line. The phosphate bed crops out in shallow gullies about 25 feet below the crest of the hill. It is only a few inches thick but contains many of the typical nodules and internal molds of mollusks in a matrix of slightly glauconitic marl; these weather out in the soil in great numbers. Here the bed is not underlain by chalk but by clay marl, which is interpreted to be the upper part of the Brownstown marl. The phosphate bed is immediately overlain by several feet of slightly sandy marl containing numerous thin flakes of fine sandy limestone of varying sizes, one-eighth to one-fourth inch thick and having a maximum length of about 3 inches; as shown below, these flakes are useful markers in identifying this phosphate bed at other localities farther to the east in Red River County.

*Chalks and marls in Red River County.*—About 11 miles east of the locality just described the continuation of the phosphatic bed was observed intersecting U. S. Highway 82, 1.8 miles south-southeast of Bagwell, Red River County. The bed is poorly exposed in the road ditch, is only a few inches thick, and has a matrix of glauconitic marl; it can be traced along the slopes in the adjoining fields by the great abundance of phosphatic nodules and molds of mollusks, which weather out in the soil and are scattered down the slope from the outcrop. Here, as at the locality last described, the marl within a few feet above the phosphate bed contains thin laminae of sandy limestone, the flaky fragments of which weather out in the soil in profusion. About 20 feet of gray marl (Brownstown) is exposed in the gullies below the phosphate bed; a sample of marl taken 20 feet below the phosphate bed yielded Foraminifera of Austin age, as determined by Cushman. Above the phosphate bed 30 feet of Taylor marl, poorly exposed, makes up the slope to the crest of the hill. Exposures of chalky marl are afforded by ditches along the highway 2½ to 3 miles south-southeast of Bagwell; Cushman determined a sample of this marl, taken 2.8 miles from Bagwell, to be of lower Taylor age.

The next observed exposure of the phosphate bed to the east is near the crest of a northward-facing slope on the road leading north by east from Clarksville, at a point 1 mile south of Vandalia. The phosphate bed is at the base of the chalky marl that weathers white, about 10 feet lower than the crest of the hill. The phosphatic materials occur in a matrix of glauconitic marl, and here again flakes of a sandy limestone occur in the chalky marl immediately above the phosphatic layer.

The phosphatic bed intersects the road to Reed's store 1½ miles north of White Rock, 0.8 mile north of a small cemetery, and about 8½ miles northeast of Clarksville; the bed may also be seen poorly exposed in the northward-facing slopes within half a mile east of the road. Here the phosphatic nodules and molds are abundant and characteristic. Particular interest attaches to this locality because here the phosphatic bed lies at the base of the thick body of chalk that forms numerous bald spots in the White Rock neighborhood, whereas at all the other localities examined west of White Rock in Red River and Lamar Counties the material overlying the phosphate bed is either chalky marl or marl. As confirmatory evidence that this is the eastward continuation of the phosphate bed observed at the other localities described above, one rather poor exposure about 1,000 feet east of the road to Reed's store revealed the presence of the tell-tale flakes of sandy limestone in the chalk within a few feet above the phosphate bed.

As the phosphate bed that lies at the base of the chalk north of White Rock continues westward through

Red River County into Lamar County, where it lies at the base of the Taylor marl, resting upon the Gober chalk, it follows that the chalk at White Rock corresponds in age to the lower part of the Taylor marl, which, in Lamar and Fannin Counties, overlies the Gober tongue; in other words, the chalk may be looked upon as a facies that merges westward through marly chalk and chalky marl into the nonchalky Taylor marl. This conclusion is not in harmony with the interpretation of Ellisor and Teagle<sup>17</sup> that the Annona chalk in Red River County, including the chalk at White Rock, should be classed as Pecan Gap chalk, which at its type locality, in northwestern Delta County, is only 40 or 50 feet thick and lies stratigraphically some 400 or 500 feet higher than the top of the Gober chalk.

#### STRATIGRAPHIC RELATIONS IN RED RIVER AND LAMAR COUNTIES

The correlations presented in this paper seem to accord with the known facts as expressed in the accompanying geologic map (pl. 44). Hill<sup>18</sup> as early as 1901 recognized the fact that the Annona chalk in Red River County is younger than the Austin chalk, and he correctly correlated the Annona with the chalk at White Cliffs on the Little River, in southwestern Arkansas.

The Pecan Gap chalk member of the Taylor marl at its type locality, in Delta County, is 50 feet or less in thickness. The chalk enters Lamar County from Delta County in the valley of the South Fork of the Sulphur River, 12 miles south of Paris, where, at the crossing of State Highway 24, its belt of outcrop is so narrow that it is completely concealed by the alluvium of the river; its width can scarcely be more than half a mile. The chalk continues as a thin, sharply defined unit in a general east-northeasterly direction through Lamar County past Deport and into Red River County in the direction of Clarksville; it maintains a narrow width of outcrop, less than half a mile to perhaps a mile, at least as far as McCoy Creek, 5 miles west-southwest of Clarksville; between McCoy Creek and Clarksville the Pecan Gap chalk passes into and forms the upper part of the Annona chalk. (See pl. 44.)

The Wolfe City sand member of the Taylor marl, which at its type locality, in Hunt County, is 100 feet or less in thickness, underlies the Pecan Gap chalk and extends eastward beneath the chalk into southeastern Lamar County, where it appears to merge into marl. The Wolfe City sand at its type locality is underlain by an estimated thickness of 400 feet or more of Taylor marl, which in turn rests upon the Gober tongue of the Austin chalk. This marl section thins somewhat as it passes eastward through Lamar County

<sup>17</sup> Ellisor, A. C., and Teagle, John, Correlation of the Pecan Gap chalk in Texas: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1506-1536, 1934.

<sup>18</sup> Hill, R. T., Geography and geology of the Black and Grand Prairies, Tex.: U. S. Geol. Survey 21st Ann. Rept., pt. 7, p. 340, 1901.

into Red River County, where it merges into the Annona chalk.

The width of the belt of outcrop of the Annona chalk east of Clarksville in the longitude of White Rock is 4 miles. The thickness of this chalk has not been accurately determined but is estimated to be 300 or 400 feet. The facts given in the foregoing text and the field relations as expressed in plate 44 indicate that the Annona as a whole in the longitude of White Rock is the age equivalent of the combined Taylor marl (lower), Wolfe City sand member, and Pecan Gap chalk member in Lamar, Delta, and Fannin Counties.

A phosphatic bed at the base of the Pecan Gap chalk at Pecan Gap is interpreted by Ellisor and Teagle as marking an unconformity of considerable importance. This bed is present at the base of the chalk through southeastern Lamar County into Red River County, and they assume that it continues to the northeast past Clarksville and is continuous with the phosphate bed at the base of the Annona chalk north of White Rock. A necessary corollary of this interpretation is that the unconformity cuts out the lower beds of the Taylor marl and the Wolfe City sand member, which, in the longitude of western Delta County, intervene between the Gober tongue and the Pecan Gap chalk. As shown on preceding pages, the phosphate bed at the base of the Annona is not continuous with the one at the base of the Pecan Gap but extends with a more nearly westward strike across Red River County into Lamar County, where it is continuous with a phosphate bed at the base of the Taylor marl, resting on the Gober chalk; in Lamar County this phosphate bed is 400 or 500 feet stratigraphically lower than the one at the base of the Pecan Gap chalk.

Ellisor and Teagle divide the Annona chalk (their Pecan Gap chalk) of northeastern Texas into three faunal zones—in ascending order, the *Flabellamina compressa* zone, the *Diploschiza cretacea* zone, and the *Bolivina incrassata* zone. Foraminifera identified from these zones are tabulated on pages 1529–1532 of their paper. They recognize all three of the zones in the Annona chalk of eastern Red River County. They also recognize the three zones at different places within the limits of the narrow belt of chalk (true Pecan Gap chalk of the present writer) that extends from Pecan Gap, Delta County, to McCoy Creek, 5 miles west of Clarksville, in Red River County (pl. 44). The species listed in the table total 106; of these, 64 range through all three zones, 26 range through the *Flabellamina compressa* and *Diploschiza cretacea* zones, and 6 range through the *Diploschiza cretacea* and *Bolivina incrassata* zones. One species is restricted to the *Flabellamina compressa* zone, 6 species are restricted to the *Diploschiza cretacea* zone, and 2 species are restricted to the *Bolivina incrassata* zone. *Flabellamina compressa* ranges through all three zones. *Bolivina incrassata* is restricted to the zone that bears its name and is said to

occur in abundance in that zone. No information is given as to the range of the species in the sediments older and younger than the three zones.

The foregoing analysis does not disclose wholly convincing evidence of the distinctiveness of the three faunal zones recognized. Such faunal differences as may appear among samples from different localities in any series of closely related sediments may perhaps be accounted for by facies differences in the sediments, or by other environmental differences, rather than by differences in the time of sedimentation. Conversely, the recurrence of similar faunal assemblages in beds of different ages, as shown by the field relations, may perhaps reasonably be ascribed to the recurrence of similar favorable environmental conditions in the later beds.

The individual beds of chalk and chalky marl that compose the Annona chalk east, northeast, and north of Clarksville are not readily traceable across the county, but the phosphate bed at the base of the Annona can be easily recognized, not only in good exposures but in the intervening fields, where the resistant phosphatic nodules and internal molds of mollusks weather out in the soil in great numbers. The distribution of this bed across Red River County north of the latitude of Clarksville, as shown in plate 44, determines the general strike of the beds to be  $7^{\circ}$  or  $8^{\circ}$  north of east. If it were true that this bed is continuous with the similar bed at the base of the Pecan Gap chalk, the strike of the beds above the phosphatic layer should be at least  $25^{\circ}$  north of east. The map accompanying the paper by Ellisor and Teagle (their fig. 1, p. 1516) is on too small a scale and is too much generalized to indicate the direction of strike accurately.

Confirmation of the strike of the Cretaceous beds in Red River County north of the latitude of Clarksville, as determined by the trace of the phosphate bed at the base of the Annona chalk, is afforded by two other easily traceable beds stratigraphically lower than the Annona. Another phosphatic bed, at the base of the Brownstown marl, has an east-west zone of outcrop across both Red River and Lamar Counties, and a few feet below it, in the Blossom sand, a bed marked by hard glauconitic, calcareous concretions is known to extend nearly across Red River County; the latter bed is here designated the *Ostrea elegantula* zone<sup>19</sup> on account of the abundance of the shells of this oyster in the concretions. Localities where one or both of these beds have been examined are described below.

On the road to Reed's store 1.5 to 1.9 miles north of the store at White Rock the Brownstown marl is poorly exposed below the Annona chalk in the northward-facing slope of Pecan Bayou Valley. Near the foot of the slope 2 miles north of the store 10 feet of glauconitic sand forming the upper part of the Blossom

<sup>19</sup> Stephenson, L. W., New Upper Cretaceous Ostreidae from the Gulf region: U. S. Geol. Survey Prof. Paper 186-A, pp. 2, 6–8, 1936.

sand is well exposed in a cut and ditch on the east side of the road; the Blossom-Brownstown contact is not exposed, but it is estimated to be about 75 feet vertically lower than the phosphate bed at the base of the Annona. In the sand are hard, concretionary sandstones containing many shells of *Ostrea elegantula* White, a few individuals of *Placenticeras* sp., and a few other fossils. The oyster is known in northeastern Texas only at this and the few other localities described below and is believed to be restricted in its vertical range to a very narrow zone.

In a small draw in a field west of the Clarksville-Vandalia road 0.4 mile south of Vandalia fossiliferous concretions like those at the locality just described weather out in the soil. They contain many shells of *Ostrea elegantula* and a few shells of *Inoceramus* sp., *Aphrodina* sp. (large), and other fossils. About 0.15 mile south of this point a few phosphatic internal molds of mollusks were found weathered out in the soil in the road ditch; these came from the phosphatic bed marking the base of the Brownstown marl.

Imprints of *Ostrea elegantula* were obtained from weathered ferruginous, glauconitic sandstone in a small earthen tank east of the Dimple road, toward the foot of the northward-facing slope of a branch valley of Tanyard Bayou 4.2 miles north by west of the public square at Clarksville. The phosphatic bed at the base of the Brownstown marl was observed poorly exposed in a small headwater branch about three-quarters of a mile southwest of the tank locality.

The base of the Brownstown marl with its characteristic phosphatic materials is poorly exposed in a public-road ditch half a mile west of the Cherry settlement, about 5 miles northwest of Clarksville.

Glauconitic, phosphatic marl marking the base of the Brownstown marl is exposed in the ditch of the old Clarksville road 2.2 miles east-southeast of Detroit. A few specimens of *Ostrea elegantula* were obtained from an indurated layer in the Blossom sand about 3 feet below the phosphatic bed.

An exposure of the Blossom-Brownstown contact is afforded by a ravine just east of the old Clarksville road 1.4 miles southeast of Detroit. The section consists of about 15 feet of glauconitic sand overlain by 10 feet of marl; the sand-marl contact is marked by a thin bed of phosphatic nodules and molds of the usual character. A concretionary sandstone about 3 feet below the contact contains shells of *Exogyra ponderosa* Roemer and internal molds of a very large nautiloid of the genus *Euterephoceras*. One shell of *Ostrea elegantula* was found in the sand about 6 feet below the contact, and several loose pieces of concretionary sandstone in the ravine at the base of the section, which had fallen from above, contained great numbers of this small oyster in a fairly good state of preservation.

Phosphatic materials weathered from the base of the Brownstown marl immediately above the Blossom

sand were observed along the old Paris-Clarksville road south of the Texas & Pacific Railway at three places within a stretch 1½ to 3½ miles west by south of Blossom, Lamar County.

Glauconitic, phosphatic marl at the base of the Brownstown marl is poorly exposed beneath an alluvial covering at several places along a small creek in the southwestern outskirts of Paris, about a quarter of a mile southeast of the crossing of the Texas & Pacific Railway and Texas & New Orleans Railroad. This bed is believed to correspond approximately in stratigraphic position to the top of the Austin chalk in Travis County, as indicated by the presence of shells of *Ostrea travisana*. (See p. 138.) In this connection it is worthy of note that the shells of *Gryphaea aucella* Roemer are present in marl exposed along U. S. Highway 271 at two places, 4½ and 7 miles north of the public square at Paris; each of these localities also yielded Foraminifera determined by Cushman to be of Austin age. The paleontologic evidence indicates that the beds cropping out in an east-west belt 7 or 8 miles wide, having its southern boundary just south of Paris, correspond in age to the upper part of the typical Austin chalk in Travis County. From north to south this belt includes the upper part of the Bonham clay, consisting in part of marl and in part of clay and sandy clay; the Blossom sand, which forms a sandy belt about 2 miles wide in the vicinity of Paris; and the lowermost part of the Brownstown marl.

#### SECTION IN RED RIVER COUNTY COMPARED WITH THAT IN SOUTHWESTERN ARKANSAS

From Red River County, Tex., the Annona chalk is traceable eastward through Bowie County into Arkansas, past Rocky Comfort, Little River County, to White Cliffs, Sevier County. According to Ellisor and Teagle,<sup>20</sup> the massive white chalk that forms the upper 60 feet of the section at White Cliffs comprises the upper one of the three faunal zones into which they divide the Pecan Gap chalk; they consider that near Clarksville, Tex., this upper zone is completely cut out by the unconformity which there separates the Annona chalk from the overlying Taylor marl (upper). Although a phosphatic conglomerate containing also a few water-worn novaculite pebbles is present at the base of this marl near Clarksville and is believed to mark an unconformity, it remains to be established that the upper 60 feet of the White Cliffs section is completely unrepresented in the Clarksville area; the occurrence of the large echinoid *Echinocorys texana* (Cragin) both in the upper part of the chalk near Clarksville and in the upper 60 feet of massive chalk at White Cliffs suggests approximate age equivalency of the containing beds, for this species is supposedly

<sup>20</sup> Ellisor, A. C., and Teagle, John, Correlation of the Pecan Gap chalk in Texas: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1509-33, 1934.

restricted to a narrow vertical range. Dane<sup>21</sup> refers the lower 50 feet of the section at White Cliffs to the upper part of his Ozan formation, and it appears that the Ozan as a whole is a sandy facies corresponding to the middle and lower parts of the Annona in Red River County. The correlation of the unconformity that Dane<sup>22</sup> recognized at the base of the Ozan formation with the unconformity marked by the phosphatic bed at the base of the Annona chalk in Red River County is probably correct.

The ostreid species *Gryphaea vesicularis* Lamarck (var.) is frequently mentioned by Ellisor and Teagle as present in the *Diploschiza cretacea* zone (the middle one of their three Pecan Gap zones). Most of the shells of this genus in this zone should more properly be referred to *Gryphaea convexa* (Say); examples of the species are illustrated in Dane's Arkansas report<sup>23</sup> under the name "*Gryphaea* sp." Although this species is common at about the horizon of the *Diploschiza cretacea* zone, it is known to have considerable vertical range in beds of lower Taylor age and is hardly a safe index fossil in close correlation; its abundance at any given locality may be due to favorable local environmental conditions.

The beds in northeastern Texas to which the name "Brownstown marl" has been applied appear to be correctly correlated with the typical Brownstown marl of southwestern Arkansas. Israelsky<sup>24</sup> has correlated the latter with the Bonham clay of Texas, but he does not state where he obtained his sample or samples of Bonham clay. As shown in figure 7, the Blossom sand appears to merge westward in Fannin County into less sandy or nonsandy clay or marl; the body of clay in the vicinity of Bonham, to which the name "Bonham" has been given, probably includes representatives of the Blossom and perhaps also the Brownstown marl. A sample collected a mile or two south of Bonham might very well yield a Brownstown microfauna, whereas a sample collected in the beds mapped as Bonham north of Paris, Lamar County, would be stratigraphically lower than the typical Brownstown and presumably would be of Tokio age. As interpreted in the present paper the main body of the Brownstown marl merges westward into the Gober tongue of the Austin chalk (fig. 7), the upper part of which is younger than the youngest beds of the typical Austin chalk in Travis County.

#### TEXAS AND ALABAMA SECTIONS COMPARED

The down-warped Mississippi embayment, which dates from early Upper Cretaceous time, has produced a wide geographic gap between the outcrops of the

Upper Cretaceous sediments of Texas and Arkansas on the one hand and those of Mississippi and Alabama on the other. The differences in the successions of sediments making up the sections in the two areas and the paucity of fossils of sufficiently restricted vertical range to serve as index markers have rendered the exact correlation of the sections somewhat difficult.

Fossil floras from the Woodbine sand of Texas and from the Tuscaloosa formation of Alabama, studied by Berry,<sup>25</sup> have been correlated with each other, with the Raritan formation of Maryland and New Jersey, and with the Cenomanian of Europe. The Eagle Ford shale (Turonian) of Texas, which is last seen in Lamar County, in the northeastern part of the State, has not been recognized at the surface east of the Mississippi River and is believed to be represented in an unconformity that is now known to separate the Tuscaloosa from the Eutaw formation entirely across Alabama. There is a paucity of fossils in the lower and middle parts of the Eutaw formation, but the few that have been found suggest an age younger than that of the Eagle Ford shale.

The Tombigbee sand member, which forms the upper part of the Eutaw formation (see fig. 7), is fossiliferous in its upper part. Some of the fossils are not known outside of the eastern Gulf region; some have not been critically studied, and their meaning in long-distance correlation is not well known; a few have value as time markers, but it happens that these few are more useful in correlating the containing beds with sections in distant areas than with the Texas section. For example, the free-floating crinoid *Marsupites americanus* Springer, found in the Tombigbee sand at Plymouth Bluff, on the Tombigbee River in Mississippi, has a close analog in *M. testudinarius* Schlotheim, in the upper Santonian of Europe, and *Marsupites* sp. is present in the Telegraph Creek formation of Montana, which immediately overlies beds of Niobrara age. The ammonite genus *Texanites* (*Mortoniceras* of authors) is represented in the Tombigbee sand by species related to *Texanites delawarensis* (Morton) from the Merchantville clay of New Jersey. Ammonites of this group have a considerable range in Texas from beds of uppermost Austin age up into about the lower one-fourth of the Taylor marl and beds of lower Taylor age, and the group is represented in the Eagle sandstone of Montana, which immediately overlies the Telegraph Creek formation. This group of ammonites, although indicating approximate correspondence in the age of the containing beds in different areas, has a considerable stratigraphic range and in our present state of knowledge does not afford a basis for the exact correlation of narrowly restricted zones; a better knowledge of the species of the group may later afford such a basis. *Gryphaea*

<sup>21</sup> Dane, C. H., Upper Cretaceous formations of southwest Arkansas: Arkansas Geol. Survey Bull. 1, pp. 58-79, 1929.

<sup>22</sup> Idem, p. 76 and fig. 3, p. 81.

<sup>23</sup> Idem, pl. 11, fig. 2, and pl. 12, figs. 3, 4.

<sup>24</sup> Israelsky, M. C., Correlation of the Brownstown (restricted) formation of Arkansas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 683-684, 1929. See also Stephenson, L. W., idem, pp. 1073-1074.

<sup>25</sup> Berry, W. E., Upper Cretaceous floras of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 112, pp. 39-41, 1919.

*wratheri* Stephenson<sup>26</sup> is common to the upper part of the Tombigbee sand and to the *Gryphaea wratheri* zone, which lies in the upper part of the type Austin chalk, 100 feet or more below its top in Travis County, Tex.; this fossil is believed to indicate only approximate synchroneity.

The nearest approach to an exact correlation of a narrowly restricted zone west and east of the Mississippi embayment is that afforded by the small oyster *Ostrea elegantula* White,<sup>27</sup> which has recently been identified from the two areas. As indicated on previous pages, this species has been collected from five localities in a very narrow zone within a few feet of the top of the Blossom sand, extending nearly across Red River and Lamar Counties, Tex. The species has also been collected in a narrow zone in marine sand of basal Selma age, overlying the Tombigbee sand, at two localities near Hatchetubbee, in Russell County, Ala. If *Ostrea elegantula* characterizes a narrowly limited zone throughout the Gulf region, as seems likely, it affords a basis for correlating the marine sand near Hatchetubbee with the upper part of the Blossom sand. As the Blossom sand has been shown to be of upper type Austin age, it follows that the Eutaw formation, including the Tombigbee sand member, which underlies the sand at Hatchetubbee, is of Austin age.

The next zone stratigraphically above the *Ostrea elegantula* zone that affords a fairly exact tie between the eastern and western Gulf regions is the *Diploschiza cretacea* zone.<sup>28</sup> In Alabama this zone lies within the Selma chalk a little above its middle; in Texas it forms the upper part of the Annona chalk in Red River County, is traceable in the Pecan Gap chalk in the central part of the State, and forms the upper part of the Anacacho limestone in Medina County.

#### SUMMARY AND CONCLUSIONS

The data presented on foregoing pages and the conclusions drawn therefrom may be summarized as follows:

1. At least five well-characterized and easily traceable faunal zones are differentiated in the upper one-fourth of the typical Austin chalk in Travis County. These zones, in ascending order, are (a) the *Inoceramus undulato-plicatus* zone, 100 feet or more below the top of the chalk; (b) the *Gryphaea wratheri* zone, closely above the preceding zone; (c) the *Exogyra tigrina* zone, about 40 feet below the top of the chalk, probably the basal bed of the Burditt marl of Adkins; (d) the *Ostrea centerensis* zone, about 30 feet below the top of the chalk; (e) the *Ostrea travisana* zone, about 10 feet below

the top of the chalk. The relation of these zones to the top of the chalk from place to place along the strike of the formation and the presence of a thin phosphatic bed at the base of the overlying Taylor marl throughout central Texas, except in Dallas County, indicate the presence of an erosional unconformity at the top of the chalk.

2. The Burditt marl of Adkins, if recognized as a separate lithologic unit, should be treated as an upper marly member of the Austin chalk; it consists essentially of chalk, marly chalk, and chalky marl; typical chalk is an important part of the unit, as shown by exposures on Little Walnut Creek upstream and downstream from the Manor road crossing, where hard, brittle chalk makes up at least the upper 20 feet of the section immediately below the basal phosphatic bed of the Taylor marl. Foraminifera collected between the *Ostrea tigrina* and *O. centerensis* zones were studied by J. A. Cushman, who regards them as constituting an Austin fauna.

3. The five zones present in the Austin chalk beneath the phosphatic bed in Travis County continue along the strike at least as far north as Bell County, except where cut out by faulting. In the vicinity of Waco the phosphatic bed rests directly upon the *Inoceramus undulato-plicatus* zone, the lowest of the five zones, the other zones having been cut out by erosion between Bell County and Waco. In Dallas County the top of the chalk has risen again until it is stratigraphically 200 or 250 feet above the *Inoceramus undulato-plicatus* zone. In Fannin County the top of the Gober tongue of the Austin chalk is estimated to be at least 400 feet above the *Inoceramus undulato-plicatus* zone, which is exposed just northwest of Whitewright; a thin phosphatic bed is present at the base of the Taylor marl, which immediately overlies the Gober tongue in Fannin County. In Lamar County the top of the Gober tongue is estimated to be 200 feet above the *Ostrea travisana* zone, which is exposed at the southwestern outskirts of Paris, indicating that the top of the Gober is stratigraphically about 200 feet higher than the top of the Austin in Travis County.

4. The hiatus between the Taylor marl and the Austin chalk differs in time value from place to place, owing in part to the erosional unconformity at the top of the Austin and in part to differences in the stratigraphic position of the base of the Taylor. At Waco the phosphatic bed is fully 900 feet below the Pecan Gap chalk; in Travis County the phosphatic bed is estimated to be only about 300 feet below the Pecan Gap; in Comal County near New Braunfels it is probably less than 50 feet below beds of Pecan Gap age; and in northeastern Texas the phosphatic bed is 400 or 500 feet below the Pecan Gap chalk.

5. The evidence indicates that in Fannin and Lamar Counties the top of the Gober tongue of the Austin chalk is of the order of 200 feet stratigraphically

<sup>26</sup> Stephenson, L. W., New Upper Cretaceous Ostreidea from the Gulf region: U. S. Geol. Survey Prof. Paper 186-A, pp. 1, 2-4, 1936.

<sup>27</sup> Idem, pp. 2, 6-8.

<sup>28</sup> Stephenson, L. W., The genus *Diploschiza* from the Upper Cretaceous of Alabama and Texas: Jour. Paleontology, vol. 8, no. 3, pp. 273-280, pl. 38, 1934; Further notes on the Cretaceous pelecypod genus *Diploschiza*: Jour. Paleontology, vol. 9, no. 7, pp. 588-591, pl. 70, figs. 1-12, 1935.

higher than the top of the type Austin in Travis County. This relation was recognized by the writer in former papers, but owing to failure to recognize a regional unconformity between the Austin and Taylor, the upper part of the Gober tongue was correlated with the lower part of the Taylor marl; it is now believed that the uppermost beds of the Gober are older than the Taylor and are assignable in time to the hiatus separating the Austin and Taylor; it follows also that the Brownstown marl is older than the Taylor. A foraminiferal fauna collected near the top of the Gober tongue near Bailey, Fannin County, was assigned by J. A. Cushman to the Austin.

6. The evidence of the Foraminifera, as interpreted by Cushman, tends strongly to confirm the conclusion here expressed, that the Austin chalk and Taylor marl in outcrop are separated by a pronounced erosional unconformity.

7. The Annona chalk, which in eastern Red River County is estimated to be 300 or 400 feet thick, is the time equivalent of the combined lower part of the Taylor marl, Wolfe City sand member, and Pecan Gap member of Lamar, Delta, and Fannin Counties. The phosphatic bed that forms the base of the Annona chalk north of White Rock, in Red River County, has been traced westward and found to be continuous with a phosphatic bed at the base of the Taylor marl just above the Gober tongue of the Austin chalk in Lamar County. The tracing of the phosphatic bed is facilitated by the presence of thin flakes of characteristic sandy limestone in the material immediately above it; in eastern Red River County these limestone flakes are in the base of the Annona chalk, whereas farther west in the same county and in eastern Lamar County they are in the base of the Taylor marl.

8. The Pecan Gap chalk is traceable from its type locality near Pecan Gap east-northeast in a narrow belt through Delta County, southeastern Lamar County, and western Red River County; it passes into and forms the upper part of the Annona chalk in central and eastern Red River County.

9. The interpretation of the stratigraphy in Red River County, as expressed above, is supported by the strike of the beds through the northern parts of Red River and Lamar Counties; the phosphatic bed at the base of the Annona chalk (strike,  $7^{\circ}$  or  $8^{\circ}$  north of east and its westward continuation at the base of the Taylor marl are approximately paralleled by a similar phosphatic bed at the base of the stratigraphically lower

Brownstown marl and by a narrow zone of fossiliferous concretions within a few feet of the top of the still lower Blossom sand; the concretions are characterized by the presence in great numbers of the small oyster species *Ostrea elegantula* White.

10. In southwestern Arkansas the Annona chalk and the underlying Ozan formation are together the approximate time equivalent of the Annona chalk in Red River County, Tex.; however, in Red River County an undetermined though probably small thickness of chalk has been removed from the top of the Annona by erosion, as shown by an unconformity separating the Annona from the overlying Taylor (upper). The phosphatic bed at the base of the Ozan formation is believed to be the eastward continuation of the phosphatic bed at the base of the Annona chalk in Red River County.

11. The species *Ostrea elegantula* White occurs in a narrow zone in marine sand of basal Selma age near Hatchetubee, Russell County, Ala., and is believed to indicate the time equivalence of the containing bed there with the upper part of the Blossom sand (of upper Austin age) of northeastern Texas, which also carries this species in a narrow zone of concretions.

12. The Tombigbee sand member of the Eutaw formation of Alabama and Mississippi underlies the Selma chalk; the Tombigbee carries a fauna which relates it in age to the upper one-fourth or less of the typical Austin chalk in Travis County, and this fauna and the meager fauna of the more typical part of the Eutaw formation below are definitely younger than the fauna of the Eagle Ford clay of Texas. The Eutaw is separated from the still lower Tuscaloosa formation (Cenomanian) by an unconformity that is believed to be the time representative in the eastern Gulf region of the Eagle Ford clay (Turonian).

13. The name "Pecan Gap chalk" is used by Ellisor and Teagle essentially in the sense of a faunal zone, rather than a lithologic unit. It is made to supplant the formation names "Annona chalk" and "Anacacho limestone", both of which have many years' priority; each of these units embraces a thicker section (several hundred feet) and a much longer time period than the typical Pecan Gap chalk (thickness less than 50 feet). There is no justification, either in priority or in the actual relations of beds, for extending the application of the name "Pecan Gap chalk" to include these two formations, and to attempt to do so tends to obscure and confuse the true stratigraphic relations.

# INFERENCES ABOUT THE ORIGIN OF OIL AS INDICATED BY THE COMPOSITION OF THE ORGANIC CONSTITUENTS OF SEDIMENTS

By PARKER D. TRASK

## ABSTRACT

Petroleum originates mainly from the organic matter in marine sediments, which is derived chiefly from remains of planktonic organisms in the overlying water. The original organic source material, represented by the plankton, is taken in as food by many other types of organisms in succession, and in this process of utilization it decreases very greatly in quantity before the time it reaches the sea floor and is deposited in the sediments. The quantity of organic material continues to diminish after it is buried in the sediments, but the rate of diminution is small compared with the rate while the organic matter is in the overlying water. The composition of the average plankton is 24 percent of protein, 3 percent of fat, and 73 percent of carbohydrates and other nonnitrogenous compounds. In recently deposited sediments the proportion is protein 40 percent, fat 1 percent, and carbohydrates and other compounds less than 60 percent. In ancient (lithified) sediments the proportion is protein 27 percent, fat 1 percent, and other compounds more than 60 percent.

As the organic matter passes from plankton to lithified sediments it tends to become more complex in composition. This is because the oxygen content decreases progressively with depth in the buried sediments, and in an environment deficient in oxygen complex organic matter becomes progressively less satisfactory as food for living organisms; thus the unutilizable residue becomes more and more complex. The influence of the lack of free oxygen in the environments in which the organic matter lies is reflected in the progressive loss of oxygen in the organic constituents between the time of formation of the plankton and the time of the burial of the organic matter in the sediments. In plankton the oxygen content of the organic constituents is estimated to be 39 percent, in recent sediments 30 percent, and in ancient sediments 23 percent. These are average figures; individual samples may vary considerably.

Estimates of the ultimate composition of the organic matter in different stages of its history afford a means of evaluating the ratio of organic matter to carbon. This ratio is a useful index in calculating the organic content of substances provided the quantity of carbon is known. The average ratio of total organic matter to carbon in plankton is 2.1, in recent sediments 1.8, and in ancient sediments 1.6.

Cellulose, fats, and simple proteins ordinarily seem to be present in sediments in amounts too small to be the principal source of petroleum. Further evidence against fats as a source of oil is the unsaturated character of the fats compared with the saturated character of petroleum; the prevalence of naphthalene and other ring compounds in crude oil and their scarcity in fats; and the chemical stability of fatty substances. Petroleum apparently must come mainly from other compounds, such as complex proteins and nonnitrogenous complexes.

The tendency of the organic constituents to come to chemical equilibrium after they have been buried to a depth at which bacterial decomposition is insignificant is regarded as a possible

factor in the generation of liquid hydrocarbons. Liquid hydrocarbons after they are formed may dissolve organic substances. The organic constituents of the resulting solution may then react with one another in an effort to reach a point of equilibrium. Repeated solution and subsequent adjustments of this character lead eventually to the formation of petroleum.

## INTRODUCTION

To solve the problem of the origin of petroleum it is essential to know something about the composition of the substances from which the oil might be derived. Much information concerning source beds has been gathered in the course of studies supported jointly by the United States Geological Survey and the American Petroleum Institute. The available data suggest certain inferences about the origin of oil, which are presented in this paper for consideration by geologists.

Petroleum is generally believed to be formed from organic substances that have accumulated in sediments. The geologic conditions under which it is found indicate that it is commonly derived from fine-grained marine deposits, though some oil possibly may have originated from continental sediments. The mother materials of petroleum, therefore, being largely confined to marine sediments, must be derived from organic matter present in the overlying water. Most of this organic matter originates in the sea water itself, but some is washed from the land.

The successive changes in the chemical nature of the mother substances of petroleum from the time these substances first get into the water until they accumulate in the underlying sediments give clues as to the processes that may take place after they have been deposited. After sediments have been buried to a depth of a few feet they cannot be collected for study by ordinary coring devices, and the changes that take place in them have to be ascertained largely by inference and by comparison with lithified sediments of different geologic ages which appear to have had a similar origin. Petroleum, apparently, is not generated until the sediments have been buried for some time.<sup>1</sup> Consequently, any method of study that affords evidence of ways in which organic substances in sediments may be altered is an aid in the solution of the problem.

<sup>1</sup> Trask, P. D., and Wu, C. C., Does petroleum form in sediments at time of deposition? Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 1451-1463, 1930.

The chemical composition of organic substances in sea water and in the underlying sediments is difficult to ascertain, because of the paucity and inadequacy of available information. The data, therefore, have to be presented in very general form, and care must be taken in drawing conclusions. The inferences presented in this paper may serve mainly to stimulate discussion and to suggest lines of study that may advantageously be pursued further.

#### DECREASE IN QUANTITY OF SOURCE MATERIAL WITH TIME

##### DECREASE IN WATER

The main source of organic matter in sediments is the floating plant life—the phytoplankton.<sup>2</sup> The phytoplankton serves as the main supply of food for the animal life of the sea, and much of it is devoured or decomposed before it is buried in the underlying sediments.

When organic matter in any form is taken in as food by another organism, part of it is assimilated into the tissues of the organism, part is excreted as unutilizable residue, and the rest is used by the organism to generate energy. The part that is converted into energy is largely destroyed in the process, leaving waste products, such as carbon dioxide and water.

The quantity of unutilizable residue in food is small, though the proportion varies somewhat with the form of food and the type of animal that eats it. In human beings the quantity of unassimilable residue is about 5 percent of the food consumed,<sup>3</sup> and this figure can be taken as generally indicative of the small proportion of unassimilable organic matter in the food eaten by other organisms, such as marine animals.

The proportion of the food transformed into body tissue also is small. If the mature stage of the animal is long compared with the growing stage, this proportion is particularly small. The plaice, a kind of flounder, may be taken as an example of an organism of this type in the sea. While the plaice is growing, about one-sixth of the food it consumes is transformed into body tissue,<sup>4</sup> but after it reaches maturity it increases very little in weight; therefore, for its life as a whole the quantity of food material transformed into protoplasm is small. If the mature stage of the organism is short compared with the growing stage, the proportion of food converted into protoplasm might be thought to be relatively large. However, bacteria, which may be taken as an example of this type of organism, utilize less than 20 percent of the energy they evolve.<sup>5</sup> Accordingly it may be presumed that

less than 20 percent of the food they consume is transformed into protoplasm. Consequently, even in the type of organism that has a relatively long growing period, probably a comparatively small proportion of the food consumed is transformed into protoplasm.

Thus the first time the planktonic organisms serve as food, a relatively large part—under ordinary conditions much more than half—is transformed into energy and is lost as organic matter; a small part is excreted as unassimilable residue; and only the part that goes into the building of protoplasm remains as organic matter more or less similar in nature to the original food material.

The organism that fed upon the plankton in turn serves as food for some other organism, with a similar transformation of organic matter into energy, residue, and a relatively small amount of new protoplasm. This process may be repeated several times. The ultimate result is an immense diminution in volume of the original organic matter, the presence of a moderate amount of unassimilable residue, and the formation of a very small proportion of living organic matter.

The unassimilable residue may still serve as food for certain types of organisms, but, as pointed out by Krogh,<sup>6</sup> being composed of waste products, it is likely to be a relatively poor source of nourishment for most forms of life. As the organisms that feed upon it are subsequently consumed by other organisms, the resulting waste products become progressively less satisfactory as sources of food, until ultimately the residue consists of rather complex substances that are resistant to decomposition. In the later stages of its history, particularly after it has been buried some distance beneath the surface of the deposits, where micro-organisms are the main forms of life present, some of the organic residue may consist of undecomposed cells of bacteria.

The nature and quantity of the ultimate residual material depends to a considerable extent upon the availability of oxygen for the oxidation of the organic substances and the resulting production of energy. In the water and in the upper few inches of the sediments the supply of oxygen is ordinarily adequate to support considerable life. In this zone, therefore, the organic matter decreases greatly in quantity. In fact, in some areas in which the water is well aerated the organic matter may be almost completely destroyed before it reaches the sea bottom, and only very little residual organic material may be deposited.

##### DECREASE IN SEDIMENTS

The organic matter that accumulates in sediments consists mainly of the resistant residual compounds. After it has been buried a few inches beneath later sediments, it is associated with little or no free oxygen.<sup>7</sup>

<sup>2</sup> Trask, P. D., Origin and environment of source sediments of petroleum, pp. 110-172, Houston, Tex., Gulf Publishing Co., 1932.

<sup>3</sup> Sherman, H. C., Chemistry of food and nutrition, p. 101, New York, Macmillan Co., 1918.

<sup>4</sup> Petersen, C. G. J., and Jensen, P. B., Valuation of the sea, I, Animal life of the sea bottom, its food and quantity: Danish Biol. Sta. Rept. 20, p. 66, 1911.

<sup>5</sup> Waksman, S. A., Principles of soil microbiology, p. 420, Baltimore, Williams, Wilkins Co., 1927.

<sup>6</sup> Krogh, A., Dissolved substances as a food of aquatic organisms: Conseil perm. expl. mer Rapports et procès-verb., vol. 75, pp. 7-37, 1931.

<sup>7</sup> ZoBell, C. E., and Anderson, D. Q., Vertical distribution of bacteria in marine sediments: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 266, 1936.

and hence is unlikely to be altered greatly during its future history. The remarkable decrease in number of bacteria within the upper 8 inches of marine sediments<sup>8</sup> is evidence of the decrease in oxidation of organic matter. Thus, the rate of decrease in quantity of organic matter is much greater during the interval between the time it is formed by the phytoplankton and the time it is buried a few inches beneath the sea floor than in the subsequent stages of its history.

The data on the organic content of recent (unconsolidated) and ancient (lithified) sediments obtained by the writer and his associates in general support this conclusion. The average decrease in organic matter within the upper 12 inches of marine sediments, as indicated by 150 samples of sediments from many types of environment, is 15 percent,<sup>9</sup> and the range of decrease is from less than 1 percent to 45 percent. Twenhofel<sup>10</sup> mentions a lake in Wisconsin in which the organic content of the sediments practically disappears within a few feet of the surface of the deposits, but complete decomposition of the organic matter within a few feet of the surface almost certainly is not a general characteristic of marine sediments. Of many thousand samples of ancient sediments analyzed by the writer and his associates,<sup>11</sup> practically all contain measurable amounts of organic matter, and the average organic content is 1.5 percent of the weight. In recent marine sediments of similar character, represented by about 2,000 analyses from many parts of the world, the average organic content is 2.5 percent.<sup>12</sup> The number of samples is so large and the localities from which they came are so widespread that the data may be considered as indicating the general order of magnitude of the organic content of recent and ancient fine-grained

marine clastic sediments. The average loss in organic content during burial is therefore of the order of magnitude of 2.5—1.5, or 1 percent, and the proportionate loss is 1.0÷2.5, or 40 percent. This figure of 40 percent naturally is an approximation, and the loss in individual sediments may differ considerably from it. Nevertheless, the loss of organic matter in buried sediments is relatively small compared with the loss of organic matter between its planktonic source and the form in which it occurs in the upper layers of sediment.

#### GENERAL COMPOSITION OF ORGANIC MATTER

##### PLANKTON

The phytoplankton (the part of the plankton consisting of plants) comprises two main groups of organisms—the diatoms, which have siliceous skeletons, and the peridineans or dinoflagellates, which consist entirely of soft parts. Other forms of plant life are present, but these two groups represent the types that are most commonly caught in the nets used in oceanographic investigation. The copepods, small crustaceans that feed on the phytoplankton, are generally considered a part of the plankton.

The composition of these three forms of plankton, as determined by Brandt,<sup>13</sup> is summarized in table 1. The results are presented on an ash-free basis and are given in terms of ether extract, crude protein, and nonnitrogenous constituents. The ether extract is roughly equivalent to the fat content; the crude protein represents the nitrogenous constituents and is 6.25 times the nitrogen content; the nonnitrogenous constituents represent the remainder of the organic matter—that is, the nitrogen-free, nonfatty compounds. The nonnitrogenous compounds correspond principally to the carbohydrates. The term "crude fiber" refers to the nonnitrogenous compounds that are insoluble in weak acid and weak alkali; cellulose is included with the crude fiber.

<sup>8</sup> Idem, p. 262. Reuszer, H. W., Marine bacteria and their role in the cycle of life in the sea, III, The distribution of bacteria in the ocean waters and muds about Cape Cod: Biol. Bull., vol. 65, pp. 480–497, 1933.

<sup>9</sup> Trask, P. D., op. cit., p. 206.

<sup>10</sup> Twenhofel, W. H., Sedimentation and stratigraphy from modern points of view: Jour. Paleontology, vol. 8, pp. 456–458, 1934.

<sup>11</sup> Trask, P. D., and Hammar, H. E., Organic content of sediments: Drilling and Production Practice, 1934, pp. 117–130, Am. Petroleum Inst., 1935.

<sup>12</sup> Trask, P. D., Origin and environment of source sediments of petroleum, pp. 249–284, Houston, Tex., Gulf Publishing Co., 1932.

<sup>13</sup> Brandt, K., Beiträge zur Kenntnis der chemischen Zusammensetzung der Plankton: Wiss. Meeresuntersuchungen, neue Folge, Abt. Kiel, Band 3, pp. 43–90, 1898.

TABLE 1.—Composition of different types of organic matter on ash-free basis

|                                    | Percent <sup>1</sup> |               |                          |                          | Ratio                    |                    |                                |
|------------------------------------|----------------------|---------------|--------------------------|--------------------------|--------------------------|--------------------|--------------------------------|
|                                    | Crude protein        | Ether extract | Nonnitrogenous compounds | Crude fiber or cellulose | Organic matter to carbon | Carbon to nitrogen | Hydrogen atoms to carbon atoms |
| Marine plankton: <sup>2</sup>      |                      |               |                          |                          |                          |                    |                                |
| Peridineans                        | 14                   | 1.5           | 85?                      | 42?                      | 2.2                      | 12.3               | 1.77                           |
| Diatoms                            | 29                   | 8             | 63                       | 0                        | 2.0                      | 8.0                | 2.2?                           |
| Copepods                           | <sup>3</sup> 65      | 8             | 22                       | 0                        | 2.0                      | 4.9                | 1.88                           |
| Average plankton                   | 24                   | 3             | 73                       | 14?                      | 2.1                      | 10.2               | 1.87                           |
| Lake plankton: <sup>4</sup>        |                      |               |                          |                          |                          |                    |                                |
| Net plankton                       | 53                   | 8             | 39                       | 5                        | 1.97                     | 6.2                | -----                          |
| Nannoplankton                      | 49                   | 5             | 46                       | 5                        | 1.98                     | 6.4                | -----                          |
| Micro-organisms: <sup>5</sup>      |                      |               |                          |                          |                          |                    |                                |
| Marine algae                       | 6                    | 3             | 85                       | 4                        | -----                    | -----              | -----                          |
| Soil fungi                         | 7-50                 | 1-10          | 37-82                    | -----                    | 2.05                     | 8-50               | 1.94                           |
| Soil bacteria                      | 40-75                | -----         | -----                    | -----                    | 1.78                     | 5±                 | 1.65                           |
| Marine invertebrates: <sup>6</sup> |                      |               |                          |                          |                          |                    |                                |
| Crustaceans                        | 75                   | 6             | 5                        | 0                        | 2.05                     | 4.0                | 1.70                           |
| Pelecypods                         | 72                   | 8             | 20                       | 0                        | 2.19                     | 4.2                | 1.67                           |
| Gastropods                         | 64                   | 9             | 25                       | 0                        | 2.10                     | 4.9                | 1.67                           |
| Echinoderms                        | 67                   | 11            | 18                       | 0                        | 2.10                     | 4.6                | 1.76                           |
| Worms                              | 64                   | 13            | 19                       | 0                        | 1.89                     | 5.1                | 1.68                           |
| Coelenterates                      | 78                   | 11            | 7                        | 0                        | 2.00                     | 4.2                | 1.66                           |
| Fishes: <sup>2</sup>               |                      |               |                          |                          |                          |                    |                                |
| Herring                            | 60                   | 38            | 0                        | 0                        | -----                    | 5?                 | -----                          |
| Flounder                           | 95                   | 5             | 0                        | 0                        | -----                    | 4?                 | -----                          |
| Marine plants: <sup>7</sup>        |                      |               |                          |                          |                          |                    |                                |
| Fresh Zostera                      | 19                   | -----         | 75                       | -----                    | 2.18                     | 11.4               | -----                          |
| Decaying Zostera                   | 6                    | -----         | 90                       | -----                    | 2.41                     | 34.9               | -----                          |
| Decomposed Zostera                 | 8                    | -----         | 88                       | -----                    | 2.15                     | 25.2               | -----                          |
| Land plants: <sup>2</sup>          |                      |               |                          |                          |                          |                    |                                |
| Hay                                | 15                   | 4             | 81                       | 29                       | -----                    | 20±                | -----                          |
| Legumes                            | 22                   | 3             | 75                       | 36                       | -----                    | 12±                | -----                          |
| Rye straw                          | 4                    | 2             | 94                       | 54                       | -----                    | 60±                | -----                          |
| Sediments: <sup>8</sup>            |                      |               |                          |                          |                          |                    |                                |
| Recent sediments                   | 40                   | 1             | 47                       | 1                        | 1.7-2.0                  | 8-12               | 1.7?                           |
| Ancient sediments                  | 27                   | 1             | 63                       | 0                        | 1.4-1.8                  | 13-20              | 1.7?                           |
| Surface soils                      | 34                   | 1             | 56                       | 12                       | 1.7-2.0                  | 9-14               | -----                          |

<sup>1</sup> Where the items do not add up to 100 percent the figures given represent material recovered during the analysis.<sup>2</sup> Brandt, K., Beiträge zur Kenntnis der chemischen Zusammensetzung der Plankton: Wiss. Meeresuntersuchungen, neue Folge, Abt. Kiel, Band 3, pp. 55-88, 1898. The figures for the average plankton represent the average composition of the plankton that is caught in nets, not the numerical average of the composition of the three main components of the plankton, except for the figure of 14 percent for crude fiber or cellulose, which is an average for the three main groups of plankton.<sup>3</sup> Does not include chitin compounds.<sup>4</sup> Birge, E. A., and Juday, C., The inland lakes of Wisconsin, The plankton, I, Its quantity and chemical composition: Wisconsin Geol. and Nat. History Survey Bull. 64, p. 196, 1922.<sup>5</sup> Waksman, S. A., Principles of soil microbiology, pp. 377-383, Baltimore, Williams, Wilkins Co., 1927; The role of bacteria in the cycle of the life in the sea: Sci. Monthly, vol. 38, pp. 35-47, 1934.<sup>6</sup> Delff, C., Beiträge zur Kenntnis der chemischen Zusammensetzung wirbelloser Meerestiere: Wiss. Meeresuntersuchungen, neue Folge, Abt. Kiel, Band 14, pp. 56-71, 1912.<sup>7</sup> Jensen, P. B., Studies concerning the organic matter of the sea bottom: Danish Biol. Sta. Rept., vol. 22, pp. 36-39, 1915.<sup>8</sup> Trask, P. D., Origin and environment of source sediments of petroleum, p. 200, Houston, Tex., Gulf Publishing Co., 1932.

The average composition of the plankton is 24 percent of protein, 3 percent of fat, and 73 percent of carbohydrates and similar nitrogen-free substances. The crude fiber is given as 14 percent, but this figure is based on the analysis of a single catch of plankton and can be considered only as indicating that the celulose compounds may be present in the basic planktonic source material. In fact, all the figures for the average composition of the plankton are based on few data and represent only a rough approximation.

Crude protein is more plentiful in animal life than in plant life. The copepods contain 65 percent of crude protein, in contrast with 29 percent in the diatoms and 14 percent in the peridineans. The diatoms and copepods each contain 8 percent of fat, the peridineans only 1.5 percent. The peridineans are rich in carbohydrate, and some forms presumably contain appreciable quantities of cellulose.

In order to illustrate the relation of the marine plankton to other forms of life, the composition of several groups of animals and plants is given in table 1. The animal forms are rich in protein and fat. The plant forms are poor in protein, rich in carbohydrate, and, as compared with animals, poor in fat. The proportion of protein, fat, and carbohydrate differs considerably in the different groups of plants and animals. Moreover, some types of organisms differ in composition during different periods of the year. This seems especially true of the plankton.<sup>14</sup>

In the absence of data for the forms of marine plankton that pass through the meshes of the net (the nannoplankton), figures for organisms of this group living in lake water in Wisconsin are included in table 1.<sup>15</sup>

<sup>14</sup> Brandt, K., op. cit., pp. 43-90.<sup>15</sup> Birge, E. A., and Juday, C., The inland lakes of Wisconsin, The plankton, I, Its quantity and chemical composition: Wisconsin Geol. and Nat. History Survey Bull. 64, p. 196, 1922.

In this lake water the nannoplankton is similar in composition to the net plankton. By analogy it might be assumed that in the sea also the nannoplankton is similar in composition to the net plankton. Thus the average for plankton given in the table may be assumed to indicate roughly the general composition of marine plankton, which may be considered a basic source of petroleum. However, in interpreting the significance of these figures with respect to the origin of oil, one should bear in mind the probability that different types of planktonic substances are not all equally good sources of oil.

#### ORGANIC MATTER IN SEDIMENTS

The composition of the organic constituents of sediments is more difficult to determine than that of plankton, because of the admixtures of inorganic debris.

The data that have been compiled indicate that recent marine sediments contain 40 percent of crude protein, and ancient sediments 27 percent. The proportion of nitrogenous compounds in the organic constituents of recent sediments, therefore, is less than in most animals and higher than in most plants. Furthermore, the proportion of nitrogenous compounds is less in ancient sediments than recent sediments.

The fat content of the organic substances in sediments, as indicated by the ether extract, is 1 percent, which is considerably less than in plants or animals. Fatty substances, however, may be present in sediments in greater amounts than 1 percent, as they may occur as insoluble soaps<sup>16</sup>—that is, they may be combined with metals, such as calcium, magnesium, or aluminum, and therefore insoluble in ether. One of the most urgent needs at present is a practicable method of ascertaining the amount of such metallic soaps in sediments.

The nonnitrogenous constituents are present in ancient sediments in greater proportion than in recent sediments, and from this it may be inferred that they are relatively more resistant to decomposition than nitrogenous compounds.

The cellulose content of marine sediments is very small. In recent sediments it forms only 1 percent of the total organic content, and in ancient sediments it is practically absent. The small content of cellulose in recent sediments and its disappearance as the sediments become progressively more deeply buried may be explained as due to the readiness with which cellulose is attacked by microorganisms.

Data on the composition of soils are given for comparison in table 1. The crude protein content of soils is 34 percent, as compared with 40 percent for recent

sediments. The lower protein content of soils may be due to the fact that the organic constituents of soils are derived to a greater extent from plants, which contain less protein than animals. The fat content of soils is approximately the same as that of sediments. Soils are richer in nonnitrogenous compounds than recent sediments, and they contain much more cellulose. The difference in the source of the organic matter would account for the greater content of carbohydrates and cellulose.

#### COMPOSITION OF ORGANIC MATTER ON BASIS OF ULTIMATE ANALYSIS

##### METHODS OF DETERMINING COMPOSITION

The segregation of organic matter into protein, fat, and carbohydrate, though generally satisfactory for living matter, is not so satisfactory for the organic constituents of sediments, which consist mainly of residual products that have resisted decomposition and therefore no longer may properly be called proteins or carbohydrates. The organic constituents of possible source materials of oil may advantageously be examined in terms of the elements of which they are composed, but this procedure, too, is accompanied by difficulties, because in sediments it is impossible to segregate the organic constituents from the inorganic constituents.

In the determination of the organic content of sediments, the total quantity of organic matter must be determined, as well as the proportion of different elements. The principal elements in organic substances are carbon, oxygen, hydrogen, and nitrogen; other elements are present but ordinarily in quantities so small that they can be ignored without serious disadvantage for the purposes of this report. On this basis the organic content can be considered as the sum of the carbon, oxygen, hydrogen, and nitrogen.

Nitrogen in sediments is found almost exclusively in the organic constituents and is readily determined. Carbon can be measured directly if the mineral carbonates are first removed with acid. Hydrogen generally cannot be determined directly, as there is no good means of separating organic from inorganic hydrogen. Oxygen also cannot be determined directly, even in organic matter that contains no admixed mineral debris.

##### OXYGEN CONTENT

In living organisms the oxygen content is ordinarily taken to be the remainder after all the other elements have been determined. On this basis, the oxygen content in average plankton is 39 percent, in marine invertebrates 34 percent, in marine worms 30 percent, and in bacteria 25 percent. (See table 2.) The oxygen content therefore seems to decrease progressively in the forms of life that feed successively on the original plankton.

<sup>16</sup> Trask, P. D., Results of distillation and other studies of the organic nature of some modern sediments: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 1228, 1927. Wells, R. C., and Erickson, E. T., The analysis and composition of the fatty material produced by the decomposition of herring in sea water: Am. Chem. Soc. Jour., vol. 55, pp. 338-341, 1933.

TABLE 2.—*Composition of different types of organic matter on basis of ultimate analysis*

[Percent. Based mainly on same sources as table 1]

|                      | Carbon | Nitrogen | Hydrogen | Oxygen |
|----------------------|--------|----------|----------|--------|
| Peridineans          | 45     | 3        | 7        | 45     |
| Diatoms              | 50     | 6        | 8        | 36     |
| Copepods             | 50     | 10       | 8        | 32     |
| Average plankton     | 48     | 5        | 8        | 39     |
| Soil fungi           | 49     | 4        | 8        | 41     |
| Soil bacteria        | 56     | 11       | 8        | 25     |
| Marine invertebrates | 48     | 11       | 7        | 34     |
| Worms                | 53     | 10       | 7        | 30     |
| Recent sediments     | 52-60  | 6        | 7-8      | .25-35 |
| Ancient sediments    | 55-71  | 4        | 8-10     | 15-30  |

In recent marine sediments the organic matter should be essentially the same in composition as in the organisms that can live in the upper layers of these sediments, such as marine invertebrates, and therefore the oxygen content of the organic matter should range chiefly between 25 and 35 percent. The deeper layers of sediment, which are inhabited mainly by bacteria, might be expected to have the minimum content of 25 percent, but the surface layers, which are at or near the point of supply of organic matter from the overlying water, would probably have more nearly the maximum content of 35 percent. The mean of the postulated minimum and maximum percentages—30 percent—seems the most reasonable single figure for the oxygen content of the organic constituents of marine clastic sediments at and shortly after the time of their deposition. However, the quantity almost certainly differs considerably in different sediments.

In ancient sediments the oxygen content of the organic constituents generally should be less than in recent sediments, because of the greater ease with which oxygen, as compared with carbon, can be lost from organic constituents under reducing conditions. Moreover, the oxygen content would probably differ among different sediments because of the different conditions to which the sediments have been subjected during and after lithification.

The smaller content of oxygen in the organic constituents of ancient sediments, as compared with recent sediments, is indicated by the greater amount of chromic acid the ancient sediments can reduce per unit of carbon. In this process of reduction both organic and inorganic constituents are oxidized, but most of the oxygen is used for oxidizing the organic substances.<sup>17</sup>

The quantity of oxygen required to oxidize the sediments varies with the carbon content. The more oxygen consumed, the less is the state of oxidation (or the greater is the state of reduction) of the sediment. The ratio of the carbon content of the sediment to the quantity of chromic acid of standard strength that a

given amount of the sediment will reduce may be used as a measure of the state of oxidation (or reduction) of the sediment. A satisfactory form to use is the ratio of the percentage of organic carbon in the organic constituents of the sediment to the number of cubic centimeters of 0.4 normal chromic acid that can be reduced by 100 milligrams of sediment. The greater this ratio, the less is the oxygen required for oxidation of the sediment and the greater the oxygen content of the organic constituents. The ratio is therefore a direct index of the oxygen content of the organic constituents and hence is called the "oxidation factor." The oxidation factor, however, cannot be used as an exact means of determining the oxygen content of the organic matter, because of the uncertainty as to the amount of oxygen consumed by the oxidation of the inorganic constituents of the sediments.

The oxidation factor for ancient sediments ranges mainly between 0.75 and 1.20 and the average is approximately 1.00. For recent sediments, according to data supplied by Waksman,<sup>18</sup> the factor is 1.20. The higher oxidation factor for recent sediments indicates that their organic constituents contain more oxygen than those of ancient sediments.

The oxygen content of the organic matter can be calculated from the oxidation factor if data are available to show the proportion of organic matter oxidized and the proportion of oxygen used for oxidation of the inorganic constituents. In the absence of accurate data on the magnitude of these two variables it does not seem practicable in this paper to attempt more than a rough calculation. The oxygen content of the organic constituents of recent sediments as estimated from a comparison with living organisms ranges between 25 and 35 percent. The oxygen content of ancient sediments is materially less and, as indicated by the oxidation factor, may be 15 to 30 percent, or an average of about 23 percent.

When these figures for the oxygen content are substituted in the equation for calculating the oxygen content from the oxidation factor, certain figures for the proportion of organic matter oxidized and the proportion of oxygen required for oxidation of inorganic constituents have to be assumed in order to make the equation balance. As the assumed figures are reasonable and in accord with known data, these estimates of the oxygen content of ancient sediments, though questionable, are presumably of the proper order of magnitude.

In a significant proportion of ancient sediments the oxidation factor is less than 0.85, which indicates that the oxygen content of their organic constituents is considerably below the average, perhaps as low as 15 percent. The hypothesis should be considered that such reduced sediments may be more favorable source beds than sediments of average reduction. The re-

<sup>17</sup> Trask, P. D., and Hammar, H. E., Degrees of reduction and volatility as indices of source beds: Drilling and Production Practice, 1935, pp. 250-266, Am. Petroleum Inst., 1936.

<sup>18</sup> Waksman, S. A., personal communication.

search project on source beds now being carried on by the United States Geological Survey and the American Petroleum Institute includes an intensive study of the relation of the oxidation factor to the occurrence of oil, to see if this factor can be used as an index of source beds.<sup>19</sup>

#### CONTENT OF CARBON, HYDROGEN, AND NITROGEN

If the amount of oxygen in the organic constituents is known the percentages of the other major constituents—carbon, hydrogen, and nitrogen—can be calculated readily.

In the average plankton the ratio of hydrogen atoms to carbon atoms is about 1.9. (See table 1.) In marine invertebrates the ratio ranges from 1.66 to 1.76 and the average is 1.7. As the marine invertebrates as a class feed on the plankton, it would appear that the planktonic organic matter loses hydrogen with respect to carbon in being transformed into the protoplasm of the animals that feed upon it. In soil bacteria, which may be considered analogous to marine bacteria, the ratio of hydrogen atoms to carbon atoms is 1.65. Bacteria feed upon the organic matter at a later stage than invertebrates, and the composition of the bacteria is similar to that of the organic substances upon which they feed.<sup>20</sup> It therefore seems probable that in the organic constituents of recent sediments the ratio of hydrogen atoms to carbon atoms should be of the same order of magnitude as in bacteria and bottom-living organisms—namely, about 1.7—though the ratio presumably varies among different sediments. The hydrogen content, accordingly, can be estimated by multiplying the carbon content by the factor 1.7. In the absence of evidence to the contrary the same ratio can be used tentatively for ancient sediments. As carbon is 12 times as heavy as hydrogen, the relative weight of the hydrogen is  $1.7 \div 12$  or 0.14 times the weight of the carbon.

In recent sediments the ratio of the weight of carbon to nitrogen is about 9;<sup>21</sup> accordingly, the weight of the nitrogen is 0.11 times the weight of the carbon. In ancient sediments the carbon-nitrogen ratio seems to range mainly between 13 and 20 and to average about 17;<sup>22</sup> the weight of the nitrogen is therefore 0.06 times the weight of the carbon.

Thus, the combined weight of the carbon, hydrogen, and nitrogen in recent sediments is  $1.0 + 0.14 + 0.11 = 1.25$  times the weight of the carbon, and in ancient sediments it is  $1.00 + 0.14 + 0.06 = 1.20$  times the weight of the carbon. In recent sediments the weight of the oxygen is estimated to be 30 percent of the total weight

of the organic matter; the weight of the carbon, therefore, is  $(100 - 30) \div 1.25 = 56$  percent; hydrogen, being 0.14 times the carbon, is 8 percent; and nitrogen, being 0.11 times the carbon, is 6 percent. (See table 3.) In average ancient sediments oxygen is assumed to be 23 percent of the total weight of the organic matter, whence carbon is 64 percent, hydrogen 9 percent, and nitrogen 4 percent. In reduced ancient sediments, where the oxygen may be as low as 15 percent, carbon is 71 percent, hydrogen 10 percent, and nitrogen 4 percent.

TABLE 3.—*Ratio of organic matter to carbon in different types of organic matter in sediments*

|                           | Percent by weight |          |        |          | Ratio of organic matter to carbon |
|---------------------------|-------------------|----------|--------|----------|-----------------------------------|
|                           | Carbon            | Hydrogen | Oxygen | Nitrogen |                                   |
| Plankton                  | 48                | 8        | 39     | 5        | 2.1                               |
| Recent sediments          | 56                | 8        | 30     | 6        | 1.8                               |
| Ancient sediments         | 64                | 9        | 23     | 4        | 1.6                               |
| Reduced ancient sediments | 71                | 10       | 15     | 4        | 1.4                               |

#### CHANGES IN COMPOSITION WITH RESPECT TO TIME

As the total quantity of organic matter represented by the original planktonic source decreases in the course of time, the relative proportions of its constituents change. The oxygen content of the organic constituents decreases from 39 percent in plankton to 15 percent in reduced ancient sediments. Carbon increases from 48 to 71 percent. Hydrogen increases from 8 to 10 percent. Nitrogen is 5 percent in plankton, 6 percent in recent sediments, and 4 percent in ancient sediments. These quantities of carbon, hydrogen, oxygen, and nitrogen refer to the average percentage by weight of the particular type of organic matter, not to the proportions of the original quantity of organic matter in the plankton.

Table 3 shows the relative changes in the carbon, hydrogen, oxygen, and nitrogen as the organic matter diminishes. The main change is the progressive loss of oxygen with respect to the other constituents. As the proportion of oxygen decreases, the proportions of carbon and hydrogen necessarily increase. The increase in nitrogen from 5 percent in plankton to 6 percent in recent sediments is mainly a mathematical consequence of the decrease in oxygen and implies no real increase in nitrogen; but the decrease to 4 percent in the ancient sediments indicates a relative loss of nitrogen during burial of the sediments.

The changes in the nature of the organic matter during the course of time may be illustrated more clearly if the composition is expressed in terms of atomic ratios rather than as percentages by weight. The percentages given in table 3 have been recalculated as atomic ratios and reduced to a common denominator in table 4. Throughout this series the carbon content has been arbitrarily taken as 18. According to this

<sup>19</sup> Trask, P. D., and Hammar, H. E., op. cit., pp. 250-266.

<sup>20</sup> Waksman, S. A., Principles of soil microbiology, pp. 377-383, Baltimore, Williams, Wilkins Co., 1927.

<sup>21</sup> Trask, P. D., Origin and environment of source sediments of petroleum, p. 21, Houston, Tex., Gulf Publishing Co., 1932.

<sup>22</sup> Trask, P. D., and Hammar, H. E., Organic content of sediments: Drilling and Production Practice, 1934, p. 118, Am. Petroleum Inst., 1935. Also data in a paper to be published in Drilling and Petroleum Practice, 1936.

calculation hydrogen decreases from 34 in average plankton to 31 in recent and ancient sediments. Oxygen decreases from 11 in plankton to 7 in recent sediments and to 3 in reduced ancient sediments. Nitrogen decreases from about 2 in plankton to 1 in ancient sediments. Thus the organic matter as it changes from plankton to organic constituents of ancient sediments loses most of its oxygen and a considerable part of its nitrogen. It must be borne in mind, however, that the figures for the atomic ratios are based on general averages and that the ratios may vary considerably among individual sediments.

TABLE 4.—*Atomic ratios of constituents of different types of organic matter in sediments*

|                           | Carbon | Hydrogen | Oxygen | Nitrogen |
|---------------------------|--------|----------|--------|----------|
| Plankton                  | 18     | 34       | 11     | 2        |
| Recent sediments          | 18     | 31       | 7      | 2        |
| Ancient sediments         | 18     | 31       | 5      | 1        |
| Reduced ancient sediments | 18     | 31       | 3      | 1        |

#### RATIO OF ORGANIC MATTER TO CARBON IN SEDIMENTS

The determination of the total quantity of organic matter in sediments is an essential step in the study of source beds. The common procedure for estimating the organic content is to determine the carbon content and multiply it by a factor which is the reciprocal of the proportion of carbon to total organic matter. This factor naturally differs for different types of sediments and for different types of organic matter. It has been calculated for each of the four groups of organic matter considered in this report. For plankton it is 2.1, for recent sediments 1.8, for ancient sediments 1.6, and for reduced ancient sediments 1.4. (See table 3.)

In previous work<sup>23</sup> the writer has assumed a ratio of 1.7 for recent sediments, which is the same that soil chemists have used for many years for soils. Recently Alexander and Byers<sup>24</sup> have questioned the propriety of a single ratio of 1.7 and have pointed out that the ratio varies considerably among different soils. They have suggested that 1.93 is probably the most satisfactory single factor. Waksman<sup>25</sup> has proposed the factor 1.92 for recent marine sediments, and Potonié and Reunert<sup>26</sup> present data that indicate the factor 1.83 for certain recent lacustrine sediments in Germany.

<sup>23</sup> Trask, P. D., Origin and environment of source sediments of petroleum, p. 18, Houston, Tex., Gulf Publishing Co., 1932.

<sup>24</sup> Alexander, L. T., and Byers, H. G., A critical laboratory review of methods of determining organic matter and carbonates in soil: U. S. Dept. Agr. Tech. Bull. 317, pp. 1-24, 1932.

<sup>25</sup> Waksman, S. A., The role of bacteria in the cycle of life in the sea: Sci. Monthly, vol. 38, pp. 35-49, 1934.

<sup>26</sup> Potonié, R., and Reunert, D., Geologisch-chemische Untersuchungen von Sapropelen des Unterucker und Sakrower Sees: Schriften aus dem Gebiet der Brennstoff-geologie, Heft 10, pp. 149-169, 1935.

Organic constituents of recent sediments, being always submerged in water, should usually be more reduced than those of soils, which are not always completely saturated with water. The ratio of organic matter to carbon in recent sediments, therefore, would as a rule probably be less than in soils. Consequently, a ratio of 1.8 presumably would be better than 1.9.

In the absence of data to the contrary the writer in previous work<sup>27</sup> assumed that the ratio in ancient sediments was 1.5. According to the data given in table 3, the ratio 1.6 would be better for general use for ancient sediments and 1.4 for reduced ancient sediments.

The writer presents these ratios of organic matter to carbon content very tentatively. In order to estimate the organic content of sediments it is necessary to use some kind of a ratio of this type. At present, the ratio of organic matter to carbon seems the most practicable, and according to available data the figures given here seem the most satisfactory.

#### INTERPRETATION OF DATA

#### POSSIBLE SOURCE MATERIALS

*General character and relative quantity of organic material.*—The foregoing attempt to discuss quantitatively the changes in the organic constituents of sediments during the course of their history seems to indicate rather clearly that only a very small proportion of the original organic matter generated by the plankton actually accumulates in sediments, and that organic constituents buried a few inches in the muds on the sea bottom do not thereafter decrease greatly in quantity.

The organic constituents in sediments consist chiefly of complex resistant compounds, which with respect to their original planktonic source are chemically reduced in that they contain comparatively little oxygen. The relatively elementary substances such as sugars, celluloses, fats, and simple proteins, of which the original plankton is mainly composed, are decomposed or altered to a considerable extent during the process of deposition and probably occur in sediments in quantities so small that they are not likely to be major sources of petroleum.

In most oil fields the proportion of the organic matter that is converted into petroleum is difficult to ascertain. In the Santa Fe Springs field of California the proportion is probably about 4 percent, though it may be as low as 2 percent or as high as 15 percent.<sup>28</sup> In other fields the amount transformed into oil may be less, but as the sediments in the Santa Fe Springs field

<sup>27</sup> Trask, P. D., Results of the American Petroleum Institute research project on origin and environment of source beds of petroleum: Am. Petroleum Inst. Production Bull. 211, pp. 19-31, 1933.

<sup>28</sup> Trask, P. D., Proportion of organic matter converted into petroleum in Santa Fe Springs field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 245-257, 1936.

are mainly Pliocene and hence relatively young, the figures given are presumably minimum figures. Any constituent present in an amount less than 1 or 2 percent of the organic matter, therefore, in all probability cannot be a major source of petroleum.

*Cellulose.*—The three main constituents of the original planktonic protoplasm are carbohydrates, fats, and proteins, but by the time the derived organic materials are deposited in the sediments their nature has changed considerably. Cellulose, though perhaps constituting 14 percent of the original plankton, ordinarily is found in amounts of 1 percent or less in recent marine sediments.<sup>29</sup> Many sediments contain no measurable trace of cellulose, and the maximum observed was in a shallow lagoon deposit, where it was 5 percent of the organic constituents. In recent marine sediments the cellulose decreases in quantity from the surface downward, and in ancient sediments it is usually not present at all.<sup>30</sup>

Because of the small quantity of cellulose found in sediments, therefore, it does not seem probable that petroleum is derived mainly from the cellulosic constituents of the sediments, as advocated by Berl.<sup>31</sup> However, as the original planktonic source material may contain as much as 14 percent of cellulose, it is possible that some of the mother substances of petroleum in sediments may be derived from cellulose.

*Other carbohydrates.*—Other carbohydrates, such as hemicelluloses, starches, and sugars, are present in recent sediments in as small quantities as celluloses, and hence in all likelihood they are not major sources of oil. The organic constituents present in the sediments, however, may be derived to a considerable extent from carbohydrates of these types in the original planktonic protoplasm. The pentoses, because of their similarity to ring compounds, such as naphthenes, have been postulated as possible mother substances of petroleum,<sup>32</sup> but they also seem to be present in sediments in quantities too small to be a main source of oil.

*Proteins.*—Proteins can be considered as possible source material, as nitrogenous compounds form about 40 percent of the organic constituents in recent sediments and 27 percent in ancient sediments.<sup>33</sup> These nitrogenous compounds are derived largely from proteins in the basic planktonic organic matter, but the proteins in the sediments consist mainly of complex resistant compounds that apparently differ considerably from the proteins in the original plankton. Petroleum contains appreciable quantities of combined

<sup>29</sup> Trask, P. D., Origin and environment of source sediments of petroleum, p. 302, Houston, Tex., Gulf Publishing Co., 1932.

<sup>30</sup> *Idem*, pp. 200-218.

<sup>31</sup> Berl, E., Origin of asphalt, oil, natural gas, and bituminous coal: *Science*, new ser., vol. 80, pp. 227-228, 1934.

<sup>32</sup> Brooks, B. T., The chemical evidence for the low-temperature history of petroleum: *Inst. Petroleum Technologists Jour.*, vol. 20, pp. 177-205, 1934.

<sup>33</sup> Trask, P. D., *op. cit.*, p. 200.

nitrogen, though the proportion ordinarily is less than in the organic constituents of the sediments from which the oil seems to be derived.

Simple proteins are present in recent marine sediments in quantities so small that they probably should not be considered as major sources of oil. The average quantity of simple water-soluble proteins in the upper layers of recent marine sediments is about 3 percent of the organic matter.<sup>34</sup> This protein content in part may represent the protoplasm of micro-organisms living in the sediment and therefore may be destroyed or considerably modified after death of the organisms. Simple proteins tend to decompose rather readily in sediments and in the overlying water.<sup>34</sup> Therefore, if petroleum is derived from proteins, it presumably comes from the more resistant, complex nitrogenous compounds.

*Fats.*—Fatty substances have been regarded by many writers<sup>35</sup> as the main source of petroleum, but this hypothesis may not be correct. The chief reasons for believing that oil is derived from fatty substances are the low oxygen content of fatty materials and their similarity in composition to paraffin hydrocarbons. However, fats are chain compounds; all petroleums contain an appreciable proportion of ring compounds, and many petroleums contain more ring compounds (naphthenic, polycyclic, and benzenoid) than chain compounds (paraffenic).<sup>36</sup> Fatty materials are either saturated or unsaturated; petroleum is composed almost entirely of saturated substances.<sup>37</sup> The iodine number of the fatty substances found in marine animals and plankton ranges chiefly between 110 and 120;<sup>38</sup> in most crude oils the iodine number is less than 20, and in some it is as low as 2.<sup>39</sup> As the iodine number is an index of the degree of unsaturation of fatty and oily substances, the fatty materials that eventually are deposited in sediments evidently are much more unsaturated than the compounds ordinarily present in crude oil.

Consequently, if petroleum is derived mainly from fats, some special process such as polymerization has to be invoked to account for the formation of the ring compounds and the almost complete absence of unsaturated compounds. If polymerization or some other process has to be assumed, why limit the source to fatty materials? Other organic substances, in all probability, could serve as well as fats.

<sup>34</sup> Hecht, F., Der Verbleib der organischen Substanz der Tiere bei meerische Einbettung: *Senckenbergiana*, Band 15, pp. 165-249, 1933. Jensen, P. B., Studies concerning the organic matter of the sea bottom: *Danish Biol. Sta. Rept.* 22, pp. 1-39, 1915.

<sup>35</sup> Notably Engler, C., and Höfer, H., *Das Erdöl*, Band 2, pp. 59-146, 1909.

<sup>36</sup> Gruse, W. A., *Petroleum and its products*, pp. 4, 36, New York, McGraw-Hill Co., 1928.

<sup>37</sup> Sakhanov, A., and Wirabianz, R., Die chemische Zusammensetzung der Erdöle der U. S. S. R.: *Petroleum*, Band 25, pp. 867-892, 1929.

<sup>38</sup> Rosenfeld, G., Studien über das Fett der Meeresorganismen: *Wiss. Meeresuntersuchungen*, neue Folge, Abt. Helgoland, Band 5, pp. 57-84, 1904.

<sup>39</sup> Sakhanov, A. and Wirabianz, R., *op. cit.*, pp. 877-882. Gruse, W. A., *op. cit.*, pp. 27-32. Gurwitsch, L., *The scientific principles of petroleum technology*, translated and revised by H. Moore, pp. 28-33, London, Chapman & Hall, Ltd., 1926.

Another argument against the derivation of oil from fatty substances is the chemical stability of such substances.<sup>40</sup> Large quantities of fatty and waxy materials (which contain fatty acid radicals) are present in oil shales of continental origin, yet oil shales of this type are associated with very few oil fields.

Furthermore, fats—that is, fatty materials soluble in carbon tetrachloride—form less than 1 percent of the organic content of recent marine sediments<sup>41</sup> and therefore apparently are present in quantities too small to be a major source of oil. Other fatty materials, such as metallic soap or waxes, may be present in sediments in larger amounts than fats.<sup>42</sup> Fatty materials tend to ionize in water, and in the presence of an excess of metallic ions they are precipitated as soaps. No data are yet available on the quantity of metallic soaps in sediments. Metallic soaps may possibly be present in sufficient amounts to account for the oil, but if they exist in such quantities the problem still remains as to how they can be transformed into naphthenic and other ring compounds.

*Other substances.*—Cellulose, carbohydrates, simple proteins, and fats, which form the major part of the organic constituents of the planktonic source material, are so much altered in the course of deposition that they form not more than 5 percent of the organic constituents of sediments and therefore are present in quantities probably too small to be main sources of petroleum. The oil evidently must come from the remaining 95 percent of the organic matter—the indigestible residues that probably consist mainly of complex compounds and are relatively deficient in oxygen. Petroleum in several areas in the United States is associated with sediments whose organic constituents are comparatively low in oxygen.<sup>43</sup>

#### ORIGIN OF OIL

The complex residual substances that constitute the main part of the organic matter in sediments may contain loosely attached radicals of chain or ring structure. Under favorable conditions, perhaps aided by polymerization or methylation,<sup>44</sup> these loosely attached radicals may become separated from their parent substances and form liquid hydrocarbons. One of the conditions that might favor such a process is the tendency of the organic constituents of sediments to come to chemical equilibrium after the sediments have

been buried beyond the limit of effective microbial action. Individual organic substances found in sediments may be relatively stable in a free state but not stable when pressed in close contact with other organic substances in a sediment. If they are unstable with respect to adjoining organic materials they will tend to reach a stable state, and liquid hydrocarbons may possibly be formed as a result of the readjustments that take place as the organic constituents endeavor to come into equilibrium. As the residual organic substances consist mainly of solids and are largely insoluble in water, the chemical changes caused in this manner would take place very slowly as compared with changes resulting from the activities of organisms.

While the organic constituents are in the overlying water or in the upper layers of sediments, alterations caused by living things greatly predominate over changes caused by purely physical and chemical agencies. In such environments the organic substances have less physical contact with one another and are, therefore, less susceptible to purely chemical (nonbiologic) changes than when in the deeper layers of sediment, where they are firmly pressed together. Consequently, they would have relatively little time to come into chemical equilibrium with one another before they would be attacked by some living organism.

As the sediments become buried deeper and deeper, the activity of living organisms becomes progressively less, and ultimately a depth is reached where the changes in the organic matter resulting from the activity of organisms becomes relatively insignificant.<sup>45</sup> The sediments thenceforth are dominated by purely physical and chemical agencies, and the organic constituents proceed toward effecting a state of equilibrium. A state of complete equilibrium, however, might never be attained because of the effect of changes in temperature and pressure to which the sediments may be subjected during the course of time.

As soon as liquid hydrocarbons were generated, they would form an oily phase insoluble in water—the ancestral petroleum. Certain organic constituents, such as some of the pigments, waxes, and fatty acids that hitherto had existed in the solid state, would be soluble in this oily liquid. Organic substances that lay near the place where the oil was first formed might be dissolved before the ancestral petroleum migrated. Other substances that lay in the path of the migrating oil might be dissolved later. The optically active constituents of petroleum might to some extent be due to such a process. The similarity between certain organic pigments in ancient and modern sediments<sup>46</sup> suggests that some substances, after being dissolved by the

<sup>40</sup> Brooks, B. T., The chemical evidence for the low-temperature history of petroleum: Inst. Petroleum Technologists Jour. vol. 20, p. 185, 1934.

<sup>41</sup> Trask, P. D., Origin and environment of source sediments of petroleum, p. 200, Houston, Tex., Gulf Publishing Co. 1932.

<sup>42</sup> Trask, P. D., Results of distillation and other studies of the organic nature of some modern sediments: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 1228, 1927. Wells, R. C., and Erickson, E. T., The analysis and composition of the fatty material produced by the decomposition of herring in sea water: Am. Chem. Soc. Jour. vol. 55, p. 338-341, 1933.

<sup>43</sup> Trask, P. D., and Keyte, W. E., Degree of reduction of sediments in the east Texas basin as an index of source beds: Oil Weekly, vol. 81, no. 10, pp. 60-70, May 18, 1936.

<sup>44</sup> Pratt, W. E., Hydrogenation and the origin of oil: Problems of Petroleum Geology, pp. 235-245, Tulsa, Okla., Am. Assoc. Petroleum Geologists, 1934.

<sup>45</sup> White, David, Geology and occurrence of petroleum in the United States: Petroleum investigation, pt. 2 (73d Cong., H. R., Comm. on Interstate and Foreign Commerce, Hearings on H. Res. 441), p. 901, 1934.

<sup>46</sup> Dhéré, C., and Hradil, G., Fluoreszenzspektrographische Untersuchungen an Oelschiefer: Schweizer. min.-pet. Mitt., Band 14, pp. 279-295, 1934.

ancestral petroleum, might persist in a relatively unchanged condition for a long time.

As soon as any materials were dissolved, the equilibrium relations of the constituents of the ancestral petroleum would be altered, and these constituents would tend to readjust themselves in an effort to come to a stable condition. As the oil migrated and dissolved new constituents, its composition would be subject to continued change. Even after it reached the reservoir, it seems evident that it would slowly alter until a final stable condition was reached. Such a concept is in accordance with the progressive paraffination of crude oils advocated by Barton.<sup>47</sup> Nevertheless, an ultimate state of complete equilibrium may never be attained. If the conditions of heat and pres-

sure should change while the ancestral petroleum was in the process of developing into crude oil, new conditions of equilibrium might be set up, and consequent readjustments in composition would ensue.

This discussion of the origin of oil by physicochemical readjustment of the organic constituents of sediments is incomplete in that it does not consider what particular types of organic substances are likely to be transformed into oil, but it seems inadvisable to speculate further in the study of possible source material until more detailed information is available on the chemical nature of the organic constituents of sediments. The most favorable mother substances of petroleum are presumably compounds deficient in oxygen. Additional data on the chemical composition of possible source materials of petroleum are urgently needed.

<sup>47</sup> Barton, D. C., Natural history of Gulf coast crude oil: Problems of Petroleum Geology, pp. 109-155, Tulsa, Okla., Am. Assoc. Petroleum Geologists, 1934.



# SOME DEEP WELLS NEAR THE ATLANTIC COAST IN VIRGINIA AND THE CAROLINAS

By W. C. MANSFIELD

## ABSTRACT<sup>1</sup>

Study of cuttings from deep wells along the Atlantic seaboard corroborates the fact, inferred several years ago from the surface distribution of the geologic formations, that the region of the

## INTRODUCTION

The purpose of this paper is to describe briefly and to illustrate (fig. 8) the major stratigraphic divisions

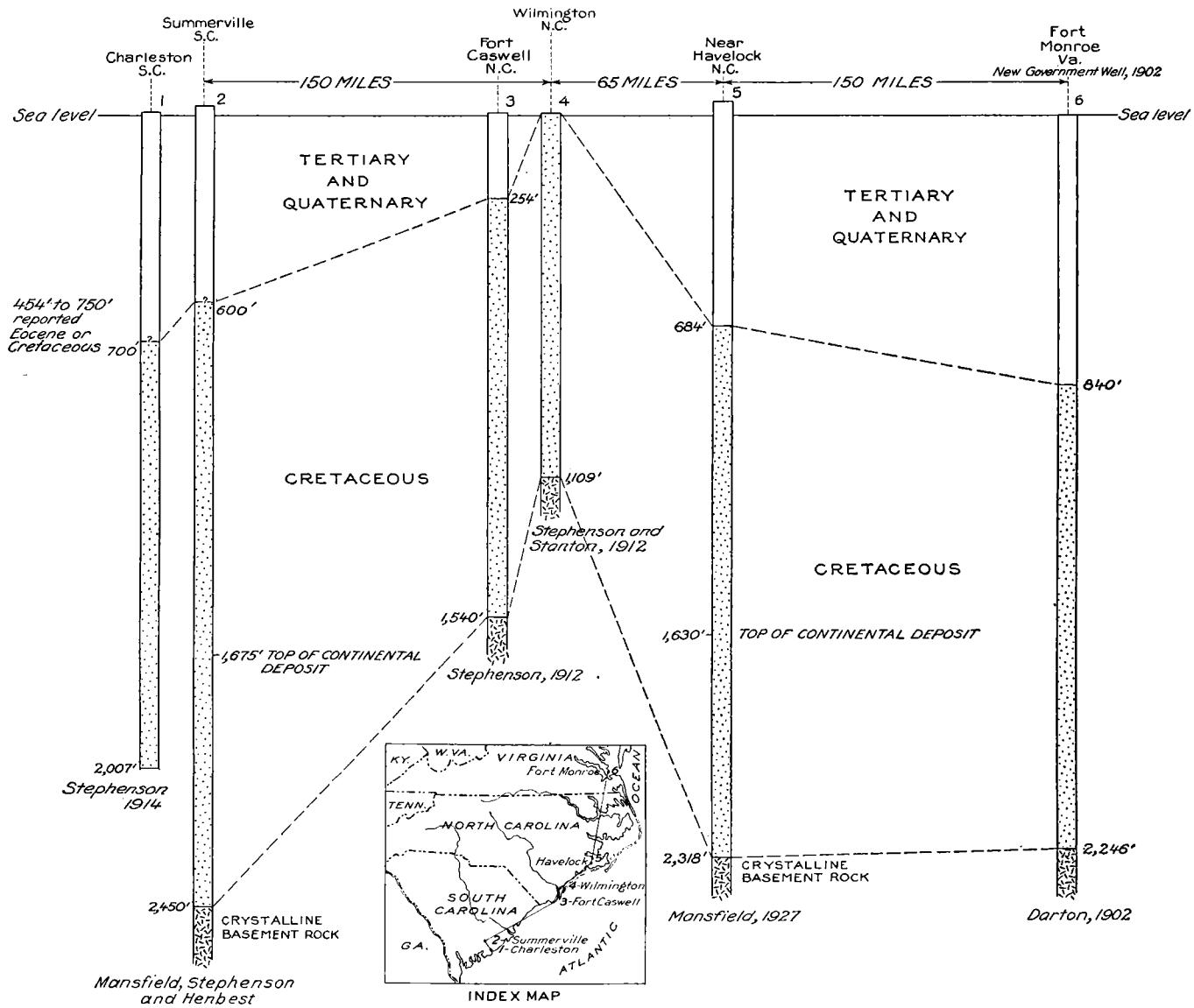


FIGURE 8.—Correlation of logs of deep wells near the Atlantic coast in Virginia and the Carolinas. Depths shown are measured from mouth of each well.

Cape Fear River in North Carolina is up-warped. Depths to crystalline bedrock in five wells are as follows: Fort Monroe, Va., 2,246 feet; near Havelock, N. C., 2,318 feet; Wilmington, N. C., 1,109 feet; Fort Caswell, N. C., 1,540 feet; Summerville, S. C., 2,450 feet. At Havelock and at Summerville the Upper Cretaceous-Eocene contact lies about 700 feet below the surface, but at Wilmington it is a few feet above sea level.

now recognized in six deep borings along the Atlantic Coastal Plain in Virginia and the Carolinas and to show the relations of these major divisions to each other.

Much of the information concerning these deep borings has already been published, but it seems desirable to give a diagrammatic summary of all of them. A

<sup>1</sup> Mansfield, W. C., Washington Acad. Sci. Jour., vol. 19, no. 13, p. 287, 1929.

complete log of the boring at Summerville, S. C., has not been published, but certain features concerning it have been briefly mentioned.

The Coastal Plain sedimentary deposits in Virginia and the Carolinas rest upon a basement composed mainly of crystalline rocks probably of pre-Cambrian age. These basement rocks are at the surface in the Piedmont Plateau, which borders the Coastal Plain on the west, but near the inner edge of the Coastal Plain, as at Halifax, Rocky Mount, and elsewhere, the upper surface of the basement dips beneath the topographic surface, and at the coast it lies deeply buried beneath sediments ranging in age from Cretaceous to Recent. The thickness of the sediments has been determined by the well borings.

#### DETAILS OF THE WELLS

The individual wells are briefly described below, beginning with the northernmost one.

*Government well at Fort Monroe, Va.*—A detailed section of the Government well at Fort Monroe has been given by Darton.<sup>2</sup> The contact of the Eocene Pamunkey group with the underlying marine Cretaceous sediments is placed at a depth of 840 feet below the surface. The basement rock was reached at a depth of 2,246 feet.

*Well near Havelock, N. C.*—A complete record of an oil-prospecting well, the Great Lake well 2, drilled near Havelock, N. C., has been published in a paper by Mansfield.<sup>3</sup> In this well the strata down to a depth of 684 feet were referred to the Tertiary and Quaternary. At that depth a stratigraphic break or unconformity marks the dividing line between the Eocene deposits above and the Cretaceous deposits below. The Cretaceous sediments are about 1,634 feet thick and comprise about 70 percent of the thickness of the sediments penetrated by the well. The nature of the sediments between approximate depths of 1,630 and 1,785 feet indicates a continental deposit. Granite, probably of pre-Cambrian age, was reached at a depth of 2,318 feet.

*Well at Wilmington, N. C.*—A complete record of a well drilled at the plant of the Clarendon Waterworks Co., Hilton Park, Wilmington, N. C., has been given by Stephenson.<sup>4</sup> The fossils were determined by T. W. Stanton. The Cretaceous sediments range from the surface down to a depth of 1,109 feet, where the basement rock was reached.

*Well at Fort Caswell, N. C.*—A record of a well drilled at Fort Caswell, N. C., near the mouth of the Cape Fear River, has been given by Stephenson.<sup>5</sup> The contact of the Tertiary and Quaternary with the

Cretaceous deposits was placed at a depth of 254 feet. The basement rock was reached at 1,540 feet. The fact that this well is nearer the coast than the well at Wilmington accounts for the greater depth to the basement rock. The Cretaceous sediments comprise about 80 percent of the deposits penetrated by the well.

*Well at Summerville, S. C.*—No complete log of the oil-prospecting well drilled at Summerville, S. C., has been published, but Cooke<sup>6</sup> has given a brief log of this well. He assigns the strata penetrated between 37½ and 313 feet to the Eocene; between 313 and 1,580 feet to the Upper Cretaceous; and below this depth questionably to the Upper Triassic.

A study of the mollusks in the upper part of the well gave no positive evidence of the exact depth of the contact between the Eocene and younger deposits or the depth of the contact between the Eocene and Cretaceous. However, around the depth of 700 feet Stephenson recognized Cretaceous fossils belonging chiefly to the genera *Belemnitella* and *Inoceramus*, and L. G. Henbest identified a Cretaceous foraminifer at a depth of 640 feet. Henbest examined the Foraminifera to a depth of 708 feet, especially to determine the position of the Eocene-Cretaceous contact. He identified the following forms, which he states may be of either Cretaceous or Eocene age: *Lenticularia* cf. *L. jonesi* Sandige (depth, 503–515 feet); *Robulus* cf. *R. cultratus* Montfort (depth 515–527 feet); *Gyroidina* sp. (depth 600–618 feet), close to *G. alabamensis* Sandige of the Ripley formation of Alabama. At a depth of 640 feet and below he recognized *Robulus navarroensis* (Plummer), which he regards as definitely a Cretaceous species (range Taylor and Navarro, both Upper Cretaceous).

In the section given in figure 8 the Cretaceous-Tertiary contact is tentatively placed at a depth of 600 feet.

The materials penetrated in the Summerville well between depths of 600(?) and 2,450 feet are similar to those in the Havelock well, in which no Triassic sediments were recognized, and are here referred in their entirety to the Cretaceous.

Beginning at a depth of 1,675 feet, the materials, consisting of reddish sandy clay with inclusions of coarse quartz grains, suggest, according to Stephenson, a delta or a terrestrial deposit and may represent the Tuscaloosa formation of the Upper Cretaceous.

A crystalline basement rock of a somewhat doubtful age was reached at a depth of 2,450 feet.

*Well at Charleston, S. C.*—A record of a well drilled at Charleston, S. C., has been published in a report by Stephenson.<sup>7</sup> The strata between depths of 454 and 750 feet yielded no determinable fossils but are referred

<sup>2</sup> Darton, N. H., U. S. Geol. Survey Geol. Atlas, Norfolk folio (no. 80), columnar section sheet, 1902.

<sup>3</sup> Mansfield, W. C., Oil-prospecting well near Havelock, N. C.: North Carolina Dept. Cons. and Devel. Econ. Paper 58, 1927.

<sup>4</sup> Stephenson, L. W., The Cretaceous formations of North Carolina: North Carolina Geol. and Econ. Survey, vol. 3, pp. 163–166, 1912.

<sup>5</sup> Idem, pp. 169–171.

<sup>6</sup> Cooke, C. W., Geology of the Coastal Plain of South Carolina: U. S. Geol. Survey Bull. 867, p. 177, 1936.

<sup>7</sup> Stephenson, L. W., A deep well at Charleston, S. C.: U. S. Geol. Survey Prof. Paper 90-H, 1914.

to the Upper Cretaceous or Eocene. At a depth of 750 feet Foraminefera were found which were regarded by J. A. Cushman as characteristic Cretaceous species.

The basement rock was not reached at 2,007 feet, the bottom of the well.

#### GENERAL FEATURES

Three of the wells—those near Havelock, at Wilmington, and at Summerville—lie about in a straight line trending N.  $56^{\circ}$  E., and this line is approximately parallel both to the coast and to the line marking the inner edge of the Coastal Plain. Wilmington is about 150 miles from Summerville and about 65 miles from the Great Lake well 2, near Havelock. The records of these wells show that the surface of the basement rock at Wilmington lies about 1,200 feet higher than it normally would be expected to lie on the assumption of a uniform dip of this surface, and this fact together with the surface distribution of the geologic formations seems to verify the opinion of Stephenson<sup>8</sup> that the lower course of the Cape Fear River approximately marks the axis of a broad structural uplift, dating from the interval marked by the unconformity between the Cretaceous and Tertiary sediments, and that the uplifted position has been maintained without marked subsidence until the present time. It follows also that the Great Lake well 2, near Havelock, N. C., is

located in a down-warped area, for the Cretaceous-Eocene contact, which at Wilmington is a few feet above sea level, was reached in the well near Havelock at a depth of 684 feet, showing a relative sinking of the old Cretaceous-Eocene erosion surface amounting to nearly 700 feet. Summerville is also in a down-warped area, for there the Cretaceous-Eocene contact lies at a depth of about 600 feet. It is also interesting to note that the upper limit of the sediments referred to a continental deposit in the well near Havelock is 1,630 feet and in the well at Summerville 1,675 feet.

Stephenson<sup>9</sup> shows a synclinal axis trending nearly northwest and crossing the Virginia and North Carolina line near the coast. This axis is south of the location of the Fort Monroe well. The basement rock lies about 30 feet deeper in the well near Havelock than at Fort Monroe. The fact that Fort Monroe is a little nearer the inner edge of the Coastal Plain and farther from the edge of the Continental Shelf than the well near Havelock may account for this slight difference in the depths at which the basement rock was reached.

Evidence supporting the existence of a northwest-southeast structural uplift near Wilmington has been recorded by MacCarthy.<sup>10</sup>

<sup>8</sup> Stephenson, L. W., Major features in the geology of the Atlantic and Gulf Coastal Plains: Washington Acad. Sci. Jour., vol. 16, no. 17, pl. 1, facing p. 466, 1926.

<sup>9</sup> Stephenson, L. W., Major marine transgressions and regressions and structural features of the Gulf Coastal Plain: Am. Jour. Sci., 5th ser., vol. 16, p. 294, fig. 12, 1928; Structural features of the Atlantic and Gulf Coastal Plain: Geol. Soc. America Bull., vol. 39, p. 839, fig. 1, 1928.

<sup>10</sup> MacCarthy, G. R., Magnetic anomalies and geologic structures of the Carolina Coastal Plain: Jour. Geology, vol. 44, no. 3, pp. 396-406, 1936.



# ADDITIONS TO SOME FOSSIL FLORAS OF THE WESTERN UNITED STATES

By ROLAND W. BROWN

## ABSTRACT

This paper summarizes a study of selected species of fossil plants in the collections of the United States Geological Survey and the United States National Museum from several localities in the western United States. It is not a complete revision of any one flora, but many new combinations are proposed in the belief that they express a more accurate taxonomic disposition of the species involved. Seven new species are described from the Latah formation at Spokane, Wash., and one from the Creede formation at Creede, Colo.

## INTRODUCTION

In the course of identifying new collections the writer, while handling the Cenozoic plants in the United States National Museum, discovered many discrepancies in the identification of types and other specimens. The notations then made are now concentrated in this paper, but they must not be regarded as a complete study or revision of any of the fossil floras involved, for, in one sense, such studies will never be complete, because new species are constantly being found that either invalidate or modify previous conclusions.

## LOCALITIES

The localities supplying the fossils under consideration are as follows:

1. *Spokane, Wash.*—The Latah formation in Washington and deposits regarded as its equivalents in Idaho have been described in several papers, of which the principal ones are United States Geological Survey Professional Papers 140-A, 154-H, 170-C, and 185-E. This formation has yielded an abundance of fossil plants, especially in the vicinity of Spokane, chiefly through the efforts of E. E. Alexander, C. O. Fernquist, and the late T. A. Bonser, many of whose specimens are here figured. This flora is rich in genera and species and consists of mosses, club mosses, horsetails, ferns, ginkgo, incense cedar, redwood, swamp cypress, keteleeria, pines, cattail, arum, smilax, hickory, walnut, sweet fern, willows, poplar, birches, alders, hornbeam, chestnut, beech, oaks, elm, zelkova, sycamore, tulip tree, magnolias, sweet gum, hydrangea, mock orange, service berry, mountain mahogany, redbud, sophora, euonymus, maples, buckthorn, linden, gordonia, laurels, cedrela, umbellularia, dogwood, black gum, grape, persimmon, huckleberries, and viburnums. This is a flora that is comparable in many respects to that in parts of the eastern United States and eastern Asia

but is in strong contrast to that now living in the region about Spokane. The decrease in annual precipitation and a probable changed distribution of the rainfall throughout the year are held to be the chief causes for the disappearance of many species from the region, for species similar to the fossils and presumably with the same climatic requirements flourish in the parks of Spokane, where they are watered.

New species are constantly being added to the Latah flora. The following, described in this paper, came from the Latah formation at Spokane:

|                              |                               |
|------------------------------|-------------------------------|
| <i>Equisetum alexanderi.</i> | <i>Euonymus pacificus.</i>    |
| <i>Betula vera.</i>          | <i>Dilodendron boreale.</i>   |
| <i>Machilus americana.</i>   | <i>Tetracera spokanensis.</i> |
| <i>Machilus asiminoides.</i> |                               |

Of these species, *Machilus americana* and *Machilus asiminoides* are similar to species now living in Asia; *Equisetum alexanderi*, *Betula vera*, and *Euonymus pacificus* resemble species in the eastern United States; and *Dilodendron boreale* and *Tetracera spokanensis* are most like species now living in Central America and the West Indies.

The age of the Latah flora is regarded as middle Miocene.

2. *Republic, Wash.*—The fossil plants from this locality occur in the light-colored dense tuffaceous shale exposed on the east side of the road at the south end of the town. These deposits rest upon or are intercalated with andesite flows and underlie Tertiary basalt. In United States Geological Survey Professional Paper 154-H, Berry merged this flora with the Latah flora from Spokane. A complete list of the material studied by Berry and of that collected by the writer on a short visit to Republic in 1934 is as follows:

|  |
|--|
| <i>Ginkgo adiantoides</i> (Unger) Heer.              |
| <i>Sequoia langsdorffii</i> (Brongniart) Heer.       |
| <i>Taxodium dubium</i> (Sternberg) Heer.             |
| <i>Thuites</i> sp.                                   |
| <i>Comptonia hesperia</i> Berry.                     |
| <i>Cercidiphyllum crenatum</i> (Unger) Brown.        |
| <i>Pinus latahensis</i> Berry.                       |
| <i>Pinus monticoleensis</i> Berry.                   |
| <i>Pinus tetrafolia</i> Berry.                       |
| <i>Pinus macrophylla</i> Berry.                      |
| <i>Fagus washoensis</i> LaMotte.                     |
| <i>Alnus elliptica</i> Berry.                        |
| <i>Alnus corallina</i> Lesquereux.                   |
| <i>Zelkova oregoniana</i> (Knowlton) Brown, n. comb. |

- Acer glabroides* Brown, n. name.  
*Acer negundooides* MacGinitie.  
*Dipteronia americana* Brown.  
*Cornus acuminata* Berry.  
*Sassafras hesperia* Berry.  
*Aralia repubicensis* Brown, n. name.  
*Liquidambar californicum* Lesquereux.  
*Porana speirii* Lesquereux.

The presence of a few species such as *Dipteronia americana*, *Aralia repubicensis*, and *Porana speirii*, which are represented by the same or closely related species in fossil floras regarded as older than the Latah flora, together with the fact that the flora occurs in deposits lying beneath Tertiary basalt that may be equivalent to the Columbia River basalt at Spokane, suggests that the flora at Republic may be somewhat older than the Latah flora—that is, probably lower Miocene.

3. *John Day Basin, Oreg.*—This is the type region of the Mascall and Bridge Creek floras. The present paper deals only with a few misidentified types from these floras. The Mascall flora is regarded as being middle or upper Miocene, and the flora from Bridge Creek as lower Miocene.

4. *Tipton, Oreg.*—The fossil flora of this locality is found in diatomaceous deposits exposed in a railroad cut 1 mile south of Tipton, in sec. 4, T. 11 S., R. 35½ E., in the Sumpter quadrangle, Oreg. An account of the geology of this region was given by Pardee and Hewett,<sup>1</sup> and the flora was studied by Oliver,<sup>2</sup> who reported 32 species of higher plants and a large number of diatoms. To these the following species, collected by the writer in 1930, are now added:

- Abies cheneyi* Mason.  
*Torreya bonseri* (Knowlton) LaMotte.  
*Castanopsis convexa* (Lesquereux) Brooks.  
*Quercus simulata* Knowlton.  
*Sassafras hesperia* Berry.  
*Mahonia reticulata* (MacGinitie) Brown, n. comb.  
*Cedrela pterafornis* (Berry) Brown.

This flora compares so well with that from the Mascall formation in the John Day Basin, 45 miles to the southwest, that it is regarded as being contemporaneous—that is, of middle or perhaps upper Miocene age.

5. *Sucker Creek, Oreg.*—This region is in the eastern part of Malheur County. Because the stratigraphy has not yet been fully resolved, the relationships of the Payette formation are somewhat in doubt, and in consequence the positions of the fossil floras found at several localities are not clear. It is probable that the age of the floras that have been assigned to the Payette formation may cover a range from lower Miocene to Pliocene.

<sup>1</sup> Pardee, J. T., and Hewett, D. F., Geology and mineral resources of the Sumpter quadrangle, Oreg.: Mineral Resources of Oregon, vol. 1, no. 6, pp. 3-128, Oregon Bur. Mines, 1914.

<sup>2</sup> Oliver, Elizabeth, A Miocene flora from the Blue Mountains, Oregon: Carnegie Inst. Washington Pub. 455, pt. 1, pp. 1-27, 5 pls., 1934.

6. *White Bird, Idaho.*—An especially rich fossil locality in reddish shale occurs along the highway 2.5 miles east of White Bird. The relation of this outcrop, which is in the foothills, to the light-colored sedimentary rocks interbedded with Columbia River basalt in the surrounding mountains, is not clear, because there has been considerable faulting and land-slipping in that area. The fossil flora, however, is so similar to the Latah flora at Spokane that they are considered to be practically contemporaneous—that is, of middle Miocene age.

7. *Idaho City, Idaho.*—In 1934 the writer revisited the locality near Idaho City from which Knowlton described part of the Payette flora. A study of the collection then made has added nothing new but suggests that the flora is similar to that from Bridge Creek, Oreg., and may be of lower Miocene age.

8. *Salmon, Idaho.*—The fossil flora here is found in lake beds exposed on both sides of the Salmon River and in escarpments farther back in the valley. C. P. Ross classes the sedimentary rocks with the Challis volcanics. The outcrop furnishing the best and most abundant plants to Ross and the writer in 1930 was at the G. W. Oliver coal mine, about 3 miles west of Salmon up Jesse Creek. The complete flora as identified is as follows:

- Fern spp.  
*Pinus* sp.  
*Sequoia langsdorffii* (Brongniart) Heer.  
*Typha lesquereuxi* Cockerell.  
*Alnus carpinoides* Lesquereux.  
*Alnus corallina* Lesquereux.  
*Alnus relatus* (Knowlton) Brown, n. comb.  
*Umbellularia dayana* (Knowlton) Berry.  
*Amelanchier dignata* (Knowlton) Brown.  
*Chamaebatia prefoliolosa* Brown.  
*Malus idahoensis* Brown.  
*Potentilla salmonensis* Brown.  
*Sassafras hesperia* Berry.  
*Acer bendirei* Lesquereux.  
*Acer glabroides* Brown, n. name.  
*Ceanothus idahoensis* Brown.  
*Rhamnus idahoensis* Brown.  
*Arctostaphylos cuneata* Brown.  
*Symporicarpos salmonensis* Brown.

In addition to these plants there are well-preserved grasshoppers and beetles, which, according to a personal communication from T. D. A. Cockerell, are very similar to species described from Florissant, Colo. This flora with *Umbellularia* and *Chamaebatia* suggests an ecologic situation much like that found in the Yosemite Valley, Calif., today. It may be of lower Miocene age.

9. *Thunder Mountain, Idaho.*—The fossil plants at this locality are derived from silicified auriferous sedimentary rocks that crop out particularly at the Dewey gold mine and vicinity, the geology of which is described by P. J. Shenon and C. P. Ross.<sup>2a</sup> The fossils

<sup>2a</sup> Shenon, P. J., and Ross, C. P., Geology and ore deposits near Edwardsburg and Thunder Mountain, Idaho: Idaho Bur. Mines and Geol. Pamph. 44, 45 pp., 19 pls., 1936.

are few and in general not well enough preserved to show details. They include ferns, pines, firs, alders, sweet fern, dogwood, and huckleberry—a flora that may indicate an upland ecology in lower Miocene time.

10. *Florissant, Colo.*—The age of the lake beds in which the fossils are found at this classic locality for fossil plants and insects continues to be a subject of discussion among paleontologists. To the writer the flora has a distinctly old aspect and seems to be of upper Oligocene or lower Miocene age. Correlations of the Latah and Florissant floras have been published on the basis of an alleged community of numerous identical species, but a careful comparison of the type specimens of these species does not substantiate such correlations. This flora needs thorough revision.

11. *Creede, Colo.*—The flora from the Miocene lake deposits in the vicinity of Creede, Colo., was described by Knowlton.<sup>2b</sup> Two undescribed specimens in the original collections are now referred to *Chamaebatiaria creedensis* Brown, n. sp.

12. *Fossil, Wyo.*—This is a notable locality in the Green River formation where the fossil fishes have claimed most interest among paleontologists. Nevertheless, the few plants found are unusually well preserved and often of great beauty—brown or black against a white or cream-colored background. Those figured here are published to supplement the illustrations of types. The Green River formation is middle Eocene.

#### CHANGES OF NAME AND NEW COMBINATIONS

Before satisfactory correlations between fossil floras can be drawn it is necessary to be reasonably certain that the species correlated are identical. In the past too many species have been named without thorough investigation of already published species, thus cluttering up the record and making further study difficult because of the inevitable expanding and compounding of those errors. As a result of examining the type specimens of species considered in this paper the writer has deemed the following changes of name and new combinations necessary. The reasons for these changes will be found in the systematic description of the several items. Unless otherwise stated all the types and figured specimens are to be found in the United States National Museum.

- Acalypha myricina* Cockerell = *Patiurus florissanti* Lesquereux.
- Acer*, fruits of, Lesquereux = *Acer bendirei* Lesquereux.
- Acer* sp. Berry = *Vitis washingtonensis* (Knowlton) Brown, n. comb.
- Acer bendirei* Lesquereux (part) = *Acer glabroides* Brown, n. name.
- Acer bendirei* Lesquereux (part) = *Platanus dissecta* Lesquereux.
- Acer chaneyi* Knowlton = *Acer osmonti* Knowlton.
- Acer dimorphum* Lesquereux = *Acer bendirei* Lesquereux.
- Acer florissanti* Kirchner (part) = *Acer osmonti* Knowlton.
- Acer gigas* Knowlton = *Acer osmonti* Knowlton.

<sup>2b</sup> Knowlton, F. H., Fossil plants from the Tertiary lake beds of south-central Colorado: U. S. Geol. Survey Prof. Paper 131, pp. 183-197, 1923.

- Acer medianum* Knowlton = *Acer bendirei* Lesquereux.
- Acer merriami* Knowlton (part) = *Acer bendirei* Lesquereux.
- Acer merriami* Knowlton (part) = *Vitis washingtonensis* (Knowlton) Brown, n. comb.
- Acer minor* Knowlton (part) = *Acer bendirei* Lesquereux.
- Acer minor* Knowlton (part) = *Acer glabroides* Brown, n. name.
- Acer oregonianum* Knowlton (part) = *Acer bendirei* Lesquereux.
- Acer oregonianum* Knowlton (part) = *Acer osmonti* Knowlton.
- Acer osmonti* Knowlton (part) = *Acer glabroides* Brown, n. name.
- Acer osmonti* Knowlton (part) = *Acer bendirei* Lesquereux.
- Aesculus hesperia* Berry = *Viburnum lantanafolium* Berry.
- Aesculus simulata* Knowlton = *Carya simulata* (Knowlton) Brown, n. comb.
- Alnus prerhombifolia* Berry = *Alnus carpinoides* Lesquereux.
- Amygdalus alexanderi* Berry = *Fagus washoensis* LaMotte.
- Andromeda delicatula* Lesquereux = *Cotinus fraterna* (Lesquereux) Cockerell.
- Apocynophyllum latahense* Berry (part) = *Magnolia latahensis* (Berry) Brown, n. comb.
- Apocynophyllum latahense* Berry (part) = *Quercus simulata* Knowlton.
- Aralia whitneyi* Lesquereux (part) = *Aralia republicensis* Brown, n. name.
- Arbutus* sp. Chaney = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Arbutus traini* MacGinitie = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Arctostaphylos knowltoni* Berry = *Vaccinium sophoroides* (Knowlton) Brown, n. comb.
- Aristolochia whitebirdensis* Ashlee = *Smilax magna* Chaney.
- Betula aequalis?* Lesquereux (part) = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Betula bryani* Knowlton = *Betula fairii* Knowlton.
- Betula elliptica* Saporta (part) = *Alnus relatus* (Knowlton) Brown, n. comb.
- Betula largi* Knowlton = *Betula fairii* Knowlton.
- Betula heteromorpha* Knowlton (part) = *Betula fairii* Knowlton.
- Betula heteromorpha* Knowlton (part) = *Alnus relatus* (Knowlton) Brown, n. comb.
- Betula thor* Knowlton = *Alnus carpinoides* Lesquereux.
- Carpites menthoidea* Knowlton = *Carpolithus* sp.
- Carpites paulownia* Knowlton = *Gordonia hesperia* Berry.
- Carpites spokanensis* Knowlton = bud scales.
- Carpolithus hibiscoidea* Brown = *Carpites boraginoides* Knowlton.
- Cassia obtusa* Knowlton = *Salix inquirenda* Knowlton.
- Cassia idahoensis* Knowlton (part) = *Sophora spokanensis* Knowlton.
- Cassia sophoroides* (Knowlton) Berry (part) = *Sophora spokanensis* Knowlton.
- Cassia sophoroides* (Knowlton) Berry (part) = *Vaccinium sophoroides* (Knowlton) Brown, n. comb.
- Castanea castaneaefolia* (Unger) Knowlton = *Castanea orientalis* Chaney.
- Castanea lesquerelii* LaMotte = *Fagus washoensis* LaMotte.
- Celastrus fernquisti* Knowlton = *Betula fairii* Knowlton.
- Celastrus fraxinifolius* Lesquereux = *Hydrangea fraxinifolia* (Lesquereux) Brown, n. comb.
- Celastrus lacoei* Lesquereux (part) = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Cercidium hesperium* Ashlee = *Cercis spokanensis* Knowlton.
- Cercis* sp. Ashlee = *Cercis spokanensis* Knowlton.
- Cercis idahoensis* Berry (part) = *Cercis spokanensis* Knowlton.
- Cercis idahoensis* Berry (part) = *Vitis washingtonensis* (Knowlton) Brown, n. comb.
- Clematis reticulata* MacGinitie = *Mahonia reticulata* (MacGinitie) Brown, n. comb.
- Comptonia acutiloba* (Lesquereux) Cockerell = *Dipteronia insignis* (Lesquereux) Brown, n. comb.

- Comptonia insignis* (Lesquereux) Cockerell = *Dipteronia insignis* (Lesquereux) Brown, n. comb.
- Corylus macquarrii* (Forbes) Heer (part) = *Tilia oregona* La Motte.
- Crataegus heterodentata* Chaney = *Acer negundo* MacGinitie.
- Diospyros princetonia* Cockerell (part) = *Vaccinium sophoroides* (Knowlton) Brown, n. comb.
- Equisetum*, underground stem, Knowlton = *Carpolithus* sp.
- Euonymus knowltoni* Berry = *Hydrangea bendirei* (Ward) Knowlton.
- Fagopsis longifolia* (Lesquereux) Hollick = *Zelkova oregoniana* (Knowlton) Brown, n. comb.
- Ficus interglacialis* Hollick = *Carpolithus* sp.
- Ficus planicostata* Lesquereux? = *Celtis obliquifolia* Chaney.
- Ficus ungeri* Lesquereux = *Salix inquirenda* Knowlton.
- Ficus?* *washingtonensis* Knowlton = *Cercis spokanensis* Knowlton.
- Fraxinus heeri* Lesquereux = *Hydrangea fraxinifolia* (Lesquereux) Brown, n. comb.
- Fraxinus praedicta* Heer (part) = *Hydrangea fraxinifolia* (Lesquereux) Brown, n. comb.
- Fraxinus ungeri* Lesquereux (part) = *Cotinus fraterna* (Lesquereux) Cockerell.
- Gleditschia praearquatica* Ashlee = *Cercis spokanensis* Knowlton.
- Grewia crenata* (Unger) Heer = *Cercidiphyllum crenatum* (Unger) Brown.
- Hydrangea florissantia* Cockerell = *Hydrangea fraxinifolia* (Lesquereux) Brown, n. comb.
- Ilex latahensis* Ashlee = *Mahonia simplex* (Newberry) Arnold.
- Juglans affinis* Kirchner = *Hydrangea fraxinifolia* (Lesquereux) Brown, n. comb.
- Juglans cryptata* Knowlton = *Carya egredia* (Lesquereux) La Motte.
- Juglans hesperia* Knowlton = *Salix inquirenda* Knowlton.
- Juglans oregoniana* Lesquereux (part) = *Pterocarya mixta* (Knowlton) Brown, n. comb.
- Juncus?* *crassulus* Cockerell (part) = *Carpolithus* sp.
- Laurus grandis* Lesquereux = *Magnolia dayana* Cockerell.
- Laurus princeps* Heer (part) = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Laurus princeps* Heer (part) = *Magnolia dayana* Cockerell.
- Laurus princeps* Heer (part) = *Quercus simulata* Knowlton.
- Laurus similis* Knowlton = *Umbellularia dayana* (Knowlton) Berry.
- Leguminosites bonseri* Berry = *Umbellularia dayana* (Knowlton) Berry.
- Lbocedrus* sp. Dorf = *Cedrela pterafornis* (Berry) Brown.
- Magnolia californica* Lesquereux = *Magnolia latahensis* (Berry) Brown, n. comb.
- Mahonia hollicki* (Dorf) Arnold = *Mahonia reticulata* (MacGinitie) Brown, n. comb.
- Malva?* *hesperia* Knowlton = *Carpolithus* sp.
- Meibomites knowltoni* Berry = *Cercis spokanensis* Knowlton.
- Meibomites lucens* Knowlton = *Cercis spokanensis* Knowlton.
- Menispermites latahensis* Berry = *Vitis washingtonensis* (Knowlton) Brown, n. comb.
- Myrica?* *idahoensis* Knowlton = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Myrica lanceolata* Knowlton = *Arbutus idahoensis* (Knowlton) Brown, n. comb.
- Myrica oregoniana* Knowlton = *Zelkova oregoniana* (Knowlton) Brown, n. comb.
- Nyssa hesperia* Berry = *Nyssa knowltoni* Berry.
- Odostemon hollicki* Dorf (part) = *Mahonia reticulata* (MacGinitie) Brown, n. comb.
- Paliurus colombi* Heer = *Cercidiphyllum crenatum* (Unger) Brown.
- Paliurus haydeni* Cockerell = *Cercis parvifolia* Lesquereux.
- Philadelphus bendirei* (Knowlton) Chaney (part) = *Sassafras hesperia* Berry.
- Phyllites* sp. Knowlton = *Salix spokanensis* (Berry) Brown, n. comb.
- Phyllites amplexicaulis* Knowlton = *Carpolithus* sp.
- Phyllites bifurcatus* Knowlton = *Acer negundo* MacGinitie.
- Phyllites crustacea* Knowlton = *Quercus simulata* Knowlton.
- Phyllites pardee* Knowlton = *Philadelphus pardee* (Knowlton) Brown, n. comb.
- Phyllites peculiaris* Knowlton = *Philadelphus pardee* (Knowlton) Brown, n. comb.
- Phyllites relatus* Knowlton = *Alnus relatus* (Knowlton) Brown, n. comb.
- Phyllites sophoroides* Knowlton = *Vaccinium sophoroides* (Knowlton) Brown, n. comb.
- Pinus knowltoni* Chaney (part) = *Cedrela pterafornis* (Berry) Brown.
- Pinus monticolensis* Berry (part) = *Cedrela pterafornis* (Berry) Brown.
- Pinus russelli* La Motte = *Cedrela pterafornis* (Berry) Brown.
- Platanus appendiculata* Lesquereux? (part) = *Aralia repubicensis* Brown, n. name.
- Populus*, bud scales, Berry = bud scales.
- Populus lesquereuxi* Cockerell (part) = *Salix inquirenda* Knowlton.
- Populus lindgreni* Knowlton (part) = *Vitis washingtonensis* (Knowlton) Brown, n. comb.
- Populus washingtonensis* Knowlton = *Vitis washingtonensis* (Knowlton) Brown, n. comb.
- Prunus rustii* Knowlton (part) = *Alnus corallina* Lesquereux.
- Prunus rustii* Knowlton (part) = *Alnus relatus* (Knowlton) Brown, n. comb.
- Pseudotsuga masoni* MacGinitie (part) = *Cedrela pterafornis* (Berry) Brown.
- Ptelea miocenica* Berry (part) = *Carya egredia* (Lesquereux) La Motte.
- Pterocarya americana* Lesquereux = *Populus lesquereuxii* Cockerell.
- Quercus* sp. Knowlton = *Quercus payettensis* Knowlton.
- Quercus* cf. *Q. pseudolyra* Lesquereux = *Acer osmonti* Knowlton.
- Quercus cognata* Knowlton = *Quercus payettensis* Knowlton.
- Quercus duriuscula* Knowlton = *Quercus pseudolyra* Lesquereux.
- Quercus obtusa* Knowlton = *Quercus simulata* Knowlton.
- Quercus praenigra* Knowlton = *Quercus payettensis* Knowlton.
- Quercus rustii* Knowlton = *Quercus payettensis* Knowlton.
- Quercus simulata* Knowlton (part) = *Salix inquirenda* Knowlton.
- Quercus simulata* Knowlton (part) = *Umbellularia dayana* (Knowlton) Berry.
- Quercus treleasei* Berry = *Sophora spokanensis* Knowlton.
- Quercus ursina* Knowlton = *Quercus merriami* Knowlton.
- Rhamnus spokanensis* Berry = *Salix spokanensis* (Berry) Brown, n. comb.
- Rhus bendirei* Lesquereux = *Carya egredia* (Lesquereux) La Motte.
- Rhus subrhomboidalis* Lesquereux = *Dipteronia insignis* (Lesquereux) Brown, n. comb.
- Rhus typhinoides* Lesquereux = *Salix inquirenda* Knowlton.
- Rhus?* sp. Knowlton = *Carya simulata* (Knowlton) Brown, n. comb.
- Ribes fernquisti* Knowlton = *Viburnum fernquisti* (Knowlton) Brown, n. comb.
- Robinia?* sp. Knowlton = *Salix spokanensis* (Berry) Brown, n. comb.
- Rulac crataegifolium* Knowlton = *Acer negundo* MacGinitie.
- Salix* sp. Knowlton = *Umbellularia dayana* (Knowlton) Berry.
- Salix dayana* Knowlton (part) = *Sophora spokanensis* Knowlton.
- Salix mixta* Knowlton (part) = *Carya egredia* (Lesquereux) La Motte.
- Salix mixta* Knowlton (part) = *Pterocarya mixta* (Knowlton) Brown, n. comb.
- Salix perplexa* Knowlton (part) = *Vaccinium sophoroides* (Knowlton) Brown, n. comb.
- Salix remotidens* Knowlton = *Salix inquirenda* Knowlton.

*Salix varians* Goeppert (part) = *Salix inquirenda* Knowlton.  
*Sapindus armstrongi* Berry = *Cedrela pteriformis* (Berry) Brown.  
*Sapindus lancifolius* Lesquereux = *Cedrela lancifolia* (Lesquereux) Brown, n. comb.  
*Sophora alexanderi* Knowlton = *Sophora spokanensis* Knowlton.  
*Sorbus chaneyi* LaMotte = *Fagus washoensis* LaMotte.  
*Trapa prenatans* Dorf = *Trapa americana* Knowlton.  
*Tsuga latahensis* Berry = bud scale.  
*Ulmus fernquisti* Knowlton = *Zelkova oregoniana* (Knowlton) Brown, n. comb.  
*Ulmus speciosa* Newberry (part) = *Ptelea miocenica* Berry.  
*Umbellularia dayana* (Knowlton) Berry (part) = *Cedrela pteriformis* (Berry) Brown.  
*Umbellularia lanceolata* Berry = *Laurus similis* Knowlton.  
*Vaccinium spokanense* Berry = *Salix spokanensis* (Berry) Brown, n. comb.

#### SYSTEMATIC DESCRIPTIONS

##### PTERIDOPHYTA (FERNS)

Plate 45, figure 1. This fragment, showing a portion of a pinna with parts of five oblong, rounded, crenulate pinnules, is very similar to species of *Osmunda*, particularly *O. claytoniana* Linnaeus, which is found in wet situations in the eastern United States. Salmon, Idaho. Miocene.

Plate 45, figure 2. This terminal portion may represent a species of *Asplenium*. Thunder Mountain, Idaho. Miocene.

Plate 45, figure 3. The venation and shape of this fern suggest the genus *Aneimia*, particularly *A. coriacea* Gray of Cuba. Salmon, Idaho. Miocene.

##### ARTHROPHYTA (HORSETAILS)

Plate 45, figure 4. This is a chain of four successively smaller, coarsely wrinkled but very finely striated underground tubers of an *Equisetum*. Thunder Mountain, Idaho. Miocene.

##### *Equisetum alexanderi* Brown, n. sp.

Plate 45, figure 5

This is a portion of a slender stem showing three nodes. Three teeth of the sheath are visible on one side of the stem, making a total of 6 or 8 for the entire sheath. Below the sheath are three pits marking the former attachment of branches.

Occurrence: Latah formation, Spokane, Wash. Miocene.

##### SPERMATOPHYTA

##### TAXACEAE

##### *Torreya bonseri* (Knowlton) LaMotte

Plate 45, figure 22

*Tumion bonseri* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 25, pl. 10, fig. 3, 1926.  
*Torreya* sp. Mason, Carnegie Inst. Washington Pub. 346, pt. 5, p. 146, pl. 1, figs. 5, 6, 1927.  
*Torreya bonseri* (Knowlton) LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 108, pl. 3, fig. 9, 1936.

The specimen illustrated here shows a feature not displayed by the type—namely, the narrow stomatal grooves paralleling the midrib.

Occurrence: Latah formation, Spokane, Wash.; Tipton, Oreg. (fig. 22). Miocene.

##### PINACEAE

##### *Abies chaneyi* Mason

Plate 45, figures 23, 24

*Abies chaneyi* Mason, Carnegie Inst. Washington Pub. 346, pt. 5, p. 149, pl. 4, figs. 1, 2, 7, 1927.

These specimens differ from those illustrated by Mason in having shorter, slenderer needles and somewhat larger scales. Whether these differences are variations in the species or indicate different species is here left an open question.

Occurrence: Tipton, Oreg. Miocene.

##### *Abies* sp.

Plate 45, figures 27, 28; plate 46, figures 1, 2

Cones 10 centimeters or more long and 2.5 centimeters in diameter, with numerous small, closely imbricated scales. Twigs, with short slightly curved needles, 1 centimeter long, blunt acuminate. Seeds 1 centimeter long with relatively broad wings.

These specimens may be compared in a general way with *Abies balsamea* (Linnaeus) Miller, of the northern United States and Canada.

Occurrence: Thunder Mountain, Idaho. Miocene.

##### *Picea* spp.

Plate 45, figures 29, 30. These appear to be partly disintegrated cones of *Picea*, but they may be a species of *Tsuga*. Tipton, Oreg. Miocene.

Plate 45, figures 18, 19. Probably seeds of *Picea*. Tipton, Oreg. Miocene.

Plate 45, figure 8. Except that this cone scale lacks the conspicuous basal bract displayed by the scales of the golden larch of eastern China, *Pseudolarix kaempferi* Gordon, it might pass for that or a related species. The cones of *Picea* do not disintegrate as readily as those of *Pseudolarix*, but it is nevertheless more probable that this scale belongs to a species of *Picea*. Republic, Wash. Miocene.

##### *Pinus* spp.

Plate 45, figure 9. A five-neededle bundle with slender needles 3 to 4 centimeters long. This may represent a species like the foxtail pine, *Pinus aristata* Engelmann, or the white-bark pine, *P. albicaulis* Engelmann. Thunder Mountain, Idaho. Miocene.

Plate 45, figure 10. Short needles in bundles of twos and threes. Perhaps a piñon. Salmon, Idaho. Miocene.

Plate 45, figure 13. Long needles in twos, but Oliver reports a bundle with remains of a third needle and identifies this pine as *Pinus knowltoni* Chaney. Tipton, Oreg. Miocene.

Plate 45, figures 11, 12. These are staminate aments. Tipton, Oreg. Miocene.

Plate 45, figures 14–17, 20, 21. Seeds of pine. Tipton, Oreg., except figure 15, from Idaho City, Idaho, and figure 21, from Thunder Mountain, Idaho. Miocene.

Plate 45, figure 26. This large pine seed compares well with those of *Pinus ponderosa* Lawson. Spokane, Wash. Miocene.

#### *Sequoia langsdorffii* (Brongniart) Heer

Plate 45, figure 25

*Sequoia langsdorffii* (Brongniart) Heer, Flora tertiaria Helveticae, Band 1, p. 54, pl. 20, fig. 2; pl. 21, fig. 4, 1855.  
Knowlton, U. S. Geol. Survey Bull. 696, p. 594, 1919.  
(See synonymy and references.)  
Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 15, 1934.  
Brown, Jour. Paleontology, vol. 9, p. 573, pl. 67, figs. 1, 2, 10, 1935.

Besides the small cone figured here there are remains of twigs of this species in the collections from Tipton.

Occurrence: Tipton, Oreg. Miocene.

#### *Thuites* sp.

Plate 45, figures 6, 7

*Thuites* sp. Knowlton, U. S. Geol. Survey Bull. 204, p. 26, pl. 1, fig. 3, 1902.

The stubby, branched appearance of the specimen shown in figure 6 suggests that it is a species of *Thuya* rather than *Libocedrus*, the remains of which are also found in the Latah formation at Spokane, Wash.

Occurrence: Latah formation, Spokane, Wash. (fig. 6); Republic, Wash. (fig. 7). Miocene.

#### SMILACEAE

##### *Smilax magna* Chaney

Plate 46, figure 15

*Smilax magna* Chaney, Walker Mus. Contr., vol. 2, p. 161, pl. 6, fig. 1, 1920.

*Aristolochia whitebirdensis* Ashlee, Northwest Sci., vol. 6, p. 78, pl. 1, fig. 3, 1932.

It is likely that *Smilax magna* was closely related to *S. wardii* Lesquereux,<sup>3</sup> from the Mascall formation of the John Day Basin, Oreg., the chief differences being that the latter had a more cordate base and was extremely elongated and narrow. Ashlee's *Aristolochia whitebirdensis*, from White Bird, Idaho, is undoubtedly *S. magna*. It is not impossible that two species of *Smilax* could have lived at the same locality, but the suspicion is also strong that a single species could have produced both *S. magna* and *S. lamarensis* Knowlton,<sup>4</sup>

<sup>3</sup> Lesquereux, Leo, Recent determinations of fossil plants from Kentucky, Louisiana, Oregon, California, Alaska, Greenland, etc., with descriptions of new species: U. S. Nat. Mus. Proc., vol. 11, p. 19, pl. 13, fig. 1, 1888.

<sup>4</sup> Berry, E. W., Revision of the flora of the Latah formation: U. S. Geol. Survey Prof. Paper 154, p. 240, pl. 63, fig. 15, 1929; Miocene plants from Idaho: U. S. Geol. Survey Prof. Paper 185, p. 105, pl. 19, fig. 7, 1934.

the latter also from both Spokane, Wash., and White Bird, Idaho.

Occurrence: Latah formation, Spokane, Wash. (fig. 15); White Bird, Idaho. Miocene.

#### SALICACEAE

##### *Salix inquirenda* Knowlton

Plate 47, figure 10

*Salix inquirenda* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 11, figs. 1, 2, 1926.  
Berry, U. S. Geol. Survey Prof. Paper 154, p. 242, 1929.  
*Salix remotidens* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 12, fig. 7, 1926.  
*Populus lesquereuxi* Cockerell. Berry, U. S. Geol. Survey Prof. Paper 170, p. 35, 1931.  
*Salix varians* Goeppert. Knowlton, U. S. Geol. Survey Bull. 204, p. 30, 1902.  
*Quercus simulata* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 154, p. 246, pl. 51, fig. 7 (not other figures), 1929.  
*Rhus typhinaoides* Lesquereux. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 44, pl. 27, fig. 5, 1926.  
*Juglans hesperia* Knowlton, U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 723, pl. 99, fig. 8, 1898.  
*Ficus ungeri* Lesquereux. Knowlton, idem, p. 731, pl. 101, fig. 5.  
*Cassia obtusa* Knowlton, idem, p. 731, pl. 100, figs. 4, 5.  
Berry, U. S. Geol. Survey Prof. Paper 154, p. 252 (not pl. 55, figs. 2, 3), 1929.

The teeth on all the specimens referred to in the synonymy are sharply serrate and thus differ characteristically from the rounded, somewhat crenate teeth exhibited by the types of *Populus lesquereuxi* Cockerell from the Florissant lake beds, to which Berry in 1931 referred *Salix inquirenda* Knowlton. The pair of prominent basal lateral veins in *Populus lesquereuxi* from Florissant also differentiates that species from *S. inquirenda*.

The last three species cited in the synonymy are from the Payette formation of Idaho. *Ficus ungeri*, although figured as having an entire margin, has in fact a margin with low, coarse, serrate teeth. *Cassia obtusa* is obscurely toothed.

Occurrence: Latah formation, Spokane, Wash. Miocene.

##### *Salix spokanensis* (Berry) Brown, n. comb.

Plate 46, figures 3–6, 8

*Robinia?* sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 44, pl. 28, figs. 7, 7a, 1926.  
*Rhamnus spokanensis* Berry, U. S. Geol. Survey Prof. Paper 154, p. 257, pl. 57, figs. 4, 5, 1929.  
*Phyllites* sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 49, pl. 29, fig. 5, 1926.  
*Vaccinium spokanense* Berry, U. S. Geol. Survey Prof. Paper 154, p. 263, pl. 64, fig. 8, 1929.

The original descriptions of the several leaves cited in the synonymy need to be amended by recording an overlooked character that brings all of them within a single species. The leaves are described as having entire margins. On the contrary, they have conspicuous basal teeth, and one specimen here figured is well

toothed more than halfway toward the apex. The smallest specimen shows the impressions of what appear to have been stipules.

The condition of being toothed near the base and not toward the apex is the reverse of the usual and makes a search for comparable living species relatively easy and fairly certain of success. The genera *Robinia*, *Rhamnus*, and *Vaccinium* are eliminated at once. In *Ailanthus altissima* (Miller) Swingle the basal teeth on the leaflets are few, large, and prominently glandular. These specimens have a venation quite different from that of *Ailanthus* and basal teeth that are only slightly, if at all, gland-tipped. Leaves with a venation and shape strikingly like these are found in several species of *Lonicera*, but the species of honeysuckle, although sometimes ciliate, are uniformly without teeth. In *L. japonica* there frequently appear leaves that are dissected into a number of rounded lateral lobes, which, however, are scarcely to be compared with the teeth of these fossil leaves.

The genus *Salix*, and particularly the species *S. commutata denudata* Bebb, a shrubby willow from the mountains of the Northwestern States, supplies leaves that duplicate fairly closely all the characters shown by the fossils.

Occurrence: Latah formation, Spokane, Wash. (figs. 3-6); Payette formation, Idaho City, Idaho (fig. 8). Miocene.

#### *Populus eotremuloides* Knowlton

Plate 47, figure 1

*Populus eotremuloides* Knowlton, U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 725, pl. 100, figs. 1, 2; pl. 101, figs. 1, 2, 1898.

*Populus occidentalis* Knowlton, idem, p. 727, pl. 99, fig. 14.

*Populus eotremuloides* Knowlton. Brooks, Carnegie Mus. Annals, vol. 24, p. 282, 1935.

La Motte, Carnegie Inst. Washington Pub. 455, pt. 5, pl. 5, figs. 7, 9, 1936.

The specimen referred to by Brooks as being in the collections of the United States National Museum is here figured to show its very remarkable resemblance to *Populus trichocarpa hastata* Henry, of the Northwestern States.

Occurrence: Sucker Creek, Oreg. Miocene.

#### MYRICACEAE

##### *Comptonia hesperia* Berry

Plate 46, figures 11-14

*Comptonia hesperia* Berry, U. S. Geol. Survey Prof. Paper 154, p. 241, pl. 50, fig. 6, 1939.

There is no doubt that these leaves are those of *Comptonia* and not *Lyonothamnus*. Endo and Morita<sup>5</sup> have decided to call their similar material from the Tertiary deposits of Japan *Comptoniphyllum*.

<sup>5</sup> Endo, Seido, and Morita, Hikoji, Notes on the genera *Comptoniphyllum* and *Liquidambar*: Tohoku Imp. Univ. Sci. Repts., 2d ser. (Geology), vol. 15, no. 2, pp. 41-53, 3 pls., 1932.

The relationship of this species to *Myrica diforme* (Berry) Chaney, from Crooked River, Oreg., is not clear to the writer, but better material from Crooked River may indicate identity of these species.

Occurrence: Latah formation, Spokane, Wash. (fig. 11); Thunder Mountain, Idaho (figs. 12-14). Miocene.

#### JUGLANDACEAE

##### *Carya egregia* (Lesquereux) LaMotte

Plate 47, figure 4; plate 57, figure 4

*Juglans egregia* Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 36, pl. 9, fig. 12; pl. 10, fig. 1, 1878. Berry, U. S. Geol. Survey Prof. Paper 170, p. 35, pl. 11, fig. 3, 1931.

*Juglans oregoniana* Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 35, pl. 9, fig. 10, 1878. Knowlton, U. S. Geol. Survey Bull. 204, p. 36, 1902. [Except *Juglans hesperia* Knowlton, which is *Salix inquirenda* Knowlton.]

Chaney, Carnegie Inst. Washington Pub. 346, p. 104, 1927. *Hicoria pseudovata* Hollick, New York Bot. Garden Mem., vol. 7, p. 395, pl. 30, figs. 1, 2, 1927.

*Carya egregia* (Lesquereux) LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 116, pl. 4, figs. 5, 6; pl. 6, figs. 1, 2, 1936. (See synonymy and discussion.)

*Ptelea miocenica* Berry. LaMotte, idem, p. 133, pl. 11, fig. 4. [Not figs. 1, 2, which remain *Ptelea miocenica* Berry.]

*Rhus bendirei* Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 15, pl. 9, fig. 2, 1888. Knowlton, U. S. Geol. Survey Bull. 204, p. 70, 1902.

*Juglans cryptata* Knowlton, idem, p. 35, pl. 6, figs. 4, 5.

*Salix mixta* Knowlton, idem, p. 32, pl. 2, fig. 12 (leaflet on left). [Not leaflet on right, which is *Pterocarya mixta* (Knowlton) Brown.]

The specimens figured are examples of this apparently widespread species, which has been discussed by LaMotte. To his synonymy are now added several more items that in the writer's opinion belong here.

Occurrence: White Bird, Idaho (pl. 57, fig. 4); Tipton, Oreg. (pl. 47, fig. 4). Miocene.

##### *Carya simulata* (Knowlton) Brown, n. comb.

*Aesculus simulata* Knowlton, U. S. Geol. Survey Bull. 204, p. 78, pl. 15, figs. 1, 2, 1902.

*Rhus?* sp. Knowlton, idem, p. 70, pl. 14, fig. 6.

The leaflets of *Aesculus* differ chiefly from these fossils in having less undulatory secondary veins and marginal teeth that are blunt-pointed, serrate, and in most species mixed, with large teeth marking the terminations of the secondary veins and smaller teeth receiving their branches. The teeth of *Carya simulata* are sharp-pointed and fairly uniform in size. The leaflets of *Aesculus* disintegrate rapidly after falling and are not likely to persist long enough to be preserved in the fossil record.

*Carya simulata* has a general resemblance to *C. egregia* (Lesquereux) LaMotte but has more numerous, less camptodrome secondaries. It also resembles *Viburnum lantanafolium* Berry, except that the secondaries of that species depart from the midrib at narrower angles.

The relationship of *Carya simulata* to living species of *Carya* is not clear, but comparisons might be suggested with the pignut hickory, *Carya glabra* Sweet, of the eastern United States.

Occurrence: Mascall formation, John Day Basin, Oreg. Miocene.

**Pterocarya mixta (Knowlton) Brown, n. comb.**

Plate 47, figures 2, 3

*Salix mixta* Knowlton, U. S. Geol. Survey Bull. 204, p. 32, pl. 2, fig. 12 (leaflet on right), 1902. [Not leaflet on left, which is *Carya egregia* (Lesquereux) LaMotte.]

*Juglans oregoniana* Lesquereux. Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 18, 1934.

Leaflets ovate-elliptic, pointed, with margins having numerous crenate-serrate teeth; bases cuneate to cordate, sessile or nearly so. Secondary veins numerous, forming conspicuous loops with the secondaries above well within the margin; branches from the loops to the teeth inconspicuous.

Although these leaflets have some resemblance to those of species of *Juglans*, yet the inconspicuous branches from the secondary veins to the marginal teeth ally them with *Pterocarya*. In *Carya* and *Juglans* the secondary veins either enter marginal teeth directly or send conspicuous branches to those teeth. No characteristic winged fruits of *Pterocarya* have been collected from the Latah formation unless some of those now called *Paliurus hesperia* Berry have been misidentified. The fruits of *Pterocarya paliurus* Batalin are so like those of *Paliurus orientalis* Hemsley, both from Hupeh Province, China, that distinction, especially of their fossil impressions, is difficult if not impossible.

*Pterocarya mixta* resembles a number of its Asiatic relatives but particularly *P. fraxinifolia* Spach.

The fossil species *Pterocarya americana* Lesquereux,<sup>6</sup> from Florissant, Colo., is equivalent to *Populus lesquereuxii* Cockerell.

Occurrence: Latah formation, Spokane, Wash. Miocene.

**BETULACEAE**

***Alnus carpinooides* Lesquereux**

Plate 48, figures 4, 5

*Alnus carpinooides* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 243, pl. 50, fig. 11; pl. 51, figs. 4, 4a, 5, 1883.

Chaney, Carnegie Inst. Washington Pub. 349, pt. 1, pp. 7-10, pls. 2-7, 1925.

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 19, 1934.

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 117, pl. 7, fig. 1, 1936.

*Betula thor* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 35, pl. 17, fig. 3, 1926.

*Alnus prerhombifolia* Berry, U. S. Geol. Survey Prof. Paper 154, p. 244, pl. 50, fig. 11, 1929.

This species seems to have been founded upon specimens that were pronouncedly broadly ovate-acuminate, with rounded-cuneate bases. The living species it most closely resembles is *Alnus tenuifolia* Nuttall, of the Western States. *Alnus carpinooides* has rather variable foliage, and it is possible that some fossil leaves from the Latah and other formations here segregated among three species—*A. carpinooides*, *A. relatus*, and *A. corallina*—may be confused and should be referred to *A. carpinooides* alone. There is, however, apparently no satisfactory basis for separating these fossil species except by arbitrarily choosing types on the basis of shape. It should also be noted that these fossil leaves resemble *Betula papyrifera* Marshall, of the northern United States.

Occurrence: Latah formation, Spokane, Wash. (fig. 5); Tipton, Oreg. (fig. 4); Salmon, Idaho. Miocene.

***Alnus corallina* Lesquereux**

Plate 48, figures 1-3

*Alnus corallina* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 243, pl. 51, figs. 1-3, 1883.

Brown, Jour. Paleontology, vol. 9, p. 575, pl. 67, fig. 15, 1935.

*Alnus hollandiana* Jennings, Carnegie Mus. Mem., vol. 8, no. 2, p. 413, pl. 24, fig. 8; pl. 25, fig. 3; pl. 28, fig. 1; pl. 30, figs. 1, 1a, 3, 1920.

*Alnus microdontoides* Jennings, idem, p. 415, pl. 24, fig. 7; pl. 30, figs. 2, 2a.

*Prunus rustii* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 43, pl. 24, figs. 4, 5, 1926. [Not Berry, U. S. Geol. Survey Prof. Paper 154, p. 252, pl. 55, fig. 1, 1929.]

The leaves of this species of *Alnus* resemble those of the living *A. rhombifolia* Nuttall and *A. rugosa* Sprengel in their ovate-elliptic shape and numerous small, uniform teeth and in the fact that nearly every secondary vein sends prominent branches to subsidiary marginal teeth.

The objection to the assignment of Knowlton's 1926 specimens and Berry's 1929 specimen to *Prunus* is based upon the well-known fact that the secondary veins of *Prunus* seldom, in evenly toothed leaves, run out directly into marginal teeth.

Occurrence: Salmon, Idaho (figs. 1, 2); Republic, Wash. (fig. 3). Miocene.

***Alnus relatus* (Knowlton) Brown, n. comb.**

Plate 49, figures 1-6

*Betula elliptica* Saporta. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 242, pl. 51, fig. 6, 1883.

*Phyllites relatus* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 48, pl. 28, fig. 8, 1926.

*Prunus rustii* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 154, p. 252, pl. 55, fig. 1, 1929.

*Betula heteromorpha* Knowlton. Brooks, Carnegie Mus. Annals, vol. 24, p. 283, pl. 5, figs. 1-3, 1935.

Leaves narrowly elliptic, acuminate, with cuneate or slightly rounded bases. Main marginal teeth few, widely spaced, with few subsidiary teeth. Branches from the secondary veins to marginal teeth relatively few, but there is a marked tendency for the secondaries to form prominent connecting intramarginal loops.

<sup>6</sup> Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 290, pl. 58, fig. 3, 1878.

This species can be matched most closely with *Alnus japonica* Siebold and Zuccarini, of Japan.

Occurrence: Latah formation, Spokane, Wash. (figs. 3, 4, 6); Salmon, Idaho (figs. 1, 2, 5). Miocene.

#### *Betula fairii* Knowlton

Plate 47, figures 5, 6, 7

*Betula fairii* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 33, pl. 17, fig. 4, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 243, 1929.

*Betula nanoides* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 34, pl. 18, fig. 2, 1926.

*Betula heteromorpha* Knowlton. Knowlton, idem, p. 34, pl. 17, figs. 5, 6.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 243, 1929.

*Betula? largei* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 34, pl. 17, figs. 1, 2, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 244, pl. 50, fig. 4, 1929.

Brooks, Carnegie Mus. Annals, vol. 24, p. 284, pl. 5, figs. 4, 5; pl. 6, fig. 1, 1935.

*Betula bryani* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 34, pl. 17, fig. 1, 1926.

*Celastrus fernquisti* Knowlton, idem, p. 44, pl. 28, fig. 2.

That some of the described leaves here cited are small and others large does not alter the fact that fundamentally they have the same shape, venation, and marginal dentition and are therefore regarded as the same species. The resemblance of this species to *Betula luminifera* Winkler, of China, is extremely close.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### *Betula vera* Brown, n. sp.

Plate 48, figures 7-11

Leaves 10 centimeters or more long, ovate or oblong-ovate, acute at the apex, narrowed to an oblique, slightly cordate base, doubly serrate with rather uniform blunt teeth. Midrib strong, secondaries evenly spaced, straight or slightly curved, few except the lowermost having branches to subsidiary teeth.

This fine species appears to be an exact duplicate of the living yellow birch, *Betula lutea* Michaux, which is found in moist situations in the uplands of the Northeastern States and Canada.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### *Corylus macquarrii* (Forbes) Heer

Plate 50, figure 6

*Corylus macquarrii* (Forbes) Heer. Newberry, U. S. Geol. Survey Mon. 35, p. 61, pl. 32, fig. 5; pl. 48, fig. 4, 1898.

Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 104, 1927. (See discussion.)

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 18, pl. 3, figs. 2, 4, 1934.

This portion of a leaf with craspedodrome secondary veins running into large, prominent, dentate teeth and with branches to subordinate smaller teeth has the form and venation of *Corylus macquarrii* (Forbes) Heer.

Occurrence: Tipton, Oreg. Miocene.

#### *Ostrya oregoniana* Chaney

Plate 48, figure 12

*Ostrya oregoniana* Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 106, pl. 9, fig. 12; pl. 10, figs. 1-4, 1927.

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 118, pl. 9, fig. 3, 1936.

This specimen with most of its secondary veins showing conspicuous branches to subsidiary teeth appears to match the specimen illustrated by Chaney's plate 10, figure 4.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### FAGACEAE

##### *Castanea orientalis* Chaney

Plate 49, figure 17

*Castanea orientalis* Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 110, pl. 12, figs. 1, 4, 1927.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 240, pl. 51, figs. 4, 5, 1929.

*Castanea castaneafolia* (Unger) Knowlton. Berry, U. S. Geol. Survey Prof. Paper 185, p. 108, 1934. (See synonymy and discussion.)

If there is any suggestive difference between the species cited in the synonymy, no one has yet pointed it out. Until that is done, if it can be done, they are hereby merged into one species. It is possible that some of the more obovate specimens heretofore identified as *Castanea orientalis* may in reality be forms of *Quercus clarnensis* Trelease.

Occurrence: Latah formation, Spokane, Wash.; White Bird, Idaho (fig. 17). Miocene.

##### *Castanopsis convexa* (Lesquereux) Brooks

Plate 49, figures 8-11

*Castanopsis convexa* (Lesquereux) Brooks, Carnegie Mus. Annals, vol. 24, p. 288, pl. 6, fig. 5; pl. 10, figs. 1, 3; pl. 12, figs. 1-6; pl. 13, figs. 4-6; pl. 18, figs. 3-5; pl. 20, fig. 4; pl. 21, fig. 16, 1935.

The four specimens figured here are examples of this species as originally conceived—that is, as a species having short lanceolate-oblong or elliptic leaves. They resemble the leaves of the bush chinquapin, *Castanopsis sempervirens* Dudley.

Occurrence: Latah formation, Spokane, Wash. (figs. 10, 11); Tipton, Oreg. (figs. 8, 9). Miocene.

##### *Fagus washoensis* LaMotte

Plate 51, figures 1-3, 8-10

*Fagus pacifica* Chaney. Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 19, 1934.

Berry, U. S. Geol. Survey Prof. Paper 185, p. 107, pl. 19, fig. 6; pl. 20, fig. 1, 1934.

Brooks, Carnegie Mus. Annals, vol. 24, p. 285, pl. 6, figs. 3, 4, 1935.

*Fagus washoensis* LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, pl. 119, fig. 8, figs. 2, 3, 5, 1936.

*Castanea lesquereli* LaMotte, idem, p. 120, pl. 9, fig. 6.

*Sorbus chaneyi* LaMotte, idem, p. 130, pl. 9, figs. 4, 5.

*Amygdalus alexanderi* Berry, Washington Acad. Sci. Jour., vol. 19, pp. 41-43, text fig. 1, 1929.

Although LaMotte says that *Fagus washoensis* differs from *F. pacifica* Chaney in being larger and in having more numerous secondaries, a longer petiole, and serrate rather than dentate teeth, one other important difference should be noted—namely, that *F. washoensis* is broadest near the middle of the blade, thus giving it an elliptic appearance, whereas *F. pacifica* is broadest at a point some distance below the middle of the blade, giving it an oblong, lance-shaped appearance.

An examination of the types of *Castanea lesquereuxi* LaMotte and *Sorbus chaneyi* LaMotte shows that they are large and small leaves, respectively, of *Fagus washoensis*, for they can be duplicated easily in the fossil collections from Tipton, Oreg., and White Bird, Idaho, and also with leaves from the living *Fagus americana* Sweet growing in the vicinity of Washington, D. C.

The specimen called *Amygdalus alexanderi* Berry, originally described as the impression of a peach stone, represents in fact two partly overlapping valves of a beech bur, as the accompanying figures of the type and a squeeze of its counterpart show (figs. 2, 3). This bur is somewhat larger than that ascribed to *Fagus pacifica* Chaney, from Crooked River, Oreg. It is associated with a large beechnut (fig. 1) and leaves in the Latah formation at Spokane, Wash. The leaves illustrated here, however, came from Tipton, Oreg.

The presence of *Amygdalus* in the fossil record of North America, though not improbable, rests uncertainly upon some rather doubtfully identified leaves and fruits.

Occurrence: Latah formation, Spokane, Wash. (figs. 1-3); Tipton, Oreg. (figs. 8-10). Miocene.

#### *Quercus castaneopsis* Lesquereux

Plate 50, figure 9

*Quercus castaneopsis* Lesquereux. Brown, U. S. Geol. Survey Prof. Paper 185, p. 55, 1934.

This large specimen, perfect except for the twisted tip, is an unusually fine example of the species. Until recently it was misplaced in a collection to which it did not originally belong in the United States National Museum.

Occurrence: Green River formation, Fossil, Wyo. Middle Eocene.

#### *Quercus consimilis* Newberry

Plate 50, figures 2-5

*Quercus consimilis* Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 505, 1883; U. S. Geol. Survey Mon. 35, p. 71, pl. 43, figs. 2-5 (not figs. 7-10), 1898.

MacGinitie, Carnegie Inst. Washington Pub. 416, pt. 2, p. 52, pl. 5, fig. 5, 1933.

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 20, 1934.

The writer has not had time to investigate fully the merits of uniting *Quercus consimilis* Newberry, *Q. simulata* Knowlton, and some other species, as has been proposed by several students. The probability

that these leaves in whole or in part may represent *Castanopsis*, as claimed by Brooks,<sup>7</sup> has not, it is felt, been completely tested.

Occurrence: Latah formation, Spokane, Wash. (figs. 4, 5); Tipton, Oreg. (figs. 2, 3). Miocene.

#### *Quercus merriami* Knowlton

*Quercus merriami* Knowlton, U. S. Geol. Survey Bull. 204, p. 49, pl. 6, figs. 6, 7; pl. 7, figs. 4, 5, 1902; U. S. Geol. Survey Paper 140, p. 35, pl. 19, figs. 4, 5, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 246, 1929.

*Quercus ursina* Knowlton, U. S. Geol. Survey Bull. 204, p. 51, pl. 7, figs. 2, 3, 1902.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 246, 1929.

These leaves from a species belonging to the black-oak group are distinguished by being relatively narrow and by having elongated, sharpened lobes showing little tendency toward subordinate lobing.

Occurrence: Mascall formation, John Day Basin, Oreg.; Spokane, Wash. Miocene.

#### *Quercus payettensis* Knowlton

Plate 49, figures 12, 13

*Quercus payettensis* Knowlton, U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 730, pl. 102, fig. 9, 1898; U. S. Geol. Survey Prof. Paper 140, p. 37, pl. 21, figs. 5-7, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 246, 1929.

*Quercus cognatus* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 36, pl. 20, figs. 1-4; pl. 21, figs. 1, 2, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 245, 1929.

Brooks, Carnegie Mus. Annals, vol. 24, p. 292, pl. 16, fig. 2, 1935.

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 113, pl. 2, fig. 1, 1936.

*Quercus rustii* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 36, pl. 21, figs. 3, 4, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 246, 1929.

*Quercus praenigra* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 37, pl. 19, fig. 6, 1926.

*Quercus* sp. Knowlton, idem, p. 37, pl. 19, fig. 7; pl. 22, fig. 9.

These leaves from a species belonging to the black-oak group are distinguished by being relatively broad, with short sharp lobes showing little tendency toward subordinate lobing. The lower half of these leaves may frequently be without lobes.

Occurrence: Payette formation, Jackass Creek, Boise County, Idaho; Latah formation, Spokane, Wash. (figs. 12, 13). Miocene.

#### *Quercus pseudolyrata* Lesquereux

Plate 50, figures 7, 8

*Quercus pseudo-lyrata* Lesquereux. Knowlton, U. S. Geol. Survey Bull. 204, p. 48, 1902. (See synonymy and discussion.)

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 20, pl. 5, fig. 4, 1934.

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 121, 1936.

*Quercus duriuscula* Knowlton, idem, p. 50, pl. 8, fig. 2.

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 114, pl. 2, fig. 8, 1936.

<sup>7</sup> Brooks, B. W., Fossil plants from Sucker Creek, Idaho: Carnegie Mus. Annals, vol. 24, p. 285, 1935.

These leaves from a species belonging to the black-oak group are distinguished by the fact that their lobes tend to be obovate and themselves lobed or cut. The specimen *Quercus duriuscula*, confidently assigned by Knowlton to the white-oak group, was found when cleaned to have strongly pointed lobes. It is therefore regarded as a form of *Q. pseudolyrata*.

Occurrence: Mascall formation, John Day Basin, Oreg.; Tipton, Oreg. (figs. 7, 8). Miocene.

#### *Quercus simulata* Knowlton

Plate 50, figure 1

*Quercus simulata* Knowlton. See synonymy as given by Berry, U. S. Geol. Survey Prof. Paper 185, p. 109, 1934; and also those given by Brooks for *Castanopsis consimilis* (Newberry) Brooks, Carnegie Mus. Annals, vol. 24, p. 285, 1935, and *Castanopsis convexa* (Lesquereux) Brooks, idem, p. 288.

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 122, 1936.

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 115, pl. 1, figs. 9, 10, 1936.

*Quercus obtusa* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 38, pl. 22, fig. 8, 1926.

*Laurus princeps* Heer. Knowlton, idem, p. 41, pl. 23, fig. 3.

*Phyllites crustacea* Knowlton, idem, p. 47, pl. 29, fig. 6.

*Apocynophyllum latahense* Berry, U. S. Geol. Survey Prof. Paper 154, p. 263, pl. 60, fig. 4 (not fig. 7), 1929.

*Rhus merrilli* Chaney. Berry, idem, p. 256, pl. 51, fig. 8.

The question whether any or all the leaves called *Quercus simulata* are a species of *Castanopsis*, as thought by Brooks, is, in the writer's opinion, not settled, and he prefers to await further study. The recent synonymy by LaMotte includes some items otherwise disposed of in this paper, as can be seen by consulting the section on changes of name and new combinations (pp. 165-167).

Occurrence: Latah formation, Spokane, Wash.; Tipton, Oreg. (fig. 1). Miocene.

#### ULMACEAE

##### *Celtis obliquifolia* Chaney

Plate 48, figure 6

*Celtis obliquifolia* Chaney, Carnegie Inst. Washington Pub. 349, pt. 3, p. 51, pl. 1, figs. 1, 3, 5, 1925; idem, Pub. 346, pt. 4, p. 115, pl. 13, fig. 12, 1927.

*Ficus planicostata* Lesquereux? Newberry, U. S. Geol. Survey Mon. 35, p. 88, pl. 46, fig. 1, 1898.

The venation, entire margin, and asymmetry of the leaf doubtfully referred to *Ficus planicostata* by Newberry substantiate its reference to *Celtis obliquifolia* Chaney. Thus far the stone fruits of *Celtis*, characterized by a distinctive reticulated surface, have not been reported from the deposits at Bridge Creek or Crooked River, Oreg.

Occurrence: Bridge Creek, Oreg. Miocene.

##### *Zelkova oregoniana* (Knowlton) Brown, n. comb.

Plate 51, figures 11-15

*Myrica oregoniana* Knowlton, U. S. Geol. Survey Bull. 204, p. 33, pl. 3, fig. 4, 1902.

*Ulmus fernquisti* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 39, pl. 19, fig. 2, 1926.

*Fagopsis longifolia* (Lesquereux) Hollick. Berry, U. S. Geol. Survey Prof. Paper 154, p. 245, pl. 50, fig. 7, 1929.

Leaves oblong-ovate or elliptic with cordate, rounded, and only slightly asymmetric bases. Tips long pointed. Margins with large, rounded, sometimes conical, blunt, single or double teeth, the subsidiary tooth missing or very obscure on some teeth. Secondary venation more or less undulate, occasionally forked. Finer venation produces a pattern of relatively larger areolae than in *Ulmus*.

The double teeth shown near the base at the left on Knowlton's figure 4 are the artist's interpolation of several offsets in the fossil impression. The teeth are single.

The leaves of this species possess characters common to both *Zelkova ulmoides* Schneider of southwestern Asia, and *Z. serrata* Makino of Japan. No fossil fruits assignable to this species have yet been detected in the strata from which the leaves were collected.

Occurrence: Mascall formation, John Day Basin, Oreg.; Spokane, Wash. (figs. 11, 13-15); Republic, Wash. (fig. 12). Miocene.

#### *Ulmus speciosa* Newberry

*Ulmus speciosa* Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 507 1883; U. S. Geol. Survey Mon. 35, p. 80, pl. 45, figs. 2-4 8, 1898. [Not other figures, especially fig. 7, which is *Ptelea miocenica* Berry.]

Knowlton, U. S. Geol. Survey Bull. 204, p. 53, 1902; U. S. Geol. Survey Prof. Paper 140, p. 39, pl. 18, fig. 6, 1926.

Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 114, 1927. [Not pl. 12, fig. 5, which is *Ptelea miocenica* Berry.]

Berry, U. S. Geol. Survey Prof. Paper 156, p. 247, 1929; Prof. Paper 170, p. 34, 1931; Prof. Paper 185, p. 110, 1934.

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 116, 1936.

*Ulmus*, fruit. Berry, U. S. Geol. Survey Prof. Paper 156, p. 247, pl. 51, fig. 1; pl. 64, figs. 3, 4, 1929.

The assumption that the fruits cited in the last member of the synonymy belong to the same species as the leaves is based upon the close resemblance of both fruits and leaves to those of *Ulmus americana* Linnaeus, of the eastern United States and Canada. The samaras called *U. speciosa* by Newberry and Chaney possess the form and the strong, reticulated venation of *Ptelea* fruits, but a restudy of the Miocene species of *Ulmus* based on better material than is now at hand may prove this assignment to be untenable.

Occurrence: Latah formation, Spokane, Wash.; Grand Coulee, Wash.; Bridge Creek, Oreg. Miocene.

#### MORACEAE

##### *Ficus mississippiensis* (Lesquereux) Berry

Plate 63, figure 4

*Ficus mississippiensis* (Lesquereux) Berry, U. S. Geol. Survey Prof. Paper 131, p. 9, pls. 6-8, 1923. (See synonymy.) Brown, U. S. Geol. Survey Prof. Paper 154, p. 284, 1929.

Occurrence: Green River formation, Fossil, Wyo. Middle Eocene. Figured specimen in Museum of Paleontology, University of Michigan.

## PLATANACEAE

*Platanus dissecta* Lesquereux

Plate 52, figures 1-3

- Platanus dissecta* Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 13, pl. 7, fig. 12; pl. 10, figs. 4, 5, 1878; U. S. Geol. Survey Terr. Rept., vol. 8, p. 249, pl. 56, fig. 4; pl. 57, figs. 1, 2, 1883.
- Berry, U. S. Geol. Survey Prof. Paper 154, p. 248, pl. 53, figs. 1, 2; pl. 61, 1929; Prof. Paper 185, p. 111, pl. 21, fig. 2, 1934.
- Brooks, Carnegie Mus. Annals, vol. 24, p. 294, pl. 17, figs. 2-4; pl. 18, figs. 1, 2, 1935.
- Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 22, pl. 3, fig. 3, 1934.
- LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 129, 1936.
- Acer trilobatum productum* (Al. Braun) Heer. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 253, pl. 59, figs. 1-4, 1883.
- Platanus aspera* Newberry, U. S. Geol. Survey Mon. 35, p. 102, pl. 42, fig. 2 [not fig. 1, which is *Tilia aspera* (Newberry) LaMotte, nor fig. 3, which is *Platanus condoni* (Newberry) Knowlton, nor other figures], 1898.
- Acer bendirei* Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 14, pl. 5, fig. 5; pl. 6, fig. 1; pl. 7, fig. 1 [not pl. 8, fig. 1, which remains *A. bendirei*], 1888.
- Celtis hesperius* Berry, Torreya, vol. 32, pp. 40-42, text fig. 1, 1932.

As pointed out by Brooks, the specimen called *Celtis hesperius* Berry is in fact *Platanus dissecta*. It is refigured here to show the points on which its transfer from *Celtis* to *Platanus* was made—namely, the two incipient lobes, the large, sharp, scalloped teeth penetrated by secondary veins, and the large base of the petiole.

Occurrence: Tipton, Oreg. (fig. 1); Latah formation, Spokane, Wash. (fig. 2); Sucker Creek, Oreg. (fig. 3). Miocene.

## LAURACEAE

*Laurus similis* Knowlton

- Laurus similis* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 185, p. 121, 1934. (See synonymy, except last member, which is referred to *Umbellularia dayana* (Knowlton) Berry.)
- Umbellularia lanceolata* Berry, U. S. Geol. Survey Prof. Paper 154, p. 260, pl. 59, fig. 1, 1929.
- LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 127, 1936. (See discussion.)

The species *Umbellularia lanceolata* lacks the characteristic looped secondary venation of *Umbellularia* and appears to be only a narrow form of *Laurus similis*. These fossils may represent a species of *Persea*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

*Machilus americana* Brown, n. sp.

Plate 53, figure 16

Leaf 6 centimeters long, entire, narrowly ovate, probably acuminate; base cuneate; petiole less than 1 centimeter long; secondary veins somewhat irregularly spaced, slightly undulate, camptodrome.

This specimen may be compared with the leaves of *Machilus henryi* Hemsley from southern China.

Occurrence: Latah formation, Spokane, Wash. Miocene.

*Machilus asiminoides* Brown, n. sp.

Plate 52, figures 9, 10

Leaves small, entire, oblanceolate, with blunt apex and gradually narrowed base; petiole relatively long, curved.

In venation and shape these small leaves are exceedingly like those of *Machilus ichangensis* Rehder and Wilson and *M. thunbergii* Nees, of southeastern China. Except for their long petioles they are also very similar to *Asimina triloba* (Linnaeus) Dunal, the pawpaw of the eastern United States.

Occurrence: Latah formation, Spokane, Wash. Miocene.

*Sassafras hesperia* Berry

Plate 53, figures 7-10

*Sassafras hesperia* Berry, U. S. Geol. Survey Prof. Paper 154, pl. 59, fig. 2, 1929.

Brooks, Carnegie Mus. Annals, vol. 24, p. 299, pl. 20, fig. 1, 1935.

*Philadelphus bendirei* Chaney. Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 21, 1934.

The type of this species, a leaf with a left-hand lobe, was mistakenly recorded as having come from the brickyard locality at Spokane, Wash. It came from Republic, Wash. The leaves on the living sassafras, *Sassafras variifolium* (Salisbury) Kuntze, are of four kinds in respect to shape—entire, right-hand lobed, left-hand lobed, and three-lobed. The specimen reported by Oliver as *Philadelphus bendirei* is a small entire leaf of *Sassafras hesperia*.

Occurrence: Republic, Wash. (fig. 8); Tipton, Oreg. (figs. 7, 9); Salmon, Idaho (fig. 10). Miocene.

*Umbellularia dayana* (Knowlton) Berry

Plate 52, figure 13

*Salix dayana* Knowlton, U. S. Geol. Survey Bull. 204, p. 31, pl. 2, figs. 9, 10, 1902; Prof. Paper 140, p. 32, pl. 12, fig. 1 [not fig. 2, which is *Sophora spokanensis* Knowlton], 1926.

*Umbellularia dayana* (Knowlton) Berry, U. S. Geol. Survey Prof. Paper 154, p. 260 [not pl. 58, fig. 4, which is *Cedrela pteriformis* (Berry) Brown], 1929.

*Salix* sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 33, pl. 12, figs. 1, 3, 1926.

*Laurus similis* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 154, p. 259, pl. 58, fig. 2, 1929.

*Quercus simulata* Knowlton. Berry, idem, p. 246, pl. 51, fig. 6 [not other figures].

*Leguminosites bonseri* Berry, idem, p. 254, pl. 56, fig. 4.

The relationship of this species to *Umbellularia oregonensis* Chaney, from the Bridge Creek and Crooked River regions of Oregon, is not clear. It is probable that these leaves do not represent *Umbellularia*.

Occurrence: Latah formation, Spokane, Wash.; Salmon, Idaho (fig. 13). Miocene.

## BERBERIDACEAE

*Mahonia reticulata* (MacGinitie) Brown, n. comb.

Plate 52, figure 4

*Clematis reticulata* MacGinitie, Carnegie Inst. Washington Pub. 416, p. 54, pl. 6, fig. 4, 1933.*Odostemon hollicki* Dorf. MacGinitie, idem, p. 55, pl. 7, figs. 1, 3, 5.*Mahonia hollicki* (Dorf) Arnold, Michigan Univ., Mus. Paleontology, Contr., vol. 5, no. 4, p. 61, pl. 2, figs. 3-8; pl. 3, figs. 5, 7, 9, 1936.

After a comparison of the type specimens of *Odostemon hollicki* Dorf, from the Pliocene of California, with the specimens called *O. hollicki* by MacGinitie, from the Miocene of Trout Creek, Oreg., the writer is convinced that the latter specimens represent a different species having smaller leaflets with coarser teeth. Arnold called attention to the fact that *Clematis reticulata* MacGinitie is an entire-margined leaflet of this species. The fragment figured here from Tipton, Oreg., appears to belong to *Mahonia reticulata* rather than *M. simplex*.

Occurrence: Tipton, Oreg. (fig. 4). Miocene.

*Mahonia simplex* (Newberry) Arnold*Berberis simplex* Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 514, 1883; U. S. Geol. Survey Mon. 35, p. 97, pl. 56, fig. 2, 1898.*Odostemon simplex* (Newberry) Cockerell, Am. Mus. Nat. History Bull., vol. 24, p. 91, 1908.

Chaney, Carnegie Inst. Washington Pub. 346, p. 116, pl. 14, figs. 7-9, 11, 1927.

*Mahonia simplex* (Newberry) Arnold, Michigan Univ., Mus. Paleontology, Contr., vol. 5, no. 4, p. 58, pl. 1, figs. 1-3, 6, 7; pl. 2, figs. 1, 2, 1936.*Ilex latahensis* Ashlee, Northwest Sci., vol. 6, p. 82, pl. 2, fig. 14, 1932.

A specimen of this species is present in the Mascall collection in the United States National Museum.

Occurrence: Mascall formation, John Day Basin, Oreg. Miocene.

## CERATOPHYLLACEAE

*Ceratophyllum praedemersum* Ashlee

Plate 45, figure 32

*Ceratophyllum praedemersum* Ashlee, Northwest Sci., vol. 6, p. 78, pl. 1, fig. 2, 1932.

Although Ashlee's specimen is not well illustrated, it seems from his description that the object figured here may be his species. This specimen appears to be a stem with nodes, at each of which is a whorl of branched, threadlike filaments that may well be leaves like those on *Ceratophyllum demersum* Linnaeus, found in ponds and slow streams throughout most of North America.

Occurrence: Latah formation, Spokane, Wash. Miocene.

## CERCIDIOPHYLLACEAE

*Cercidiphyllum crenatum* (Unger) Brown*Cercidiphyllum crenatum* (Unger) Brown, Jour. Paleontology, vol. 9, p. 575, pl. 68, figs. 1, 6, 8-10, 1935. (See synonymy.)

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 126, 1936.

*Paliurus columbi* Heer. Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 16, 1888.*Grewia crenata* (Unger) Heer. Knowlton, U. S. Geol. Survey Bull. 204, p. 80, 1902.

The specimens referred to by Knowlton and Lesquereux were inadvertently overlooked in the writer's publication of the new combination in 1935, but they belong with this species.

Occurrence: Mascall formation, John Day Basin, Oreg.

## MAGNOLIACEAE

*Magnolia dayana* Cockerell*Magnolia dayana* Cockerell, Am. Naturalist, vol. 44, p. 35, 1910. [For *M. lanceolata* Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 24, pl. 6, fig. 4, 1878.]

Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 24, fig. 3, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 250, 1929; Prof. Paper 185, p. 112, 1934.

*Laurus grandis* Lesquereux. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 24, fig. 1, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 259, pl. 58, fig. 3, 1929.

*Laurus princeps* Heer. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 250, pl. 58, fig. 2, 1883.Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 23, figs. 1, 2 [not fig. 3, which is *Quercus simulata* Knowlton], 1926.

None of the Latah specimens appear to conform to the characters illustrated by the types of *Laurus grandis* Lesquereux, from Corral Hollow, Calif., but all the specimens grouped under the present synonymy agree with the specimen first called *Magnolia dayana* Cockerell by Knowlton in 1926 as well as with those originally called *M. lanceolata* Lesquereux and later changed to *M. dayana* by Cockerell. That these leaves may be *Persea* or *Rhododendron* rather than *Magnolia* is a reservation to be kept in mind.

Occurrence: Latah formation, Spokane, Wash. Miocene.

*Magnolia latahensis* (Berry) Brown, n. comb.*Magnolia* sp. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 41, pl. 27, fig. 1, 1926.*Magnolia californica* Lesquereux. Berry, U. S. Geol. Survey Prof. Paper 154, p. 250, 1929.*Apocynophyllum latahense* Berry, idem, p. 263, pl. 60, fig. 7 [not fig. 4, which is *Quercus simulata* Knowlton].

The irregular, undulatory, and forked secondary venation of these entire leaves differentiates them from

*Magnolia dayana* Cockerell. They resemble the living species *M. grandiflora* Linnaeus and *M. virginiana* Linnaeus, of the southeastern United States.

The specimens referred by Berry to *Magnolia californica* Lesquereux differ from Lesquereux's types sufficiently to make it possible to refer some to *M. latahensis* and one to *Fagus washoensis* LaMotte, as it has the secondary venation and marginal teeth of that species.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### SAXIFRAGACEAE

##### *Hydrangea bendirei* (Ward) Knowlton

Plate 53, figures 1, 2

*Marsilea bendirei* Ward, U. S. Geol. Survey 5th Ann. Rept., p. 446, 1885.

*Porana bendirei* (Ward) Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 16, pl. 8, fig. 4, 1888.

*Hydrangea bendirei* Knowlton. Merriam, California Univ., Dept. Geology, Bull., vol. 2, p. 309, 1901.

Knowlton, U. S. Geol. Survey Bull. 204, p. 60, pl. 9, figs. 6, 7, 1902; Prof. Paper 140, p. 42, pl. 24, fig. 6, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 251, 1929. [Not pl. 52, fig. 7, which is *Porana speirii* Lesquereux.]

*Euonymus knowltoni* Berry, U. S. Geol. Survey Prof. Paper 154, p. 255, pl. 56, fig. 9, 1929; Prof. Paper 185, p. 117, 1934.

The presence of undoubted sterile *Hydrangea* flowers in the Latah formation suggested a search for possible leaves that would confirm the identification. It is believed that those called *Euonymus knowltoni* are the required leaves, for they as well as the flowers compare well with those of the living *H. strigosa* Rehder, from northern Hupeh, China.

Occurrence: Latah formation, Spokane, Wash. Miocene.

##### *Hydrangea fraxinifolia* (Lesquereux) Brown, n. comb.

Plate 53, figures 5, 6

*Fraxinus praedicta* Heer. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7, p. 229, pl. 40, fig. 3, 1878.

*Celastrus fraxinifolius* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 184, pl. 33, figs. 2-4, 1883.

*Fraxinus heerii* Lesquereux, idem, p. 169, pl. 33, figs. 5, 6.

*Juglans affinis* Kirchner, St. Louis Acad. Sci. Trans., vol. 8, p. 184, pl. 13, fig. 2, 1898.

*Hydrangea florissantia* Cockerell, Am. Jour. Sci., 4th ser., vol. 26, p. 67, text fig. 2; p. 541, 1908. [For *Rhus rotundifolia* Kirchner, St. Louis Acad. Sci. Trans., vol. 8, p. 184, pl. 12, fig. 2, 1898.]

Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 269, 1916.

Although one of the sepals is missing from the type *Hydrangea* flower here refigured from the Florissant lake beds, there seems to be little doubt that the generic assignment is correct. The sepals are slightly petioled, whereas those of *H. bendirei* (Ward) Knowlton, from the Latah formation at Spokane, Wash., appear to be sessile. The flowers of *H. bendirei* are uniformly larger than those of *H. fraxinifolia*.

The presence of *Hydrangea* flowers in the Florissant beds prompted a search of the collections for possible

confirmatory leaves, with the result that those formerly called *Celastrus fraxinifolius*, together with others cited in the synonymy, are selected as the most probable representatives of the species. They, like the similar but larger leaves from the Latah formation, compare very well with the leaves of *H. strigosa* Rehder, from western Hupeh, China. The leaf identified as *Fraxinus praedicta* Heer by Lesquereux is fragmentary, and it cannot be referred to the European types from Oeningen, Germany.

Occurrence: Florissant, Colo. Miocene.

#### *Philadelphus pardee* (Knowlton) Brown, n. comb.

Plate 62, figures 5-10

*Phyllites pardee* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 48, pl. 29, fig. 13, 1926.

*Phyllites peculiaris* Knowlton, idem, p. 48, pl. 29, fig. 2.

This species is characterized by having a cuneate to rounded base, remotely spaced, dentate teeth, and a tendency toward palmate venation. The curving secondary veins run rather directly into marginal teeth. Except for this fact, these leaves simulate those of *Philadelphus lewisii* Pursh, of the Northwestern States. A living species also closely comparable to the fossils is *Viburnum stellatum* Hemsley, of Mexico. It is possible that these leaves may be variant forms of *Viburnum fernquisti* (Berry) Brown.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### HAMAMELIDACEAE

##### *Liquidambar californicum* Lesquereux

Plate 61, figures 9, 10

*Liquidambar californicum* Lesquereux. Berry, U. S. Geol. Survey Prof. Paper 185, p. 113, 1934. (See synonymy and discussion.)

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 21, 1934.

Occurrence: Potlatch Creek, between Arrow Junction and Juliaetta, Latah County, Idaho.

#### ROSACEAE

##### *Amelanchier dignata* (Knowlton) Brown

Plate 53, figure 11

*Amelanchier dignata* (Knowlton) Brown, Jour. Paleontology, vol. 9, p. 577, pl. 69, figs. 5, 6, 1935. (See synonymy and discussion.)

Occurrence: Latah formation, Spokane, Wash. Miocene.

##### *Cercocarpus antiquus* Lesquereux

Plate 57, figure 6

*Cercocarpus antiquus* Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 37, pl. 10, figs. 6-11, 1878; U. S. Geol. Survey Terr. Rept., vol. 8, p. 265, pl. 45 B, fig. 2, 1883.

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 22, 1934.

Although this specimen is fragmentary, it can be readily identified as belonging to *Cercocarpus antiquus* Lesquereux.

Occurrence: Tipton, Oreg. Miocene.

***Cercocarpus paeledifolius* Berry**

Plate 56, figure 13

*Cercocarpus paeledifolius* Berry, U. S. Geol. Survey Prof. Paper 154, p. 252, pl. 64, fig. 7, 1929.

Occurrence: Latah formation, Spokane, Wash. Miocene.

***Chamaebatiaria creedensis* Brown, n. sp.**

Plate 57, figures 8, 9

These specimens, which resemble small ferns or mosses, are bipinnate leaves with minute, obovate, ultimate divisions. Appendages similar to these divisions appear along the rachis.

This species may be compared with the living fern-bush or desert-sweet, *Chamaebatiaria millefolium* (Torrey) Maximowicz, a fragrant shrub, 2 to 6 feet high, that grows at altitudes of 5,500 to 9,500 feet along the east slopes of the Sierra Nevada and along hillsides and canyons from southern Oregon to Arizona. *Chamaebatiaria creedensis* is likely to be confused with a somewhat similar fossil from another genus, *Chamaebatia prefoliolosa* Brown, described from the lake beds at Salmon, Idaho. The latter, however, has tripinnate leaves like its living counterpart, *Chamaebatia foliolosa* Bentham.

Occurrence: Creede formation, Creede, Colo. Miocene.

**LEGUMINOSAE**

***Cercis parvifolia* Lesquereux**

Plate 54, figures 2-5

*Cercis parvifolia* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 201, pl. 31, figs. 5-7, 1883.

Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 276, pl. 25, figs. 1, 2, 1916.

*Paliurus haydeni* Cockerell, Am. Mus. Nat. History Bull., vol. 24, p. 102, 1909. [For *P. orbiculatus* Saporta. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 188, pl. 38, fig. 12, 1883.]

The leaf called *Paliurus haydeni* cannot be distinguished from *Cercis parvifolia* and is therefore assigned to that species. Additional leaves and a pod from the H. F. Wickham collection received in 1934 by the National Museum are figured. There being no other similar fruits assignable to *Cercis* from the Florissant lake beds, this pod is assumed to belong to the species that produced the leaves of *Cercis parvifolia*.

Occurrence: Florissant, Colo. Miocene.

***Cercis spokanensis* Knowlton**

Plate 54, figures 8-12

*Cercis? spokanensis* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 43, pl. 29, fig. 9, 1926.

*Meibomites lucens* Knowlton, idem, p. 44, pl. 28, fig. 10.

*Ficus? washingtonensis* Knowlton, idem, p. 46, pl. 25; pl. 26, figs. 1-3.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 248, pl. 54, figs. 1-3; pl. 55, figs. 5, 6; pl. 62, 1929; Prof. Paper 185, p. 111, 1934.

*Meibomites knowltoni* Berry, U. S. Geol. Survey Prof. Paper 154, p. 253, pl. 56, fig. 7, 1929.

*Cercis idahoensis* Berry, Torrey Bot. Club Bull., vol. 57, p. 240, text fig. 1; pl. 9, figs. 1-3 [not fig. 4, which is *Vitis washingtonensis* (Knowlton) Brown], 1931; U. S. Geol. Survey Prof. Paper 185, p. 114 [not pl. 21, fig. 1, which is *V. washingtonensis*]; pl. 22, figs. 1-3 [not fig. 4, which is *V. washingtonensis*]; pl. 23, figs. 5, 6 [not figs. 3, 4, which are *V. washingtonensis*], 1934.

*Cercis* sp. Ashlee, Northwest Sci., vol. 6, p. 80, pl. 1, fig. 7 [not fig. 7 A, which is *V. washingtonensis*], 1932.

*Cercidium hesperium* Ashlee, idem, p. 80, pl. 2, fig. 9.

*Gleditschia praequatica* Ashlee, idem, p. 89, pl. 2, fig. 8.

The presence of well-preserved *Cercis*-like pods in the Latah and related formations prompted a reexamination of all the available leguminous material for the purpose of determining what and how much of it might belong to a single species. The result is the synonymy given above.

First of all, a statement about the pods. They are remarkably like pods of living species of *Cercis* but differ in being rounder at the ends and in having wider wings. Moreover, the venation of the wings is transverse, whereas that of living *Cercis* is parallel to the margin, or only very slightly oblique. It would seem, therefore, that, instead of *Cercis*, a closely related genus would be indicated for these pods; but a search through the Leguminosae of the United States National Herbarium failed to produce a satisfactory suggestion. The pods are therefore tentatively left in the genus *Cercis*.

Besides general agreement in shape and in their finer venation pattern, all the leaves cited in the synonymy agree in two particulars that unite them uncontroversially in a single species—namely, a swollen top of the petiole at the base of the blade and two strong pairs of lateral primary veins. This kind of acropetiolar enlargement so conspicuous in *Cercis* and other legumes is absent in *Ficus*, to which some of these fossil leaves were assigned, and also in the leaves associated by Berry with the *Cercis* pods but now transferred to *Vitis*. The latter leaves, moreover, have secondary veins and branches that run squarely into marginal teeth or toothlike undulations. In *Cercis* the lateral primaries are camptodrome and never run squarely into the margin, but they and their branches loop upward well within the margin to the veins next above.

*Meibomia* has a pinnate, not palmate venation and is therefore eliminated as a reference for the leaves here designated *Meibomites*.

Two of the larger fossil leaves, although like the smaller ones and like *Cercis* in general, have pointed lobes near the apex, thus suggesting reference to a genus other than *Cercis*, the living species of which only rarely exhibit such lobes. Species of living leguminous genera, such as *Pueraria* and *Strophostyles*, and some

species of *Passiflora* that occasionally display pointed lobes, differ from the fossils in having only one pair of lateral primary veins, or possibly a very inconspicuous second pair, and the pods of the legumes are unlike the fossils.

The conclusion from this evidence, therefore, is that the *Cercis*-like pods were produced by the same plant that bore the *Cercis*-like leaves. What relationship, if any, there is between this species and the somewhat similar leaves from Chalk Bluffs, Calif., called *Ficus sordida* Lesquereux,<sup>8</sup> the writer is not prepared to say.

Occurrence: Latah formation, Spokane, Wash. (figs. 8, 9, 11, 12); White Bird, Idaho (fig. 10). Miocene.

#### *Sophora spokanensis* Knowlton

Plate 60, figures 1, 2

*Sophora spokanensis* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 44, pl. 28, fig. 6, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 253, pl. 56, figs. 5, 6, 1929; Prof. Paper 185, p. 116, 1934.

*Sophora alexanderi* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 43, pl. 28, figs. 3-5, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 253, pl. 56, figs. 2, 3, 1929; Prof. Paper 185, p. 116, 1934.

*Cassia idahoensis* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 154, p. 252, pl. 55, figs. 2, 3, 1929; Prof. Paper 185, p. 114, 1934.

*Cassia sophoroides* (Knowlton) Berry, U. S. Geol. Survey Prof. Paper 154, p. 253, pl. 56, fig. 1, 1929.

*Salix dayana* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 12, fig. 2 [not fig. 1, which is *Umbellaria dayana* (Knowlton) Berry], 1926.

*Quercus treleasii* Berry, U. S. Geol. Survey Prof. Paper 154, p. 247, pl. 52, figs. 1-3, 1929.

The 50 or more specimens of this species in the United States National Museum collection from the Latah formation show that these leaves vary greatly in shape, although the fundamental venation remains the same. If more than one species is represented there seems to be no satisfactory method of separating them. That this is a species of *Sophora* may be doubted, for equally good comparisons can be made with *Robinia*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### RUTACEAE

##### *Ptelea miocenica* Berry

Plate 51, figures 4, 5

*Ptelea miocenica* Berry, U. S. Geol. Survey Prof. Paper 170, p. 39, pl. 12, fig. 7, 1931.

MacGinitie, Carnegie Inst. Washington Pub. 416, pt. 2, p. 59, pl. 11, fig. 1, 1933.

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 133, pl. 11, figs. 1, 2, 1936. [Not fig. 4, which is *Carya egregia* (Lesquereux) LaMotte.]

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 119, pl. 2, figs. 5, 7, 1936.

*Ulmus speciosa* Newberry, U. S. Geol. Survey Mon. 35, p. 80, pl. 45, fig. 7, 1898. [Not other figures.]

Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 114, pl. 12, fig. 5, 1927.

<sup>8</sup> Lesquereux, Leo, Fossil plants of the auriferous gravel deposits of the Sierra Nevada: Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 17, pl. 4, figs. 6, 7, 1878.

It is possible that several species of *Ptelea* are here confused and that some specimens may represent *Ulmus* or some other genus instead of *Ptelea*. Dorf's figure 7, unfortunately upside down and not showing the remains of the calyx, which are present in the specimen itself, represents the best preserved and most authentic fossil *Ptelea* fruit the writer has yet seen. LaMotte's figure 1 also represents a good specimen and resembles most closely Newberry's *Ulmus speciosa*, here refigured (fig. 4). Chaney's figure 5 appears to be a small example of the latter. Berry's type of *Ptelea miocenica*, also refigured here (fig. 5) because the original figure depicts veins not present in the specimen, resembles the large samaras of some species of *Ulmus* more closely than those of *Ptelea*. MacGinitie's figure 1, although fragmentary, may well represent *Ptelea* foliage. It is evident that better material must be collected before the uncertainties here indicated can be resolved.

Occurrence: Bridge Creek, Oreg. (fig. 4); Grand Coulee, Wash. (fig. 5). Miocene.

#### MELIACEAE

##### *Cedrela lancifolia* (Lesquereux) Brown, n. comb.

Plate 60, figures 3, 4

*Sapindus lancifolius* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 182, pl. 32, figs. 3-6 [not pl. 37, fig. 9, which is *Oreodaphne lancifolia* (Lesquereux) Brown], 1883.

The writer, in a previous paper,<sup>9</sup> written before the discovery of the *Cedrela* seed here figured from the Florissant collections, made *Sapindus lancifolius* Lesquereux synonymous with *S. dentoni* Lesquereux, from the Green River formation. Now, although they are strikingly similar, they must be separated, the former to become *Cedrela lancifolia* and the latter to remain, together with *S. winchesteri* Knowlton, as species of *Sapindus*. That they may be species of *Cedrela* seems extremely likely, but no *Cedrela* seeds have yet been reported from the Green River formation to confirm this suspicion.

Lesquereux's figures of *Sapindus lancifolius*, with the exception of figure 3, show petioled leaflets with symmetric bases. The specimens themselves, however, are noticeably asymmetric, though not as strongly so as the additional specimen figured here. The secondary veins of these leaflets are more numerous and the tips are more attenuated than in most leaflets of modern species of *Cedrela*. These petioled leaflets must not be confused with those of *S. coloradensis* Cockerell, which are sessile or only slightly petiolulate.

The seed is smaller than that of *Cedrela pteriformis* (Berry) Brown, from the Latah formation at Spokane, Wash.

Occurrence: Florissant, Colo. Miocene.

<sup>9</sup> Brown, R. W., The recognizable species of the Green River flora: U. S. Geol. Survey Prof. Paper 185, p. 61, 1934.

**Cedrela pteriformis (Berry) Brown**

Plate 52, figure 12; plate 60, figures 5-10

- Cedrela pteriformis* (Berry) Brown, Jour. Paleontology, vol. 9, p. 579, pl. 67, fig. 21, 1935. (See synonymy.)  
*Umbellularia dayana* (Knowlton) Berry, U. S. Geol. Survey Prof. Paper 154, p. 260, pl. 58, fig. 4, 1929.  
*Sapindus armstrongi* Berry, idem, p. 254, pl. 63, fig. 14.  
*Pinus knowltoni* Chaney. Mason, Carnegie Inst. Washington Pub. 346, pt. 5, p. 148, pl. 2, fig. 3, 1927.  
*Pinus monticola* Berry. LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 110, pl. 5, figs. 1, 4, 1936.  
*Pinus russelli* LaMotte, idem, p. 110, pl. 5, figs. 2, 3.  
*Pseudotsuga masonii* MacGinitie. LaMotte, idem, p. 111, pl. 2, figs. 6, 7, 1936.  
*Libocedrus* sp. Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 108, pl. 1, fig. 4, 1936.

The leaflets of living species of *Cedrela* are more or less asymmetric, entire, blunt-pointed, and with regularly spaced, camptodrome secondary veins. In size they vary considerably in the same or different species. A leaflet of *C. mexicana* Roemer from Mexico is figured here for comparison with the fossil leaves cited in the synonymy. The presumption is ventured that these leaves and seeds represent a single biologic species. To this assemblage of evidence for the presence of *Cedrela* in some Miocene floras of the Western States is now added what appears to be the capsule of *Cedrela* from deposits near Tipton, Oreg. This fruit is an obovate, blunt-pointed capsule, the base of which is not subtended by calyx lobes but is naked, as are the mature capsules of living *Cedrela*.

It may be that several species of *Cedrela* are here made synonymous with *Cedrela pteriformis*, but more material must be collected and studied to determine this possibility. It seems likely that some and perhaps all of the leaflets called *Sapindus oregonianus* Knowlton are in reality leaflets of *Cedrela*.

Occurrence: Latah formation, Spokane, Wash. (figs. 5-8, 10); Tipton, Oreg. (fig. 9). Miocene.

**ANACARDIACEAE*****Cotinus fraterna* (Lesquereux) Cockerell**

- Cotinus fraterna* (Lesquereux) Cockerell, Torreya, vol. 6, p. 12, 1906.  
 Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 279, pl. 24, fig. 1, 1916. (See synonymy.)  
*Andromeda delicatula* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 175, pl. 34, figs. 10, 11, 1883.  
*Fraxinus ungeri* Lesquereux. Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 286, pl. 22, fig. 3, 1916.

The conspicuous forking of the secondary veins readily identifies these oblanceolate long-petioled leaves.

Occurrence: Florissant, Colo. Miocene.

***Rhus longepetiolata* (Lesquereux) Brown**

Plate 55, figures 2, 3

- Rhus longepetiolata* (Lesquereux) Brown, U. S. Geol. Survey Prof. Paper 185, p. 60, 1934. (See synonymy and discussion.)

The specimens figured here have somewhat larger teeth than the types but are otherwise in agreement.

Occurrence: Green River formation, Fossil, Wyo. Middle Eocene. Figure 2 in Museum of Paleontology, University of Michigan. Figure 3 in United States National Museum.

**CELASTRACEAE*****Euonymus pacificus* Brown, n. sp.**

Plate 56, figures 10, 11

Leaves ovate-lanceolate, sessile or short-petioled, crenulate, with blunt apex and cuneate to rounded base. Secondary veins unite to form conspicuous loops well within the margin. Ultimate venation is a rather striking uniform quadrangular meshwork pattern.

The living counterpart of this species seems to be the strawberry bush, *Euonymus americanus* Linnaeus, of the eastern United States.

Occurrence: Latah formation, Spokane, Wash. Miocene.

**ACERACEAE*****Acer bendirei* Lesquereux**

Plate 58, figures 20-22

- Acer bendirei* Lesquereux, U. S. Nat. Mus. Proc., vol. 11, p. 14, pl. 8, fig. 1 [not pl. 5, fig. 5; pl. 6, fig. 1; pl. 7, fig. 1, which are *Platanus dissecta* Lesquereux], 1888.  
*Acer dimorphum* Lesquereux, idem, p. 15, pl. 9, fig. 1.  
*Acer*, fruits of. Lesquereux, idem, p. 15, pl. 6, figs. 2, 3.  
*Acer oregonianum* Knowlton, U. S. Geol. Survey Bull. 204, p. 75, pl. 13, figs. 5-8, 1902.  
 Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 24, 1934.  
*Acer minor* Knowlton, idem, p. 76, pl. 14, fig. 2 [not fig. 3, which is *A. negundo* MacGinitie].  
*Acer medianum* Knowlton, idem, p. 76, pl. 14, figs. 4, 5.  
*Acer osmonti* Knowlton. Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 126, pl. 18, figs. 8, 9, 1927.  
*Acer merriami* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 170, p. 39, pl. 13, fig. 13, 1931.  
 MacGinitie, Carnegie Inst. Washington Pub. 416, pt. 2, p. 61, pl. 10, fig. 1, 1933.  
 LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 135, pl. 12, fig. 7, 1936.  
 Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 120, pl. 3, fig. 8, 1936.

Both the leaves and fruits associated here compare very well with those of *Acer macrophyllum* Pursh, of the Pacific region from California to Alaska.

The fruits, although somewhat variable in size, may be distinguished by the fact that the lower wing margin usually narrows abruptly and forms a deep, rounded sinus behind the seed.

The most typical fossil leaf of this species so far figured is that called by MacGinitie *Acer merriami*. The type of *A. merriami* Knowlton, from the Mascall formation, cited by MacGinitie, is a large-lobed leaf with a strongly cordate base, fairly large scalloped dentate teeth, and a pronounced pinnate secondary venation. It is clearly an example of *Platanus dissecta* Lesquereux.

Occurrence: Salmon, Idaho (fig. 21); Tipton, Oreg. (figs. 20, 22). Miocene.

***Acer glabroides* Brown, n. name**

Plate 58, figures 13-15

- Acer bendirei* Lesquereux. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 27, fig. 3, 1926.
- Acer osmonti* Knowlton. Chaney, Carnegie Inst. Washington Pub. 346, pt. 4, p. 126, pl. 17, fig. 6; pl. 18, figs. 1, 3, 5, 1927.
- Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 24, 1934.
- Brooks, Carnegie Mus. Annals, vol. 24, p. 298, pl. 20, fig. 2, 1935.
- LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 137, 1936.
- Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 121, 1936.
- Acer minor* Knowlton. Berry, U. S. Geol. Survey Prof. Paper 154, p. 256, pl. 64, fig. 2, 1929.
- Acer trilobatum productum?* (Alexander Braun) Heer. Knowlton, U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 733, pl. 102, fig. 3, 1898.

Some of the leaves and fruits associated here have severally or jointly been compared with those of the dwarf maple, *Acer glabrum* Torrey, of the Western States.

The fruits of this species, although resembling those of *Acer bendirei* Lesquereux in many respects, are smaller, and their lower wing margin generally continues in a smooth curve, more or less conspicuously, along the base of the seed to the scar of attachment.

Occurrence: Salmon, Idaho (fig. 13); Latah formation, Spokane, Wash. (fig. 14); Bridge Creek, Oreg. (fig. 15). Miocene.

***Acer lesquereuxii* Knowlton**

Plate 58, figure 3

- Acer lesquereuxii* Knowlton, U. S. Geol. Survey Bull. 152, p. 26, 1898; Prof. Paper 131, p. 169, 1923.
- Brown, U. S. Geol. Survey Prof. Paper 185, p. 61, 1934.

No other maple-leaf species than *Acer lesquereuxii* having been reported from the Green River formation, it is assumed that the samara here figured, also the first from that formation, belongs to the same species. This winged seed is 2.3 centimeters long and displays a rather short scar of attachment. This samara must not be confused with *Anacardites schinoloxus* Brown,<sup>10</sup> which, although superficially like a maple seed, is a winged anacardiaceous fruit.

Occurrence: Green River formation, Fossil, Wyo. Middle Eocene. Figured specimen in Museum of Paleontology, University of Michigan.

***Acer negundoides* MacGinitie**

Plate 58, figure 1

- Acer negundoides* MacGinitie. Brown, Jour. Paleontology, vol. 9, p. 580, pl. 69, figs. 9-11, 1935. (See synonymy and discussion.)

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 136, pl. 1, figs. 3, 4, 1936.

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 121, pl. 3, fig. 2, 1936.

*Rulac crataegifolium* Knowlton, U. S. Geol. Survey Bull. 204, p. 77, pl. 16, fig. 7, 1902.

*Phyllites bifurcatus* Knowlton, idem, p. 85, pl. 16, fig. 2.

*Crataegus heterodontata* Chaney, Walker Mus. Contr., vol. 2, p. 175, pl. 16, figs. 1, 2, 1920.

Although the fossil samaras of box elder are not uncommon in some of the Miocene floras of the Western States, no undoubted compound leaves with the required characters have yet been reported. Knowlton's *Rulac crataegifolium* and the fragment called *Phyllites bifurcatus*, however, appear to be leaflets of such a compound leaf, for they can be matched easily with leaflets from *A. negundo* Linnaeus. Because of the fragmentary and somewhat doubtful status of these species, the writer urges that an exception be made here to a strict application of the rules of nomenclature in order that so apt a term as *negundoides* be not lost.

Occurrence: Latah formation, Spokane, Wash. (fig. 1); Mascall formation, John Day Basin, Oreg. Miocene.

***Acer osmonti* Knowlton**

Plate 58, figures 16-18

- Acer osmonti* Knowlton, U. S. Geol. Survey Bull. 204, p. 72, pl. 13, fig. 3, 1902.

*Acer gigas* Knowlton, idem, p. 76, pl. 14, fig. 1.

*Acer chaneyi* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 27, fig. 2, 1926.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 256, pl. 63, fig. 13, 1929.

MacGinitie, Carnegie Inst. Washington Pub. 416, pt. 2, p. 61, 1933.

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 26, pl. 5, fig. 3, 1934.

Brooks, Carnegie Mus. Annals, vol. 24, p. 297, pl. 19, fig. 5; pl. 21, fig. 1a, 1935.

Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 120, 1936.

*Quercus* cf. *Q. pseudo-lyrata* Lesquereux. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 36, pl. 22, fig. 2, 1926.

*Acer florissanti* Kirchner. Berry, U. S. Geol. Survey Prof. Paper 185, p. 118, pl. 24, figs. 5-7, 1934.

*Acer oregonianum* Knowlton. Berry, idem, p. 118, pl. 24, fig. 1.

The type of this species is indistinguishable from those described by Berry from White Bird, Idaho, and the latter appear to differ from *Acer florissanti* Kirchner, from Florissant, in being less sharply lobed, but a close relationship is indicated. These leaves are most nearly like those of the silver maple, *A. saccharinum* Linnaeus, of the eastern United States. The comparison is emphasized by the fact that associated with the leaves at White Bird are samaras that also simulate those of the silver maple more closely than any other species. The beak is pointed and the scar of attachment very oblique and short.

Occurrence: Latah formation, Spokane, Wash. (fig. 16); Mascall formation, John Day Basin, Oreg.; Tipton, Oreg. (fig. 17); White Bird, Idaho (fig. 18). Miocene.

<sup>10</sup> Brown, R. W., Additions to the flora of the Green River formation: U. S. Geol. Survey Prof. Paper 154, p. 288, pl. 73, fig. 8, 1929.

**Dipteronia insignis (Lesquereux) Brown, n. comb.**

Plate 59, figures 10-12

*Myrica insignis* Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 312, 1876; U. S. Geol. Survey Terr. Rept., vol. 7, p. 135, pl. 65, figs. 7, 8, 1878.  
*Comptonia insignis* Cockerell, Colorado Univ. Studies, vol. 3, p. 173, 1906; Am. Mus. Nat. History Bull., vol. 24, p. 81, 1908.

Berry, Am. Naturalist, vol. 40, p. 1906.

Brown, U. S. Geol. Survey Prof. Paper 185, p. 54, 1934.

*Comptonia acutiloba* (Lesquereux) Cockerell, Colorado Univ. Studies, vol. 3, p. 173, 1906; Am. Mus. Nat. History Bull., vol. 24, p. 81, 1908. [Described as *Myrica latiloba* Heer var. *acutiloba* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7, p. 134, pl. 17, fig. 13, 1878.]

*Rhus subrhomboidalis* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, p. 195, pl. 41, figs. 16-19, 1883.

All the leaflets cited in the synonymy can be matched satisfactorily by the variable leaflets from the living *Dipteronia sinensis* Oliver, of central and western China, and it is assumed that they belonged to the same species that produced the characteristic winged samaras recorded now for the first time from Florissant.

The samaras do not differ greatly from those called *Dipteronia americana* Brown,<sup>11</sup> from Republic, Wash., but the accompanying leaves, especially those formerly called *Comptonia insignis* Cockerell, appear to be more strongly toothed or incised than those of *D. americana*, and the species are therefore tentatively held to be distinct. The writer, until he found the *Dipteronia* seeds in the Florissant collections, thought that *C. insignis* represented the leaflets of *Koelreuteria*, but that probability must be left to the leaflets called *Rhus hilliae* Lesquereux.

Occurrence: Florissant, Colo. Miocene.

**SAPINDACEAE****Dilodendron boreale** Brown, n. sp.

Plate 59, figure 9

Only one fragmentary leaflet of this species has yet appeared in the Latah formation, but enough of it is preserved to permit identification. The leaflet is 4 centimeters long, elliptic-lanceolate, with apparently a slightly rounded, inequilateral base. Tip missing. The few teeth are long and rounded on both upper and lower margins to a blunt point. The notches between the teeth are deep and acute. A secondary vein, curving slightly, runs into each tooth, and an intermediate secondary runs to the notch, where it forks, sending a minute branch to each adjacent tooth.

This leaflet is almost identical with those of *Dilodendron bipinnatum* Radlkofler, a small tree of Bolivia, Peru, and Brazil. It differs from the leaflets of a somewhat similar tree, *Dipterodendron costaricense* Radlkofler, of Central America and Panama, chiefly in

<sup>11</sup> Brown, R. W., Miocene leaves, fruits, and seeds from Idaho, Oregon, and Washington: Jour. Paleontology, vol. 9, p. 580, pl. 67, figs. 6, 12, 1935.

having a rounded not a sharply cuneate base. Some of the leaflets of *Dipteronia americana* Brown, from Republic, Wash., are superficially like *Dilodendron boreale* but differ in having double teeth, the smaller subsidiary teeth being entered by branches from the secondary vein that enters the main tooth.

Occurrence: Latah formation, Spokane, Wash. Miocene.

**RHAMNACEAE****Paliurus florissanti** Lesquereux

Plate 56, figure 7

*Paliurus florissanti* Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7, p. 274, pl. 50, fig. 18, 1878.

*Acalypha myricina* Cockerell, Torreya, vol. 9, p. 117, 1909.

Occurrence: Florissant, Colo. Miocene.

**Paliurus hesperius** Berry

Plate 56, figures 8, 9

*Paliurus hesperius* Berry, Am. Jour. Sci., 5th ser., vol. 16, p. 40, figs. 1-3, 1928; U. S. Geol. Survey Prof. Paper 154, p. 257, pl. 57, fig. 1, 1929; Prof. Paper 170, p. 39, pl. 13, figs. 1-5, 1931; Prof. Paper 185, p. 119, 1934.

The leaf figured here is somewhat narrower than the types but illustrates the same kind of venation and marginal dentition. The fruit is like those figured from Grand Coulee, Wash. It is possible that these leaves may represent *Ceanothus* or *Zizyphus* rather than *Paliurus*, and the fruits may belong to *Pterocarya mixta* (Knowlton) Brown, n. comb.

Occurrence: Latah formation, Spokane, Wash. Miocene.

**Rhamnus idahoensis** Brown

Plate 56, figure 4

*Rhamnus idahoensis* Brown, Jour. Paleontology, vol. 9, p. 581, pl. 69, fig. 13, 1935.

The small and somewhat fragmentary type from Salmon, Idaho, was compared with *Rhamnus alnifolia* L'Héritier. The present specimen from Spokane, Wash., is larger, shows the serrulate margin to better advantage, and suggests that the species is almost identical with *R. purshiana* De Candolle, of the Northwestern States.

Occurrence: Salmon, Idaho; Latah formation, Spokane, Wash. (fig. 4). Miocene.

**VITACEAE****Vitis washingtonensis** (Knowlton) Brown, n. comb.

Plate 56, figures 5, 6; plate 57, figures 1, 2

*Populus washingtonensis* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 31, pl. 15, fig. 1, 1926.

*Populus lindgreni* Knowlton, Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 31, pl. 14, figs. 4-7, 1926. [Not other Knowlton references.]

Berry, U. S. Geol. Survey Prof. Paper 185, p. 106, 1934.

*Acer merriami* Knowlton, Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 45, pl. 28, fig. 1, 1926. [Not other Knowlton references.]

*Acer* sp. Berry, U. S. Geol. Survey Prof. Paper 154, pl. 57, fig. 6, 1929.

*Menispermites latahensis* Berry, idem, p. 249, pl. 52, fig. 4.

*Cercis idahoensis* Berry, Torrey Bot. Club Bull., vol. 57, p. 240, pl. 9, fig. 4 [not figs. 1-3], 1930; U. S. Geol. Survey Prof. Paper 185, p. 114, pl. 21, fig. 1; pl. 22, fig. 4 [not figs. 1-3]; pl. 23, figs. 3, 4 [not figs. 5, 6], 1934.

The margins of these leaves vary from being merely undulate to having large rounded lobelike teeth or short rounded dentate teeth. Besides the fact that the venation is fundamentally the same in all the leaves included in the foregoing synonymy, both lobed and unlobed forms, a conspicuous feature of that venation is that the secondaries and their branches run either into teeth or squarely to the margin where teeth should be. In *Cercis* the lateral primaries as well as their branches form loops well within the margin and never run completely into the margin. In *Populus*, except perhaps *P. alba* Linnaeus, the teeth, even if superficially appearing dentate, under magnification are seen to be either crenate or crenate-serrate. The same criticisms eliminate the species of Menispermaceae as biologic equivalents of the lobed specimens called *Menispermites latahensis*.

The leaves of most living species of Vitaceae have more pointed leaves and a stronger tendency toward palmate venation than is shown by these fossils. Nevertheless, the venational and marginal characters suggest *Vitis* more strongly than any other genus. No seeds of *Vitis* have yet been reported from the Latah formation at Spokane, but a seed, *V. bonseri* Berry, is recorded from similar beds at Grand Coulee, where the leaves are also abundant.

Occurrence: Latah formation, Spokane, Wash. (pl. 56, fig. 6); White Bird, Idaho (pl. 56, fig. 5; pl. 57, figs. 1, 2). Miocene.

#### TILIACEAE

##### *Tilia aspera* (Newberry) LaMotte

Plate 62, figure 4

*Tilia aspera* (Newberry) LaMotte, Carnegie Inst. Washington Pub. 455, pt. 3, p. 45, pl. 1, figs. 1-3; pl. 2, figs. 1, 2, 1935. (See synonymy.)

LaMotte, Carnegie Inst. Washington Pub. 455, pt. 5, p. 138, 1936.

The statement by LaMotte that "*Tilia hesperia* occurs associated with leaves of *T. aspera* in the Latah upper Miocene of Spokane, Washington", needs modification, for the specimens identified by Berry as *Platanus aspera* (now *T. aspera*) are *P. dissecta* Lesquereux, with one exception, which is a large leaf of *Cebatha heteromorpha* (Knowlton) Berry.

Occurrence: Bridge Creek, Oreg.; Latah formation, Spokane, Wash. (fig. 4). Miocene.

##### *Tilia oregonia* LaMotte

*Platanus aspera* Newberry [part], U. S. Geol. Survey Mon. 35, p. 102, pl. 59, fig. 3, 1898.

*Tilia* sp. Chaney, Am. Jour. Sci., 5th ser., vol. 8, p. 131, 1934.

*Tilia oregonia* LaMotte, Carnegie Inst. Washington Pub. 455, pt. 3, p. 47, pl. 3, figs. 1-6, 1935.

*Corylus macquarrii* (Forbes) Heer. Newberry, U. S. Geol. Survey Mon. 35, p. 61, pl. 48, fig. 4 [not pl. 32, fig. 5], 1898.

Newberry's citation of the occurrence of *Corylus macquarrii* did not state that the specimen here made synonymous with *Tilia oregonia* came from Bridge Creek, Oreg. Although these leaves may be compared with some species of *Tilia*, their symmetrical bases and generally doubly serrate, blunt or rounded teeth arouse a persistent suspicion that they may be the leaves of *Acer* instead of *Tilia*, particularly resembling the nonlobed leaves of *A. tataricum* Linnaeus, of southeastern Europe and Asia. LaMotte's reference of Newberry's figure 3 to this species does not seem to be justified. The strongly asymmetric base and long coarse teeth show that it is a small leaf of *T. aspera* (Newberry) LaMotte.

Occurrence: Bridge Creek, Oreg. Miocene.

#### STERCULIACEAE

##### *Sterculia coloradensis* Brown

Plate 61, figure 13

*Sterculia coloradensis* Brown, U. S. Geol. Survey Prof. Paper 154, p. 290, pl. 74, figs. 6, 7, 1929.

The present specimen is figured here to amplify the conception of the species, which was founded upon somewhat imperfect specimens. There is apparently a close relationship between this species and *Sterculia wilcoxensis* Berry,<sup>12</sup> from the Wilcox group.

Occurrence: Green River formation, Fossil, Wyo. Middle Eocene. Figured specimen in Museum of Paleontology, University of Michigan.

#### DILLENIACEAE

##### *Tetracera spokanensis* Brown, n. sp.

Plate 63, figures 6, 7

Leaves large, narrowly obovate, with entire margins halfway or more toward the apex, then with low, distant serrate teeth marking the extremities of the curved, equally spaced secondary veins. The nature of the tip is unknown, because that feature is missing in the smaller specimen and appears to have been damaged in the larger specimen. The general appearance of these leaves suggests that of some oaks, beeches, and chestnuts, but the finer, more subdued cross venation between the secondaries, the entire margin on the lower half of the blade, and the conspicuous obovateness seem, as a group of characters, to be more closely duplicated in leaves of the genus *Tetracera*, particularly in *T. volubilis* Linnaeus, from Mexico and Central America. (Compare sheet 1135757 of the U. S. National Herbarium.)

This species differs from *Tetracera oregona* Chaney and Sanborn<sup>13</sup> in being more obovate in shape and in

<sup>12</sup> Berry, E. W., The lower Eocene floras of the southeastern United States: U. S. Geol. Survey Prof. Paper 131, p. 17, pl. 14, figs. 1, 2; pl. 15, figs. 3, 4, 1922.

<sup>13</sup> Chaney, R. W., and Sanborn, E. I., The Goshen flora of west-central Oregon: Carnegie Inst. Washington Pub. 439, p. 87, pl. 31, figs. 5-7, pl. 32, fig. 1, 1933.

having less prominent teeth. There is perhaps more than a resemblance between *T. spokanensis* and the oaks called *Quercus nevadensis* Lesquereux,<sup>14</sup> from Chalk Bluffs, Calif.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### TERNSTROEMIACEAE

##### *Gordonia hesperia* Berry

Plate 52, figures 5-8

*Ternstroemites idahoensis* (Knowlton) Berry, U. S. Geol. Survey Prof. Paper 154, p. 258, pl. 58, fig. 1, 1929. [For *Myrica? idahoensis* Knowlton, U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 724, pl. 99, fig. 7, 1898, which has been transferred to *Arbutus idahoensis* (Knowlton) Brown.]

*Gordonia idahoensis* (Knowlton) Berry, Am. Jour. Sci., 5th ser., vol. 18, pp. 429-432, 1929.

*Gordonia hesperia* Berry, idem, p. 430, text figs. 1, 2, 1929 [not to include *Carpolithus pteriformis* Berry, which is *Cedrela pteriformis* (Berry) Brown]; U. S. Geol. Survey Prof. Paper 170, p. 41, pl. 13, figs. 7, 8, 1931.

*Carpites paulownia* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 50, pl. 29, fig. 12, 1926.

As the first two members of the synonymy are based upon a type that is now transferred to another genus, the suggested name for this species, on the reasonable assumption that the leaves and seeds belong together, is *Gordonia hesperia* Berry. The leaves of *G. hesperia* resemble those of *Arbutus idahoensis* (Knowlton) Brown very closely but can be distinguished by the fact that the secondary venation of *A. idahoensis* is more irregular, undulatory, and forked, and the marginal teeth are rounded, crenate-serrate, whereas those of *G. hesperia* are sharply serrate with the tips sometimes incurved. These leaves, although assigned to *Gordonia*, also bear a strong resemblance to those of the cherry laurel, *Prunus laurocerasus* Linnaeus, of southeastern Europe and southwestern Asia. The capsule *Carpites paulownia* Knowlton, because of the remnants of calyx at its base, is now thought to be the fruit of *Gordonia* rather than *Cedrela*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### TRAPACEAE

##### *Trapa americana* Knowlton

Plate 55, figures 5, 6

*Trapa americana* Knowlton. (See synonymy by Brown, Jour. Paleontology, vol. 9, p. 581, pl. 67, fig. 17, 1935.)

*Trapa prenatans* Dorf, Carnegie Inst. Washington Pub. 476, pt. 2, p. 122, pl. 3, fig. 6, 1936.

The specimen figured by the writer in 1935 came from diatomaceous beds equivalent to the Latah formation, on Potlatch Creek between Arrow Junction and Juliaetta, Latah County, Idaho. Those figured here came from the same locality as the types—namely, half a mile northeast of Idaho City, on the north side of the road leading to Norman. At this site the reddish-

brown sandy clay contains many impressions of these nuts and a few fragmentary dicotyledonous leaves, but none of the leaves can be identified as belonging to *Trapa*.

These large specimens resemble those called *Trapa yokoyamae* Nathorst,<sup>15</sup> from Japan, except that Nathorst describes his specimens as having been four-horned, whereas the Idaho specimens appear to have had only two horns, unless the cavities at the sides represent crushed horns.

Occurrence: Payette formation, Idaho City, Idaho. Miocene.

#### ARALIACEAE

##### *Aralia republicensis* Brown, n. name

Plate 55, figure 7

*Platanus appendiculata* Lesquereux? Berry, U. S. Geol. Survey Prof. Paper 154, p. 249, pl. 52, fig. 5, 1929.

*Aralia whitneyi* Lesquereux. Berry, idem, p. 260.

The venation, as well as the entire margins of these specimens, suggests that they represent a single species. In addition to the evidence from these morphologic characters is the fact that wherever a "*Platanus*" or "*Aralia*" leaf of this kind without acropetiolar appendages occurs, one with such appendages is also usually present. Such association must be regarded as more than coincidence.

These leaves differ from *Platanus appendiculata* Lesquereux in having entire margins and more numerous, regular, equally spaced secondary veins. They differ from *Aralia whitneyi* Lesquereux chiefly in having fewer, shorter, and broader lobes, but a close relationship between these species is nevertheless suspected.

Occurrence: Republic, Wash. Miocene.

#### CORNACEAE

##### *Cornus ovalis* Lesquereux

Plate 63, figure 5

*Cornus ovalis* Lesquereux, Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 23, pl. 6, figs. 1, 2, 1878.

Chaney, Carnegie Mus. Washington Pub. 346, pt. 4, p. 131, pl. 19, figs. 1-3 [probably not fig. 4, which may be *Hydangea*], 1927.

The specimen figured here can be matched easily with leaves from the Pacific dogwood, *Cornus nuttallii* Audubon. It appears to be indistinguishable from the species described by Lesquereux from Table Mountain, Calif., and by Chaney from Crooked River, Oreg. *C. ovalis* differs from *C. acuminata* Berry,<sup>16</sup> from Republic, Wash., in having a much more broadly oval shape. The tip of this specimen is not preserved, so that comparison of the two specimens as regards that feature cannot be made.

Occurrence: Latah formation, Spokane, Wash. Miocene.

<sup>14</sup> Lesquereux, Leo, Fossil plants of the auriferous gravel deposits of the Sierra Nevada: Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 5, pl. 2, figs. 3, 4, 1878.

<sup>15</sup> Nathorst, A. G., Zur fossilen Flora Japan's: Paleont. Abh., Band 4, Heft 3, p. 21, pl. 7 (23), figs. 6-8, 1888.

<sup>16</sup> Berry, E. W., Revision of the flora of the Latah formation: U. S. Geol. Survey Prof. Paper 154, p. 260, pl. 59, fig. 3, 1929.

***Nyssa knowltoni* Berry**

Plate 62, figures 1-3

*Nyssa knowltoni* Berry, U. S. Geol. Survey Prof. Paper 154, p. 261, pl. 59, fig. 7, 1929; Prof. Paper 185, p. 122, 1934.

*Nyssa hesperia* Berry, U. S. Geol. Survey Prof. Paper 170, p. 42, pl. 13, figs. 9-11, 1931.

The two leaves figured here show that occasional pointed lobes or teeth on leaves of this species indicate a probable relationship with *Nyssa aquatica* Marshall, of the southeastern United States. There being no other detectable leaf species, it is assumed that the characteristic seeds called *N. hesperia* belong to *N. knowltoni*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

**ERICACEAE*****Arbutus idahoensis* (Knowlton) Brown, n. comb.**

Plate 59, figures 2-4

*Myrica? idahoensis* Knowlton, U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 724, pl. 99, fig. 7, 1898.

*Myrica lanceolata* Knowlton, idem, p. 724, pl. 99, figs. 5, 6.

*Betula aequalis?* Lesquereux. Knowlton, idem, p. 728, pl. 102, fig. 5.

*Arbutus* sp. Chaney, Carnegie Inst. Washington Pub. 349, pt. 2, p. 36, 1925.

*Celastrus lacoci* Lesquereux. Berry, U. S. Geol. Survey Prof. Paper 154, p. 255, 1929.

*Laurus princeps* Heer. Berry, idem, p. 259, pl. 58, fig. 5.

*Arbutus trainii* MacGinitie, Carnegie Inst. Washington Pub. 416, pt. 2, p. 64, pl. 12, fig. 3; pl. 13, figs. 1, 2, 1933.

Brooks, Carnegie Mus. Annals, vol. 24, p. 300, pl. 21, fig. 3, 1935.

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 26, 1934.

These leaves are lanceolate-elliptic and generally with margins having rounded crenate-serrate teeth. They resemble most closely the leaves of *Arbutus arizonica* Sargent, of southern Arizona and Mexico. That they are not variant leaves of *A. matthesii* Chaney, with which they are associated in the Latah flora, is problematic. Some of these leaves are difficult to distinguish from those of *Gordonia idahoensis* (Knowlton) Berry.

Occurrence: Latah formation, Spokane, Wash. (figs. 2-4); near Montour, Gem County, Idaho; Trout Creek, Oreg. Miocene.

***Arbutus matthesii* Chaney**

Plate 59, figures 1, 5, 6

*Arbutus matthesii* Chaney, Carnegie Inst. Washington Pub. 346, pt. 3, p. 131, pl. 20, figs. 1, 3-5, 1927.

The leaves illustrated here are reproduced to show further variability in this species, which is most like *Arbutus menziesii* Pursh, of the Pacific coast region. The margins of *A. matthesii* may be entire or sharply serrate, as in *A. menziesii*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

***Vaccinium sophoroides* (Knowlton) Brown, n. comb.**

Plate 61, figures 1-3, 11

*Phyllites sophoroides* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 48, pl. 26, fig. 8, 1926.

*Cassia sophoroides* (Knowlton) Berry, U. S. Geol. Survey Prof. Paper 154, p. 253 [not pl. 56, fig. 1, which is *Sophora spokanensis* Knowlton], 1929.

*Diospyros princeonaria* Cockerell. Berry, U. S. Geol. Survey Prof. Paper 154, p. 263, pl. 59, fig. 6; pl. 60, figs. 1-3, 1929.

*Salix perplexa* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 32, pl. 12, fig. 5, 1926.

*Arctostaphylos knowltoni* Berry, U. S. Geol. Survey Prof. Paper 154, p. 261, pl. 59, fig. 4, 1929.

These entire-margined oblanceolate leaves can be definitely assigned to the Ericaceae instead of *Cassia*, *Diospyros*, or *Salix*. The basis for this positive assurance is the minutely papillated appearance of the under surface, a feature shown by living species of Ericaceae but not by *Cassia*, *Diospyros*, or *Salix*. The revolute, entire margin, mucronulate apex, camptodrome venation, and shape of these leaves can be duplicated in the genera *Azalea* and *Vaccinium*, although most of the species of *Azalea* that compare with the fossils in shape have serrulate margins. The venation of the fossils agrees best with that in the leaves of the farkleberry, *Vaccinium arboreum* Marshall, of the eastern United States. The writer therefore has the impression that these leaves represent a species of *Vaccinium*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

***Vaccinium bonseri serrulatum* Berry**

Plate 61, figure 8

*Vaccinium bonseri serrulatum* Berry, U. S. Geol. Survey Prof. Paper 154, p. 262, pl. 63, figs. 19, 20, 1929.

This small leaf seems to be the same species as that described by Berry from the Latah formation at Spokane, Wash.

Occurrence: Thunder Mountain, Idaho. Miocene.

**EBENACEAE*****Diospyros andersonae* Knowlton**

Plate 60, figures 12-17, 21

*Diospyros andersonae* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 46, pl. 27, fig. 6, 1926.

The well-preserved calyx, *Diospyros andersonae*, described by Knowlton indicated that persimmon leaves and seeds might also be found in the Latah formation. Those figured here, resembling closely *D. virginiana* Linnaeus, of the southeastern United States, are believed to belong to the same species that produced the calyx. The seeds are somewhat smaller than those of *D. virginiana* but agree in every other particular, as can be seen by comparison with a figured specimen of that species (fig. 18).

Occurrence: Latah formation, Spokane, Wash. Miocene.

## CAPRIFOLIACEAE

*Viburnum fernquisti* (Berry) Brown, n. comb.

Plate 56, figure 2

*Ribes fernquisti* Berry, U. S. Geol. Survey Prof. Paper 154, p. 251, pl. 63, fig. 21, 1929; Prof. Paper 170, p. 38, pl. 12, fig. 2, 1931.

Describing this species, Berry remarked:

With the exception that some modern leaves of *Ribes* tend to have a cordate base, this Latah species shows all the foliar features of the genus, especially in the form of the teeth and in the position and disposition of the veins.

Most species of *Ribes* are or tend to be five- or more-lobed, each lobe consisting of mammillately rounded, sometimes double teeth, so that the general appearance of the leaf is that of being cut-lobed. The venation accordingly tends to be virgate rather than curving-crasspedodrome, as in these fossils. In short, the fossils can be matched much more closely with the leaves of the aceroid viburnums, such as *Viburnum opulus* Linnaeus, *V. pauciflorum* Pylaie, and *V. acerifolium* Linnaeus, and are therefore transferred to that genus.

Occurrence: Latah formation, Spokane, Wash.; Grand Coulee, Wash.; Coeur d'Alene, Idaho (fig. 2). Miocene.

*Viburnum lantanafolium* Berry

Plate 63, figure 1

*Viburnum lantanafolium* Berry, U. S. Geol. Survey Prof. Paper 154, p. 264, pl. 60, fig. 6, 1929.

Oliver, Carnegie Inst. Washington Pub. 455, pt. 1, p. 27, figs. 1, 2, 1934.

*Aesculus hesperia* Berry, idem, p. 256, pl. 56, fig. 8.

Although these leaves resemble the leaflets of *Aesculus* somewhat in shape, they differ in having a more undulatory secondary venation and marginal teeth that are fairly uniform in size, rounded-conical, abruptly blunt-pointed, mostly dentate but some with a slight tendency to be crenate-serrate. The teeth of *Aesculus* are blunt-rounded, serrate, and in most species mixed, with large teeth marking the termination of the secondary veins and smaller teeth receiving their branches. The narrow angle of departure from the midrib of the undulatory and much branched secondary veins, the obovate shape, and the uniform size of the teeth suggest the genus *Viburnum*, and especially the obovate leaves of such living species as *V. lantana* Linnaeus, of southeastern Europe and Asia, *V. dilatatum* Thunberg, of Japan, and *V. erubescens* Wallich, of China.

Fossil leaves that resemble *Viburnum lantanafolium* are those called *Aesculus simulata* Knowlton,<sup>17</sup> from the Mascall formation in the John Day Basin, Oreg., but the secondary veins of *A. simulata* are more numerous, are less strongly branched, and in general depart from the midrib at a wider angle; and the teeth

have a sharper appearance. In short, *Aesculus simulata* probably represents a species of *Carya* rather than *Aesculus* or *Viburnum*.

Occurrence: Latah formation, Spokane, Wash.; Tipton, Oreg. (fig. 1). Miocene.

## FOSSILS OF UNCERTAIN BOTANIC AFFINITY

*Porana speirii* Lesquereux

Plate 61, figure 14

*Porana speirii* Lesquereux. Brown, Jour. Paleontology, vol. 9, p. 583, pl. 69, figs. 1-3, 1935. (See synonymy and discussion.)

Occurrence: Green River formation, Fossil, Wyo. Middle Eocene. Figured specimen in Museum of Paleontology, University of Michigan.

*Carpites boraginoides* Knowlton

Plate 62, figure 13

*Carpites boraginoides* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 49, pl. 29, fig. 7, 1926.

*Carpolithus hibiscoides* Brown, Jour. Paleontology, vol. 9, p. 584, pl. 67, fig. 19, 1935.

Instead of being an aggregation of four nutlets, as Knowlton thought, suggesting the family Boraginaceae, these objects are five-loculed fruits, but their identity is unknown.

Occurrence: Latah formation, Spokane, Wash. Miocene.

*Carpolithus* sp.

Plate 63, figures 2, 3

*Equisetum*, underground stem. Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 24, pl. 9, fig. 1; pl. 26, fig. 5; pl. 29, fig. 8, 1926.

*Malva?* *hesperia* Knowlton, idem, p. 47, pl. 29, fig. 11.

Berry, U. S. Geol. Survey Prof. Paper 185, p. 120, pl. 24, fig. 2, 1934.

*Phyllites amplexicaulis* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 47, pl. 29, fig. 3, 1926.

*Carpites menthoidea* Knowlton, idem, p. 49, pl. 26, fig. 4.

Berry, U. S. Geol. Survey Prof. Paper 154, p. 264, 1929.

*Ficus interglacialis* Hollick, New York Bot. Garden Jour., vol. 16, p. 405, pls. 34, 35, 1927.

Berry, U. S. Geol. Survey Prof. Paper 170, p. 37, 1931.

The writer has nothing to add toward the identification of this many-named but as yet botanically unidentified species, except to point out that the five names in the synonymy apply to different views or phases of the same objects.

Occurrence: Latah formation, Spokane, Wash. (fig. 3); White Bird, Idaho (fig. 2). Miocene.

*Carpolithus* sp.

Plate 61, figure 15

*Juncus?* *crassulus* Cockerell. Berry, U. S. Geol. Survey Prof. Paper 154, p. 240, 1929.

The specimens from the Latah formation compared by Berry with *Juncus crassulus* Cockerell,<sup>18</sup> from the

<sup>17</sup> Knowlton, F. H., Fossil flora of the John Day Basin, Oreg.: U. S. Geol. Survey Bull. 204, p. 78, pl. 15, figs. 1, 2, 1902.

<sup>18</sup> Cockerell, T. D. A., The fossil flora of Florissant, Colo.: Am. Mus. Nat. History Bull., vol. 24, p. 79, pl. 10, figs. 44, 45, 1908.

Florissant lake beds, are entirely different objects. *J. crassulus* Cockerell (pl. 61, fig. 16) is a small spherical fruit with the remains of two styles and is surrounded at the base by a ciliated or fringed perianth twice as long as the fruit itself. It is therefore not like any living species of *Juncus*.

The Latah specimens are cymose clusters of small spherical fruits, each of which is surrounded by a five-lobed, united perianth and surmounted by two styles. These also are apparently not related to *Juncus*.

Occurrence: Latah formation, Spokane, Wash. Miocene.

#### Leaves

Plate 49, figures 14, 15. These are narrow, lanceolate leaves, sparingly toothed near the apex. The venation and areolation suggest affinity with *Quercus* or *Castanopsis*. Tipton, Oreg. Miocene.

Plate 49, figure 16. This is a sparingly small-toothed lanceolate leaf in which all the secondary veins run into marginal teeth. Affinity with *Quercus* or *Alnus* is suggested. Spokane, Wash. Miocene.

Plate 53, figure 12. A thick, oblanceolate leaf with sharply serrate margin. The venation is obscure. Probably *Berberis*. Republic, Wash. Miocene.

Plate 53, figures 13, 14. Small, lanceolate, petioled leaves with serrate margins. They may represent a species of *Salix*. Spokane, Wash. Miocene.

Plate 54, figure 6. An ovate, entire-margined leaf. Secondaries few, widely but regularly spaced, camptodrome. Spokane, Wash. Miocene.

Plate 55, figure 1. An ovate leaf with sparingly toothed margin. Spokane, Wash. Miocene.

Plate 55, figure 4. An orbicular, entire-margined leaf with a long, stout petiole. Fossil, Wyo. Middle Eocene.

Plate 57, figure 5. This is the upper half of a leaf with large, conical double teeth. Tipton, Oreg. Miocene.

Plate 59, figure 14. An elongated leaf with serrate margin and a secondary venation that appears irregular, broken, and branched. It bears a close resemblance to the illustrations of *Rhus myricaefolia* Lesquereux.<sup>19</sup> Spokane, Wash. Miocene.

#### Bud scales

*Carpites spokanensis* Knowlton, U. S. Geol. Survey Prof. Paper 140, p. 49, pl. 26, fig. 6, 1926.

*Populus*, bud scales, Berry, U. S. Geol. Survey Prof. Paper 154, p. 243, pl. 50, fig. 4; pl. 63, fig. 8; Prof. Paper 185, p. 106, 1934.

*Tsuga latahensis* Berry, U. S. Geol. Survey Prof. Paper 154, p. 239, pl. 63, figs. 3, 4, 1929.

The writer has examined more than a hundred specimens of bud scales from the Latah and related deposits and is convinced that several genera are represented, notably *Ulmus*, *Fagus*, *Liriodendron*, *Tilia*, and perhaps *Populus*. Their separation, however, is a difficult matter, involving perhaps more guesswork than application of sound distinguishing criteria.

Occurrence: Latah formation, Spokane, Wash.; Tipton, Sumpter quadrangle, Oreg.; White Bird, Idaho. Miocene.

#### Flowers

Plate 59, figure 7. A distorted calyx, probably of *Diospyros*. Spokane, Wash. Miocene.

Plate 61, figure 12. A five-parted calyx or corolla. Fossil, Wyo. Middle Eocene.

#### Miscellaneous

Plate 45, figure 31. Plant or animal (?). Fossil, Wyo. Middle Eocene.

Plate 60, figure 20. An open cone of a conifer simulating a calyx of persimmon (*Diospyros*). Florissant, Colo. Miocene.

<sup>19</sup> Lesquereux, Leo, Fossil plants of the auriferous gravel deposits of the Sierra Nevada: Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, no. 2, p. 31, pl. 1, figs. 5-7, 1878.

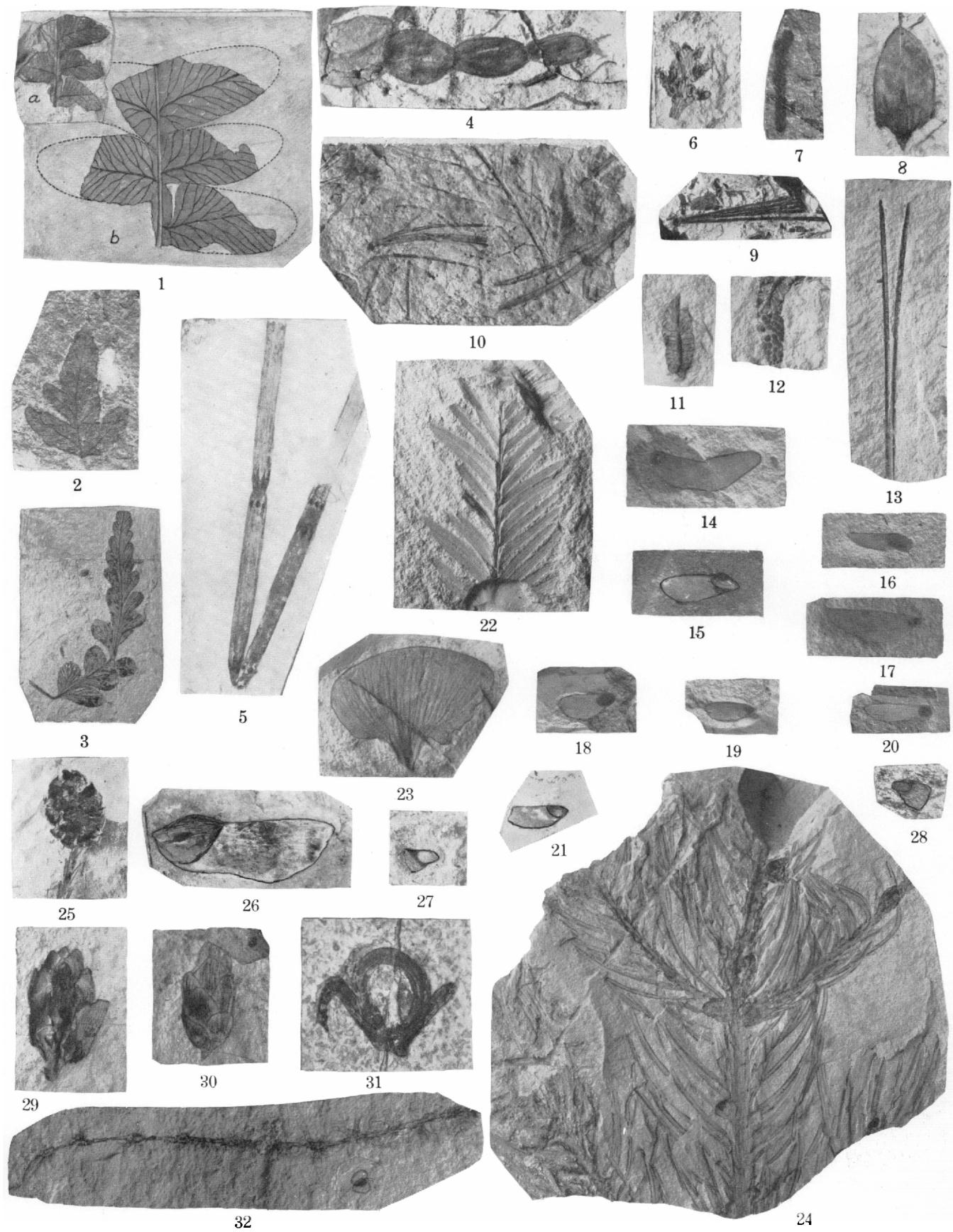
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**PLATES 45-63**

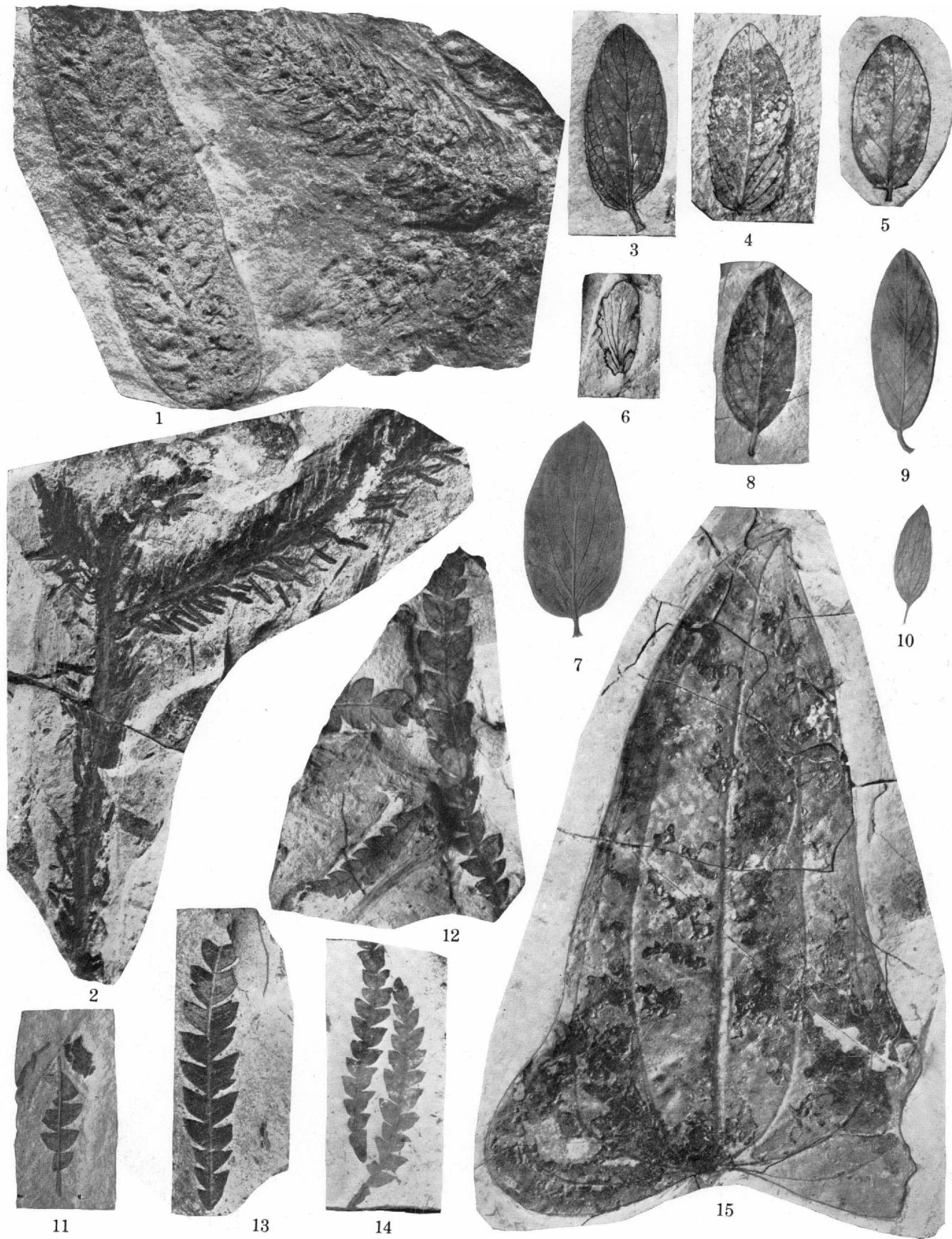
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PLATE 45

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| FIGURE 1. Fern. Salmon, Idaho-----   | 167  |
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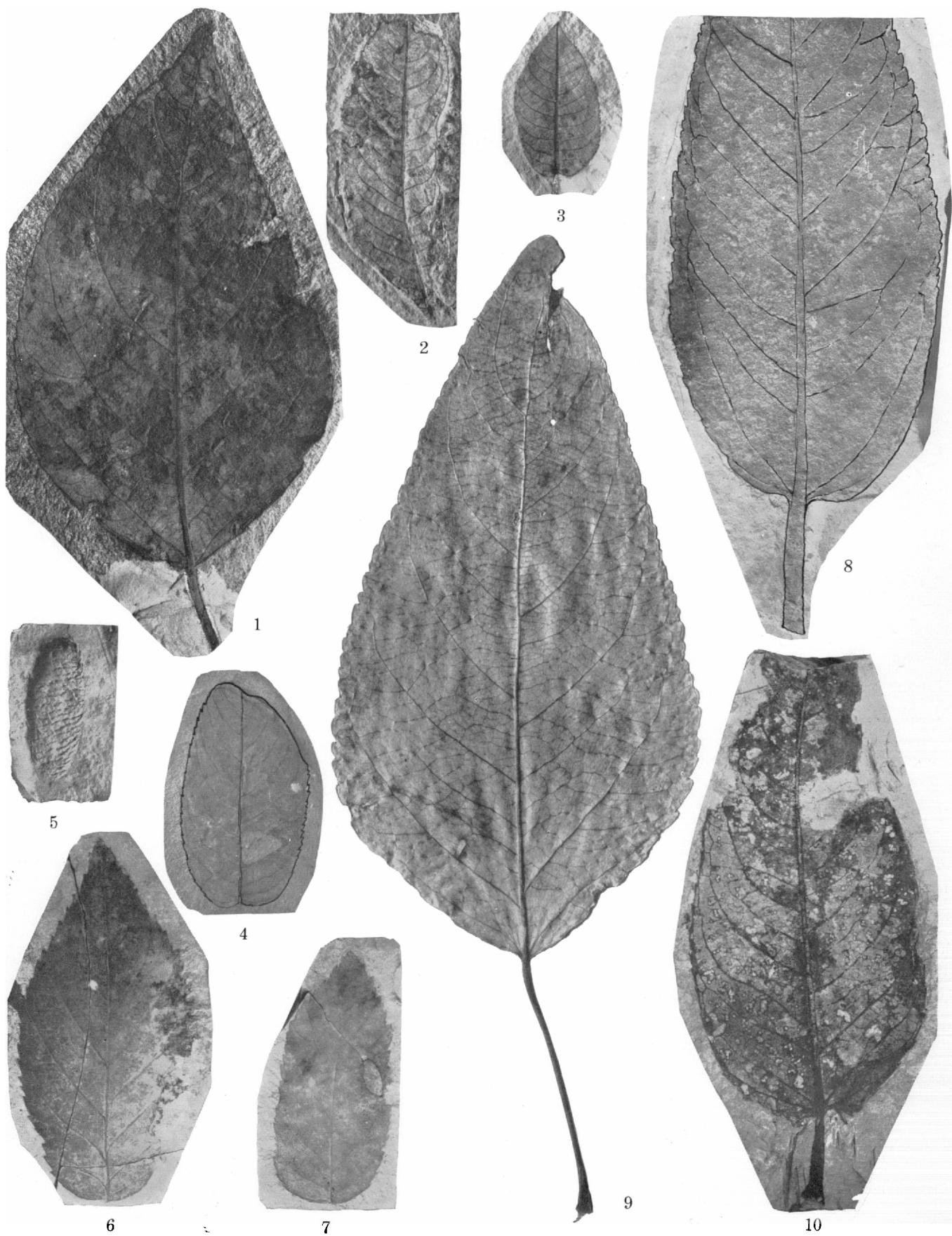
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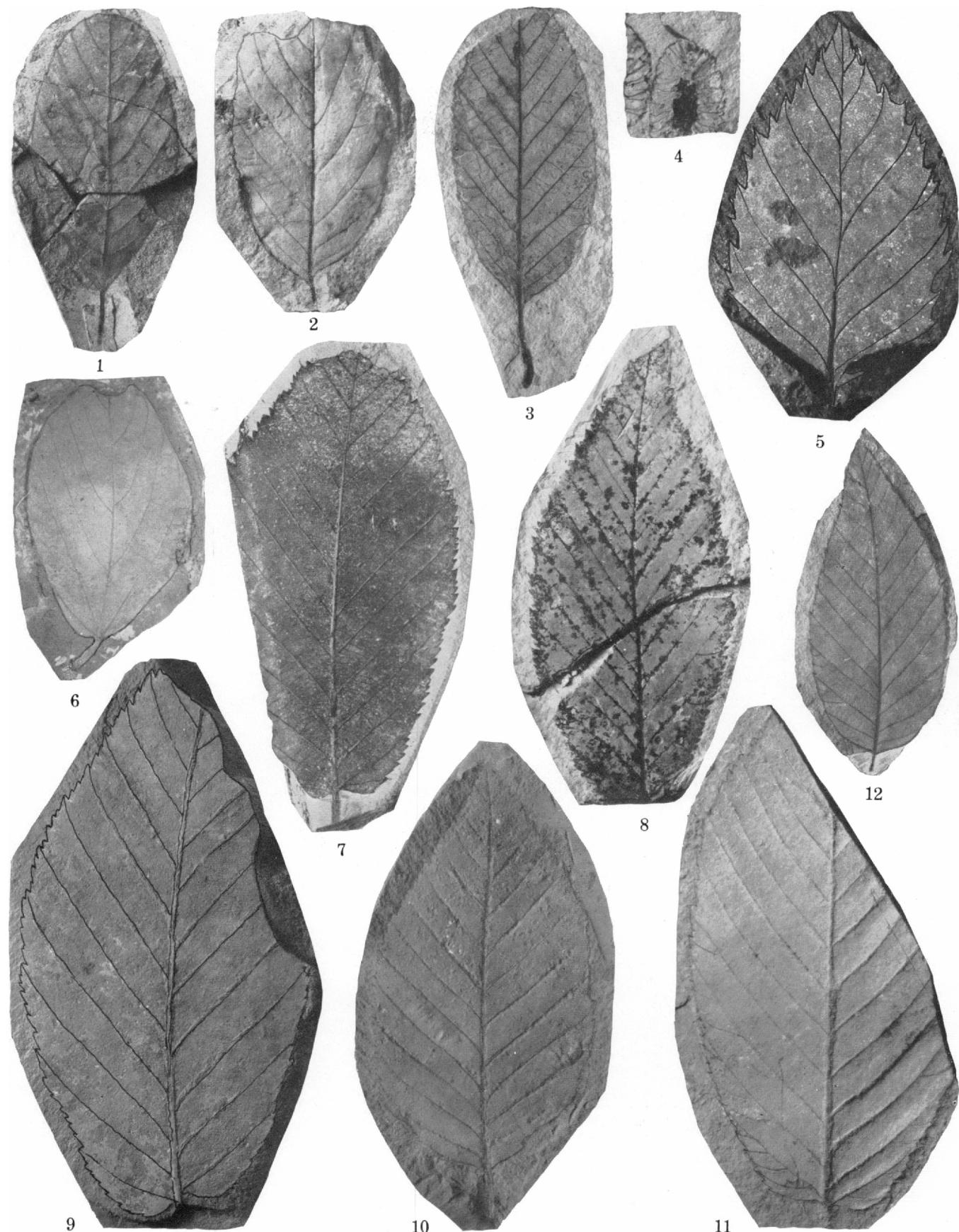
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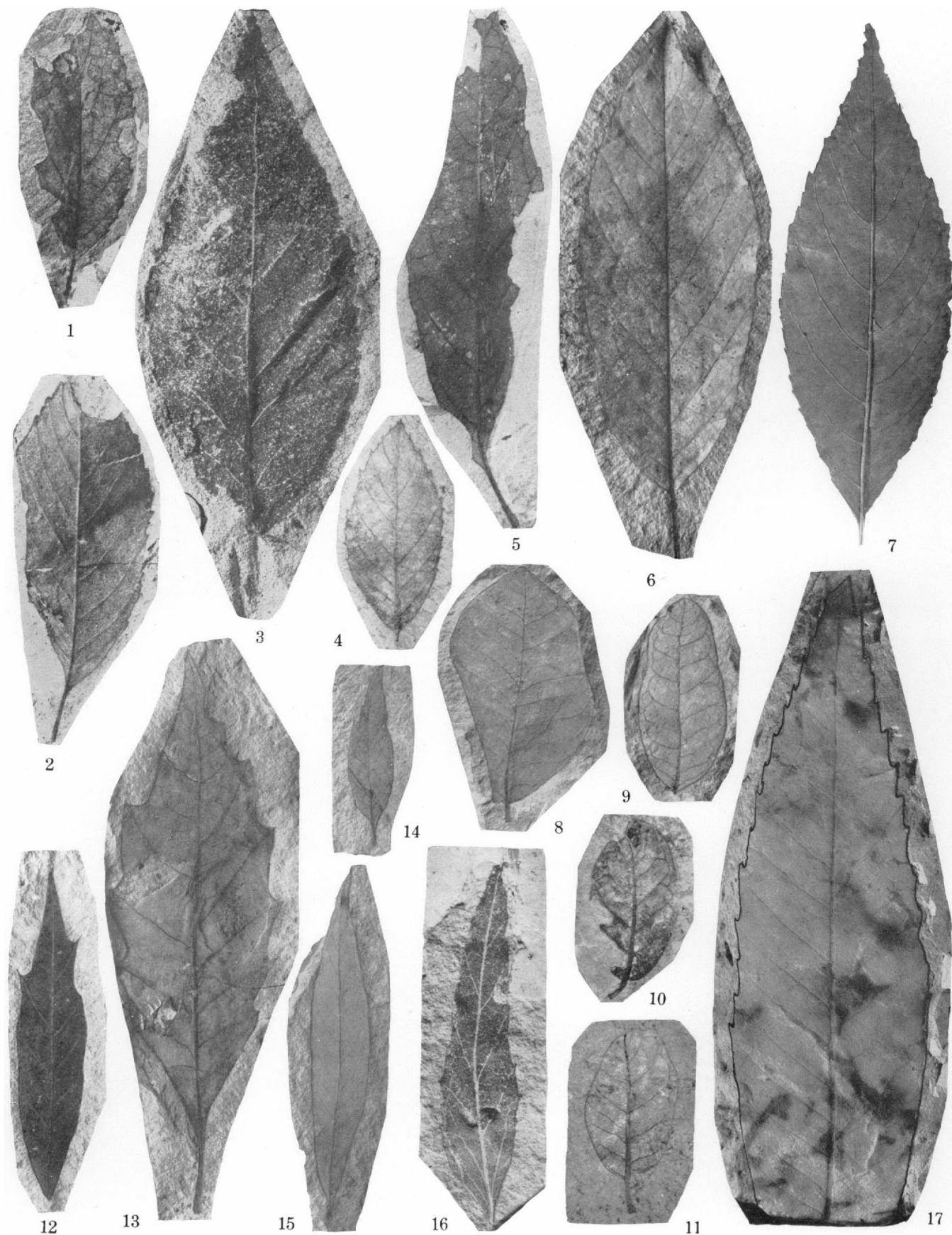


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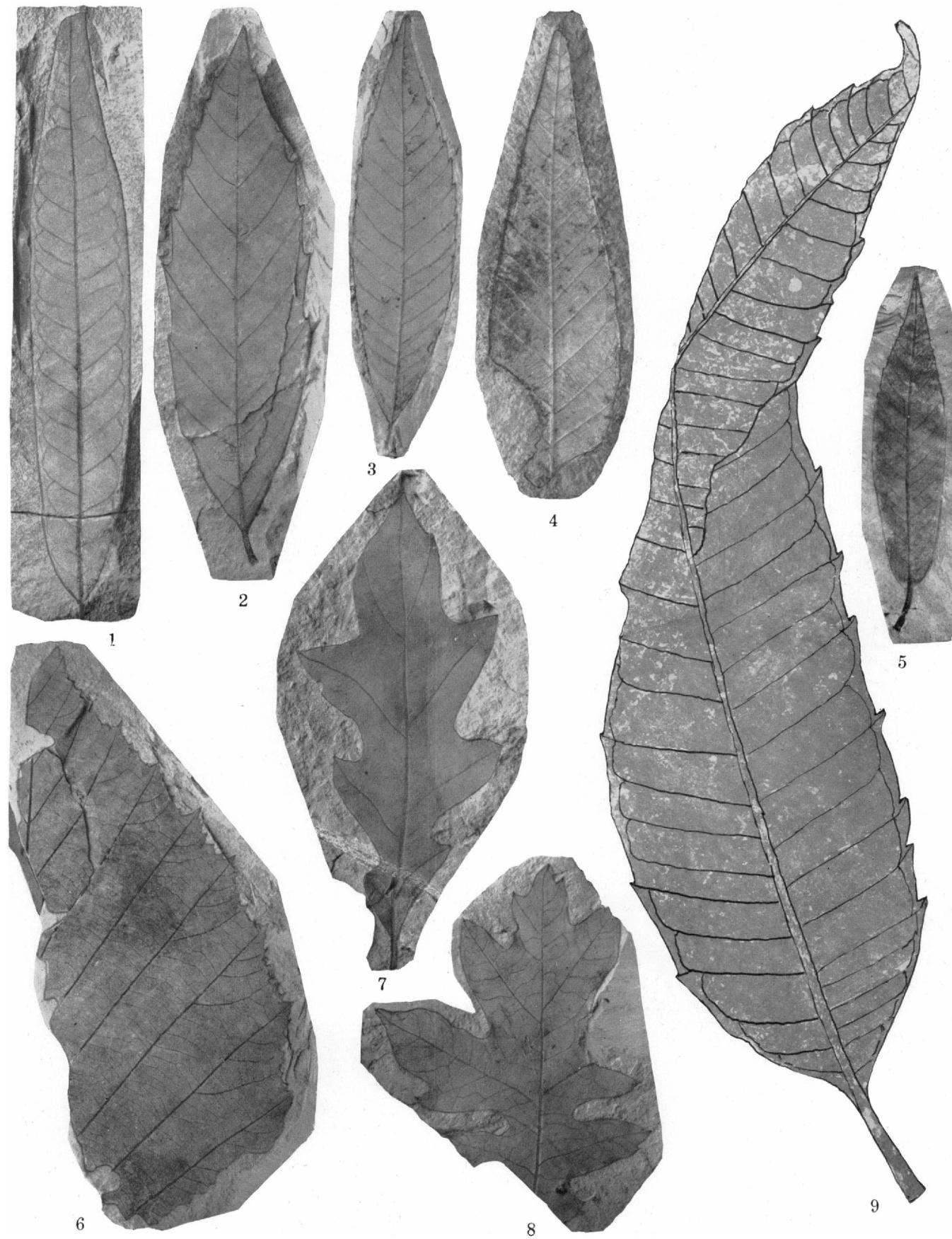
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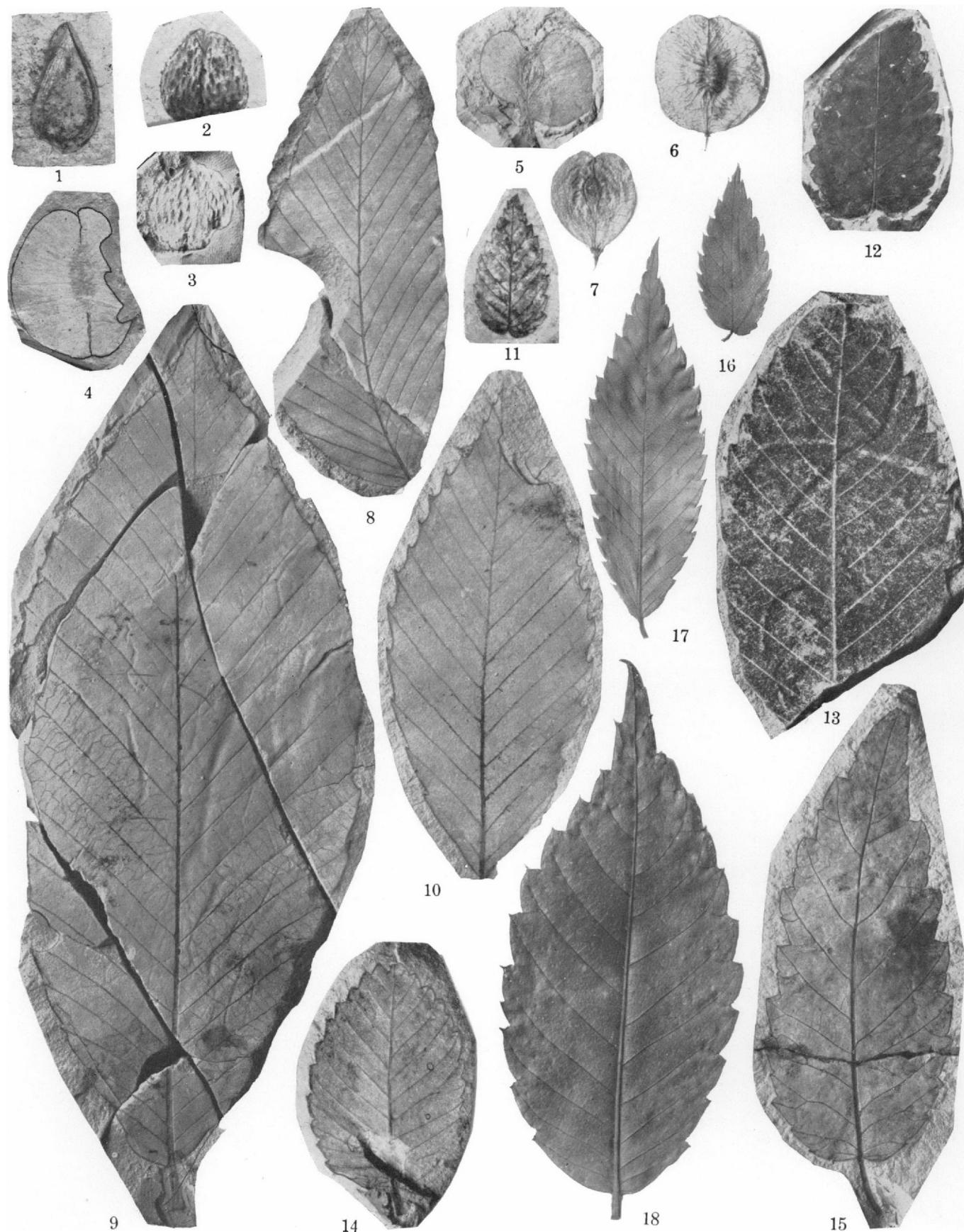
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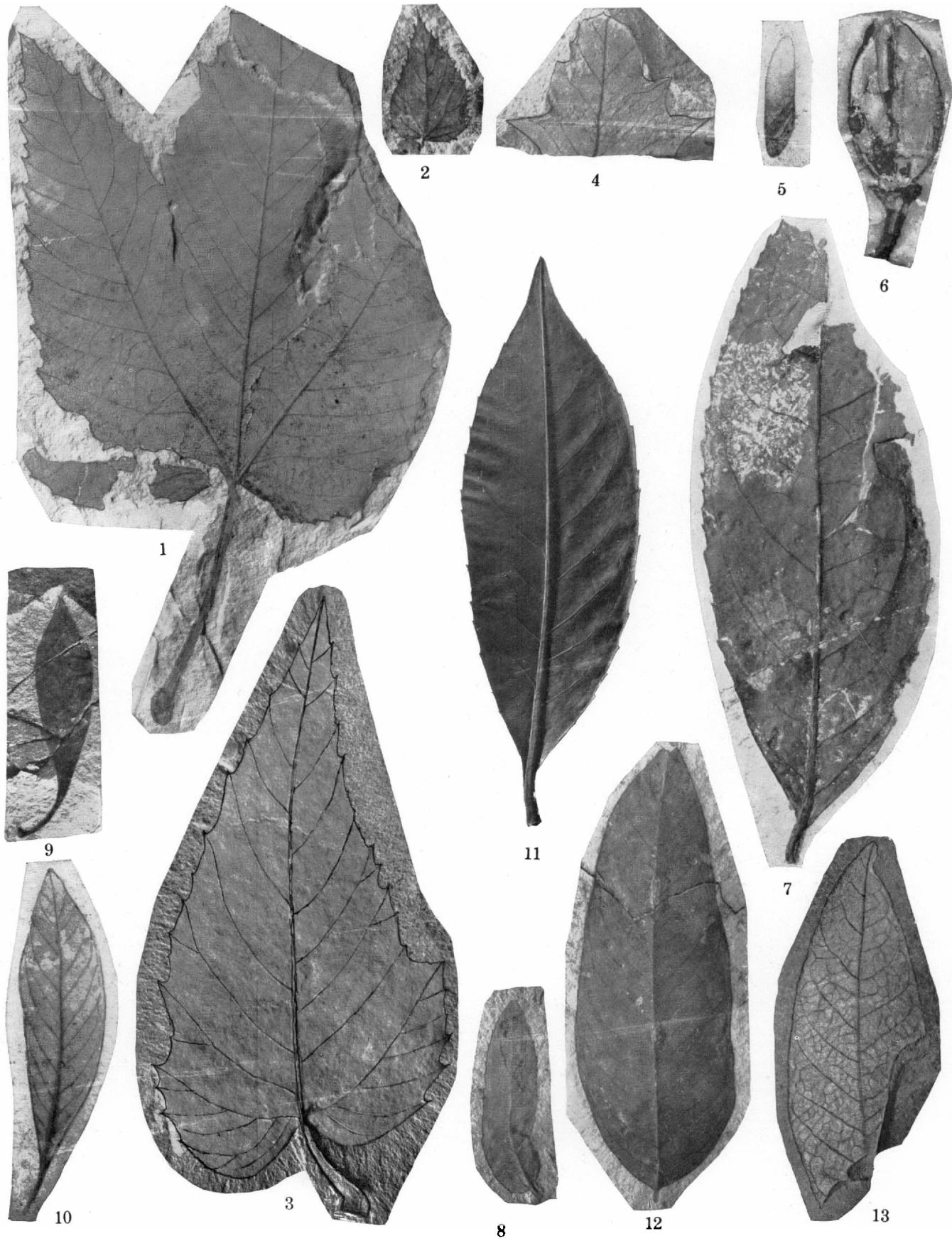
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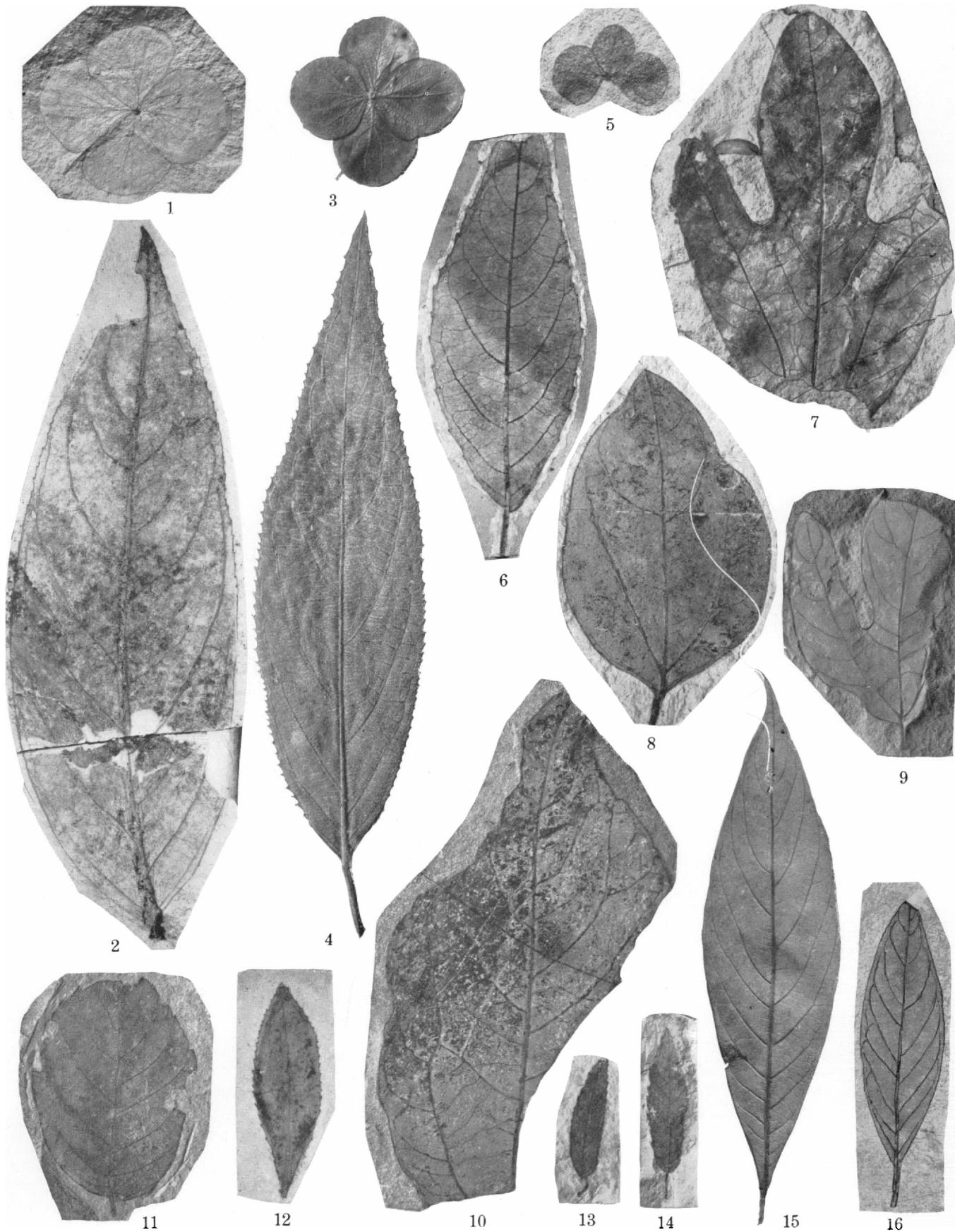
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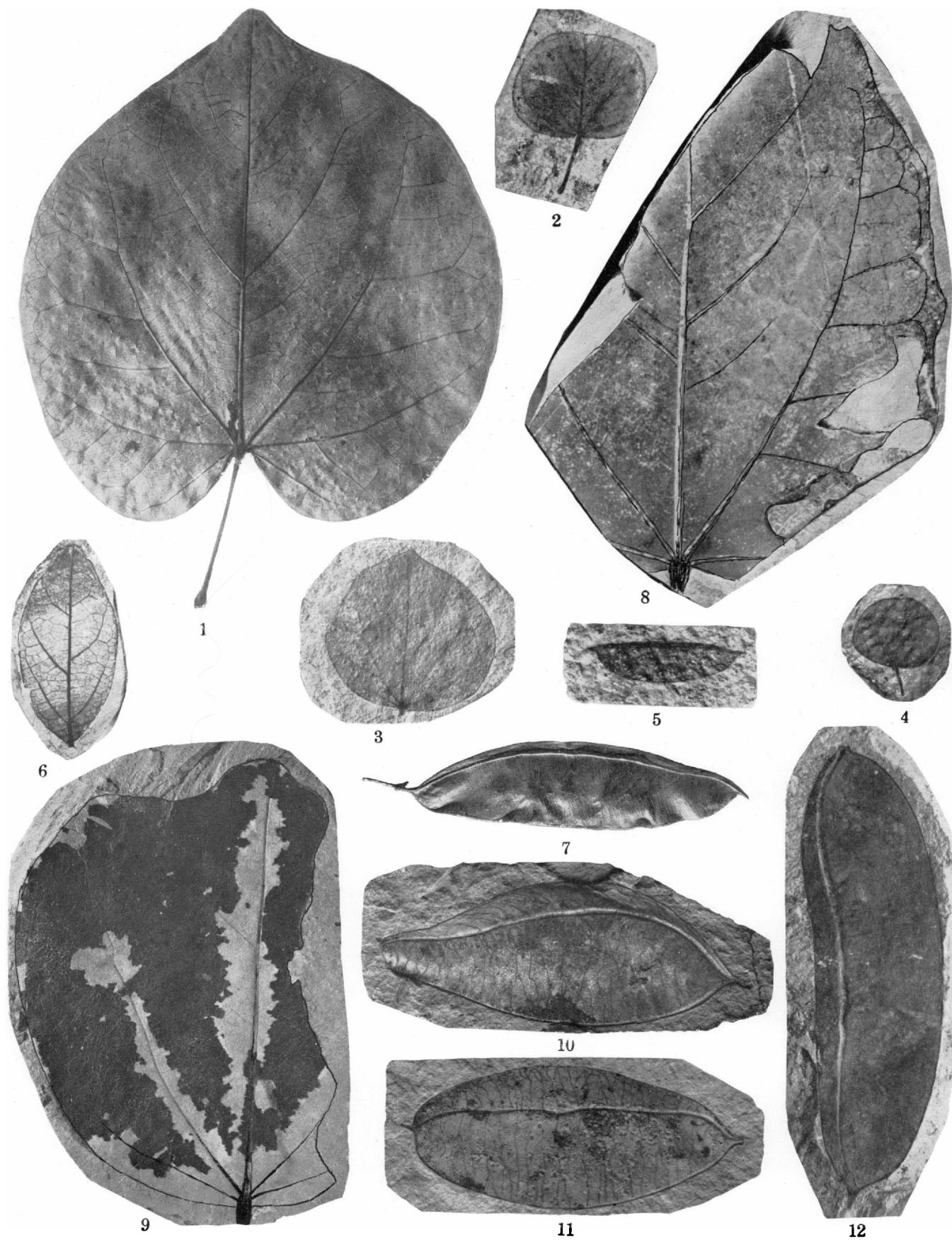
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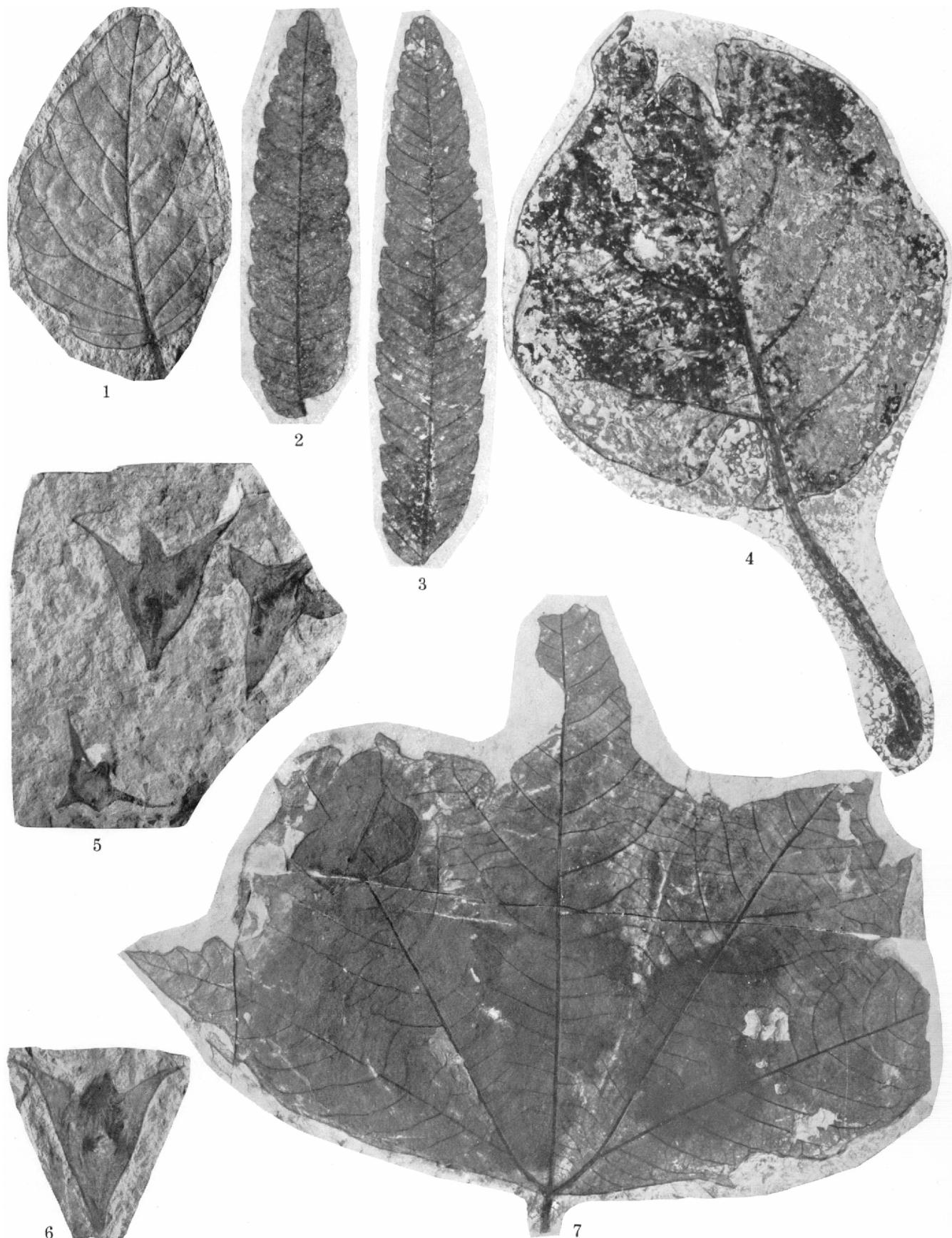
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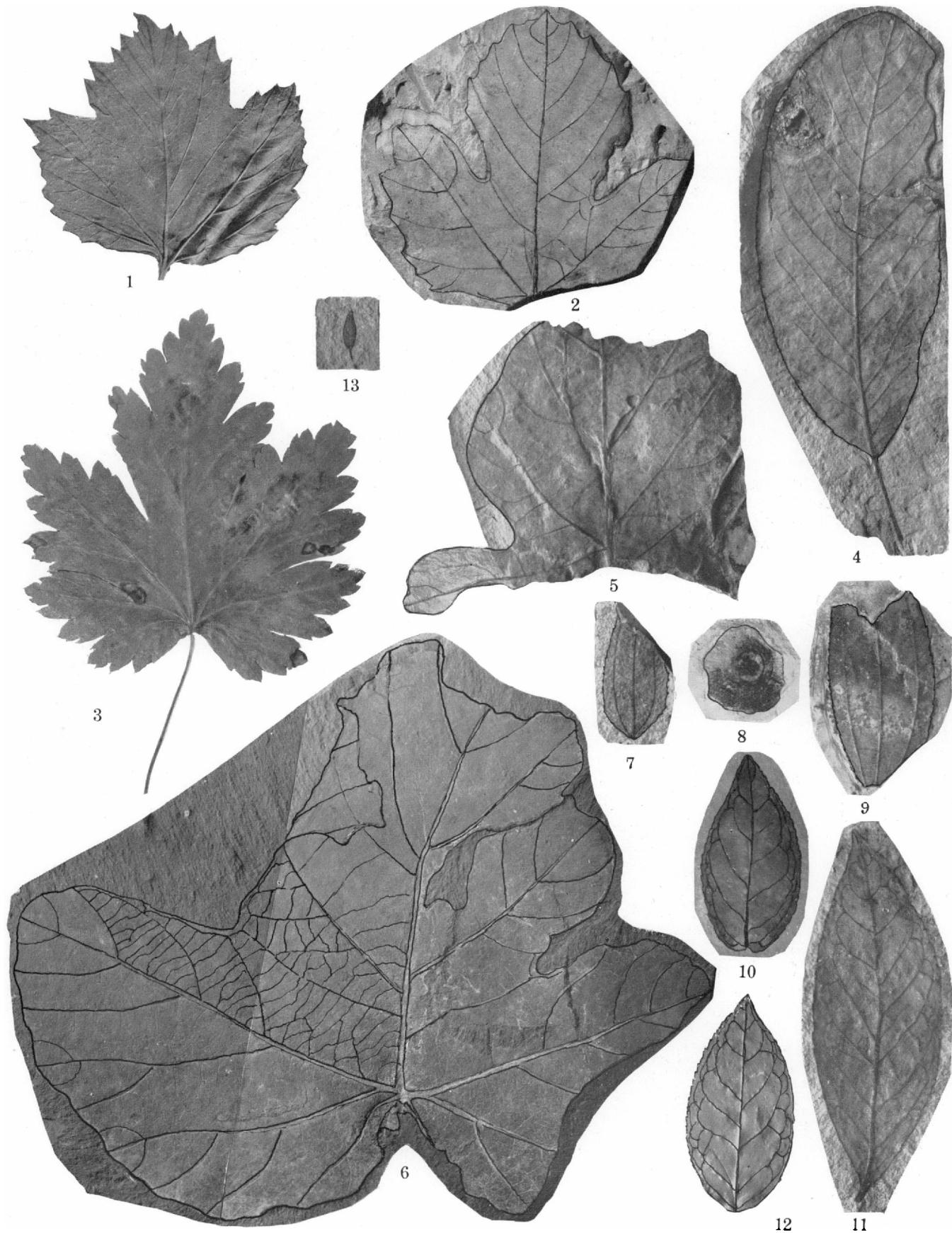
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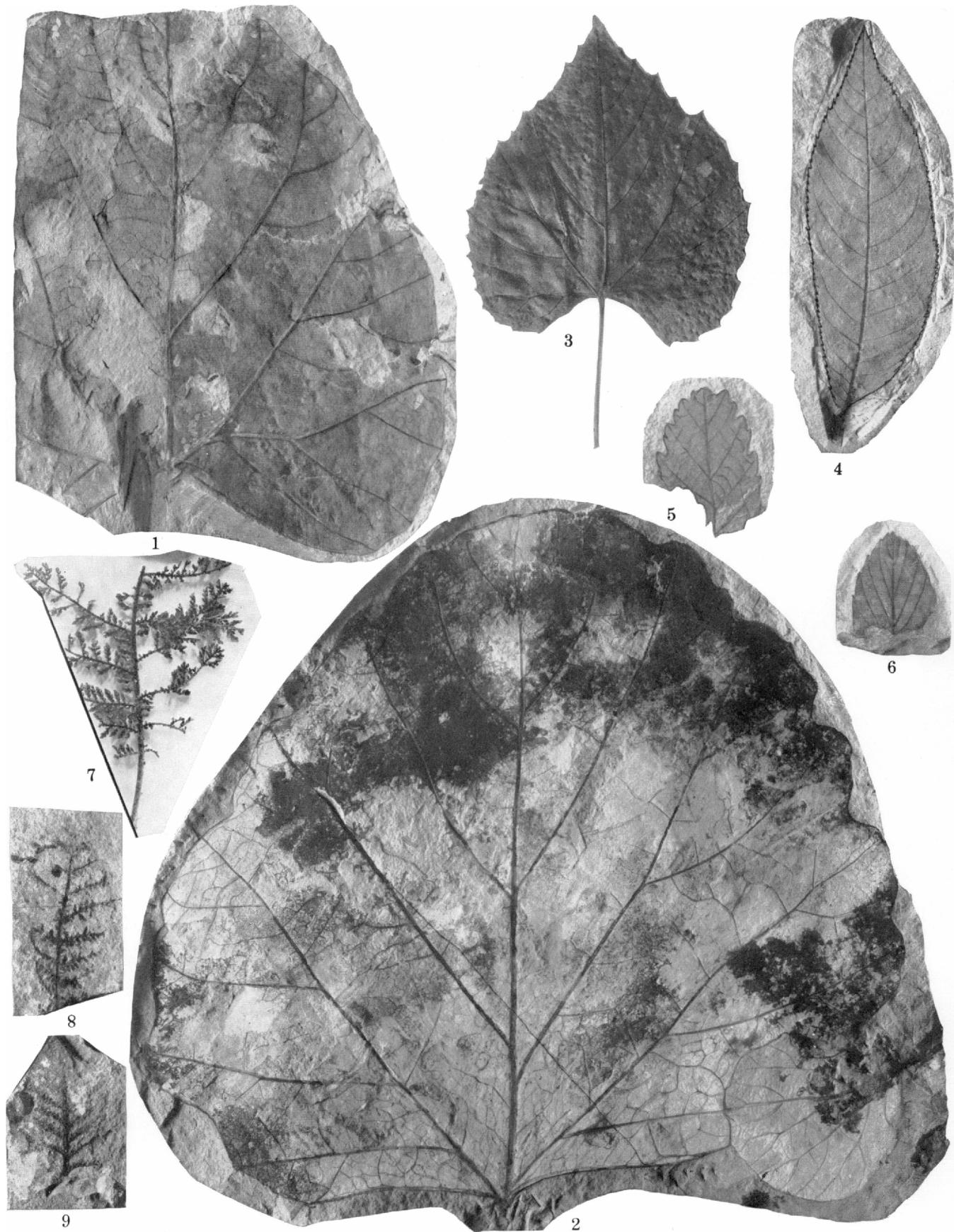
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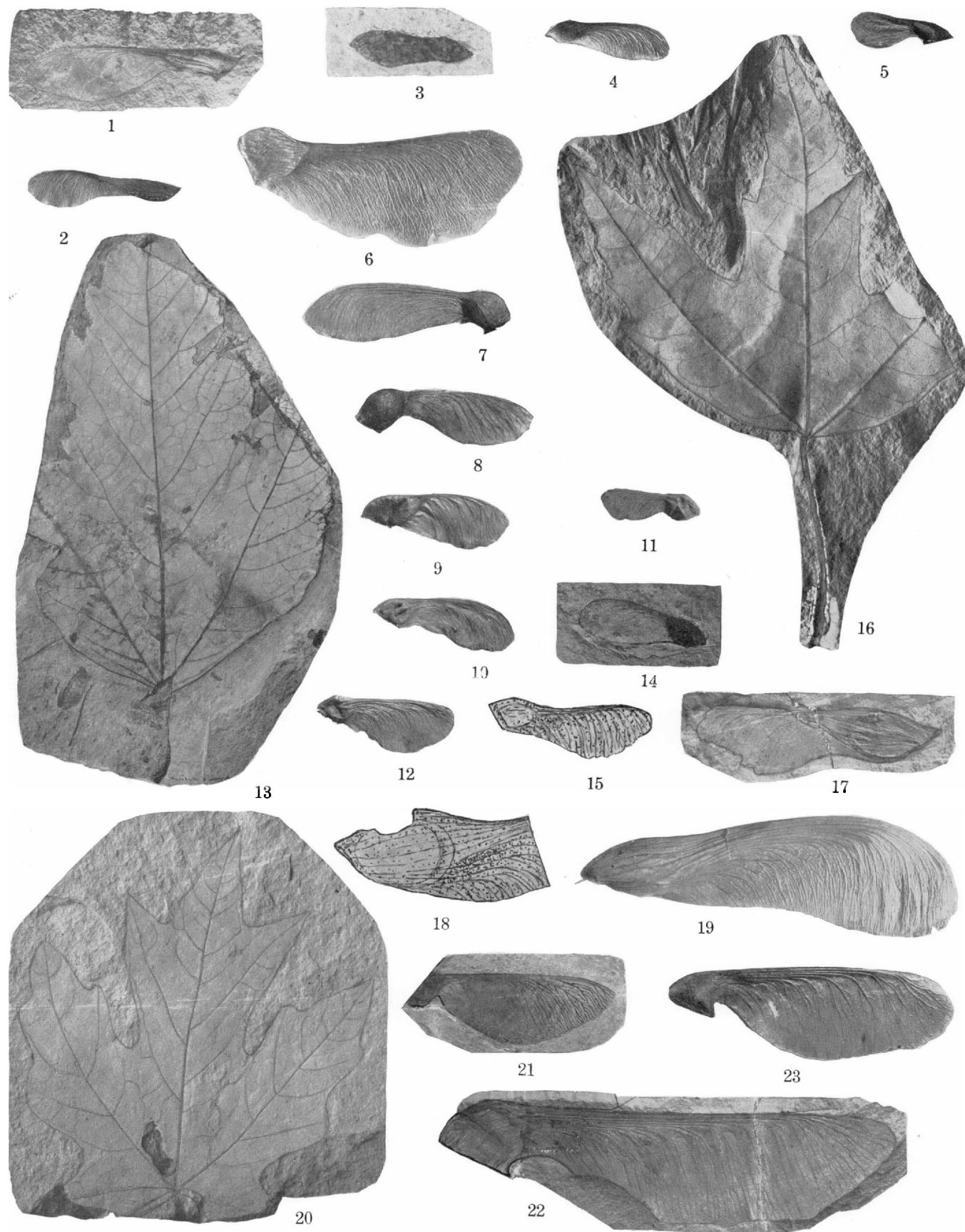
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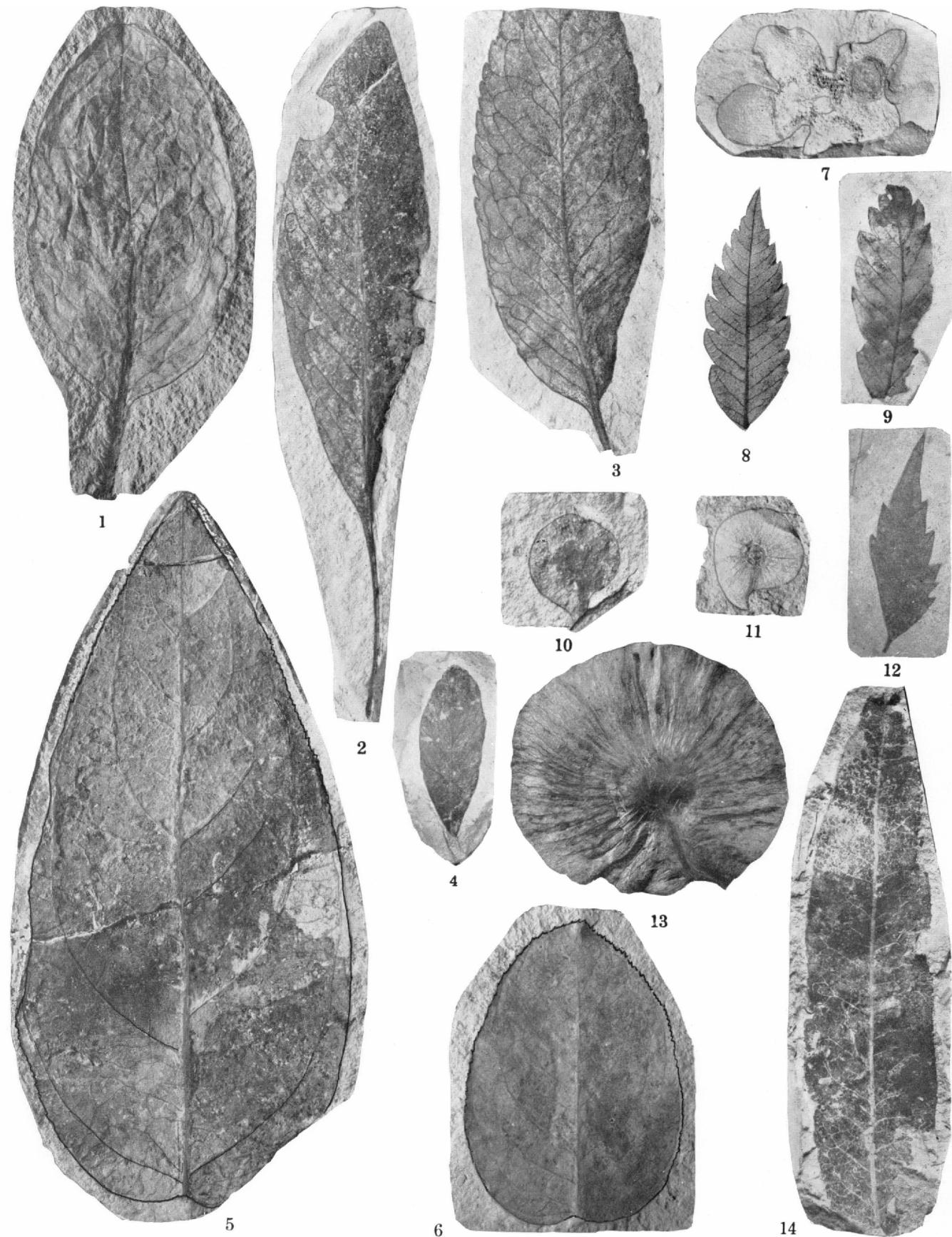
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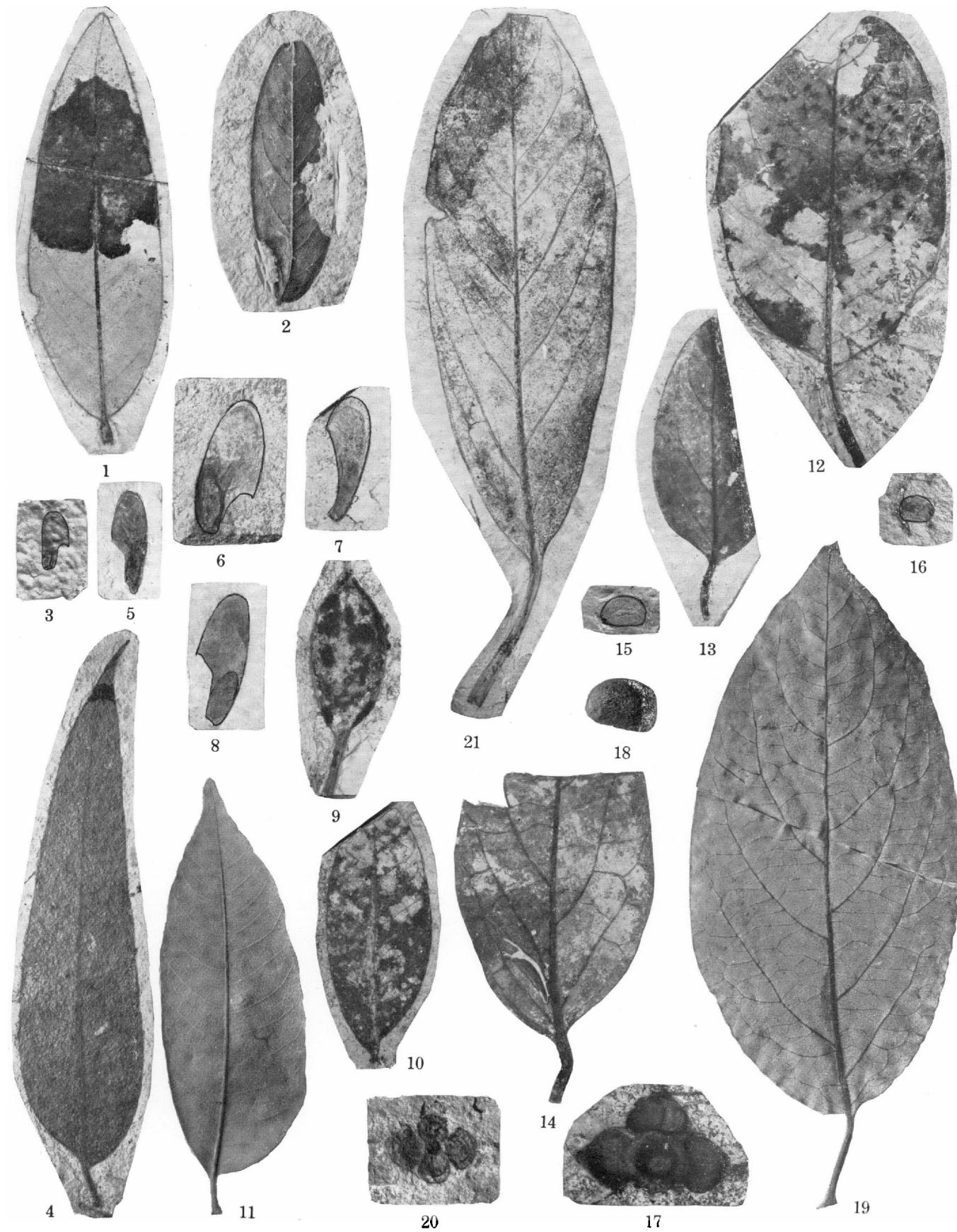
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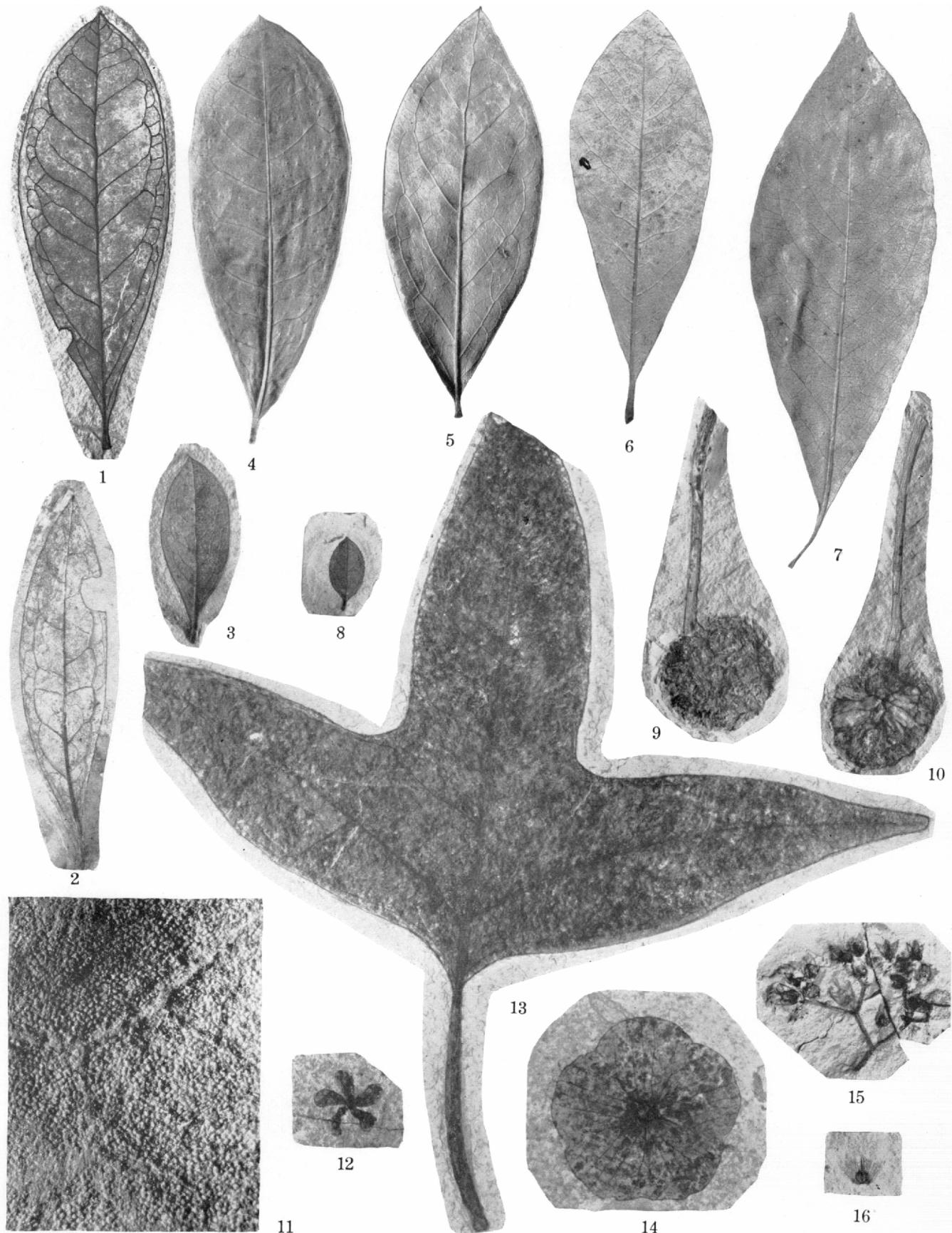
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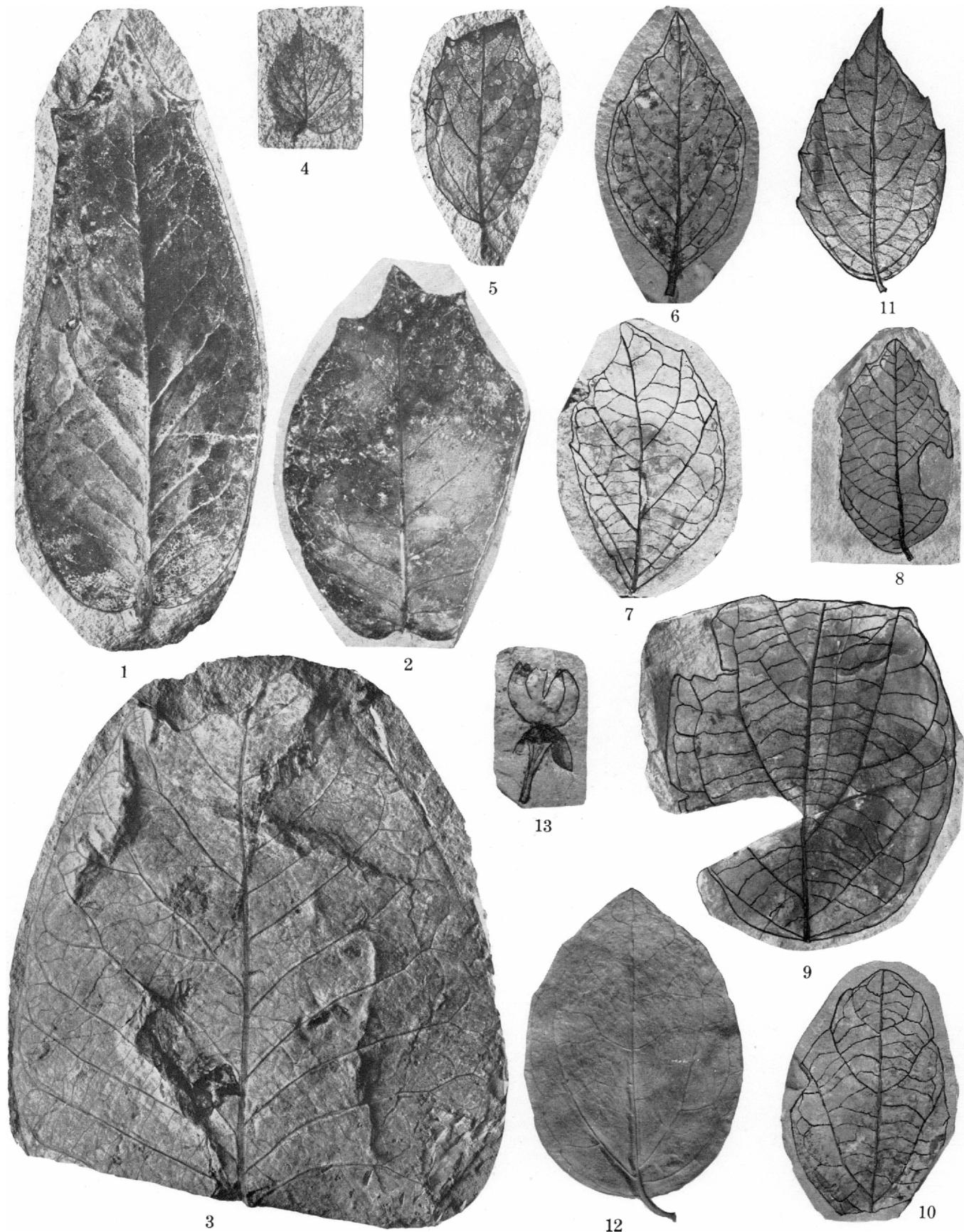
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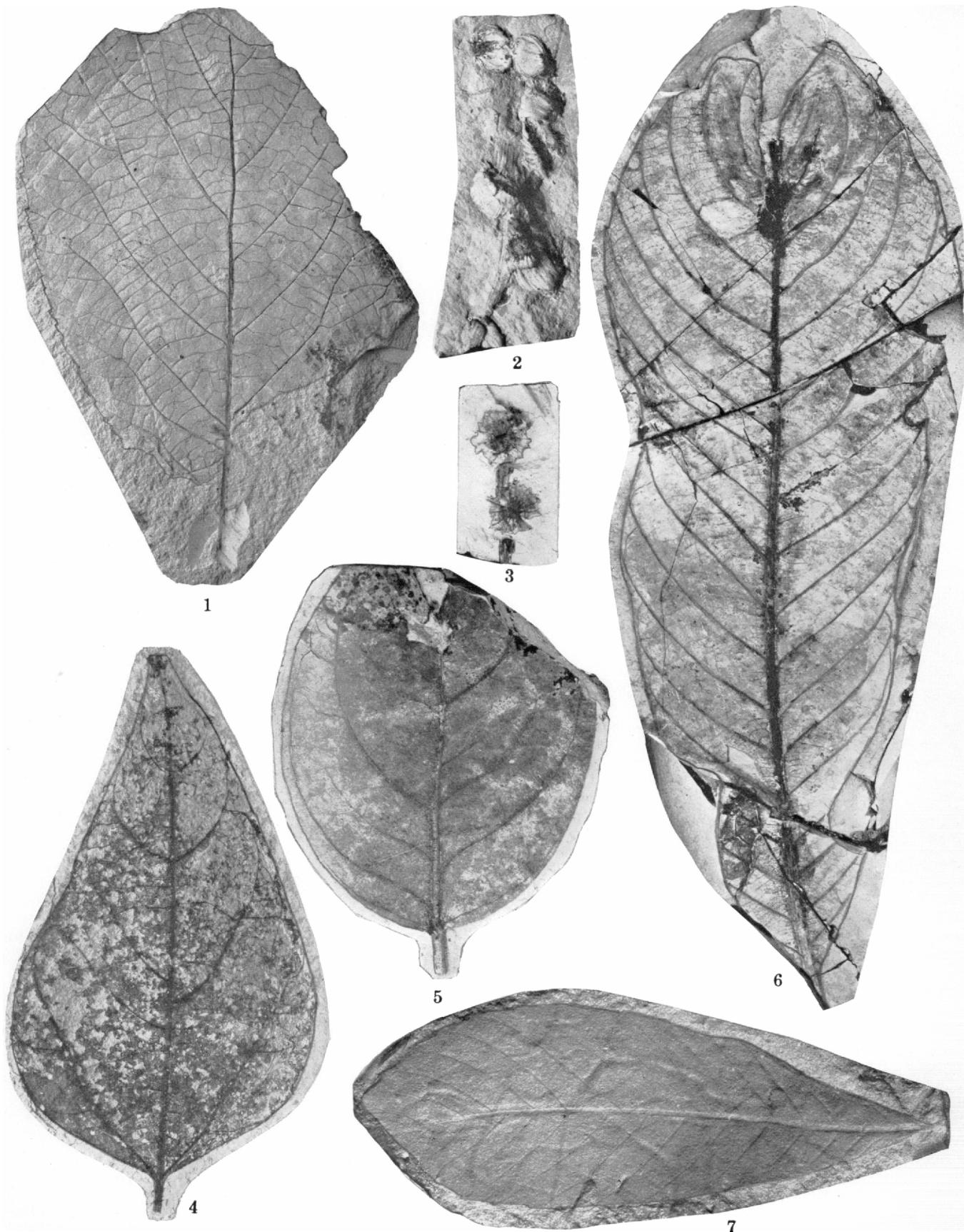
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**THE STRATIGRAPHY OF THE UPPER CRETACEOUS ROCKS NORTH OF THE ARKANSAS RIVER IN EASTERN COLORADO**

By C. H. DANE, W. G. PIERCE, and J. B. REESIDE, Jr.

**ABSTRACT**

A comparison of the stratigraphic sections of the rocks of Benton age in western Kansas and the southern foothill region of eastern Colorado indicates the probability that the lower members of the Greenhorn of Kansas merge westward into the upper part of the Graneros shale of the foothills, the Greenhorn of the type locality being much thinner than that of western Kansas and the Graneros of the type locality being much thicker than the Graneros of western Kansas. The Greenhorn of Prowers County, Colo., north of the Arkansas River, has, however, the thickness of the Kansas Greenhorn, and the member subdivisions of the Greenhorn made in Kansas can also be recognized in Prowers County. The Carlile shale, which overlies the Greenhorn, contains at the top the persistent but variable Codell sandstone member. This member, which contains the Carlile fauna, is believed to have been deposited in shallow water under conditions that were maintained for a considerable period of time. The faunal discontinuity between the Carlile and the overlying Niobrara formation is believed to represent a time lapse, although no evidence was seen to indicate subaerial erosion of the Carlile.

In the foothill region of Colorado the Niobrara consists of the Timpas limestone member and the overlying Apishapa shale member. The Timpas includes in its upper part limy shales and thin limestone beds which, in Kansas, have been excluded from the basal Hays limestone member. The Hays limestone member appears to be a more satisfactory lithologic and faunal unit, and the name is therefore extended into that part of Colorado east of the foothills and north of the Arkansas River. Similarly, the name "Smoky Hill" is extended from the chalk member of that name in Kansas to the marl member overlying the Hays limestone in eastern Colorado.

The basal portion of the overlying Pierre shale consists of black shale nearly devoid of fossils, to which the name "Sharon Springs member" is extended from the type locality in Wallace County, Kans. The overlying portion of the Pierre shale was not sufficiently studied to warrant the establishment of member names, although the "rusty zone", "tepee zone", and "transition zone" of previous authors are recognized.

The known invertebrate faunas of the several formations are briefly described, and the fauna of the overlying Fox Hills sandstone is also discussed because of its close relationship to the fauna of the "transition zone" of the Pierre shale.

**INTRODUCTION**

During parts of the summers of 1931 and 1932 C. H. Dane and W. G. Pierce spent about 8 months on a reconnaissance examination of a large area of the High Plains of eastern Colorado north of the Arkansas River. A few additional observations on the lower part of the Upper Cretaceous section in the southern foothills re-

gion were made by C. H. Dane in the fall of 1933. The invertebrate faunas collected during this reconnaissance have been studied by J. B. Reeside, Jr., who has also contributed many hitherto unpublished data. Although detailed work has been done in several areas in this region, no summary of the stratigraphy has been published for many years, and it has therefore seemed appropriate to publish the data gathered in the present study and to correlate them with the previous work. Because of the large size of the area traversed, it was not possible to make a rigorous examination of any specific problem, though considerable information was obtained concerning the lower portion of the Upper Cretaceous.

The location of the area within which most of the observations here recorded were made is shown on the index map (fig. 9), which also shows the location of some areas covered by previous reports.

The geologic map (pl. 64) shows the areas of outcrop of the principal stratigraphic divisions with reference to the major geographic and cultural features of the region. The base was taken from the United States Geological Survey map of Colorado compiled in 1922, with minor modifications of land lines, drainage, and culture observed by the writers in the field or suggested by more recently compiled maps. The mapping was done wholly by sketching, either on county maps or on so-called military maps of the Colorado State Highway Commission, which show towns, railroads, and graded roads with considerable accuracy.

The formations exposed are of Upper Cretaceous and Tertiary age. The Cretaceous rocks were laid down in the widespread seas that covered much of the western interior of the United States at that time. During the period in which the earlier deposits accumulated there was some differential warping of the crust, but subsidence later became more pronounced in an area centering somewhat north of Denver. During the epoch of subsidence a basin was formed which filled with sediments as it subsided, the later Cretaceous rocks thus having a much greater thickness toward the central part of the basin. Toward the end of the Cretaceous and early in the Tertiary the rising Rocky Mountains shed great quantities of debris eastward to form a series of nonmarine deposits. Although the

seas had withdrawn, the basin continued to subside until deposition ceased, probably in early Eocene time. The latest structural movements accompanying the rise of the Rocky Mountains completed the outline of the sedimentary basin and made it a structural basin as well. There ensued a period in which erosion was predominant, and the main outlines of the present areal geology of the Cretaceous rocks were formed by the beveling of the inclined strata. Somewhat later, in middle and late Tertiary time, gravelly debris was

deposited over the surface, and even where not concealed by younger deposits they may be weathered into smooth ungravelled sod-covered slopes in which the details of the lithology cannot be determined. No attempt has been made to indicate on the map the distribution of terraces, wash, or eolian deposits, which in places conceal the Tertiary as well as the Cretaceous rocks. The extent of the present alluvial plain of the Arkansas River is shown only approximately.

#### EARLIER WORK

The first comprehensive studies of the Cretaceous stratigraphy of the Arkansas Valley were begun by G. K. Gilbert in 1893 with the mapping of the Pueblo quadrangle.<sup>1</sup> Mapping of the Apishapa quadrangle<sup>2</sup> was begun in the following year, and a subsequent reconnaissance of the more easterly portion of the valley led to the publication in 1896 of Gilbert's report on the underground water of the Arkansas Valley in eastern Colorado.<sup>3</sup> The description of the Denver Basin,<sup>4</sup> a more northerly area of the foothills and adjoining plains, was published at about the same time, though based on field work of the preceding decade. In the succeeding years several other folios<sup>5</sup> were issued that followed closely the outlines of the stratigraphy laid down by Gilbert and that dealt with areas of the southern foothills and adjoining plains. In 1906 Darton's broader study<sup>6</sup> of the geology and underground water of the Arkansas Valley was published. With the appearance of the Castle Rock folio<sup>7</sup> in 1915 and the Colorado Springs folio<sup>8</sup> in 1916 the earlier phase of the geologic study of the region came to an end, and most of the larger features of the geology had been outlined. Several detailed reports on areas in the Arkansas Valley in Colorado have since appeared, and some features of the stratigraphic relations have been touched upon in other papers. In recent years several detailed studies have been made of the Upper Cretaceous rocks in western Kansas.<sup>9</sup> In these studies finer division of the Cretaceous beds has been made than in

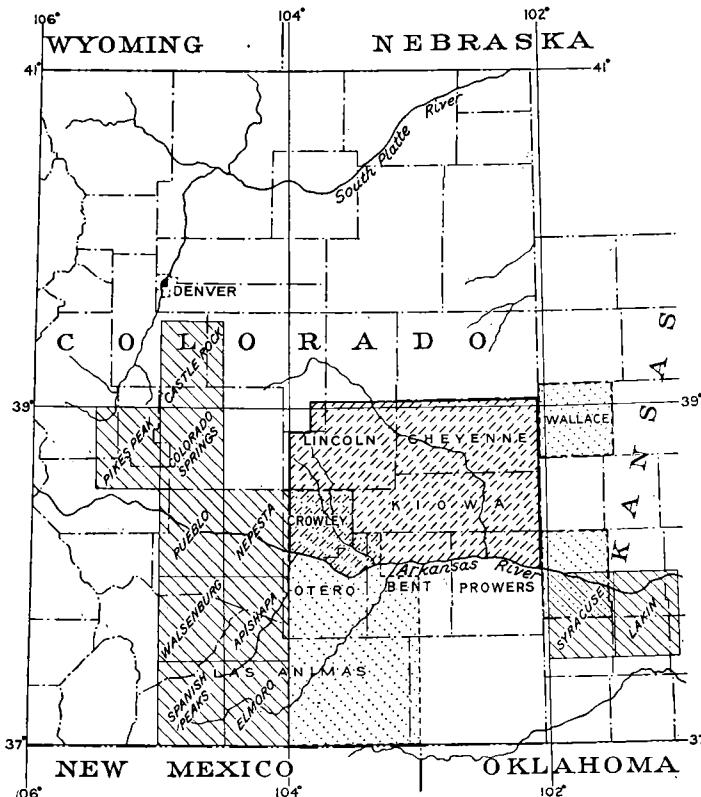


FIGURE 9.—Index map showing location of area in eastern Colorado considered in this report (shown by short-dashed lines) and of some areas described in previous reports, including folios of the Geologic Atlas of the United States (cross-lined) and reports of the Colorado and Kansas Geological Surveys (dotted).

swept out from the mountains by streams, and widespread though comparatively thin deposits of gravel and sand were laid down. The great plain thus built up sloped gently eastward, its materials concealing the underlying Cretaceous rocks far east of the mountain front. Renewed erosion in still later epochs has cut away much of this plain and exposed the underlying rocks, but large areas of it still remain, and beneath these areas the Cretaceous rocks are wholly concealed. Even where the present surface has been cut below the level of the High Plains deposits, there are extensive areas where the Cretaceous rocks are concealed by relatively late terrace deposits at several levels, surface wash, and sand dunes, and the alluvial deposits of the larger streams. For the greater part also the Creta-

<sup>1</sup> Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), 1897.

<sup>2</sup> Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), 1912.

<sup>3</sup> Gilbert, G. K., U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 351-601, 1896.

<sup>4</sup> Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 1896.

<sup>5</sup> U. S. Geol. Survey Geol. Atlas, Elmoro folio (no. 58), 1899; Walsenberg folio (no. 68), 1900; Spanish Peaks folio (no. 71), 1901; Nepesta folio (no. 135), 1906.

<sup>6</sup> Darton, N. H., Geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Prof. Paper 52, 1906.

<sup>7</sup> U. S. Geol. Survey Geol. Atlas, Castle Rock folio (no. 198), 1915.

<sup>8</sup> U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (no. 203), 1916.

<sup>9</sup> Bass, N. W., Geologic investigations in western Kansas, pt. 2, Geology of Hamilton County: Kansas Geol. Survey Bull. 11, 1926. Elias, M. K., The geology of Wallace County, Kans.: Kansas Geol. Survey Bull. 18, 1931.

the rocks of equivalent age in eastern Colorado. Although the observations recorded in this paper were made in reconnaissance, they show that some of the smaller units set up in Kansas can be recognized also in eastern Colorado. Much of the area offers small promise of results to be obtained from detailed work, but in places exposures are sufficient to justify more careful stratigraphic study than has yet been carried out.

#### THE FORMATIONS

In the area shown on plate 64 the Upper Cretaceous rocks include the formations from the Dakota sandstone to the lower part of the Pierre shale. West and north of the mapped area the higher part of the Pierre shale is present, overlain by the Fox Hills sandstone, the Laramie formation, and the Dawson arkose. The uppermost beds of the Pierre shale and higher Cretaceous rocks are not discussed at length in this paper, but certain observations, particularly the record of fossil collections, are given.

The stratigraphic divisions of the Upper Cretaceous rocks described in this paper are as follows:

- Fox Hill sandstone.
- Pierre shale:
  - Transition zone.
  - Tepee zone.
  - Rusty zone.
  - Sharon Springs shale member (barren zone).
- Niobrara formation: (Foothill region, Colo.)
  - Smoky Hill marl member. } { Apishapa shale member.
  - Hays limestone member. } { Timpas limestone member.
- Carlile shale:
  - Codell sandstone member.
  - Blue Hill shale member.
  - Fairport chalky shale member.
- Greenhorn limestone.
- Graneros shale.
- Dakota sandstone.

#### DAKOTA SANDSTONE

The Dakota sandstone, which is the basal formation of the Upper Cretaceous series of this region, crops out in a narrow strip adjacent to the alluvial plain along the north side of the Arkansas River and extends from the northwestern part of T. 23 S., R. 51 W., to the southwestern part of T. 22 S., R. 47 W. Only the upper part of the formation is exposed. In the exposures observed by the writers it consists principally of buff and white, uniformly fine-grained, cross-bedded sandstone, with weathered surfaces pitted. As much as 40 feet of sandstone of this type is exposed at one locality, but elsewhere the exposed thickness is much less. The total thickness is somewhat variable but probably does not exceed 100 feet.<sup>10</sup> Where a more nearly complete

section is exposed south of the Arkansas River it is described as a hard massive or quartzitic sandstone.<sup>11</sup> Carbonaceous and lignitic layers and fossil leaves of Upper Cretaceous age are found locally in the sandstone.

#### GRANEROS SHALE

Exposures of the next overlying formation, the Graneros shale, occur in a narrow belt north of the Arkansas River and extending from a point south of Fort Lyon on the east to a point south of Wiley on the west, and also east of Holly in a small area near the Kansas-Colorado State line.

The Graneros shale was defined by Gilbert<sup>12</sup> as a laminated argillaceous shale from 200 to 210 feet thick, the lowest formation of the Benton group. It was named from a creek in the northern part of the Walsenburg quadrangle.

The formation consists predominantly of dark-gray to black fissile noncalcareous shale. Because it is soft and easily erodible and because of the widespread deposition of terrace sands along the Arkansas River, exposures are so small and scattered that little information on the details of lithology, thickness, and stratigraphic relations can be obtained in this area.

The basal part of the Graneros is exposed at various places from sec. 4, T. 23 S., R. 51 W., eastward to the southwestern part of T. 22 S., R. 49 W. The basal Graneros in this area consists of well-bedded nonsandy shale, with thin bentonite beds at places. Although the basal contact was everywhere concealed, there seems to be an abrupt change in lithology from the cross-bedded sandstone of the underlying Dakota sandstone. In other areas there is a transition zone of sandy shale at the base of the Graneros. In Hamilton County, Kans., the basal 8 or 10 feet of the formation contains lenses of impure sandstone and sandy shale and layers of iron concretions 2 to 8 inches in diameter.<sup>13</sup> South of the Arkansas River, in the La Junta area,<sup>14</sup> several feet of alternating shales and sandstones at the top of the Dakota form a transition to the overlying Graneros, and similar transitional relations have been observed in the vicinity of Pueblo<sup>15</sup> and of Colorado Springs.<sup>16</sup>

<sup>10</sup> Duce, J. T., Geology of parts of Las Animas, Otero, and Bent Counties; Colorado Geol. Survey Bull. 27, pt. 3, pp. 89-90, 1924.

<sup>11</sup> Darton, N. H., Geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Prof. Paper 52, pp. 25-27, 1906.

<sup>12</sup> Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 564, 570, 1896.

<sup>13</sup> Bass, N. W., Geologic investigations in western Kansas, pt. 2, Geology of Hamilton County: Kansas Geol. Survey Bull. 11, p. 72, 1926.

<sup>14</sup> Patton, H. B., Underground water possibilities for stock and domestic purposes in the La Junta area, Colo.: Colorado Geol. Survey Bull. 27, pt. 1, p. 14, 1924.

<sup>15</sup> Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

<sup>16</sup> Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (no. 203), p. 8, 1916.

In Hamilton County, Kans.,<sup>17</sup> the Graneros shale is from 60 to 65 feet thick. It is believed to have about the same thickness in the extreme eastern portion of the Arkansas Valley in Colorado, where, in addition, the same divisions of the overlying Greenhorn limestone may be recognized as in Hamilton County. In the northeastern part of Bent County, Colo., however, the Graneros shale is estimated by the writers to be about 200 feet thick, and although the overlying Greenhorn limestone is there incompletely exposed, it seems to be much thinner than in western Kansas. This relation suggests that the Graneros has thickened westward at the expense of the Greenhorn. In the western part of Bent County and in Otero County<sup>18</sup> the Graneros has a thickness of about 200 feet, and farther west<sup>19</sup> it is from 200 to 220 feet thick. In a section measured by the writers at Colorado City, west of Colorado Springs, the Graneros shale is 210 feet thick.

Lithologic subdivisions of the Graneros were not distinguishable in the small scattered exposures observed within the area covered by this report. In the region of La Junta and farther west in the Arkansas Valley<sup>20</sup> the middle portion of the Graneros includes nearly black shales which contrast with somewhat lighter colored shales above and below. The subdivision into a nearly black middle portion and lighter-colored upper and lower portions is also recorded farther south in the vicinity of Walsenburg and Trinidad.<sup>21</sup> The thickness in those localities is given as 200 to 210 feet. This is also about the thickness of the Graneros exposed at a locality about 10 miles northwest of Vermejo Park, on the east flank of the Sangre de Cristo Range, in New Mexico near its northern boundary. A calcareous concretionary zone occurs at 30 to 40 feet above the base, and a thin calcareous sandstone or sandy limestone occurs 45 to 50 feet below the top. In the Apishapa quadrangle<sup>22</sup> a bed of impure, sparingly fossiliferous limestone 12 to 14 inches thick lies from 65 to 75 feet above the base, and a 6-inch bed of hard sandstone occurs a few feet above the limestone. At 80 feet above the base of a section of Graneros measured by the writers at Colorado City, west of Colorado Springs, there is a prominent thin-bedded sandstone 1 foot thick with 2 feet 6 inches of gray sandy shale below it. Over the western part of the area described in this report and a considerable region to the west and south the Graneros

seems to maintain a fairly uniform thickness, and it is likely that a few individual beds in it may be recognized and traced over large areas.

Bentonite beds from a fraction of an inch to a few inches thick occur at several horizons within the Graneros. Although they afford a potentially useful means of detailed correlation, the inadequacy of exposures over much of the portion of eastern Colorado here discussed makes it unlikely that such detailed correlation can be effected without very careful recording of the formation where it is penetrated by wells. Southwest of Las Animas a bed of bentonite 3 feet thick<sup>23</sup> occurs about 85 feet above the base of the Graneros and has been recorded as "talc" in several wells drilled for water in the La Junta region. No beds of equal thickness are known elsewhere in this region. Beds of similar thickness have, however, been recorded in the lower part of the Benton<sup>24</sup> shale of northeastern Colorado, which is the equivalent of the Graneros shale and the overlying Greenhorn and Carlile formations of the Arkansas Valley.

The fauna of the Graneros shale is scanty and imperfectly known. A small simple oyster somewhat larger and more regular in form than *Ostrea congesta* is abundant in sandy limestone near the top of the Graneros shale in the region of the Apishapa quadrangle.<sup>25</sup> Gilbert, during his work in the Arkansas Valley, collected from the lower part of the Graneros the following fossils, largely unnamed species: Corals, several species; pelecypods, *Leda* sp., *Arca* sp., *Inoceramus* aff. *I. bellvuensis* Reeside, *Pteria* sp., *Pecten* sp., *Lucina* sp., *Dosinopsis* sp.; scaphopod, *Dentalium* sp.; gastropods, *Turritella whitei* Stanton, *Mesostoma occidentalis* Stanton, *Cinulia?* sp., *Actaeon propinquus* Stanton; cephalopods, a nautiloid, *Mammites* sp., *Metacalycoeras* sp., *Borissjakoceras* sp., *Turrilites* sp. Bass<sup>26</sup> reported *Ostrea* n. sp., small simple type, and *Inoceramus*, n. sp. related to *I. fragilis* Hall and Meek from western Kansas.

A section of the Benton shale was measured by the writers along the south fork of Bear Creek 1.3 miles south of the place where the main road from Mount Morrison to Denver crosses the Dakota sandstone hogback. About 10 feet above the top of the Dakota sandstone and thus in beds equivalent to the Graneros shale the writers collected *Holcolepis pulchellus* Cockerell and *Leucichthys vagans* Cockerell, species originally described from the Mowry shale. Several other small lots of fossils were collected at horizons 250 to 300 feet

<sup>17</sup> Bass, N. W., op. cit., p. 72.

<sup>18</sup> Patton, H. B., op. cit., p. 14.

<sup>19</sup> Gilbert, G. K., op. cit. (Pueblo folio), p. 3. Fisher, C. A., U. S. Geol. Survey Geol. Atlas, Nepesta folio (no. 135), p. 2, 1906.

<sup>20</sup> Patton, H. B., op. cit., p. 14. Gilbert, G. K., op. cit. (Pueblo folio), p. 3. Fisher, C. A., op. cit., p. 2. Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), p. 5, 1912.

<sup>21</sup> U. S. Geol. Survey Geol. Atlas, Walsenburg folio (no. 68), p. 1, 1900; Elmoro folio (no. 58), p. 1, 1899.

<sup>22</sup> Stose, G. W., op. cit., p. 5.

<sup>23</sup> Patton, H. B., op. cit., pp. 14-15.

<sup>24</sup> Mather, K. F., Gilluly, James, and Lusk, R. G., Geology and oil and gas prospects of northeastern Colorado: U. S. Geol. Survey Bull. 796, pp. 81-83, 1928.

<sup>25</sup> Stose, G. W., op. cit., p. 6.

<sup>26</sup> Bass, N. W., op. cit., p. 73.

above the base of the Benton in this section. These lots include the species in the following list:

- Globigerina sp.
- Globotruncana sp.
- Inoceramus sp.
- Ostrea sp.
- Ptychodus sp.

#### GREENHORN LIMESTONE

The Greenhorn limestone was differentiated as a formation by Gilbert.<sup>27</sup> It was so named from Greenhorn station, 14 miles south of Pueblo, and Greenhorn Creek. The formation as described by Gilbert is from 25 to 40 feet thick and consists of alternating beds of fine-grained, compact, pale bluish-gray limestone and light-gray laminated calcareous shale. The Greenhorn as recognized in western Kansas, however, has a thickness of 100 to 130 feet and includes three recognizable members in some places and four in others. It seems desirable to compare the exposures of the formation along the north side of the Arkansas Valley in Colorado with the thicker and divisible section of western Kansas.

In Hamilton County, Kans., which adjoins Colorado, Bass<sup>28</sup> recognized three members of the Greenhorn—the Bridge Creek limestone member at the top, the intermediate Hartland shale member, and the basal Lincoln limestone member. The Bridge Creek member consists of an alternation of limy shale and chalky limestone having a thickness of 74 feet, four-fifths of which consists of shale. It merges into the overlying Carlile shale with no apparent lithologic change but is separable from the Carlile faunally. Below the Bridge Creek member is a unit of calcareous shale, the Hartland shale member. This is 23 feet thick and almost devoid of limestone but contains, like the Bridge Creek member, many layers of bentonitic clay. The Lincoln limestone member, although consisting predominantly of calcareous shale, contains numerous thin beds of hard finely banded gray limestone that weathers brown. These beds are most abundant near the top and base of the member, which is 35 feet thick.

These divisions of the Greenhorn may also be recognized north of the Arkansas River in eastern Prowers County, Colo. The Bridge Creek member is exposed along the west side of Cheyenne Creek from the NW $\frac{1}{4}$  sec. 8, T. 23 S., R. 41 W., northward to the NE $\frac{1}{4}$  sec. 6 of the same township. A partial and approximate section follows:

<sup>27</sup> Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 564-565, 570, 1896.

<sup>28</sup> Bass, N. W., op. cit., pp. 66-70.

Partial section of Bridge Creek member of Greenhorn limestone on west side of Cheyenne Creek in Prowers County, Colo.

|   | Ft. | in. |
|---|-----|-----|
| Limestone, gray; weathers into hard yellowish-gray irregular flat slabs; numerous <i>Inoceramus labiatus</i> —          | 6   |     |
| Concealed—  | 1   | 6   |
| Limestone, gray, with <i>Inoceramus labiatus</i> —  | 6   |     |
| Concealed—  | 2   |     |
| Limestone, gray, with <i>Inoceramus labiatus</i> —  | 2   | 6   |
| Concealed—  | 3   | 6   |
| Limestone, gray—  | 6   |     |
| Concealed—  | 3   | 8   |
| Limestone, gray—  | 4   |     |
| Concealed—  | 1   |     |
| Limestone, gray—  | 4   |     |
| Concealed—  | 5   | 6   |
| Limestone, gray, with <i>Inoceramus labiatus</i> —  | 8   |     |
| Concealed—  | 1   | 6   |
| Limestone, gray, with <i>Inoceramus labiatus</i> —  | 8   |     |
| Concealed—  | 5   | 6   |
| (Above this point the section is approximate.)  |     |     |
| Limestone, gray, bedded—  | 6   |     |
| Shale, chalky, poorly exposed—  | 1   | 8   |
| Limestone, chalky, thin-bedded—   | 5   |     |
| Shale, chalky, poorly exposed—  | 1   |     |
| Limestone, white, chalky—   | 3   |     |
| Shale, chalky, thin-bedded, with a few hard white and gray limestone lenses less than half an inch thick—               | 2   | 11  |
| Bentonite—  |     | 5   |
| Limestone, gray; weathers white; single bed, with vertical joints from 2 to 8 inches apart; upper part somewhat chalky— | 6   |     |
| Shale, chalky, paper-bedded—  | 1   | 10  |
| Limestone, gray; weathers white; single bed, with vertical joints from 2 to 8 inches apart—                             | 4   |     |
| Shale, chalky, well bedded, with a few layers of gray crystalline limestone one-sixteenth inch thick—                   | 1   | 5   |
| Limestone, gray; weathers white; in lenses as much as 2 inches thick and 6 inches long—                                 | 2   |     |
| Shale, chalky, well bedded, with one zone of limestone lenses 2 inches thick below the water level of a dug pool—       |     |     |
| Total measured—   | 44  | 3   |

This section when plotted can be correlated at least approximately with the lower part of the section of the Bridge Creek member published by Bass.<sup>29</sup> The 5-inch bentonite bed resting on 6 inches of limestone can be correlated with a similar bed near the base of the Hamilton County section, and a zone of abundant fossils 30 to 40 feet higher appears in both sections. Many of the intermediate limestone beds also seem to match. Unfortunately the exposures along Cheyenne Creek were not sufficiently good to permit the recognition of other bentonite beds. However, near the southeast corner of the SW $\frac{1}{4}$  sec. 12, T. 23 S., R. 41 W., a bed of bentonite 5½ inches thick crops out above a bed of limestone 6 inches thick and below chalky shale. This

<sup>29</sup> Idem, fig. 21.

may well be the bed measured in the section west of Cheyenne Creek, given above.

In the SE $\frac{1}{4}$  sec. 12, T. 23 S., R. 42 W., somewhat more than 40 feet of soft chalky shale is exposed. These beds contain scattered limestone lenses as much as 2 inches thick but no continuous beds of limestone. They represent the Hartland shale member. Below them in the NE $\frac{1}{4}$  sec. 18 and NW $\frac{1}{4}$  sec. 17, T. 23 S., R. 41 W., the basal part of the Greenhorn is exposed above the Graneros shales. The beds include chiefly calcareous shales, but also hard crystalline limestone beds as much as 2 inches thick, which weather into hard yellowish and brownish plates. The limestone beds constitute only about 10 percent of the exposed rocks but because of their resistance to erosion are conspicuous on the outcrop. These lowest exposures of the Greenhorn correspond in lithology and probably also in thickness with the Lincoln limestone member as recognized in western Kansas.

In the SW $\frac{1}{4}$  sec. 11, T. 23 S., R. 42 W., exposures of the uppermost part of the Greenhorn limestone include beds of gray limestone and chalky marl. Part of the limestone, however, occurs as flat but rounded lenses or concretionary lenses from 6 to 12 inches thick.

The upper part of the Greenhorn limestone is also exposed in the NW $\frac{1}{4}$  sec. 18 and the W $\frac{1}{2}$  sec. 7, T. 22 S., R. 44 W. It consists of alternating beds of chalky marl and gray limestone, and the limestone beds have a thickness of 6 to 12 inches and carry numerous specimens of *Inoceramus labiatus*. There are also some lenses of hard gray crystalline limestone largely composed of fossil shells. In somewhat lower Greenhorn exposures in this vicinity there are less numerous impressions of *Inoceramus labiatus* and other fossils, and the limestones are less platy in habit, breaking rather into irregular chunks. Exposures of the lower part of the Greenhorn that might include possible equivalents of the Hartland shale member and Lincoln limestone member were not observed. In the north-central part of sec. 7, T. 22 S., R. 44 W., a partial section of the top of the Greenhorn limestone and basal part of the overlying Fairport chalky shale member of the Carlile shale was measured, as follows:

*Partial section of top of Greenhorn limestone and base of Carlile shale in sec. 7, T. 22 S., R. 44 W.*

Fairport chalky shale member of Carlile shale:

|   | Ft. in. |
|---|---------|
| Chalky shale.   |         |
| Limestone, gray, with <i>Inoceramus</i>   | 3       |
| Chalky shale  | 2 3     |
| Limestone, gray   | 3       |
| Chalky shale  | 2 6     |
| Limestone, white, hard; breaks in curving plates and flat slabs; in part weathering to yellowish gray | 5       |

*Partial section of top of Greenhorn limestone and base of Carlile shale in sec. 7, T. 22 S., R. 44 W.—Continued*

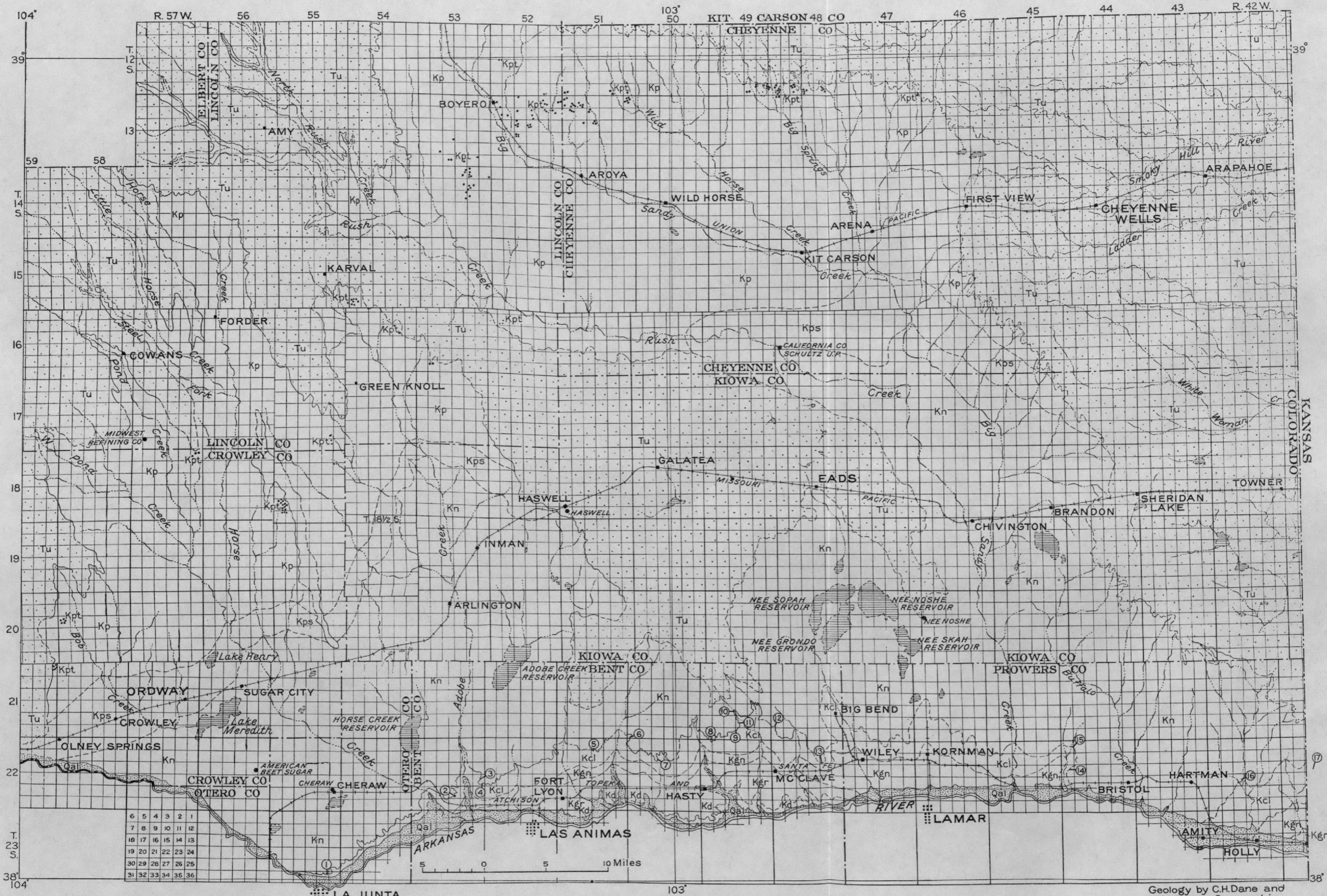
|  | Ft. in. |
|--|---------|
| Fairport chalky shale member of Carlile shale.—Contd.  |         |
| Chalky shale, white, thin-bedded   | 3       |
| Chalk, white; breaks into thin chips   | 4       |
| Partial thickness  | 9       |
| Greenhorn limestone:   |         |
| Limestone, light gray, dense, in part weathering to yellowish gray, less fossiliferous than lower beds; breaks along vertical joints into flat and irregular vertical plates | 10      |
| Chalky marl, gray, in part thin-bedded gray limestone; numerous <i>Inoceramus</i> and oyster shell fragments   | 3 10    |
| Limestone, gray  | 4       |
| Chalky marl, poorly exposed  | 10      |
| Limestone, gray, dense; breaks into numerous irregular flat slabby plates and chips; in part stained rusty yellow; <i>Inoceramus labiatus</i>                                | 5       |
| Chalky marl, soft, poorly exposed  | 1 2     |
| Limestone, gray; breaks into thin flat chips in lower 2 inches; <i>Inoceramus labiatus</i>   | 6       |
| Chalky marl, in part flaky and paper-bedded  | 1 1     |
| Limestone, gray; weathers very light gray; dense, with an irregular lower surface. Contains abundant <i>Inoceramus labiatus</i>  | 7       |
| Chalky marl, flaky and paper-bedded in part  | 1 1     |
| Limestone, chalky, gray; breaks into irregular flat chips  | 3       |
| Chalky marl, yellowish gray, flaky and paper-bedded in part  | 1+      |
| Partial thickness  | 11 11   |
| Total measured   | 20 11   |

No precise correlation can be made of this partial section with the partial section measured along Cheyenne Creek. The lower part may include some beds equivalent to the upper part of the Cheyenne Creek section, or it may include only beds higher than the top of the section measured on Cheyenne Creek.

The thickness and lithology of the Greenhorn in the region north of Lamar are very imperfectly known, but there is some suggestion that a thickness comparable with that farther east may be present and that the underlying Graneros has also a small thickness like that of western Kansas.

Somewhat farther west, 1 $\frac{1}{2}$  miles north of McClave, a section was measured of the upper part of the Greenhorn, possibly including some of the lowest part of the Fairport chalky shale member of the Carlile shale:

|   | Ft. in. |
|---|---------|
| Section of upper part of Greenhorn limestone 1 $\frac{1}{2}$ miles north of McClave |         |
| Shale, marly  | 5+      |
| Limestone   | 4       |
| Shale, calcareous, tan  | 5       |
| Limestone, gray   | 2       |
| Shale, calcareous   | 1 1     |
| Limestone, gray, with <i>Inoceramus labiatus</i>                                    | 3       |



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The Library Of  
WAYNE LOEL

*Section of upper part of Greenhorn limestone 1½ miles north of McClave—Continued*

|   | Ft. in. |
|---|---------|
| Chalky marl, tan, with shell fragments                      | 3       |
| Limestone, gray   | 3       |
| Marl, tan   | 1       |
| Limestone, light blue gray, with <i>Inoceramus labiatus</i> | 5       |
| Marl and shale  | 2       |
| Limestone, marly  | 6       |
| Shale and marl  | 1       |
| Limestone, light gray                                       | 6       |
| Shale, calcareous   | 3       |
| Limestone, light gray                                       | 4       |
| Marl  | 2       |
| Limestone, blue gray, with <i>Inoceramus labiatus</i>       | 10      |
| Marl, tan   | 10      |
| Limestone   | 3       |
| Marl, tan   | 8       |
| Limestone, blue gray, hard                                  | 3       |
| Marl, with a small amount of limestone                      | 2       |
| Marl and shale, buff  | 8       |
| Limestone, gray   | 5       |
| Marl  | 1       |
| Limestone, granular, soft                                   | 3       |
| Marl, shaly, tan, with <i>Inoceramus labiatus</i>           | 7       |
| Limestone, white to light gray                              | 9       |
| Marl, with a small amount of limestone                      | 2       |
| Limestone, gray, with <i>Inoceramus labiatus</i>            | 5       |
| Marl, tan   | 1       |
| Limestone, white  | 6       |
| Marl, tan   | 1       |
| Limestone, blue gray  | 1½      |
| Marl  | 10      |
| Limestone   | 1½      |
| Marl, tan   | 1       |
| Limestone, light gray                                       | 6       |
| Marl  | 2       |
| Limestone, blue gray, hard                                  | 1½      |
| Marl, tan and light gray                                    | 1       |
| Limestone, blue gray  | 8       |
| Marl, tan and dirty brown                                   | 4       |
| Limestone, light gray, vertically jointed                   | 1±      |
| Marl, tan   | 4       |
| Limestone, white  | 10      |
| Marl, tan   | 3       |
| Bentonite   | 11      |
| Shale, chalky   | 7       |
| Limestone, white  | 7       |
| Shale, chalky tan   | 3       |
| Limestone, white  | 6       |
| Shale, chalky tan   | 10      |
| Limestone, white  | 6       |
| Marly chalk   | 10      |
| Total measured  | 2       |
|   | 56 8½   |

Small exposures of the upper part of the Greenhorn limestone in the SW $\frac{1}{4}$  sec. 16, T. 22 S., R. 50 W., along the western part of the south line of sec. 8, T. 22 S., R. 50 W., in the SE $\frac{1}{4}$  sec. 11, T. 22 S., R. 51 W., and in the northern part of sec. 35, T. 22 S., R. 53 W., show that it persists westward as a lithologic unit of alternating limestone and chalky shale beds, but its thickness is not known, and exposures of the lower part were not observed.

In the NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec. 5, T. 24 S., R. 54 W., south of the Arkansas River, exposures of Greenhorn limestone about 30 feet thick show that it consists of beds of white limestone from 4 to 8 inches thick interbedded with gray calcareous shale in beds 6 to 12 inches thick. *Inoceramus labiatus* is present in abundance at these exposures.

In the Pueblo quadrangle<sup>30</sup> the Greenhorn has a thickness of 35 to 50 feet. East of that area, in the Nepesta quadrangle,<sup>31</sup> it has an aggregate thickness of 50 feet, and to the south, in the Apishapa quadrangle,<sup>32</sup> it is reported to be about 30 feet thick. In the Walsenburg quadrangle it is described as consisting of layers, from 3 to 4 inches thick, of dove-colored limestone, separated by partings of gray shale. The aggregate thickness is about 30 feet. At a locality 10 miles northwest of Vermejo Park, on the east flank of the Sangre de Cristo Range, in New Mexico near its northern boundary, the Greenhorn, as separated by the writers, includes 25 feet of such alternating limestones and shales and also 25 feet of hard gray limy shale overlying them. The Greenhorn may also be recognized farther west in southwestern Colorado and on the east side of the San Juan Basin in northwestern New Mexico as a similar thin unit of alternating beds of limestone and shale. In the La Junta region<sup>33</sup> the total thickness is about 50 or 60 feet. In view of the fact that the thickness of the Greenhorn in western Kansas is from 100 to 130 feet, it seems likely that the lower members of the Greenhorn in Kansas merge westward into the upper part of the Graneros shale. This inference is supported by the westward thickening of the Graneros shale.

The thickness of the rocks of Benton age in the aggregate remains nearly the same from west to east, as shown by the plotted logs of several wells (fig. 10) and also by the thicknesses given for the several formations by writers on various areas (to defer, for the present, consideration of an anomalously thin Carlile shale section in the La Junta region). The published descriptions of the upper portion of the Graneros where it has a thickness of 200 feet also suggest that its content of calcareous shale and limestone is greater than that of the Graneros of western Kansas and that it may represent an equivalent of the lower portion of the Greenhorn of Kansas. For example, in the La Junta region<sup>34</sup> the Graneros contains thin limy beds 40 to 50 feet below the top of the formation, and in the Apishapa quadrangle<sup>35</sup> a thin fossiliferous platy sand-

<sup>30</sup> Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

<sup>31</sup> Fisher, C. A., op. cit., p. 2.

<sup>32</sup> Stose, G. W., op. cit., p. 6.

<sup>33</sup> Patton, H. B., op. cit., p. 15.

<sup>34</sup> Idem, pp. 14-15.

<sup>35</sup> Stose, G. W., op. cit., p. 5.

stone is found about 45 feet below the top of the Graneros. Farther west, however, in a section measured by the writers at Colorado City, west of Colorado Springs, the upper portion of the Graneros contains no limy beds. In this section the Graneros is 210 feet thick and the Greenhorn somewhat more than 20 feet. The width of outcrop of the Greenhorn as shown on the geologic map diminishes rather abruptly westward from the vicinity of Wiley.

So far as known the Greenhorn in Colorado is transitional into the overlying Carlile shale as well as into the underlying Graneros shale. A paleontologic distinction between Carlile and Greenhorn is reported in western Kansas and may exist also in eastern Colorado.

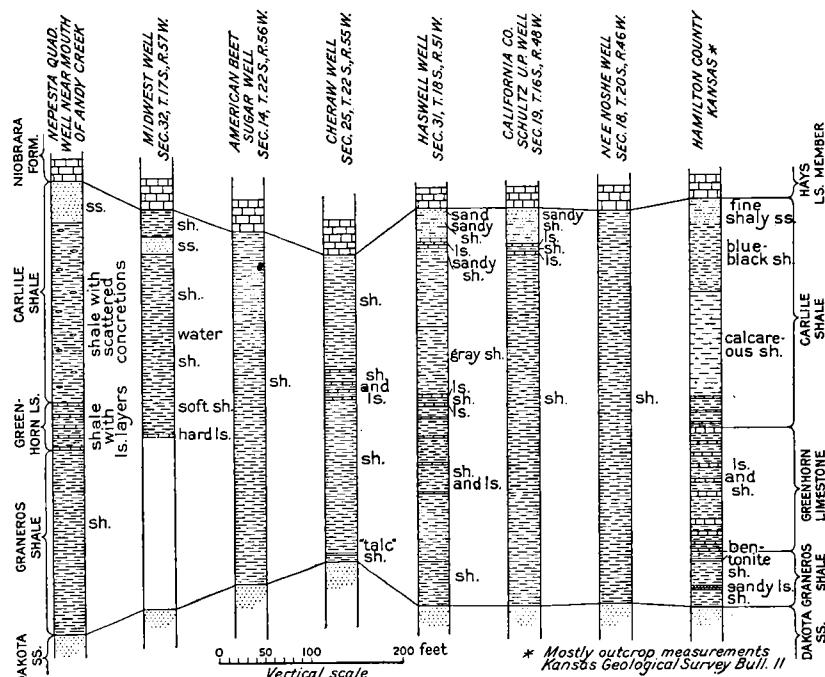


FIGURE 10.—Graphic sections showing the thickness of the rocks of Benton age at various places in the Arkansas Valley as given by driller's logs of several wells, with a comparison of the stratigraphic section of these rocks as divided in Hamilton County, Kans., and in the Nepesta quadrangle, Colo.

The fossils recorded from the Graneros of eastern Colorado are of types also found in the Greenhorn and may therefore have come from shaly beds equivalent to the lower part of the Greenhorn.

Fossils other than a few species of Foraminifera and *Inoceramus labiatus* are not common in the Greenhorn limestone. Seven collections made by the writers contain the following species. The large numbers (15743, etc.) in this and other lists of localities are the numbers in the United States Geological Survey Mesozoic invertebrate collection.

|                                       | Locality            |
|---------------------------------------|---------------------|
| <i>Globigerina</i> sp.                | 1, 2, 3, 6          |
| <i>Globotruncana</i> sp.              | 2                   |
| <i>Inoceramus labiatus</i> Schlotheim | 1, 2, 3, 4, 5, 6, 7 |
| <i>Inoceramus</i> sp.                 | 1                   |

|   | Locality |
|---|----------|
| <i>Lunatia?</i> sp.   | 2        |
| <i>Exiteloceras pariense</i> (White)                                  | 7        |
| 1. 15743, Mount Morrison-Bear Creek locality. (See p. 210.)           |          |
| 2. 15818, secs. 16 and 17, T. 22 S., R. 50 W.                         |          |
| 3. 16068, NW 1/4 sec. 18, T. 22 S., R. 44 W., along Cottonwood Creek. |          |
| 4. 16069, SW 1/4 sec. 7, T. 22 S., R. 44 W.                           |          |
| 5. 16076, NE 1/4 sec. 11, T. 22 S., R. 48 W.                          |          |
| 6. 16077, NW 1/4 sec. 30, T. 22 S., R. 46 W.                          |          |
| 7. 16078, NE 1/4 sec. 12, T. 22 S., R. 49 W.                          |          |

The rarer species, however, include a considerable variety of forms. Reeside has under study collections from the Greenhorn limestone of the Arkansas Valley and the foothill region of Colorado that contain the

following forms in addition to those listed above: Echinoid, *Sternotaxis?* n. sp.; brachiopod, *Crania* n. sp.; pelecypods, *Inoceramus* cf. *I. lamarcki* Parkinson, *Ostrea* sp., *Sauvagesia?* sp.; gastropods, *Cerithium?* sp., *Anchura?* sp., *Aporrhais* (*Perissoptera*) *prolabiata* White, *Anisomyon?* sp.; cephalopods, *Neptychoceras* sp., *Baculites gracilis* Shumard, *Tragodesmoceras* n. sp., *Watinoeceras?* *coloradoense* (Henderson), *Watinoeceras?* n. sp., *Romaniceras* n. sp., *Neocardioceras septemseriatus* (Cragin), *Thomasites* n. sp., *Mammites* n. sp., *Neptychites* n. sp., *Scaphites* n. sp., *Pseudotissotia* (*Choffaticeras*) n. sp., *Metoicoceras whitei* Hyatt, *Metoicoceras* cf. *M. irwini* Moreman. Morrow<sup>36</sup> records *Tragodesmoceras bassi* Morrow from Colorado.

#### CARLILE SHALE

The Carlile shale was named by Gilbert<sup>37</sup> from Carlile Spring and Carlile station, 21 miles west of Pueblo. It was described as a gray argillaceous shale 175 to 200 feet thick. In the Pueblo quad-

rangle the upper fourth contains some sand, and the topmost portion is described as a yellow friable sandstone. Farther east "the sandstone is often replaced by a purplish limestone." Large septarian calcareous concretions occurring 20 to 50 feet below the top of the formation are also noted.

In Russell County, Kans., the Carlile shale was divided into two members, the Blue Hill shale member above and the Airport chalky shale member<sup>38</sup> below. These subdivisions were later recognized in Ellis and

<sup>36</sup> Morrow, A. L. Cephalopods from the Upper Cretaceous of Kansas: Jour. Paleontology, vol. 9, no. 6, p. 468, pl. 53, fig. 1, 1935.

<sup>37</sup> Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 565-566, 570, 1896.

<sup>38</sup> Rubey, W. W., and Bass, N. W., The geology of Russell County, Kans.: Kansas Geol. Survey Bull. 10, p. 33, 1925.

Hamilton Counties.<sup>39</sup> In Ellis County a fine-grained sandstone about 20 feet thick at the top of the Carlile shale was named the Codell sandstone bed of the Blue Hill member by Bass. The Codell sandstone bed was also found in Hamilton County, Kans., near the Colorado State line, where it consists of sandstone about 2 feet thick in the upper part, underlain by 20 feet of sandy shale. The subdivisions of the Carlile shale made in Kansas are distinguishable also in the Arkansas Valley in eastern Colorado. As it is now generally regarded as desirable to eliminate the application of names to units of less than member rank, the Codell sandstone as herein described is considered to be a member of the Carlile shale, equivalent in rank to the Blue Hill shale member, which underlies it, and to the Fairport chalky shale, which is the basal member of the Carlile shale in the area of this report. The Codell sandstone has previously been recognized as a member of the Benton shale in northeastern Colorado.<sup>40</sup>

#### FAIRPORT CHALKY SHALE MEMBER

In Hamilton County, Kans., the Fairport chalky-shale member consists of calcareous blue-black shale in the upper part, which becomes more limy and somewhat lighter in color downward. Thin beds of chalky limestone alternate with limy shales in the basal 35 feet. The member as a whole has a thickness of nearly 150 feet. The contact with the overlying Blue Hill was not sharply distinguished. At the base the Fairport lithologically resembles the upper part of the Greenhorn limestone, but is paleontologically distinguishable from it.

At most places in the area shown on the map this lowest member of the Carlile is poorly exposed in comparison with the two overlying members. There are some typical exposures of the upper part of the Fairport in the NW $\frac{1}{4}$  sec. 28, T. 22 S., R. 41 W. The exposures consist of yellowish well-bedded chalky shale with rather numerous specimens of *Ostrea* sp., *Inoceramus* sp., fragmentary remains of fish, and rarer ammonites.

The best exposures of the Fairport member are in the SE $\frac{1}{4}$  sec. 6 and the NE $\frac{1}{4}$  sec. 7, T. 22 S., R. 44 W. At the base it is much like the upper part of the underlying Greenhorn, as shown in the measured section on page 212, but has possibly a somewhat more chalky aspect. The proportion of limestone diminishes rapidly upward, and the bulk of the exposures consists of chalky shale. In the SW $\frac{1}{4}$  SE $\frac{1}{4}$  sec. 6 a hard thin-bedded oyster-shell limestone near the top of the Fairport makes a small ledge. There are, however, some

chalky marls above it, and the contact with the overlying Blue Hill shale member is not sharply distinguishable.

Small exposures in the northeastern part of T. 22 S., R. 48 W., show that much of the Fairport there consists of chalky marl with lenses of hard gray crystalline limestone a fraction of an inch thick. Oyster shells are abundant, as are also impressions of *Inoceramus* shells. Beds of limestone as much as 1 foot thick are locally present.

The contact between the Fairport and the overlying Blue Hill in sec. 27 and the NE $\frac{1}{4}$  sec. 34, T. 21 S., R. 49 W., cannot be precisely set, but near the top of the Fairport is a bed 1 to 6 inches thick of very fine grained sandy crystalline limestone or calcareous sandstone. This bed is really an aggregate of lenticular beds 1 inch or less thick. Some of the lenses consist of closely packed oyster shells, and many of them carry broken *Inoceramus* fragments, worn shark teeth, and oyster shells. Below the bed lie slightly calcareous well-bedded shales and marly shales. There is apparently considerable variation in the lime content of individual beds, which range from one-sixteenth to one-half inch thick. The proportion of calcareous or marly shales increases downward, and the lamination of the rock becomes less regular and less distinct. The lowest exposures consist of light-gray chalky marl, with numerous fish scales, oysters, and *Inoceramus* impressions. At least 25 feet of the upper part of the Fairport is exposed.

Somewhat more than 20 feet of chalky marl of the Fairport is also exposed in the SW $\frac{1}{4}$  sec. 9 and the NE $\frac{1}{4}$  sec. 16, T. 22 S., R. 50 W. The basal part of the overlying Blue Hill member is concealed.

The Fairport chalky shale member is 147 feet thick in Hamilton County, Kans.,<sup>41</sup> as determined from the log of a water well. No complete measurements of the member were made in eastern Colorado, but the member is estimated to be from 75 to 125 feet thick.

In the La Junta region and farther west in the Nepesta and Pueblo quadrangles<sup>42</sup> the Fairport chalky shale member cannot be recognized from the descriptions of the Carlile shale given in the literature. In a section of the Carlile measured by the writers at Colorado City, west of Colorado Springs, 55 feet of gray limy shale underlies black noncalcareous shale and overlies gray limestone assigned to the Greenhorn limestone.

#### BLUE HILL SHALE MEMBER

The Blue Hill shale member consists predominantly of black fissile noncalcareous shale. In the lower part

<sup>39</sup> Bass, N. W., Geologic investigations in western Kansas, pt. 1, Geology of Ellis County: Kansas Geol. Survey Bull. 11, p. 26, 1926; pt. 2, Geology of Hamilton County: Idem, p. 63.

<sup>40</sup> Mather, K. F., Gilluly, James, and Lusk, R. G., op. cit. (Bull. 796), p. 81.

<sup>41</sup> Bass, N. W., op. cit., p. 65.

<sup>42</sup> Patton, H. B., op. cit., pp. 42-43. Fisher, C. A., op. cit., p. 2. Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

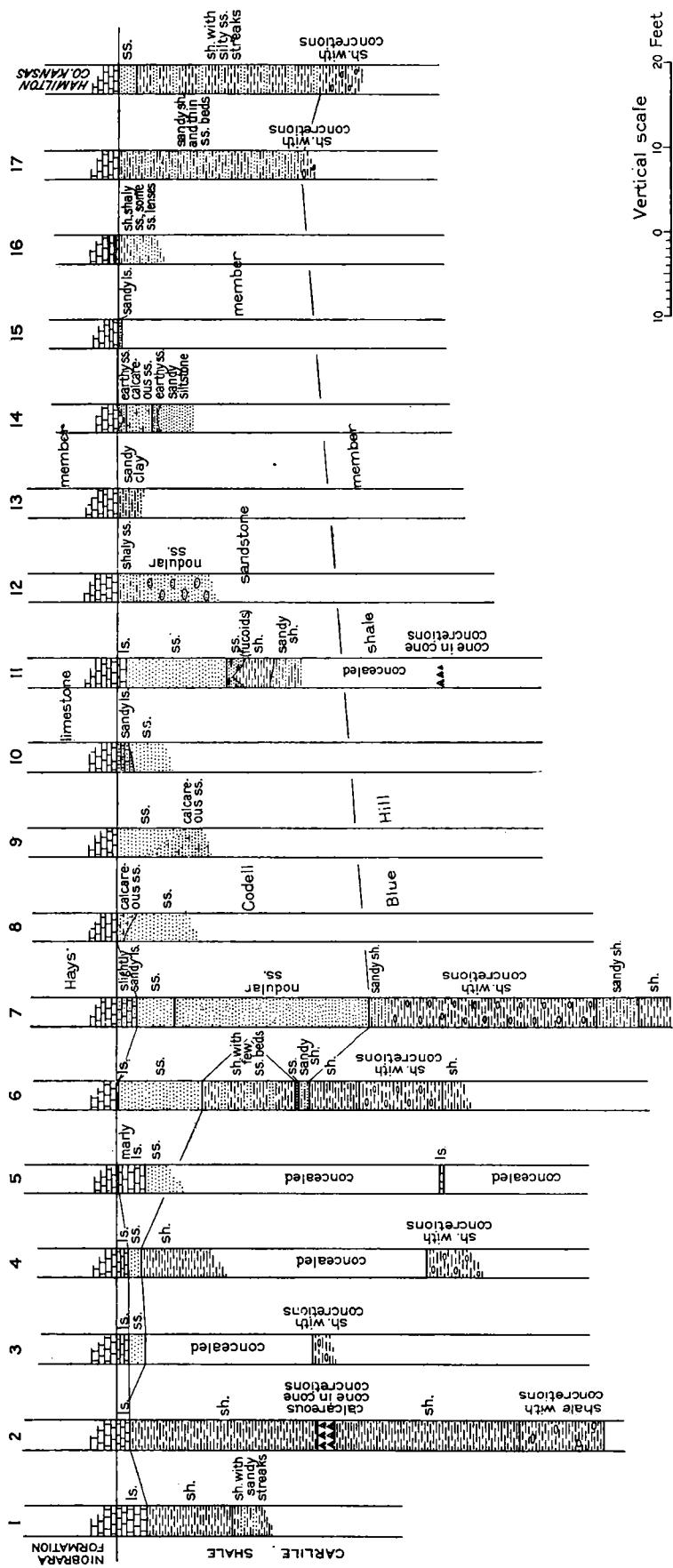


FIGURE 11.—Graphic sections of the Codee sandstone member and part of the underlying Blue Hill shale member of the Carlile shale.

there is some calcareous shale, and the unit is not sharply separable from the underlying Fairport. The uppermost part consists of slightly sandy shale, locally as much as 30 feet thick. In the upper part of the member there are almost everywhere large calcareous septarian concretions. These are commonly several feet in diameter and may be as much as 10 feet. The material of which they are composed is a dull bluish-gray dense argillaceous limestone, but they weather yellowish tan. They are abundantly seamed with septaria of calcite in coarse translucent tan crystals. Cone-in-cone structure is developed on many of the upper surfaces. These large septarian concretions may occur through a zone from 5 to 30 feet in thickness, in most places about 10 feet. The stratigraphic position of the zone, however, seems to vary somewhat, for they may occur from 20 to 55 feet below the top of the Carlile shale. (See fig. 11.) Concretions of the same nature and at the same stratigraphic position in the Carlile shale have been described as far west as the Pueblo quadrangle<sup>43</sup> and also to the east in Kansas.<sup>44</sup>

### **CODELL SANDSTONE MEMBER**

At the top of the Carlile shale is a persistent but rather variable unit consisting of sandstone and sandy shale. This is the Codell sandstone member. Where originally described in Ellis County, Kans.,<sup>45</sup> it consists chiefly of sandstone with some shaly sandstones interbedded. At the base it grades into the shale beds of the Blue Hill member. The Codell becomes less sandy southward, and in Hamilton County, Kans., it is made up of about 20 feet of gritty shale containing thin streaks of shaly sandstone, overlain by 2 feet of sand at the top.

At the easternmost locality observed by the writers (locality 17, pl. 64), along Cheyenne Creek in Kansas, a third of a mile southeast of the northeast corner of sec. 17, T. 22 S., R. 41 W. (Colorado), the Codell consists of 22 feet of soft, nodular-weathering sandy shale. Near the

<sup>43</sup> Gilbert, G. K., op. cit., p. 3.

<sup>44</sup> Bass, N. W., op. cit., p. 63.

<sup>45</sup> Idem, p. 28.

center of sec. 21, T. 22 S., R. 42 W. (locality 16, pl. 64), good exposures of the upper part of the Codell in a creek bank show that it consists of regularly bedded gray shale and lighter-colored, fine-grained shaly sand, with a few lenses of yellowish-gray hard sandstone.

Near the center of sec. 18, T. 22 S., R. 44 W. (locality 14, pl. 64), the upper part of the Codell is exposed in the wall of the Amity Canal ditch. At this place it has a somewhat different aspect. (See fig. 11.) At the top is a bed of soft earthy sand from 6 to 12 inches thick. Below this is a hard calcareous sandstone or sandy limestone 3 feet thick, of a rusty-brown color. Irregular bedding is outlined by sheets and lenses of softer earthy sandstone, which is cross-bedded within lenses. Fucoids interlace through the rock in great numbers. It also contains the typically prismatic fragments of *Inoceramus* shells. Below this hard bed is 6 to 12 inches of soft earthy sand, which is underlain by soft gray sandy siltstone. In sec. 6, T. 22 S., R. 44 W., the top bed of the Codell is a hard brown, slightly sandy limestone. It is underlain by soft sandy siltstone. Good exposures of the Codell were not observed for about 20 miles west of this locality.

In a deep gully along the east side of the section-line road between secs. 10 and 11, T. 22 S., R. 48 W. (locality 13, pl. 64), however, the Codell consists of gray sandy clay mottled irregularly with white and light-gray sand, and no hard beds were observed in it. At several localities in the southwestern part of T. 21 S., R. 49 W., one or more beds of hard dark brownish-gray calcareous sandstone are present in the Codell. Such beds were observed as much as 12 feet below the top and also near or at the top. Characteristically they contain fish scales, fucoids, *Halymenites major*, and other fossil impressions. The mass of the Codell is soft crumbly silty sandstone, poorly bedded, and for the most part having a nodular or lumpy surface in vertical though somewhat weathered exposures.

West of locality 8 (pl. 64 and fig. 11) there is a hard gray bituminous limestone at all exposures observed. This limestone ranges from a few inches to several feet in thickness and is believed to be the bed which has been widely termed "Niobenton." Weathering to a rusty-brown color and having a rough granular fracture, it has the appearance of a calcareous sandstone, but in reality it contains only a small percentage of sand. It is characteristically interlaced with fucoids and carries numerous other fossils, including shark teeth. Even where thin it is notably persistent. It is much more resistant to erosion than the underlying beds and forms a definite escarpment. The thickness of the soft sandy shale and earthy sand of the Codell diminishes rapidly westward from about 30 feet in

T. 22 S., R. 50 W., to less than 5 feet in the western part of T. 22 S., R. 51 W. (See fig. 11.) In the south-central part of T. 22 S., R. 53 W., and thence southwestward there is no appreciable sand or sandy shale below the hard gray limestone. The limestone is, however, recognized to the west, in the La Junta region.<sup>46</sup>

A petrographic examination of several specimens of the hard bed at the top of the Carlile shows that in most places it is a limestone that contains 3 percent or less of sand, but in some places it contains about 60 percent of sand. In the SE $\frac{1}{4}$  sec. 21, T. 21 S., R. 49 W., there are lenses of bituminous limestone in a bed as much as 6 inches thick of shale and sandstone cemented with lime, which overlies a hard sandstone bed that is as much as 18 inches thick. (See pl. 65, D.) The upper bed contains less than 2 percent of sand and the lower bed about 60 percent. The minerals in either the predominantly limestone or predominantly sandstone beds, after the CaCO<sub>3</sub> has been removed, are found to be practically the same and in roughly the same proportions. This is also true of the Codell sand. These minerals and their approximate proportions, as determined by M. N. Bramlette, of the United States Geological Survey, are as follows:

Quartz, 50 percent or more.

Orthoclase, 20 percent, more or less.

Chert grains, 10 to 15 percent.

Indeterminate aggregates, 10 to 15 percent.

A little sodic plagioclase.

Zircon, green and brown tourmaline, rare.

The writers regard the hard limestone (so-called "Niobenton") at the top of the Carlile in the westernmost part of the area as forming part of the Codell sandstone—in fact, as being the sole representative of the Codell in that area. Similar limestones occur within or at the top of the more typical Codell farther east, having the same abundance of fucoids, shark teeth, fish fragments, and imprints and casts of the same types of invertebrate fossils. As has been shown, these limestones contain a small percentage of sand, which in its more general aspects of composition and grain size at least is like that of the more sandy phases of the Codell. Moreover, limestone of this type is not present in either the underlying Blue Hill or the overlying Niobrara formation. As there is good reason to believe that the nondeposition of sand at this horizon in the La Junta region and perhaps somewhat farther west is a local phenomenon, it seems better to regard the contemporaneous limestone at the same horizon as a phase of the Codell.

<sup>46</sup> Patton, H. B., op. cit., pp. 17-18.

About 5 miles west of Pueblo, on the north side of the Arkansas River, the following section of the top of the Carlile was measured by the writers:

*Section of Carlile shale 5 miles west of Pueblo*

Niobrara formation.

Carlile shale:

|   | Feet     |
|---|----------|
| Shale, gray   | 1        |
| Sandstone, light gray, hard, massive; weathers brown; <i>Halymenites major</i> and many fucoids, particularly near the base. Makes a vertical ledge, but the top few feet weathers back to a slope  | 15       |
| Shale, gray, and sandstone, thin-bedded, cross-bedded, with large ripple marks. This unit is separated by prominent shale partings above and below but is highly variable in lithology from place to place                                | 4        |
| Sandstone, earthy; weathers dark gray to almost white, with the most part a yellowish tinge; weathers into irregular small nodular masses and has a "knotted" appearance on vertical or steep exposures; merges downward into sandy shale | 20       |
| Shale, sandy  | $30 \pm$ |
| Shale, gray.  |          |
| Total measured  | 70±      |

At Colorado City, west of Colorado Springs, the top bed of the Carlile is a light-gray, thin-bedded, shaly sandstone from a fraction of an inch to 10 inches thick, containing vast numbers of *Inoceramus*. Below it is 9 feet 4 inches of hard brown calcareous sandstone with many fish teeth and scales, *Ostrea* sp., *Inoceramus*, probably *I. fragilis*, *Scaphites warreni* Meek and Hayden, and *Prionocyclus wyomingensis* Meek. This sandstone is ripple-marked, and the ripples have a wave length of 2 to 5 inches. Farther north, at Perry Park, in the NW $\frac{1}{4}$  sec. 24, T. 9 S., R. 68 W., a similar hard limy sandstone about 4 feet thick was observed.

Sandstone has been found at the top of the Carlile in many wells in northeastern Colorado;<sup>47</sup> and the Codell sandstone, 3 to 20 feet or more thick, has also been recognized on the outcrop in the northern foothill region.<sup>48</sup> It has been recorded also in most of the wells drilled within the area of the map. Its absence in a driller's log (see fig. 10) does not necessarily mean that the member is not present, as it may not have been noticed or recorded.

The top of the Carlile shale at the type locality<sup>49</sup> is a yellow friable sandstone, which corresponds in stratigraphic position and general lithologic features with the Codell sandstone. Similar sandstone at the top of the Carlile has also been found farther south in the Walsenburg quadrangle. The Carlile is there dark-gray shale, 170 to 180 feet thick, with 10 to 15 feet of yellow sandstone at the top, capped by bituminous

limestone 2 to 4 feet thick. Still farther south, in the Spanish Peaks quadrangle, the Carlile includes 200 feet of dark-gray shale which grades near the top into 10 feet of sandy shale and friable yellowish sandstone, with an overlying layer of purplish bituminous limestone 1 to 2 feet thick.

The top of the Carlile, as observed by the writers on the north side of the Huerfano River in the extreme western part of the Walsenburg quadrangle, includes a considerably greater thickness of sand than is given in published descriptions. There is at least 25 feet of medium-hard light-gray fine-grained sandstone, buff colored and nodular-weathering in the lower part. Above this is 9 feet of soft sand and sandy shale, and at the top a bed 2 feet thick of hard brown-weathering gray limestone, which has an irregular under surface, contains abundant broken fossils and shark teeth, and at the top appears to be interbedded with thin streaks of soft sandy shale.

Sandstone at the top of the Carlile as a persistent lithologic unit apparently does not extend southward into New Mexico, however, for at a locality northwest of Vermejo Park (on Gold Creek west of old Pinafore post office) the upper part of the Carlile consists of yellowish-gray shale with septarian concretions and a few thin beds of hard, somewhat sandy, highly fossiliferous limestone.

The Codell sand is a source of nonflowing artesian water in a large area north of the Arkansas River, especially in the vicinity of Eads and Chivington, but the water is not potable and in some wells is unfit for stock use.

Nine samples of water were collected in the vicinity of Eads and Chivington from wells that obtain water from the horizon of the Codell sand. Partial analyses by the water-resources branch of the United States Geological Survey show that all the samples have a large amount of dissolved mineral matter. The smallest amount of total dissolved solids in any sample was 1,700 parts per million and the greatest was over 10,000 parts per million; most of them were between 2,500 and 6,500 parts. In all the samples the calcium carbonate content was small, which is surprising in view of the fact that the Codell is overlain by 50 feet or more of limestone and locally itself contains calcareous beds. The principal mineral constituents are sodium salts, bicarbonate, chloride, and sulphate. There is, however, a large difference in the relative amounts of these constituents, even in wells that are a mile or less apart, a difference difficult to explain unless it is assumed that there is little or no lateral movement in the aquifer. A greater number of samples and a more complete analysis of each will be necessary before any tentative conclusions can be drawn as to the nature of the water movement.

<sup>47</sup> Waldschmidt, W. A., Characteristics of older Cretaceous formations of northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, no. 4, pp. 415-416, 1933.

<sup>48</sup> Mather, K. F., Gilluly, James, and Lusk, R. G., op. cit. (Bull. 796), p. 81.

<sup>49</sup> Gilbert, G. K., op. cit. (17th Ann. Rept., pt. 2), pp. 565-566, 570.

## POSSIBILITY OF UNCONFORMITY AT TOP OF CODELL

The Codell sandstone clearly represents the widespread occurrence of a set of environmental conditions different from those under which the deposition of the underlying rocks of Benton age occurred, or from those under which the overlying Niobrara formation was laid down. The Graneros and Greenhorn formations particularly give evidence that the sediments which compose them were deposited in moderately deep water, almost certainly below the depth of wave agitation—for individual beds even of small thickness persist for considerable distances. The lower part of the Carlile is also evenly bedded, but much of the Codell was clearly deposited within the reach of wave and current agitation. This is shown not only by its sandy composition but also by the irregularity and cross-bedding which in places appear within it. Ripple marks have been observed at some places, and the shark teeth locally present are worn by abrasion. In a larger way the differences in lithology of the member from place to place indicate that it was deposited under the variable conditions to be expected in a shallow-water environment.

Although in many places thin and possibly locally absent, the Codell is surprisingly widespread, extending over most of eastern Colorado and western Kansas, with little significant variation in content or bedding. The Codell therefore seems to represent a time when deposition had filled a large area of the Cretaceous sea to a level at which the deposited material was within the reach of wave agitation. There is reason to believe that this condition was maintained for a considerable period.

Johnson<sup>50</sup> has already summarized the evidence for an unconformity at the base of the overlying Niobrara formation, concluding that "Sufficient time, at least \* \* \* elapsed to account for a complete cessation of deposition of one type, its alteration, and, in places, partial erosion and the development of conditions under which sediment of a completely new type was deposited." Certainly the abrupt change in fauna from the Carlile to the Niobrara suggests, even if the difference in lithologic character of the formations is discounted, that there was a lapse of time that permitted the development of new faunas.

Johnson also cites as evidence of unconformity a "thin conglomerate containing plentiful fish teeth, well-rounded pebbles, and phosphate nodules" which "occurs at the base of the Niobrara in all the areas studied." The pebbles are described as small, smooth, and well rounded, some as much as 3 inches in diameter. They consist chiefly of black chert but also of quartzite and

white quartz, and they occur together with phosphate nodules and shark teeth in a matrix of gray to brown crystalline sandy limestone. Although pebbles are also reported at this horizon in southeastern Colorado, none were observed by the writers in the outcrops extending from La Junta eastward to the Kansas State line. The possibly similar bituminous limestone with some shark teeth (and phosphatic nodules?) occurring there at the top of the Carlile has already been described (p. 217). This rock is, however, faunally and lithologically allied with the Codell, to which it is assigned by the writers. The base of the overlying Niobrara formation is for the most part sharp and locally slightly irregular. Angular discordance was nowhere observed. Particularly from T. 22 S., R. 53 W., to T. 22 S., R. 51 W., however, the basal contact of the Niobrara is somewhat obscure. The hard brown limestone assigned to the Codell by the writers appears to grade upward into the overlying gray or white limestone, and locally lenses of hard brown limestone like the underlying rock also appear in the basal Niobrara. Also the brown limestone itself becomes somewhat lighter colored eastward. The gradation, in fact, is so pronounced that the hard brown limestone has been interpreted by Patton<sup>51</sup> as merging into the basal limestone bed of the Niobrara. Patton supposed that the occurrence near the bottom of the Niobrara of a fossil identified as *Inoceramus labiatus*, a characteristic Benton form, reinforced this interpretation. It is now known, however, that an *Inoceramus* much like *Inoceramus labiatus* but distinct from it is present in many places in the lowest beds of the Niobrara. On the whole the appearance of the contact itself as seen by the writers neither suggests nor disproves unconformable relations.

In some areas local thinning of the Carlile suggests the possibility that the thinning may be due to erosion in those areas before the deposition of the Niobrara. Notably in the vicinity of La Junta the Carlile is abnormally thin. A section measured by Patton<sup>52</sup> shows a thickness of 130 feet. The logs of wells at Cheraw and Swink indicate that the Carlile is about 125 feet thick. (See fig. 10.) The logs of other wells in the vicinity of La Junta show that the beds of Benton age are from 50 to 75 feet thinner than to the east or west, and this thinning presumably also is due entirely to thinning of the Carlile. To the west, the Carlile is from 210 to 225 feet thick in the Nepesta quadrangle<sup>53</sup> and 200 to 232 feet thick in the Apishapa quadrangle;<sup>54</sup> east of Las Animas it is probably over 200 feet thick, and in Hamilton County, in western Kansas,

<sup>50</sup> Johnson, J. H., Unconformity in Colorado group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 14, no. 6, pp. 789-794, 1930.

<sup>51</sup> Patton, H. B., op. cit., pp. 18, 21.

<sup>52</sup> Idem, p. 17.

<sup>53</sup> Fisher, C. A., U. S. Geol. Survey Geol. Atlas, Nepesta folio (no. 135), p. 2, 1906.

<sup>54</sup> Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), p. 6, 1912.

about 250 feet thick. If the writers' view is accepted, that the hard brown limestone above described is to be assigned to the Codell, the thinning of the Carlile in the vicinity of La Junta takes place within the Carlile and not as a result of erosion at the base of the overlying Niobrara. The thinning is thus presumably to be ascribed to lesser deposition in that area. The sandy phase of the Codell thins out over the same area, but its diminution from 30 feet to the vanishing point is not adequate to explain the total thinning of 50 to 75 feet, part of which must therefore be due to thinning of lower beds in the Carlile. Lest the thinning of the sandy Codell westward be interpreted as due to erosional unconformity at the base of the hard brown limestone, it should be pointed out that the sandy phase appears to merge westward into nonsandy beds by intertonguing and also that the distinctive zone of septarian concretions at the top of the Blue Hill shale member appears to maintain approximately its vertical distance from the base of the Niobrara across the area in which there is no Codell sand. (See fig. 11.) For some reason, therefore, the area about La Junta appears to have received less sediment than the surrounding regions. A plausible explanation for similar features in the Benton stratigraphy in other areas in eastern Colorado has already been offered by Johnson and Aurand.<sup>55</sup> They suggest that structural features in existence during early Cretaceous time were rising slowly throughout Benton time, sufficiently high to divert or check the velocity of the submarine currents. "Part of the time their tops seem to have been approximately at the plane of equilibrium, where, though the waters were free to pass over them, there was almost no erosion or deposition, though deposition was taking place around the sides."

As neither the local thinning of the Carlile and absence of the Codell member nor the details of the contact between the Niobrara and Carlile offer incontrovertible evidence of unconformity at the base of the Niobrara, the writers believe that the most valid evidence of such unconformity is the faunal discontinuity between the two formations. There seems no reason to suppose that the top of the Carlile emerged above sea level and was eroded. The faunal discontinuity seems rather to indicate a period at which the top of the Carlile sediments stood at wave base, with submarine erosion counterbalancing deposition. This was followed by subsidence or the deepening of the sea waters from some more remote cause, and in these less agitated waters the calcareous sediments of the Niobrara were deposited.

#### FAUNA

Fossils collected from the Fairport and Codell members include the following forms:

| Codell sandstone member :  | Locality         |
|--|------------------|
| <i>Inoceramus fragilis</i> Hall and Meek-----                      | 1, 2, 3, 7       |
| <i>Inoceramus dimidiatus</i> White-----                            | 7                |
| <i>Inoceramus</i> sp-----  | 6                |
| <i>Ostrea lugubris</i> Conrad-----                                 | 2, 3, 4          |
| <i>Ostrea</i> sp-----  | 1                |
| <i>Gryphaea</i> sp-----  | 3                |
| <i>Scaphites warreni</i> Meek and Hayden-----                      | 1, 2, 3          |
| <i>Prionocyclus wyomingensis</i> Meek-----                         | 1, 2, 3, 5, 6, 7 |
| <i>Lamna?</i> sp-----  | 1, 3             |
| <i>Ptychodus</i> sp-----   | 3                |
| Fairport chalky shale member :                                     |                  |
| <i>Inoceramus</i> sp-----  | 8, 9, 10         |
| <i>Ostrea</i> sp-----  | 8, 10            |
| <i>Baculites</i> sp-----   | 8                |
| <i>Exiteloceras</i> cf. <i>E. pariense</i> (White)-----            | 8                |
| <i>Prionotropis woolgari</i> (Mantell)-----                        | 8, 9, 10         |
| 1. 15746, Colorado City, west of Colorado Springs.                 |                  |
| 2. 15758, NW $\frac{1}{4}$ sec. 24, T. 9 S., R. 68 W., Perry Park. |                  |
| 3. 15820, SW $\frac{1}{4}$ sec. 9, T. 22 S., R. 50 W.              |                  |
| 4. 15823, SE $\frac{1}{4}$ sec. 35, T. 21 S., R. 50 W.             |                  |
| 5. 16066, SW $\frac{1}{4}$ sec. 32, T. 21 S., R. 48 W.             |                  |
| 6. 16070, NE $\frac{1}{4}$ sec. 6, T. 22 S., R. 44 W.              |                  |
| 7. 16084, NE $\frac{1}{4}$ sec. 26, T. 21 S., R. 49 W.             |                  |
| 8. 15822, NE $\frac{1}{4}$ sec. 16, T. 22 S., R. 50 W.             |                  |
| 9. 16067, SE $\frac{1}{4}$ sec. 27, T. 21 S., R. 49 W.             |                  |
| 10. 16074, northeast corner sec. 34, T. 21 S., R. 49 W.            |                  |

Bass<sup>56</sup> reports from the lower 18 feet of the Fairport shale member of Hamilton County, Kans., the following species: *Globigerina bulloides* D'Orbigny, *Inoceramus fragilis* Hall and Meek, *Inoceramus labiatus* Schlotheim (broad variety), *Ostrea* cf. *O. congesta* Conrad, *Baculites gracilis* Shumard, *Prionotropis woolgari* (Mantell), *Ichthyodectes?* sp. From the Blue Hill shale member Bass<sup>57</sup> reports *Inoceramus* sp. (fragments) and *Prionocyclus wyomingensis* Meek. From the top of the Codell Bass<sup>58</sup> reports *Inoceramus fragilis* Hall and Meek, *Ostrea congesta* Conrad (float?), *Prionocyclus wyomingensis* Meek, *Ptychodus* sp., *Lamna?* sp., *Corax?* sp., coprolites, and phosphate nodules.

#### NIOBRARA FORMATION

The Niobrara formation is the uppermost formation of the Colorado group. It is distinctly separated from the underlying Carlile shale but less readily separable from the overlying Pierre shale, the lowest formation of the Montana group. It includes about 700 feet of beds, chiefly chalk and chalky shale but with a well-marked, persistent limestone member, from 50 to 65 feet thick, at the base. This limestone is continuous in outcrop with the limestone member of the Niobrara

<sup>55</sup> Johnson, J. H., and Aurand, H. A., A preliminary contribution to the Benton paleogeography of eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, no. 7, pp. 850-853, 1929.

<sup>56</sup> Bass, N. W., op. cit., p. 66.

<sup>57</sup> Idem, pp. 64-65.

<sup>58</sup> Idem, p. 65.

*A. A GROUP OF "TEPEE BUTTES."*

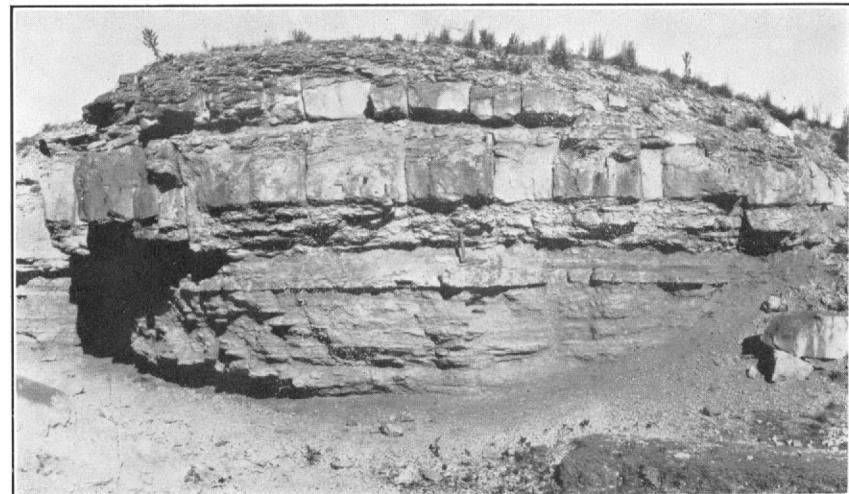
Small conical hills in the Pierre shale formed by the greater resistance to weathering of large masses of limestone. Looking north from the center of sec. 3, T. 17 S., R. 65 W.

*C. TYPICAL OUTCROP OF THE LOWER PART OF THE SMOKY HILL MARL MEMBER OF THE NIOMBRARA FORMATION.*

Looking northwest from the SW $\frac{1}{4}$  sec. 16, T. 21 S., R. 49 W.

*B. DETAILED VIEW OF WEATHERED TOP OR CORE OF A "TEPEE BUTTE" IN THE NE $\frac{1}{4}$  SEC. 35, T. 12 S., R. 49 W.*

The rock is an impure limestone in which *Lucina occidentalis* is exceedingly abundant.

*D. CONTACT BETWEEN THE HAYS LIMESTONE MEMBER OF THE NIOMBRARA FORMATION AND THE CODELL SANDSTONE MEMBER OF THE CARLILE SHALE IN THE SE $\frac{1}{4}$  SEC. 21, T. 21 S., R. 49 W.*

The hammer rests on a hard bed of calcareous sandstone within the Codell, about 2 feet below the base of the Hays limestone.



formation in western Kansas that has long been called "Fort Hays limestone" and is equivalent to it in lithology, thickness, and age, so far as known. The writers propose that the limestone at the base of the Niobrara within the area which they have mapped be called the "Hays<sup>59</sup> limestone member" and that the overlying portion of the Niobrara be called the "Smoky Hill marl member", to correspond with the usage of "Smoky Hill" for the upper chalk member of the Niobrara formation in the adjoining area of western Kansas.

The Niobrara formation of southeastern Colorado has heretofore been divided into a lower member, the Timpas limestone, and an upper member, the Apishapa shale. These previously defined units differ somewhat from those recognized in western Kansas and from those recognized by the writers north of the Arkansas River in eastern Colorado.

According to Stose,<sup>60</sup> the Timpas limestone was named by Gilbert from Timpas Creek, which flows through the southeast corner of the Apishapa quadrangle and thence into the Arkansas River. The description of the Timpas limestone by Gilbert<sup>61</sup> is quoted below, in part:

The general thickness of the Timpas is 175 feet, and it may be characterized as a series of limestones and calcareous shales with prevailing pale colors.

At the base is a limestone series about 50 feet thick. The individual beds range in thickness from a few inches to 3 feet, the average being about 1 foot. They are separated by layers of gray shale, usually 1 or 2 inches thick. The limestone has a light-gray color, which becomes creamy white on weathered surfaces. It is compact and rather fine grained and where exposed to the weather breaks up into rough flakes, of which the longer dimensions are parallel to the bedding. This peculiarity ordinarily serves to distinguish it from the Greenhorn limestone, which cleaves into vertical plates. \* \* \* In its lower layers are small nodules of iron sulphide, which are converted by the chemical reaction of the air to limonite. As the limestone is broken up and removed by the action of weather, the more resistant nodules are freed from their matrix so as to lie loose on the surface. They are of a dark-brown color and of oval or cylindrical form, with a diameter of about half an inch. Their surfaces are not even but are set with angular projections, the end of crystals. \* \* \*

The upper limit of the limestone is indefinite. It passes gradually into a light-gray limy shale, which contains occasional thin beds of limestone and has a total thickness of 100 or 125 feet, terminating at top in one or two layers of chalky limestone containing several species of fossil shells and also the remains of fishes.

The Hays limestone member as recognized by the writers is probably closely equivalent to the "limestone

<sup>59</sup> The shorter name "Hays" has been adopted for this member with the approval of R. C. Moore, State geologist of Kansas. The name of the type locality has for some time been "Hays."

<sup>60</sup> Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), p. 6, 1912.

<sup>61</sup> Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 566-567, 1896.

series about 50 feet thick" at the base of the Timpas as defined in earlier reports. In the region mapped, and in some sections examined in adjoining areas, the limestone unit about 50 feet thick forms a natural, convenient, and practicable unit. It is, moreover, the unit readily recognizable in records of deep wells, both in this area and in northeastern Colorado.<sup>62</sup>

The Timpas was differentiated in the La Junta region,<sup>63</sup> but farther east the limestone bed at the top of the Timpas was not recognized with assurance nor mapped by the writers. This may be in part attributable to scarcity and discontinuity of exposures. Two limestone beds, each 1 foot or less in thickness and separated by 12 feet of cream-colored or tan chalk, are exposed in the eastern part of sec. 23, T. 23 S., R. 55 W., and may lie near the top of the Timpas formation as previously defined. In the eastern part of sec. 27, T. 21 S., R. 53 W., along Adobe Creek, there is a bed of white limestone about 4 feet thick underlain by chalk which may also be near the same horizon. These limestone beds are included by the writers in the Smoky Hill marl. Even were exposures adequate, there is some doubt that the Timpas limestone as previously defined is a stratigraphic unit of widespread usefulness within the area described by the writers.

*Inoceramus deformis*, which is abundant in the Hays limestone member, does not occur above it, and immediately overlying beds contain large flat *Inoceramus (Haplascapha) grandis*. These fossils appear to have distinct ranges over most of the region of western Upper Cretaceous sedimentation, regardless of lithologic environment. There is thus some suggestion that the lithologic unit of the Hays limestone is also a faunal unit. The unit named "Timpas limestone" by Gilbert therefore includes in its upper part beds that are both lithologically and faunally more closely allied to the upper part of the Niobrara. The names "Timpas" and "Apishapa" have, however, been applied to mappable units over a large area west and southwest of the area in which the writers have had opportunity to make detailed observations and should therefore be retained for areas in which the propriety of distinguishing the Hays limestone member has not yet been made evident.

#### HAYS LIMESTONE MEMBER

The term "Fort Hays" (from the former fort of that name in Ellis County, Kans.) was first used by Mudge<sup>64</sup> as a division name, defined thus: "The massive stratum of limestone above described, together with all the deposits above the sandstone of the Dakota, I shall call the Fort Hays division." This included all the strata

<sup>62</sup> Waldschmidt, W. A., op. cit., pp. 412-415.

<sup>63</sup> Patton, H. B., op. cit., pp. 43-44.

<sup>64</sup> Mudge, B. F., Notes on the Tertiary and Cretaceous periods of Kansas: U. S. Geol. and Geog. Survey Terr. 9th Ann. Rept., p. 289, 1877.

from the top of the Dakota to the base of the present Smoky Hill member. Williston<sup>65</sup> later restricted the name to include only the present Hays limestone member.

The Hays limestone member includes beds of white to cream-colored, chalky limestone 6 inches to 3 feet thick separated by beds of gray calcareous shale 1 to 6 inches thick. The limestone makes up nearly three-fourths of the member. Near the base there are numerous small irregular or capsule-shaped nodules of pyrite (or marcasite?) from one-fourth to three-fourths of an inch in longest dimension. The surface of these nodules is made up of an aggregate of interlocking cubical crystals. In the lower foot or two of the member there are small lenses of hard gray limestone which have a petrolierous odor on fresh fracture and resemble the limestone bed that in places forms the top of the Codell sandstone member of the Carlile.

The following section of the Hays limestone member was measured approximately midway east and west within the area covered by the map:

*Section of Hays limestone member of the Niobrara formation  
in secs. 16 and 21, T. 21 S., R. 49 W.*

Niobrara formation.

Smoky Hill marl member:

|   | Ft.   | in. |
|---|-------|-----|
| Shale, tan; weathers yellow.                                      |       |     |
| Limestone, white  | 4     |     |
| Shale, chalky, gray to tan; weathers tan-yellow                   | 5     |     |
| Hays limestone member:  |       |     |
| Concealed, limestone and shale                                    | 17    | 1/2 |
| Shale, chalky, light tan  | 7     |     |
| Limestone, white  | 3     | 2   |
| Limestone and shale, interbedded, partly concealed                | 4     | 6   |
| Limestone, white; contains <i>Inoceramus deformis</i> and fucoids | 2     | 3   |
| Limestone, white, chalky, and gray shale                          | 4     |     |
| Limestone, white, chalky, irregular bedding                       | 1     | 8   |
| Chalk, shaly, white to gray                                       | 5     |     |
| Limestone, white  | 10    |     |
| Shale, gray to tan; contains many <i>Inoceramus deformis</i> ?    | 5     |     |
| Limestone, white, chalky  | 1     | 4   |
| Chalk, white  | 2     |     |
| Limestone, white; weathers into small tabular pieces              | 2     | 6   |
| Chalk, shaly  | 1     |     |
| Limestone, white  | 10    |     |
| Shale, tan to gray; contains <i>Inoceramus</i> sp.                | 6     |     |
| Limestone, white; lower 2 feet massive                            | 3     | 6   |
| Chalk, shaly, tan to gray   | 1 1/2 |     |
| Limestone, white  | 1     | 2   |
| Chalk, tan  | 1     |     |
| Limestone, white  | 8     |     |
| Shale, chalky, tan  | 5     |     |
| Shale, blue   | 3     |     |
| Limestone, white  | 1     | 10  |

*Section of Hays limestone member of the Niobrara formation  
in secs. 16 and 21, T. 21 S., R. 49 W.—Continued*

Niobrara formation—Continued.

Smoky Hill marl member—Continued.

|  | Ft. | in.   |
|--|-----|-------|
| Chalk, tan, and limestone  |     | 1 1/2 |
| Limestone, white   | 1   | 5     |
| Shale, greenish gray   |     | 6     |
| Limestone, white   |     | 8     |
| Chalk, tan   |     | 1     |
| Limestone, white   |     | 2     |
| Shale, blue gray, calcareous   |     | 6     |
| Limestone, white; weathers into tabular pieces   | 1   | 1     |
| Shale, gray, chalky  |     | 2     |
| Limestone, white; contains abundant <i>Inoceramus deformis</i>                           | 1   | 3     |
| Chalk, tan, and gray calcareous shale  |     | 7     |
| Limestone, white   |     | 7     |
| Chalk, tan   |     | 1     |
| Limestone, white   |     | 3     |
| Shale, gray, calcareous  |     | 6     |
| Limestone, white   |     | 10    |
| Chalk, tan to gray   |     | 2     |
| Limestone, white; irregular bedding; weathers into tabular pieces                        | 1   |       |
| Shale, tan, chalky   |     | 6     |
| Limestone, white   |     | 9     |
| Chalk, light gray, shaly   |     | 2     |
| Limestone, white, irregular  |     | 2     |
| Chalk, light gray, shaly   |     | 3 1/2 |
| Limestone, white   | 1   |       |
| Limestone, white, and tan chalk  |     | 8     |
| Limestone, white   | 1   | 6     |
| Chalk, tan, shaly  |     | 2     |
| Limestone, white   | 1   | 3     |
| Shale, tan, chalky   |     | 3     |
| Limestone, white, containing capsule-shaped pyrite nodules                               |     | 3     |
| Codell sandstone member:   |     |       |
| Sandstone and shale, gray, cemented with lime; contains lenses of hard limestone         |     | 0-6   |
| Sandstone, gray to brown, hard; contains fish scales, fragments of fossils, and fucoids. |     |       |
| From 0 to  | 1   | 6     |
| Sandstone, gray, fine-grained.   |     |       |
| Total measured   | 71  | 8     |
| Thickness of Hays limestone  | 64  | 4     |

The thickness of the Hays in the above section is about 65 feet. In Hamilton County, Kans.,<sup>66</sup> the thickness of the member is 61 feet. In the Nepesta quadrangle<sup>67</sup> and adjoining areas the thickness of the limestone unit at the base of the Timpas is about 50 feet.

The Hays limestone is much more resistant to weathering than the beds above or below and consequently generally forms an escarpment or cliff. It is exposed almost continuously from La Junta to a point north of McClave. Thence eastward, however, it is poorly exposed. East of Lamar the base of the lime-

<sup>65</sup> Williston, S. W., The Niobrara Cretaceous of western Kansas: Kansas Acad. Sci. Trans., vol. 13, pp. 108-109, 1893.

<sup>66</sup> Bass, N. W., op. cit., p. 62.

<sup>67</sup> Fisher, C. A., op. cit., p. 2.

stone swings southward across the Arkansas River but swings back before the Kansas line is reached.

#### SMOKY HILL MARL MEMBER

Although the entire thickness of the Smoky Hill marl member is present, little is known of it in detail because of poor exposures (pl. 65, C). It lies upon the white chalky limestone beds of the Hays member, from which it is easily distinguishable because it is softer and has a characteristic yellowish-orange color. The Smoky Hill contains beds of white limestone, but they are in most places only a few inches thick and are separated by much greater thicknesses of yellowish chalk. Several thin bentonite beds have been noted within the Smoky Hill, as well as beds of dark-tan and bluish shale. Much of the Smoky Hill has a tan to yellow color when fresh, and practically all of it has some shade of yellowish orange on weathered exposures. Another distinguishing feature is the occurrence of small white calcareous flecks throughout the chalk, which give it a mottled "salty" appearance. The total thickness of the Smoky Hill is not known precisely, but from well logs it is believed to be between 600 and 700 feet. Within probably the upper 100 feet of this member are chalk beds that are somewhat harder and purer than the beds below. On weathered outcrops the bedding planes have opened, and these horizontal or tabular spaces are loosely filled with needlelike interstitial calcite in which the larger dimension of the crystals is perpendicular to the bedding. As a whole, the Smoky Hill is well stratified and thin-bedded. It is practically all calcareous, but the larger part of it may be properly termed marl rather than chalk.

*Inoceramus (Haploscapha) grandis* is the most diagnostic fossil of the Smoky Hill member. Complete well-preserved specimens are seldom found, but in places large fragments covered with oyster shells are numerous. Fish scales are abundant in some exposures of the upper part of the member.

#### NIobrara FORMATION IN SOUTHERN FOOTHILL REGION

The Timpas limestone has been differentiated as far south as the area of the Spanish Peaks folio,<sup>68</sup> in which it is described as 200 feet thick, including a lower portion, 45 to 50 feet thick, consisting chiefly of limestone. Just a short distance to the south, along the east flank of the Sangre de Cristo Range in extreme northern New Mexico, however, limestone forms a much smaller proportion of the Niobrara formation, as shown in the following section:

Section of Niobrara formation on Gold Creek, west of old Pinacate post office, northwest of Vermejo Park on the road to Costilla, Colfax County, N. Mex.

Pierre shale.

#### Niobrara formation:

|  | Ft. in.       |
|--|---------------|
| Shale, hard, gray, calcareous; thickness (estimated)   | 250           |
| Shale, hard, gray, calcareous, with a zone of thin lenticular beds of hard gray calcareous sandstone near the top; thickness (estimated) | 500           |
| Limestone, gray, in beds 4 inches to 1 foot 4 inches thick, with intervening beds of gray calcareous shale                               | 8             |
| Shale, gray, calcareous  | 4             |
| Bentonite  | 1             |
| Shale, gray, calcareous  | 10            |
| Bentonite  | 5             |
| Shale, gray  | 7             |
| Bentonite  | 4             |
| Shale, gray, calcareous, with thin lenses and beds of hard gray marl   | 2 6           |
| Rusty streak.  |               |
| Shale, gray, calcareous  | 1 3           |
| Bentonite  | 2             |
| Shale, gray, calcareous, some thin shaly limestone beds  | 2             |
| Bentonite?   | $\frac{1}{4}$ |
| Shale, gray, calcareous  | 1 2           |
| Bentonite  | 4             |

Thickness of Niobrara formation, about 770

Carlile shale: Gray shale with septarian concretions and thin beds of hard sandy limestone.

This section is of interest in representing the character of the Niobrara formation at a place probably near the southwesterly limit at which a limestone unit equivalent to the Hays limestone of the Arkansas Valley is present in the Cretaceous section.

The rather conspicuous bentonite zone in the basal part of the Niobrara in the preceding section has not been described in previously published reports and was not observed by the writers along the Arkansas River. There is a suggestion, however, that it extends some distance northward along the east flank of the Sangre de Cristo Range into Colorado. Bentonite beds, probably in the basal part of the Niobrara, were observed at a locality about 6 miles south of Stonewall, in western Las Animas County, Colo. (west of Trinidad). Still farther north, on the north side of the Huerfano River just northeast of the bridge at Badito, there is a soft concealed interval of 10 feet above the sand at the top of the Carlile shale. At the top of the concealed interval are soft bedded marls, and at the base of it there may be some bentonite. The softer beds making the interval of concealment were included by the writers in the Niobrara formation.

<sup>68</sup> Hills, R. C., U. S. Geol. Survey Geol. Atlas, Spanish Peaks folio (no. 71), p. 1, 1901.

## FAUNA

The following fossils were collected by the writers from the Niobrara formation:

|   | Locality    |
|---|-------------|
| Smoky Hill marl member:   |             |
| <i>Inoceramus</i> sp.   | 2, 9, 10    |
| <i>Inoceramus deformis</i> Meek?  | 8           |
| <i>Inoceramus</i> aff. <i>I. stantoni</i> Sokolow?  | 8           |
| <i>Ostrea congesta</i> Conrad   | 1, 2, 9, 10 |
| <i>Baculites codyensis</i> Reeside  | 2           |
| Fish remains, undetermined  | 10, 11      |
| Hays limestone member:  |             |
| <i>Globigerina</i> sp.  | 5           |
| <i>Inoceramus deformis</i> Meek   | 3, 4, 7     |
| <i>Inoceramus</i> aff. <i>I. stantoni</i> Sokolow   | 7           |
| <i>Ostrea congesta</i> Conrad   | 5           |
| <i>Ostrea</i> sp.   | 6, 7, 8     |
| <i>Scaphites ventricosus</i> Meek and Hayden  | 3           |
| 1. 16071, NE $\frac{1}{4}$ sec. 6, T. 22 S., R. 44 W.   |             |
| 2. 16080, NW $\frac{1}{4}$ sec. 19, T. 20 S., R. 43 W.  |             |
| 3. 15745, Mount Morrison-Bear Creek locality. (See p. 210.)   |             |
| 4. 15747, Colorado City, west of Colorado Springs.  |             |
| 5. 15751, Cuesta ridge on east flank of small anticline on Arkansas River about 7 miles west of Pueblo. |             |
| 6. 15811, SE $\frac{1}{4}$ sec. 24, T. 22 S., R. 53 W.  |             |
| 7. 16073, NW $\frac{1}{4}$ sec. 32, T. 21 S., R. 44 W.  |             |
| 8. 16075, SW $\frac{1}{4}$ sec. 27, T. 20 S., R. 49 W.  |             |
| 9. 16079, NW $\frac{1}{4}$ sec. 17, T. 19 S., R. 44 W.  |             |
| 10. 16081, SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 26, T. 20 S., R. 43 W.                                |             |
| 11. 16082, NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 34, T. 17 S., R. 44 W.                                |             |

The late Prof. I. A. Keyte collected from beds at a horizon near the top of the Apishapa shale (top of Smoky Hill member of this paper), southwest of the area treated here, the following forms: Pelecypods, *Inoceramus* sp., *Turnus* n. sp.; gastropod, *Anchura?* sp.; cephalopods, *Eutrephoceras* sp., *Baculites asper* Morton, *Baculites codyensis* Reeside, *Scaphites vermiciformis* Meek and Hayden, *Scaphites ventricosus* Meek and Hayden with several varieties, *Placenticeras* sp., *Texanites* cf. *T. pseudotexanus* (Grossouvre). G. K. Gilbert collected from the upper part of the Niobrara northwest of Pueblo a very large specimen of *Inoceramus undulatoplacatus* Roemer.

## PIERRE SHALE

The lower part of the Pierre shale is present in the area shown on the map (pl. 64). It is poorly exposed, but lithologic subdivisions can be recognized and can be traced through the scattered outcrops available for examination. Much of the upper part of the formation lies outside of the area shown on plate 64, and the uppermost beds are not treated in detail in this paper, though certain data on these beds that have been collected are given on pages 230-231.

## LOWER PART

Several divisions have been recognized in the lower part of the Pierre shale of eastern Colorado and in that of western Kansas by previous students of these areas. It does not yet appear possible, however, to

establish definite correlations between the series of units set up in the several areas. As set forth below, the writers propose to apply in the Arkansas Valley only one formal member name, the "Sharon Springs shale member", using for the present only informal names for other divisions.

Before describing the exposures of the lower part of the Pierre in the mapped area, however, it seems best to describe the nature of this part of the Pierre shale farther west, where exposures are more complete.

The lower part of the Pierre shale is well exposed along the south side of Little Fountain Creek in the northern part of sec. 18, T. 16 S., R. 66 W., about 6 miles somewhat south of west from the town of Fountain, in the Colorado Springs quadrangle. The Pierre and underlying Niobrara dip generally eastward and northeastward at angles of  $10^{\circ}$  to  $15^{\circ}$ , the dip diminishing toward the east. The basal portion of the Pierre includes an estimated thickness of 550 feet of thin-bedded dark-gray shale. There are a few thin beds of hard yellowish-gray sandy limestone and a few beds a small fraction of an inch thick of yellowish earthy sand, also a few beds of bentonite. The only fossil remains observed were fish scales. At the top of this lithologic unit, near the center of the north line of sec. 18, there is a zone of large gray septarian concretions, seamed with brownish crystalline calcite. Immediately above this zone lie brownish-gray and dark-gray shales, with numerous reddish-brown calcareous beds and small flattish red-brown concretions. This lithology continues upward for an estimated thickness of 450 feet, and at the top the shales contain numerous fossils, chiefly *Inoceramus sagensis* Owen and *Baculites ovatus* Say.

The general subdivision of the lower part of the Pierre described above was also recognized by Gilbert<sup>69</sup> in the vicinity of Pueblo. He says:

The Barren zone, so called on account of the rarity of its fossil remains, lies at the bottom of the series and is 400 to 500 feet thick. It is of bluish-gray color and in its lower part resembles the Niobrara shale in the tendency to divide into papery layers, rough from the crystallization of selenite. The Rusty zone, 600 feet thick, is also bluish gray in color but is comparatively free from gypsum. It contains many concretions composed of lime carbonate and iron carbonate, and these are of oval form, measuring, usually, from 1 foot to 2 feet across. Their material is originally dark gray but under the action of the weather turns a rusty brown, and the soil derived from the formation is usually so strewn with their angular fragments as to appear reddish brown. The Baculite zone, 100 to 200 feet thick, is pale gray and is so called from the abundance of a fossil shell of that name.

The "Barren zone" and "Rusty zone" of the Pierre are also recognized and described by Lavington,<sup>70</sup> who

<sup>69</sup> Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

<sup>70</sup> Lavington, C. S., Montana group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, no. 4, pp. 398-400, 1933.

states that they are present in the Canon City-Florence district. Lavington<sup>71</sup> believes that in northeastern Colorado the Baculite zone recognized by Gilbert is not persistent over widespread areas.

In the Nepesta quadrangle, which lies to the east of the Pueblo quadrangle, Fisher<sup>72</sup> recognized in the Pierre a basal black shaly "barren zone", 400 to 500 feet thick, succeeded by 500 feet of dark-gray shale with numerous rusty concretions of iron and lime carbonate, and this in turn by 100 to 200 feet of somewhat lighter gray shale with numerous baculites.

Eastward to the Kansas line in the area shown on the map (pl. 64) small isolated outcrops show that the divisions recognized above carry through eastward. Some 2.4 miles north of Olney Springs are outcrops of shale with rusty concretionary beds and gray septarian concretions, representing a zone 300 to 350 feet above the base of the Pierre shale. These outcrops are probably near the base of the "rusty zone" and indicate a somewhat diminished thickness of the basal "barren zone", which is not exposed in this locality. Outcrops near the base of the Pierre in a large ditch in the southwest corner of sec. 29, T. 20 S., R. 56 W., northeast of Lake Henry, consist chiefly of thin-bedded gray and dark-gray shale that is neither sandy nor calcareous. One thin bed of white bentonitic clay and two beds of red clay less than 1 inch thick were observed, and also a few yellowish and slightly sandy beds. About 3 miles northeast of Lake Henry, in the bank of Pond Creek where it crosses the line between secs. 16 and 17, T. 20 S., R. 56 W., are outcrops of shale which are estimated to be not more than 300 feet above the base of the Pierre. The lower part of the exposure consists of gray and dark-gray bedded shale, slightly sandy toward the top. The upper part consists of gray somewhat sandy shale and gray shale with abundant yellow and brown resinous fragmentary remains of fishes. One reptilian rib, possibly that of a mosasaur, was observed. There are some sandy layers. At the base of the upper part is a layer of soft white bentonitic clay. In the upper part of the exposure are large dark-gray dense limestone concretions. This exposure apparently represents the top of the basal "barren zone" of the Pierre. Although it is not definitely known to be immediately overlain by beds in which the rusty-weathering carbonate concretions are abundant, the next overlying exposures exhibit the "rusty zone" lithology.

The basal portion of the Pierre is exposed also west and northwest of Haswell. The beds are mostly dark nonsandy shales with numerous gypsum crystals, though there are a few thin purplish-brown concretionary beds and some bentonite beds, of which one has a thickness of 3½ inches. In the NW¼ sec. 16,

T. 18 S., R. 52 W., a zone of large gray dense septarian limestone concretions in gray shale is succeeded upward by shale in which the dark reddish-brown "rusty zone" concretions are abundant. These exposures may represent the top of the basal "barren zone" of the Pierre, which cannot much exceed 200 feet in thickness in this vicinity.

In the area intervening between the exposures northeast of Lake Henry and the exposures west of Haswell no outcrops having the lithology of the basal Pierre were observed. In the NW¼ sec. 14, T. 18 S., R. 54 W., there are exposures of shale with abundant rusty-brown concretions less than 2 miles west of topographically higher exposures of calcareous shale that apparently belongs to the Niobrara formation. It seems more likely that this occurrence is due to a somewhat steeper northwestward dip at this place than to absence of the "barren zone."

In the western part of sec. 29, T. 15 S., R. 46 W., an exposure shows calcareous concretions with septaria of crystalline calcite embedded in gray to black nonsandy shale with much soft powdery gypsum. This exposure may also represent the top of the "barren zone" of the basal Pierre.

Detailed studies in Wallace County, Kans., enabled Elias<sup>73</sup> to subdivide the lower part of the Pierre into several members, the lowest of which, the Sharon Springs member, conforms in lithology with the "barren zone" of the Pierre of eastern Colorado. The Sharon Springs member is 155 feet thick. It is overlain by the beds called "Weskan member" by Elias, which are succeeded by his Lake Creek member and that in turn by his Salt Grass member. These three members are characterized by abundant limonitic concretions, which have a rusty appearance. They have a combined thickness of 430 feet and appear to be equivalent to the "rusty zone" of the Pierre of eastern Colorado.

The writers propose to extend the name "Sharon Springs member" into eastern Colorado to include the basal black-shale member above described, which is equivalent to the "barren zone" previously recognized. They feel that the overlying "rusty zone" has not yet been sufficiently studied or its upper limit in Colorado determined with sufficient accuracy to warrant designation by a specific name.

Although the Sharon Springs member as above defined appears to be a widespread and homogeneous unit of black clay shale which is present also in the northern foothill region and is recognized by drillers in northeastern Colorado,<sup>74</sup> scattered observations indicate that the lowest part of the Pierre may be more variable in its lithologic features in the southern foothill region.

<sup>71</sup> Lavington, C. S., op. cit., p. 403.

<sup>72</sup> Fisher, C. A., op. cit., p. 2.

<sup>73</sup> Elias, M. K., The geology of Wallace County, Kans.: Kansas Geol. Survey Bull. 18, pp. 58-116, 1931.

<sup>74</sup> Lavington, C. S., op. cit., p. 399.

On the north side of Apache Creek,  $1\frac{1}{2}$  miles southwest of Hayden Butte, in the Walsenburg quadrangle, there are extensive exposures of an earthy sandstone about 60 feet thick. Near the middle is a zone of large limestone concretions. Below the sandstone dark shale with rusty concretionary beds a few inches thick is exposed for 50 feet, more or less, and above it lie black thin-bedded shales with some rusty streaks. The exact stratigraphic position of the exposures was not ascertained, but they are clearly in the lower part of the Pierre, possibly about 500 feet above the base. *Inoceramus sagensis* Owen and *Baculites asper* Morton were collected from concretions about 5 feet above the top of the sandstone.

On the north side of the Huerfano River 3 miles northeast of Badito there are exposures of an earthy gray and buff well-bedded sandstone, for the most part well indurated, with some brown concretionary beds. Overlying the sandstone is 5 feet of sandy shale with a concretionary zone at the top from which *Inoceramus sagensis* Owen, *Baculites asper* Morton, and *Scaphites nodosus* Owen var. were collected. This concretionary zone is overlain by black paper-bedded shales that contain a few rusty concretionary beds. Below the sandstone there is sandy shale with some rusty concretionary beds and a few yellow flattish concretions 1 foot thick and as much as 20 feet in length. The interval from the sandstone described to the top of the Niobrara was not determined but is probably more than 300 feet. The two exposures of sandstone described may be the Apache sandstone of Prommel.<sup>76</sup>

Still farther south, at a locality 6 miles north of Stonewall, road cuts expose the lower part of the Pierre shale, which at this place dips vertically. Although penetrated by sills of dark igneous rock and possibly somewhat squeezed and faulted, these exposures give a good idea of the lithology of the lower part of the Pierre. A carefully estimated section is as follows:

*Section of Pierre shale 6 miles north of Stonewall*

| Pierre shale:   | Feet |
|---|------|
| Shale, black-----   | 200  |
| Sandstone, fine-grained, earthy, lumpy-bedded, and sandy shale-----   | 20   |
| Shale, slightly sandy. In the upper part are two beds of yellow-weathering concretionary limestone and a few thin streaks of shaly limestone----- | 260  |
| Shale, light gray, lumpy-bedded, with some small rusty concretions-----   | 120  |
| Concealed-----  | 40   |
| Shale, like that exposed next above-----  | 150  |
| Shale, black, thin-bedded. In the basal part are a very few thin sand streaks-----  | 100  |
| Thickness exposed-----  | 890  |

Niobrara formation: Shale, calcareous, with a thin dense impure limestone bed in the upper part.

<sup>76</sup> Lavington, C. S., op. cit., p. 399.

In the western part of the town of Pueblo, 0.6 mile north of the Arkansas River and 0.6 mile east of Dry Creek, outcrops of the basal part of the Pierre reveal a sandy lithology not observed in areas to the north or east. At this place the exposures display alternating beds of dark-gray shale and yellowish-weathering sandy shale, overlain by at least 10 feet of very fine grained yellow earthy sand, some beds of which are soft, though others are cemented by lime to a hard coherent rock. This sandy zone may be as much as 300 feet stratigraphically above the highest exposures of Niobrara observed by the writers, but as it appears to lie near to or even below the Niobrara-Pierre contact as mapped by Gilbert, the sand presumably lies in the basal part of the Pierre. These beds contain fish scales and numerous macerated plant remains, together with a few invertebrate fossils. (See collection 15753, p. 230.)

#### UPPER PART

In the area north of the Arkansas River a wholly satisfactory lithologic or faunal subdivision of the Pierre above the "rusty zone" is difficult to make. In part this is due to the absence of readily distinguishable differences or reliable key beds in the thick mass of shaly rocks. In part also it is due to the wide expanse of exposure with low dip and broadly level topography, with a resulting lack of extensive vertical exposures. There is also much concealment by younger unconformable Tertiary and later deposits. The differentiation of the Pierre is further complicated by the fact that the original thickness of the formation diminished by several thousand feet across the area which is now eastern Colorado.

Several previous writers have differentiated the "tepee zone" of the Pierre, distinguished by the presence of "tepee buttes"—small, sharply conical hills, formed by the superior resistance to weathering of large concretionary masses of limestone. (See pl. 65, A, B.) As defined by Gilbert,<sup>77</sup> the zone is 1,000 feet thick, overlying the "Baculite zone" and including the upper part of the Pierre as exposed in the Pueblo quadrangle. According to Fisher's description of the Pierre of the Nepesta quadrangle, the zone is 500 feet thick, underlain as in the Pueblo area by about 1,200 feet of shales but overlain by about 600 feet of light-gray sandy shales.

Two zones of tepee buttes were recognized near Fountain by Lavington.<sup>77</sup> East of Hugo, in the southwestern part of T. 11 S., R. 52 W., there are large concretionary masses much like tepee cores, but probably having less vertical than horizontal extent. These occur

<sup>76</sup> Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

<sup>77</sup> Lavington, C. S., op. cit., p. 402.

several hundred feet above the main series of tepee buttes.

In the vicinity of Fountain, in the Colorado Springs quadrangle, the writers estimated that the "tepee zone" was roughly 1,500 feet thick and the overlying portion of the Pierre shale was also 1,500 feet thick. As these estimates agree moderately well with the thicknesses of 1,275 feet for the "tepee zone" and 1,885 feet for the overlying Pierre shale measured by Lavington,<sup>78</sup> the writers believe that their estimate of 2,000 feet of the Pierre shale below the "tepee zone" west of Fountain and south of Little Fountain Creek may be correspondingly reliable. The total thickness of the Pierre in the Colorado Springs region is therefore about 5,000 feet. If these estimates are correct, the "tepee buttes" occur considerably lower in the section in the Pueblo region, where they are found at horizons beginning 1,200 feet above the base of the Pierre and only 200 feet above the top of the "rusty zone."

As the total thickness of the Pierre is known to diminish greatly southward from Colorado Springs,<sup>79</sup> the lower occurrence of "tepee buttes" in the Pueblo region may be due to thinning of the 1,000 feet of shaly beds below the "tepee zone" in the vicinity of Fountain to about 200 feet near Pueblo. In fact, Lavington<sup>80</sup> believes that on the west side of Baculite Mesa, northeast of Pueblo, small conical buttes from the overlying "tepee zone" actually range down into the "rusty zone." The "tepee zone" also apparently thins southward from Colorado Springs to Pueblo and eastward from Pueblo to about 500 feet in the Nepesta region and in the region north of Olney Springs, Ordway, and Arlington. In this region also the interval between the base of the "tepee zone" and the top of the "rusty zone" is apparently less than 100 feet. The base of the zone in which "tepee buttes" occur is about 1,350 feet above the base of the Pierre southwest of Boyero and about 1,100 feet above the base north of Kit Carson. Exclusive of the Sharon Springs member and the overlying "rusty zone" at these places the intervening part of the Pierre shales below the "tepee zone" thins eastward from perhaps 650 feet southwest of Boyero to 400 feet north of Kit Carson. It should be understood that the thicknesses given above are estimates only.

Because the "tepee buttes" occur in widely separated groups and because the concretions that form them are embedded in shale in which no distinguishable lithologic or faunal zones have yet been discovered, there is no real assurance that these concretions are actually confined to a stratigraphically definable zone in the Pierre shale. Nevertheless, from their distribution it

seems probable to the writers that they are restricted to a certain zone whose limits differ somewhat from place to place, that this zone diminishes southeastward in thickness, and that the shales below it but above the "rusty zone" also diminish southeastward in thickness.

In form, the tepee buttes, as their name implies, are low conical hills rising above the general level of the surrounding country. At the top of each is an irregular cap of light-gray or brown limestone, much fractured and containing great numbers of fossil shells, among which *Lucina occidentalis* is everywhere predominant. The shells are more or less completely recrystallized to translucent or transparent calcite, normally with a yellowish cast, and the containing rock is in places seamed with intersecting veinlets of similar calcite. On some of the buttes the limestone rock reveals a poorly defined, irregular horizontal stratification. The slopes of most of the buttes expose the shale in which the limestone masses are embedded, but almost all of them are thickly strewn with disintegrated fragments of the hard rock exposed at the top. It is obvious that the topographic form of the buttes is due to the greater resistance to erosion of the central capping mass of limestone. As the result of the most critical study of the origin of the tepee buttes which has been made, Gilbert and Gulliver<sup>81</sup> concluded that the limestone masses had the general form of vertical cylindrical cores, and this conclusion has been followed by all subsequent observers. Inasmuch as it seems to the writers that the same topographic form might well be produced by an essentially equidimensional concretionary mass, it is unfortunate that exposures of the vertical dimension of the tepee cores are rare. The greatest height of a core actually observed by Gilbert was 18 feet, and the horizontal dimensions of this core were not stated. In only one tepee butte examined by the writers could it be definitely ascertained that the vertical dimension was greater than the horizontal.

Tepee cores have, however, been reported to have vertical dimensions of as much as 50 feet,<sup>82</sup> and the shape of one core has been described as tapering downward like an inverted cone.

The tepee-core rock has been described as follows:<sup>83</sup>

The tepee rock is essentially a calcium carbonate, the ratio of calcium carbonate to magnesium carbonate being 18 to 1 in the single sample analyzed. That sample contained also 12 percent of argillaceous material. For comparative purposes, analyses were also made of the enclosing shale and of one of the ordinary concretions of the shale, the determinations showing that the tepee rock does not differ materially in composition from the concretions, and that the argillaceous material is practically identical with the shale. This permits us to regard

<sup>78</sup> Lavington, C. S., op. cit., fig. 1.

<sup>79</sup> Hills, R. C., U. S. Geol. Survey Geol. Atlas, Walsenburg folio (no. 68), p. 2, 1900.

<sup>80</sup> Lavington, C. S., op. cit., pp. 399-400.

<sup>81</sup> Gilbert, G. K., and Gulliver, F. P., Tepee buttes: Geol. Soc. America Bull., vol. 6, pp. 333-342, 1895.

<sup>82</sup> Fisher, C. A., U. S. Geol. Survey Geol. Atlas, Nepesta folio (no. 68), p. 2, 1906.

<sup>83</sup> Gilbert, G. K., and Gulliver, F. P., op. cit., pp. 336-337.

the argillaceous material as included shale, and therefore an impurity rather than an essential constituent of the tepee rock.

The rock has a coarse texture, breaks with rough fracture, and its general color is a light, warm gray. It is full of fossil shells, and the microscope shows that they are embedded in a matrix which is composed of fragments of shell, water-worn grains of calcite, Foraminifera, and clay. Cross sections of *Lucina* shells show that the original shell structure remains, although the lime of the shell has been recrystallized into calcite. Inside of the shell wall there is a band of radiating crystals of calcite, showing well-marked spherulitic structure. The calcareous ooze which must have at first occupied the central cavity of the shell has recrystallized into very pure calcite, leaving the clay impurities at one side of the shell. This central calcite crystal is the same individual which has replaced the lime of the shell, for the two parts extinguish together, the cleavage cracks extend from the center through the outside, and when the spherulitic band is faulted the clear calcite is continuous through the cracks. Experiments showed the spherulitic layer to be slightly less soluble in dilute hydrochloric acid than the clearer calcite.

In a few thin sections examined by the writers there is considerable variation in the nature of the rock. On the whole, the proportion of shell material is much less than half of the total bulk. In some of the *Lucina* shells there is a division of the shell into three zones—an outer band that is composed of relatively few calcite crystals, a wider central layer of fibrous calcite with flamboyant extinction, and an inner layer of variable thickness which consists of small calcite crystals interlocking in a granular mass that grades into the matrix filling the shell. This granular layer is not common, and where it is absent the fibrous layer grades into the matrix. The fibrous layer may also be absent from either one or both valves of the shell, but the outer layer of large calcite crystals retains a sharp boundary with the shell filling, although it may be partly or wholly replaced by chlorite. No central calcite crystals were observed within the matrix that fills the shells.

The bulk of the rock is fine-grained, consisting of intimately intermixed clay and calcite. Although the distribution of these materials varies greatly, there is a marked tendency for the clay to occur in somewhat darker, cloudier patches, in cross section having a circular, elliptical, or irregular shape. These clay patches range from 0.1 to 1 millimeter in diameter in different slides examined but exhibit less size variation in individual slides. Although the appearance of some of them suggests a coprolitic origin, it seems probable that most of them may represent flocculated clay pellets. In some slides granular interlocking areas of calcite occur in a fine-grained clay-calcite matrix; darker patches, chiefly of clay, occur in the same type of matrix; and patches of clay occur in areas of more coarsely crystalline calcite. Some of the clay patches are irregular and bounded by areas of calcite grains with crystal outlines. These irregular clay masses seem to be segregations produced during recrystallization of the rock.

Brown, darkly translucent or black opaque organic matter of various types occurs in small and broken fragments throughout much of the rock. In some areas, notably in the matrix within one *Lucina* shell near the hinge and within the outer calcite layer of another *Lucina* shell, in lines paralleling the shell banding, are minute nearly black grains, 15 to 50 microns across, which from their crystal form were pyrite, but which because of their slight translucency and reddish-brown color in reflected light now appear to be of limonitic composition. The writers' thanks are due to C. S. Ross, of the Geological Survey, for confirmatory examination of these grains and some advisory comments on the nature of the rock in general.

The clastic content of the rock is small and variable, some slides showing virtually none and others having an appreciable amount of very angular grains of quartz, feldspar, and accessory ferromagnesian minerals. The grains observed were as much as 0.2 millimeter in diameter.

Foraminifera were observed in most of the slides but are not numerous.

Gilbert<sup>84</sup> concluded that the most satisfactory explanation of the tepee cores was that each "was the site of a colony of *Lucina* and that the remains of each perishing generation furnished in some way conditions favorable to the life of the next", although he considered that knowledge of the tepees at that time was not sufficient to definitely establish this as the correct explanation. Some of the difficulties in accepting the theory of colonial origin, as above outlined, were pointed out by Gilbert. In the first place the predominant shell of the tepee cores, *Lucina*, is neither known to be a colonial species nor to be a species that would especially flourish on the presumably more stable foundation afforded by the shells and broken shell fragments of preceding generations. *Lucina* occurs in some abundance in the adjoining shales and is found elsewhere in sandy shales and sandstones. Some of the shells in the tepee cores are wholly embedded in the matrix and in general are no more commonly adjacent to or resting on other shells than would be expected from their relative abundance in the rock. Nor is it known that individuals of *Lucina* at any stage utilized or required an attachment. In the second place, the bulk of the material of the tepee cores is fine-grained calcite and clay, which gives no indication of being of organic origin, except for the possible coprolitic structures mentioned above.

On the other hand, the slight differences observed between the matrix within and outside the shells and other features of the rock suggest that it is an original sedimentary deposit rather than a concretionary aggregate, and the particular abundance of *Lucina* shells

<sup>84</sup> Gilbert, G. K., and Gulliver, F. P., op. cit., p. 339.

indicates contemporaneously favorable life conditions of some sort for them.

It seems possible that such favorable conditions might be provided by submarine springs of low volume but relatively high concentration in calcium carbonate. It has already been pointed out by Gilbert<sup>85</sup> that springs of sufficient volume to build a tufalike core would produce a concentric structure in the cores, which has not been found. On the other hand, a spring or seep of low volume on the sea floor might simply provide an abundance of mineral salts in solution, which would produce locally a favorable site for the growth of many kinds of organisms. A feature of the distribution of the buttes, which might be construed as favoring the hypothesis of submarine springs, is their tendency to alignment in rows. The lines of buttes in various places trend in diverse directions, so that this tendency to alignment does not produce any discernible systematic arrangement of the tepees as a whole, but locally the alignment is pronounced and should be explained by any satisfactory theory of their origin, as should also the tendency of the buttes to occur in groups or clusters.

As an interesting speculation, the writers advance the hypothesis that the predicated submarine springs arose from the pressing out of connate water during the compaction of the sediments deposited to the north in the more rapidly subsiding portion of the Denver Basin. The "tepee zone" contains the same fauna in general as the Hygiene sandstone member and overlying sandstone members in the Pierre shale of the northern foothills, where the total thickness of the Pierre shale is much greater. These sandstones alternate with intervening shaler zones and diminish in thickness southward and southeastward. As they were deposited in the more rapidly subsiding portion of the basin, the tapering margins of the sandy wedges would gradually acquire a gentle upward slope to the southeast, outward and upward from the basin. It seems possible that with the compaction of the sediments connate water of high mineral content would be squeezed out of muds and sandy silts into overlying tongues of sand that might then serve as channel courses for the movement of water upward and southward, there to escape upward through the soft sediments of the sea floor along local lines of weakness. H. F. Davies<sup>86</sup> has suggested a more direct relationship of the tepee buttes to the Hygiene and other sandstones, supposing that they may represent offshore deposition of the colloidal silica and calcium carbonate left in solution at the outer margins of deposition of the sandy materials.

Whatever the actual mode of origin of the tepee cores, if their vertical dimension is materially greater

than their horizontal dimension, it seems that there must have been a balance of some sort between the rate of deposition of the surrounding sediments and the rate of accumulation of the tepee core rock, in order that the required conditions for forming that rock might persist in one locality through the long period of time that must have been required to build up the tepee core and deposit the surrounding shale. That there were some variations in conditions from time to time is seen by the irregular nature of some exposed side walls of cores. In Gilbert's words, they "exhibit shoulders, shelves, and overhangs, besides being rugose in detail." In general, it may be concluded that such conditions could be maintained only in places where the rate of shell and calcium carbonate accumulation could keep pace with the rate of sedimentation. Where sediments accumulated more rapidly nearer the source of supply, such conditions could not long be maintained. On the other hand, the rate of accumulation of the shells would also seem to be a variable one, depending on available supplies of necessary materials for shell construction.

The foregoing discussion of the origin of the tepee cores is intended primarily to emphasize the point that the nature of the masses themselves indicates that they represent a type of deposition which would occur at a certain time within a geographically limited belt, and that this belt of tolerance would be very likely to migrate to and fro, owing to variations in the rate of supply of the sandy sediment that was being deposited farther north and to variations in the rate of subsidence of the basin. If so, the shale that contains the tepee cores probably has an intertonguing relation with the enclosing shales that are barren of the tepee masses.

The part of the Pierre shale above the "tepee zone" is composed of sandy shale and soft sandstone, particularly in the upper part. It is lithologically a transition unit from the dominantly fine sedimentary beds of the Pierre shale to the sandstone of the Fox Hills. As will be seen from the faunal lists below, it is likewise in its upper part a transition zone from the faunal assemblage characteristic of the Pierre shale to that characteristic of the Fox Hills sandstone. Neither top nor base of this transition zone is sharply defined, but it is certainly some hundreds of feet thick and appears to be characterized faunally by *Inoceramus fibrosus* (Meek and Hayden), *Baculites grandis* Hall and Meek, and several species of *Discoscaphites*. It is notable that in this region in the upper part of the transition zone and in the base of the overlying Fox Hills sandstone an association of such forms as *Inoceramus sagensis* Owen and *Baculites grandis* Hall and Meek with the *Discoscaphites* and species of *Sphenodiscus* is not uncommon. In other regions where Pierre and Fox Hills are recognized this association is so rare as to be virtually nonexistent.

<sup>85</sup> Gilbert, G. K., and Gulliver, F. P., op. cit., p. 339.

<sup>86</sup> Lavington, C. S., op. cit., p. 402.

## FAUNA

The fossils collected from the Pierre shale by the writers are listed below. The first list contains fossils from the beds between the transition zone and the base of the "tepee zone", with the exception of collections 15752, 15753, 15757, 15864, and 15962, which came from the lower part of the formation. The second list includes fossils from the transition zone in the uppermost part of the Pierre.

*Fossils from the Pierre shale below the transition zone*

|  | Locality   |
|--|--|
| <i>Cliona</i> sp., borings   | 31   |
| <i>Inoceramus barabini</i> Morton  | 3, 21, 24  |
| <i>Inoceramus sayensis</i> Owen  | 5, 6,<br>7, 8, 9, 11, 12, 13, 15, 16, 18, 22, 26, 31 |
| <i>Inoceramus</i> sp.  | 14, 20, 28, 29, 30, 31                               |
| <i>Ostrea</i> cf. <i>O. congesta</i> Conrad  | 24, 28   |
| <i>Anomia</i> sp., probably new  | 11   |
| <i>Lucina occidentalis</i> Morton  | 9, 10, 15, 17, 23, 25, 26, 28, 30                    |
| <i>Lucina subcrassa</i> Meek and Hayden  | 25   |
| <i>Lucina</i> sp.  | 19, 31   |
| <i>Mactra gracilis</i> Meek and Hayden   | 4, 30  |
| <i>Mactra canonensis</i> Meek  | 1, 2, 4  |
| <i>Dentalium gracile</i> Hall and Meek   | 11, 30   |
| <i>Lunatia dakotensis</i> Henderson  | 30   |
| <i>Aporrhais</i> sp.   | 25   |
| <i>Fasciolaria</i> sp.   | 25   |
| <i>Anchura</i> sp.   | 16, 29?  |
| <i>Baculites compressus</i> Say  | 9, 31  |
| <i>Baculites ovatus</i> Say  | 2, 7, 25, 30   |
| <i>Baculites ovatus</i> Say var. <i>haesi</i> Reeside  | 5, 26  |
| <i>Baculites</i> sp.   | 11, 12, 16, 27, 28, 29                               |
| <i>Exiteloceras?</i> sp.   | 25   |
| <i>Didymoceras</i> cf. <i>D. beecheri</i> Hyatt  | 26   |
| <i>Parapachydiscus complexus</i> (Meek)  | 29   |
| <i>Acanthoscaphites nodosus</i> (Owen) typical form  | 31   |
| <i>Acanthoscaphites nodosus</i> (Owen) var.  | 1, 9, 10, 20, 28                                     |
| <i>Acanthoscaphites quadrangularis</i> (Meek)  | 24, 27   |
| <i>Acanthoscaphites</i> sp.  | 15, 18, 22   |
| <i>Placenticeras meeki</i> Boehm   | 11   |
| <i>Hypsodon?</i> <i>radiatulus</i> Cockerell   | 6  |
| 1. 15732, Leyden Gulch, north of Golden, about 5,000 feet above the base of the Pierre.                                |  |
| 2. 15733, Leyden Gulch, nearly the same as 15732.  |  |
| 3. 15734, Leyden Gulch, nearly the same as 15732.  |  |
| 4. 15735, Leyden Gulch, nearly the same as 15732.  |  |
| 5. 15752, opposite Piñon station, 6.2 miles north of Eden on Pueblo-Colorado Springs highway.                          |  |
| 6. 15753, west of Pueblo, north of Arkansas River, east of Dry Creek Valley.   |  |
| 7. 15757, northeast corner sec. 18, T. 16 S., R. 66 W., south of Little Fountain Creek, southwest of Colorado Springs. |  |
| 8. 15759, SE $\frac{1}{4}$ sec. 15, T. 15 S., R. 65 W., at bridge on abandoned railroad grade.                         |  |
| 9. 15750, near center of sec. 3, T. 17 S., R. 65 W., 1 mile southeast of Little Buttes.* <sup>87</sup>                 |  |
| 10. 15809, NW $\frac{1}{4}$ sec. 19, T. 15 S., R. 57 W.  |  |
| 11. 15810, secs. 14 and 23, T. 17 S., R. 55 W.   |  |
| 12. 15812, NE $\frac{1}{4}$ sec. 27, T. 15 S., R. 55 W.  |  |
| 13. 15841, along highway, sec. 3, T. 11 S., R. 54 W.   |  |

\*<sup>87</sup> Collections made from the core rock of tepee buttes are indicated by asterisks.

|   | <i>Fossils from the Pierre shale below the transition zone—Contd.</i> |
|---|---|
| 14. 15843, SW $\frac{1}{4}$ sec. 36, T. 13 S., R. 56 W.   | 14?   |
| 15. 15847, NE $\frac{1}{4}$ sec. 30, T. 13 S., R. 56 W.   | 17?   |
| 16. 15854, NW $\frac{1}{4}$ sec. 26, T. 14 S., R. 55 W.   | 18?   |
| 17. 15855, SW $\frac{1}{4}$ sec. 14, T. 14 S., R. 57 W.   | 19?   |
| 18. 15858, NE $\frac{1}{4}$ sec. 36, T. 10 S., R. 53 W.   | 20?   |
| 19. 15859, NE $\frac{1}{4}$ sec. 34, T. 10 S., R. 52 W.   | 21?   |
| 20. 15860, SE $\frac{1}{4}$ sec. 30, T. 10 S., R. 51 W.   | 22?   |
| 21. 15861, NE $\frac{1}{4}$ sec. 26, T. 8 S., R. 50 W.  | 23?   |
| 22. 15862, SE $\frac{1}{4}$ sec. 35, T. 9 S., R. 51 W.  | 24?   |
| 23. 15863, SE $\frac{1}{4}$ sec. 28, T. 11 S., R. 52 W.   | 25?   |
| 24. 15864, NW $\frac{1}{4}$ sec. 22, T. 13 S., R. 51 W.   | 26?   |
| 25. 15755, 3.1 miles north of Belle Plaine, which is 2.7 miles east of Fountain Creek at Pueblo.  | 27?   |
| 26. 15756, same locality as 15755, 40 feet higher.  | 28?   |
| 27. 15808, sec. 1, T. 21 S., R. 59 W., 5.3 miles north of Olney Springs.*                         | 29?   |
| 28. 15813, 2.6 miles south of Karval.   | 30?   |
| 29. 15962, NE $\frac{1}{4}$ sec. 34, T. 14 S., R. 67 W., 500 feet above base of Pierre.           | 31?   |
| 30. 15963, SW $\frac{1}{4}$ sec. 20, T. 14 S., R. 66 W., brick pit southeast of Colorado Springs. | 32?   |
| 31. 16072, NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 1, T. 13 S., R. 47 W.*                          | 33?   |
|   | <i>Fossils from the "transition zone" of the Pierre shale</i>         |
|   | Locality  |
| <i>Robulus</i> sp.  | 5, 10, 20, 27   |
| <i>Serpula?</i> sp.   | 20  |
| <i>Lingula</i> sp.  | 3, 8  |
| <i>Solenites</i> <i>bilobus</i> White   | 3   |
| <i>Nucula planimarginata</i> Meek and Hayden  | 3, 4, 8, 13   |
| <i>Nucula larimerensis</i> Reeside  | 17?, 18   |
| <i>Nucula</i> sp.   | 6, 20, 22?, 26, 27  |
| <i>Yoldia scitula</i> Meek and Hayden   | 28  |
| <i>Yoldia evansi</i> Meek and Hayden  | 3, 4, 5, 6, 15, 19, 28  |
| <i>Yoldia</i> sp.   | 18?   |
| <i>Perissonota?</i> sp.   | 4   |
| <i>Inoceramus sayensis</i> Owen   | 20, 22, 28, 31, 36  |
| <i>Inoceramus altus</i> Meek?   | 39  |
| <i>Inoceramus fibrosus</i> (Meek and Hayden)  | 4, 6, 7, 9,<br>10, 11, 12, 16, 17, 18, 22, 25, 30, 31                 |
| <i>Inoceramus</i> sp.   | 9, 27, 38   |
| <i>Pteria nebrascana</i> Evans and Shumard  | 26, 32  |
| <i>Pteria</i> sp.   | 20  |
| <i>Pecten nebrascensis</i> Meek and Hayden  | 28  |
| <i>Lima</i> n. sp., several   | 4   |
| <i>Crenella elegantula</i> Meek and Hayden  | 14  |
| <i>Pholadomyia</i> n. sp.   | 14  |
| <i>Cuspidaria ventricosa</i> Meek and Hayden  | 4, 8  |
| <i>Venicia humilis</i> Meek and Hayden  | 19  |
| <i>Eriphylla gregaria</i> Meek and Hayden?  | 3   |
| <i>Lucina occidentalis</i> Morton   | 10, 23, 27, 30  |
| <i>Lucina</i> sp.   | 3, 6, 19, 26?   |
| <i>Protocardia subquadrata</i> Evans and Shumard  | 4, 15, 17   |
| <i>Tellina scitula</i> Meek and Hayden  | 19  |
| <i>Mactra gracilis</i> Meek and Hayden  | 1, 2, 11, 13,<br>22, 28, 34, 35, 36, 38, 40, 41                       |
| <i>Mactra canonensis</i> Meek   | 33  |
| <i>Mactra</i> sp.   | 14?, 17   |
| <i>Dentalium gracile</i> Hall and Meek  | 20, 27?   |
| <i>Dentalium</i> sp.  | 4   |
| <i>Lunatia dakotensis</i> Henderson   | 3, 9?, 20, 33   |
| <i>Lunatia</i> sp.  | 27, 37?   |
| <i>Turritella</i> sp., probably new   | 3   |
| <i>Fasciolaria?</i> cf. <i>F. cheyennensis</i> Meek and Hayden                                    | 4?, 20  |

| <i>Fossils from the "transition zone" of the Pierre shale—Contd.</i>                                 |  | <i>Locality</i> |
|--|--|-----------------|
| <i>Anchura?</i> sp.  |  | 31?             |
| <i>Haminea subcylindrica</i> (Meek)  |  | 3               |
| <i>Cinulites</i> ( <i>Oligoptychia</i> ) <i>concinna</i> Hall and Meek                               |  | 3, 32           |
| <i>Baculites grandis</i> Hall and Meek   | 2, 11, 12, 17, 20, 24, 25, 29?, 31         |                 |
| <i>Baculites</i> sp.   | 7, 17, 28, 34, 35, 36, 37, 38, 40?         |                 |
| <i>Discoscapites conradi</i> (Morton)  |  | 30, 39          |
| <i>Discoscapites cheyennensis</i> (Owen)   |  | 3               |
| <i>Discoscapites mandanensis</i> (Morton)  |  | 5, 17, 22       |
| <i>Discoscapites</i> cf. <i>D. abyssinus</i> (Morton)  |  | 20              |
| <i>Discoscapites</i> cf. <i>D. nicolleti</i> (Morton)  |  | 22              |
| <i>Discoscapites</i> sp.   | 4, 6, 7, 8, 9, 11, 16, 18, 20, 22?, 23, 27 |                 |
| <i>Acanthoscaphites</i> sp.  |  | 33?, 35, 37?    |
| <i>Sphenodiscus lenticularis</i> (Owen)  |  | 6               |
| <i>Belcmnitella bulbosa</i> Meek and Hayden  |  | 26              |
| Decapod crustacean, undetermined   |  | 4               |
| 1. 15802, north tributary of Fountain Creek, north of Colorado Springs.                              |  |                 |
| 2. 15806, SW $\frac{1}{4}$ sec. 35, T. 13 S., R. 58 W.   |  |                 |
| 3. 15814, 15.1 miles north of Limon on Brush road.   |  |                 |
| 4. 15815, 15.1 miles north of Limon on Brush road, above 15814.                                      |  |                 |
| 5. 15816, 21.3 miles from Limon, just east of road bridge across Beaver Creek on road to Agate.      |  |                 |
| 6. 15825, NE $\frac{1}{4}$ sec. 24, T. 2 S., R. 55 W.  |  |                 |
| 7. 15826, 9.1 miles north of Last Chance store.  |  |                 |
| 8. 15827, NE $\frac{1}{4}$ sec. 15, T. 3, S., R. 56 W.   |  |                 |
| 9. 15828, SW $\frac{1}{4}$ sec. 5, T. 2 S., R. 55 W.   |  |                 |
| 10. 15830, NW $\frac{1}{4}$ sec. 6, T. 10 S., R. 55 W.   |  |                 |
| 11. 15832, SE $\frac{1}{4}$ sec. 36, T. 9 S., R. 55 W.   |  |                 |
| 12. 15834, NW $\frac{1}{4}$ sec. 30, T. 9 S., R. 55 W.   |  |                 |
| 13. 15804, one-eighth mile north of southeast corner sec. 3, T. 14 S., R. 58 W.                      |  |                 |
| 14. 15838, SW $\frac{1}{4}$ sec. 33, T. 3 S., R. 58 W.   |  |                 |
| 15. 15842, northeast corner sec. 1, T. 2 S., R. 58 W.  |  |                 |
| 16. 15844, SW $\frac{1}{4}$ sec. 7, T. 2 S., R. 53 W.  |  |                 |
| 17. 15845, SW $\frac{1}{4}$ sec. 29, T. 11 S., R. 56 W., East Rush Creek.                            |  |                 |
| 18. 15848, NW $\frac{1}{4}$ sec. 6, T. 2 N., R. 55 W.  |  |                 |
| 19. 15849, southwest corner sec. 1, T. 5 N., R. 59 W.  |  |                 |
| 20. 15850, center sec. 4, T. 13 S., R. 57 W., Rush Creek.  |  |                 |
| 21. 15851, NE $\frac{1}{4}$ sec. 30, T. 13 S., R. 58 W., Little Horse Creek.                         |  |                 |
| 22. 15852, S $\frac{1}{2}$ sec. 20, T. 13 S., R. 58 W.   |  |                 |
| 23. 15853, N $\frac{1}{2}$ sec. 26, T. 12 S., R. 56 W.   |  |                 |
| 24. 15856, S $\frac{1}{2}$ sec. 7, T. 14 S., R. 57 W.  |  |                 |
| 25. 15857, NW $\frac{1}{4}$ sec. 13, T. 14 S., R. 58 W., Horse Creek.                                |  |                 |
| 26. 15875, SW $\frac{1}{4}$ sec. 16, T. 8 N., R. 57 W.   |  |                 |
| 27. 15876, E $\frac{1}{2}$ sec. 4, T. 8 N., R. 55 W., South Pawnee Creek.                            |  |                 |
| 28. 15956, SW $\frac{1}{4}$ sec. 31, T. 13 S., R. 66 W., Monument Creek north of Colorado Springs.   |  |                 |
| 29. 15961, center SW $\frac{1}{4}$ sec. 30, T. 13 S., R. 66 W.                                       |  |                 |
| 30. 15969, SE $\frac{1}{4}$ sec. 3, T. 1 N., R. 43 W., 3 miles east of Wray.                         |  |                 |
| 31. 15971, NW $\frac{1}{4}$ sec. 6, T. 2 S., R. 42 W.  |  |                 |
| 32. 16307, SE $\frac{1}{4}$ sec. 5, T. 3 S., R. 57 W.  |  |                 |
| 33. 15955, SW $\frac{1}{4}$ sec. 21, T. 14 S., R. 66 W., 2 miles southeast of Colorado Springs.      |  |                 |
| 34. 15957, NW $\frac{1}{4}$ sec. 31, T. 13 S., R. 66 W., Monument Creek, north of Colorado Springs.  |  |                 |
| 35. 15958, NW $\frac{1}{4}$ sec. 31, T. 13 S., R. 66 W.  |  |                 |
| 36. 15960, NW $\frac{1}{4}$ sec. 31, T. 13 S., R. 66 W.  |  |                 |
| 37. 15970, near center sec. 21, T. 2 S., R. 43 W.  |  |                 |
| 38. 15805, NW $\frac{1}{4}$ sec. 2, T. 14 S., R. 58 W., bank of Horse Creek 250 feet east of bridge. |  |                 |
| 39. 15836, NE $\frac{1}{4}$ sec. 13, T. 9 S., R. 56 W.   |  |                 |
| 40. 15803, line between secs. 3 and 10, T. 14 S., R. 58 W.   |  |                 |
| 41. 15807, E $\frac{1}{2}$ sec. 33, T. 13 S., R. 58 W.   |  |                 |

## FOX HILLS SANDSTONE

The Fox Hills sandstone, which overlies the Pierre shale, outcrops north and northwest of the area shown on plate 64. Its geographic distribution and some features of its stratigraphic relations with the Pierre shale are briefly discussed in another paper <sup>88</sup> dealing with the later Cretaceous formations of the Denver Basin. Because of the faunal relationships between the transition zone of the Pierre shale and the Fox Hills sandstone it is desirable to include in this paper a summary of identifications of fossils collected from the Fox Hills.

As used by the writers the name "Fox Hills sandstone" is applied to a unit ranging from 200 to a little more than 300 feet in thickness, consisting in the lower part of buff or brown sandstone and sandy shale that contains large gray to brown hard sandy concretions and in the upper part chiefly of soft sand or poorly consolidated white sandstone. In general this is also the way the Fox Hills of eastern Colorado was restricted by the Rocky Mountain Association of Petroleum Geologists in 1932.<sup>89</sup>

Because the contact of the Fox Hills sandstone and the Pierre shale is transitional in many places and because the zones of large concretions at the base of the Fox Hills were not traced in detail over the complete area from which collections were made, the fossils collected from the Fox Hills sandstone are shown in two lists. The first shows species in lots whose position is somewhat doubtful; that is, they may possibly belong to the transition zone of the Pierre shale, though the writers believe them more likely to represent Fox Hills horizons; the second shows the species in lots assigned with confidence.

The fauna contains many species that appear first in sandy rocks at various horizons in the Montana group of other areas, though such species as *Baculites grandis* Hall and Meek, *Discoscapites conradi* (Morton), and *Sphenodiscus lenticularis* (Owen) always indicate a very late Cretaceous horizon wherever found. Some of the lots—for example, collection 15865—show a definite admixture of nonmarine elements, a not unusual occurrence in the Fox Hills.

## Fossils probably from the lower part of the Fox Hills sandstone

|   | <i>Locality</i> |
|---|-----------------|
| <i>Solemya bilix</i> White                              | 3               |
| <i>Solemya?</i> sp.                                     | 8               |
| <i>Pteria nebrascana</i> Evans and Shumard              | 5, 6            |
| <i>Volsella</i> cf. <i>V. meeki</i> (Evans and Shumard) | 4               |
| <i>Crenellid elegans</i> Meek and Hayden                | 5               |
| <i>Platidomyia</i> n. sp.                               | 3               |

<sup>88</sup> Dane, C. H., and Pierce, W. G., Dawson and Laramie formations in southeastern part of Denver Basin, Colo.: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 10, pp. 1308-1328, 1936.

<sup>89</sup> Lovering, T. S., Aurand, H. A., Lavington, C. S., and Wilson, J. H., Fox Hills formation, northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 16, no. 7, pp. 702-703, 1932.

*Fossils probably from the lower part of the Fox Hills sandstone—Continued*

|  | <i>Locality</i> |
|--|-----------------|
| <i>Lucina occidentalis</i> Morton  | 3               |
| <i>Sphaeriola cordata</i> Meek and Hayden  | 2               |
| <i>Cardium whitei</i> Dall   | 3, 5            |
| <i>Tellina</i> sp.   | 5               |
| <i>Mactra</i> sp.  | 7               |
| <i>Dentalium</i> sp.   | 5, 8            |
| <i>Lunatia</i> sp.   | 8               |
| <i>Pyrifusus newberryi</i> Meek and Hayden   | 8               |
| <i>Baculites grandis</i> Hall and Meek   | 1               |
| <i>Discoscaphites</i> sp.  | 2, 8            |
| 1. 15736, Leyden Gulch.  |                 |
| 2. 15831, near center sec. 23, T. 5 S., R. 58 W.   |                 |
| 3. 15866, center sec. 1, T. 1 S., R. 58 W.   |                 |
| 4. 15868, SE $\frac{1}{4}$ sec. 36, T. 1 N., R. 58 W.  |                 |
| 5. 15869, NE $\frac{1}{4}$ sec. 25, T. 1 S., R. 58 W.  |                 |
| 6. 15870, SW $\frac{1}{4}$ sec. 31, T. 1 S., R. 57 W.  |                 |
| 7. 15874, SW $\frac{1}{4}$ sec. 31, T. 1 S., R. 57 W.  |                 |
| 8. 15964, NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 14, T. 13 S., R. 59 W., along road and bank of Horse Creek. |                 |

*Fossils from the Fox Hills sandstone*

|  | <i>Locality</i>                         |
|--|---|
| <i>Nucula larimerensis</i> Reeside               | 5, 9, 12                                |
| <i>Nucula planimarginata</i> Meek and Hayden     | 6, 7, 9, 10, 11, 12, 18                 |
| <i>Nucula</i> sp.                                | 13, 20                                  |
| <i>Yoldia evansi</i> Meek and Hayden             | 8                                       |
| <i>Yoldia</i> sp.                                | 17                                      |
| <i>Arca</i> n. sp.                               | 2                                       |
| <i>Gervillia subtortuosa</i> Meek and Hayden     | 2                                       |
| <i>Pteria nebrascana</i> Evans and Shumard       | 14, 20                                  |
| <i>Ostrea glabra</i> Meek and Hayden             | 15                                      |
| <i>Unio?</i> sp.                                 | 15                                      |
| <i>Anomia</i> sp.                                | 7, 20                                   |
| <i>Mytilus?</i> sp.                              | 20                                      |
| <i>Crenella elegantula</i> Meek and Hayden       | 19, 20                                  |
| <i>Pholadomya</i> n. sp.                         | 8, 14, 20                               |
| <i>Tancredia americana</i> Meek and Hayden       | 7                                       |
| <i>Lucina occidentalis</i> Morton                | 16                                      |
| <i>Sphaeriola cordata</i> Meek and Hayden        | 2, 14                                   |
| <i>Cardium whitei</i> Dall                       | 6, 7, 9, 10, 11, 13, 14, 15, 17, 18, 20 |
| <i>Protocardia subquadrata</i> Evans and Shumard | 6, 14, 20                               |
| <i>Dosiniopsis nebrascensis</i> Meek and Hayden  | 2                                       |
| <i>Dosiniopsis?</i> sp.                          | 13, 14                                  |
| <i>Tellina scitula</i> Meek and Hayden           | 14, 20                                  |
| <i>Tellina equilateralis</i> Meek and Hayden     | 15                                      |
| <i>Sanguinolaria?</i> sp.                        | 20                                      |
| <i>Mactra gracilis</i> Meek and Hayden           |   |
| <i>Mactra formosa</i> Meek and Hayden            | 7, 11, 13                               |

*Fossils from the Fox Hills sandstone—Continued*

|  | <i>Locality</i>         |
|--|-------------------------|
| <i>Mactra</i> sp.  | 2, 6?, 14, 17           |
| <i>Dentalium gracile</i> Hall and Meek   | 2, 6, 9, 10, 14, 18, 20 |
| <i>Dentalium</i> sp.   | 11                      |
| <i>Lunatia concinna</i> Meek and Hayden  | 9, 10                   |
| <i>Lunatia subcrassa</i> Meek and Hayden   | 7, 17                   |
| <i>Turritella?</i> sp.   | 17                      |
| <i>Mcclania?</i> sp.   | 15                      |
| <i>Fusus?</i> sp.  | 10, 14                  |
| <i>Fasciolaria (Piestochilus) culbertsoni</i> Meek and Hayden  | 7, 13                   |
| <i>Fasciolaria (Piestochilus) scarboroughi</i> Meek and Hayden   | 7                       |
| <i>Haminea</i> sp.   | 13, 17                  |
| <i>Cinulia</i> sp.   | 20                      |
| <i>Baculites ovatus</i> Say?   | 3                       |
| <i>Baculites</i> sp.   | 1?                      |
| <i>Discoscaphites conradi</i> (Morton)   | 14?, 20                 |
| <i>Sphenodiscus (Coahuilites) cf. S. (C.) pleurisepta</i> Conrad   | 4                       |
| <i>Sphenodiscus lenticularis</i> (Owen)  | 3, 9                    |
| <i>Sphenodiscus</i> sp.  | 13                      |
| <i>Belemnitella bulbosa</i> Meek and Hayden  | 8                       |
| <i>Mesojassoides gigantea</i> Oman   | 20                      |
| <i>Lamna</i> sp.   | 15, 17                  |
| Crocodile tooth  | 15                      |
| Rolled leaves and wood   | 20                      |
| 1. 15737, Leyden Gulch.  |                         |
| 2. 15748, east side of Fountain Creek, north of Colorado Springs, half a mile south of Pikeview station. |                         |
| 3. 15749, Fountain Creek, west of south end of the south lake of the two below Pikeview station.         |                         |
| 4. 15835, northeast corner sec. 29, T. 4 S., R. 58 W.  |                         |
| 5. 15817, sec. 33, T. 6 S., R. 57 W.   |                         |
| 6. 15819, same locality as 15817, but higher.  |                         |
| 7. 15821, NE $\frac{1}{4}$ sec. 1, T. 7 S., R. 58 W.   |                         |
| 8. 15824, sec. 32 or 33, T. 6 S., R. 57 W.   |                         |
| 9. 15829, sec. 8, T. 7 S., R. 57 W., south of Beaver Creek.  |                         |
| 10. 15833, southwest corner sec. 23, T. 5 S., R. 58 W.   |                         |
| 11. 15837, SW $\frac{1}{4}$ sec. 3, T. 5 S., R. 58 W.  |                         |
| 12. 15839, north-central part of sec. 28, T. 8 S., R. 57 W.  |                         |
| 13. 15840, northeast corner sec. 13, T. 8 S., R. 57 W.   |                         |
| 14. 15846, SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 11, T. 5 N., R. 59 W.                                  |                         |
| 15. 15865, SE $\frac{1}{4}$ sec. 31, T. 1 S., R. 59 W.   |                         |
| 16. 15867, SE $\frac{1}{4}$ sec. 35, T. 1 N., R. 58 W.   |                         |
| 17. 15871, center sec. 27, T. 2 S., R. 58 W.   |                         |
| 18. 15872, N $\frac{1}{2}$ sec. 12, T. 2 S., R. 58 W.  |                         |
| 19. 15873, same locality as 15872, float.  |                         |
| 20. 16306, 500 feet south of northeast corner sec. 27, T. 1 S., R. 58 W.                                 |                         |

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## THE CORRELATION OF THE UPPER CAMBRIAN SECTIONS OF MISSOURI AND TEXAS WITH THE SECTION IN THE UPPER MISSISSIPPI VALLEY<sup>1</sup>

By JOSIAH BRIDGE

The Upper Cambrian section in the upper Mississippi Valley has long been accepted as the standard for North America, largely because it was the first to be studied in detail, because it contains a large number of distinct faunas, and because it is still the best-known and the most complete Upper Cambrian section in the Middle West. Various classifications have been proposed from time to time, but the latest and most detailed is that used by the ninth annual field conference of the Kansas Geological Society in the summer of 1935.<sup>2</sup>

It is not the purpose of this paper to discuss the merits and demerits of the Kansas Geological Society's classification, which is frankly a compromise that will require further elaboration, refinement, modification, and the elimination of certain names and their replacement by others before it can be generally accepted. Reference to it in this paper does not imply that it has been accepted either by the writer or by the United States Geological Survey. The proposed reduction of formations to three or four is certainly a step forward, for the Conference seems to have kept the definition of a formation—that is, a cartographic unit—firmly in mind and has drawn the boundaries on that basis. Whether some of the units now classed as members should be regarded as formations or not is beyond the scope of this paper. The proposed column is noteworthy in that it presents the most complete sequence of faunas published to date, and in their proper order, thereby facilitating the correlation with other sections.

Table 1 of this paper presents a tentative correlation of the Upper Cambrian of three different areas—the upper Mississippi Valley, Missouri, and central Texas. The sequence of faunas as worked out in the upper Mississippi Valley is shown in the first column, and the presence of these faunas in the various stratigraphic units is indicated by a dot, or, if doubtful, by an interrogation point.

The determination of the succession of faunas is largely the work of Ulrich and Resser, Edwards, and Raasch; and although they are not in complete agreement concerning details of the stratigraphy, they and all other students of the Upper Cambrian of the Pacific province of North America agree very closely as to the details of the faunal succession.

The upper Mississippi Valley section is dominantly clastic, whereas the sections in Missouri and Texas are in the main calcareous. Therefore, lithologic correlations have been of very little value. Many of the faunas and especially certain elements of them are distinctly facies faunas, and this, together with the lack of study of the Missouri and Texas sections and certain miscorrelations in the upper Mississippi Valley section which have only recently been corrected, has greatly retarded correlations among these three areas.

Recent work in Texas by Miss Christina Lochman and the writer has shown that the section in the Central Mineral Region is nearly as complete as the upper Mississippi Valley section and that most of the faunal zones of the latter are present there. As now classified by the United States Geological Survey for the forthcoming geologic map of Texas, the Upper Cambrian of Texas comprises three formations and part of a fourth. These formations were all established on the basis of lithology and without direct reference to the newly proposed upper Mississippi Valley classification. There is, however, a striking similarity between the two classifications.

The Hickory sandstone, which forms the base of the Texas Cambrian section, appears to grade upward into the limestones of the Cap Mountain formation, and together these formations make a unit which is roughly the equivalent of the Dresbach formation of the Conference classification.

As the Hickory thickens the Cap Mountain thins, the combined thickness of the two formations remaining about constant. A further proof of the gradational character of the two formations is the presence of the *Cedaria* zone in both formations. This relationship will be more fully described in a forthcoming paper by Miss Lochman. The *Crepicephalus* zone is present, although *Crepicephalus* itself is not a common form. The dominant genera of this zone are *Tricrepicephalus*, which extends downward into the *Cedaria* zone, and *Coosia*. The *Aphelaspis* zone, characterized by *Aphelaspis depressa* (Shumard), is well developed and is probably the most widespread of all the Cap Mountain faunal zones. It occurs in the highest limestone beds of the formation immediately beneath a thick bed of glauconitic sandstone which Paige<sup>3</sup> included in the Cap

<sup>1</sup> Presented before the Paleontological Society, Dec. 27, 1935.

<sup>2</sup> Kansas Geol. Soc., Guidebook, Ninth Annual Field Conference, upper Mississippi Valley, p. 18, fig. 1 and elsewhere, 1935.

<sup>3</sup> Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Llano-Burnet folio (no. 183) p. 45 (field ed.), p. 6 (library ed.), 1912.

TABLE 1.—Tentative correlation of Upper Cambrian of upper Mississippi Valley, Missouri, and central Texas

| Faunas   |                    | Upper Mississippi Valley<br>(Kansas Geological Society Conference classification, 1935) | Missouri<br>(U. S. Geological Survey, 1936) | Texas<br>(U. S. Geological Survey,<br>1936) |
|--|--------------------|---|---|---|
| Gasconadia.  | Ord.               | Oneota dolomite   | Gasconade dolomite                          | •   |
| Burenoceras.   |                    | Not represented   | Van Buren formation                         | ?   |
| Plethopeltis.  |                    | Madison [sandstone] member  | •   | ?   |
| Acheilops.   |                    | Jordan [sandstone] member   | Jordan sandstone of Ulrich                  | Ellenburger limestone (lower part) •        |
| Eurekia-Euptychaspis.                                      |                    |   | Norwalk sandstone of Ulrich                 |   |
| Dikelocephalus minnesotensis.                              |                    | Lodi [shale and siltstone] member   | •   | ?   |
| Scaeogyra.   |                    | St. Lawrence dolomite [member]  | •   | Potosi dolomite •                           |
| Lower Dikelocephalus.                                      | Upper Cambrian     | Mazomania formation of Ulrich   | Bad Axe [sandstone] member                  | ?   |
| Briscoia.  |                    | Franconia formation   | Hudson [sandstone] member                   | Doe Run dolomite                            |
| Prosaukia.   |                    |   | •   | ?   |
| Ptychaspis.  |                    |   | •   | Derby dolomite                              |
| Billingsella.  |                    |   | •   | Elvins group                                |
| Eoorthis.  |                    |   | Goodenough [sandstone] member               | •   |
| Camaraspis.  |                    |   | Ironton [sandstone] member                  | •   |
| Hypseloconus, a local shore phase of the Camaraspis fauna. |                    |   | Galesville [sandstone] member               | Davis formation                             |
| Aphelaspis.  | Dresbach formation |   | •   | •   |
| Crepicephalus.   |                    |   | Eau Claire [sandstone] member               | •   |
| Cedaria.   |                    |   | •   | •   |
|  |                    |   | Mount Simon [sandstone] member              | Lion Mountain sandstone member              |
|  |                    |   |   | Cap Mountain formation                      |
|  |                    |   |   | Hickory sandstone                           |
|  |                    |   |   |   |

Mountain formation. This sandstone, which is perhaps the best horizon marker in the Central Mineral Region, is here designated the "Lion Mountain sandstone member of the Cap Mountain formation." The name is taken from Lion Mountain, in the northwestern part of the Burnet quadrangle. The section of the Cap Mountain formation exposed along State Highway 29 on the southwest side of Lion Mountain is much thicker and far superior to the type section on Cap Mountain.

The presence of the three faunas in both the upper Mississippi Valley and Texas definitely establishes the equivalence of this part of the section. Whether the Lion Mountain sandstone member is to be considered the full equivalent of the Galesville member of the Conference classification is, of course, purely conjectural.

In Missouri the lower portion of the Upper Cambrian section is composed of the Lamotte sandstone and the Bonneterre dolomite. The contact between the two formations is believed to be gradational, although St. Clair<sup>4</sup> has postulated an unconformity between them. The *Cedaria* fauna has been found in the lower 50 feet of the Bonneterre dolomite along the Farmington anticline east of the St. Francois Mountains, where the basal beds are predominantly limestone, and this occurrence serves to tie this portion of the section with the uppermost Hickory and basal Cap Mountain of Texas and with the lower part of the Eau Claire member of the Conference classification for the upper Mississippi Valley. The *Crepicephalus* and *Aphelaspis* faunas

<sup>4</sup> St. Clair, Stuart, Geology of Ste. Genevieve County, Mo.: Missouri Bur. Geology and Mines, vol. 22, pp. 37, 44, 1928.

have not been found in Missouri, but one or both of them might well occur in the upper portion of the Bonneterre dolomite, which thus far has yielded no fossils.

Overlying the Cap Mountain formation in Texas is the Wilberns formation, which comprises all the strata between the top of the Lion Mountain sandstone member and the base of the Ellenburger limestone. It is almost exactly the equivalent of the Franconia of the Conference classification, or of the Franconia and Mazomanie of Ulrich's classification.<sup>5</sup> The base of the Wilberns is marked by the widespread *Camaraspis* fauna, which serves to correlate it with the Ironton sandstone member of the Franconia. The other important trilobite genera in this assemblage are *Elvinia*, *Burnetia*, *Housia*, *Irvingella*, and *Pterocephalia*. Overlying the *Camaraspis* zone are the *Eoorthis* and *Billingsella* or *Taenicephalus* faunules, which together make up the *Conaspis* zone and serve to correlate this portion of the Wilberns with the Goodenough member of the Conference classification. The upper zones of the Wilberns are not as definitely known, but the *Ptychaspis*, *Prosaukia*, and *Briscoia* faunas are known to be present, and there are indications of the lower *Dikelocephalus* zone. These are contained in the so-called "post-Wilberns beds—Fort Sill and Signal Mountain faunal equivalents" of Dake and Bridge,<sup>6</sup> but until these formations are better known it seems wise to restrict the names "Fort Sill" and "Signal Mountain" to rocks in the type areas (Wichita and Arbuckle Mountains, Okla.). Beds carrying these faunas were locally included in the Wilberns formation by Paige, although at places he assigned beds at the same horizons to the Ellenburger limestone. The Wilberns as now defined includes these beds.

In Missouri the *Camaraspis*, *Eoorthis*, and *Taenicephalus* faunas occur in the Davis formation and serve to correlate it with the lower portion of the Wilberns and with the lower part of the Franconia (Ironton and Goodenough members of the Conference classification). A further tie between Missouri and the upper Mississippi Valley is found in the peculiar assemblage of gastropods known as the *Hypseloconus* fauna. This is distinctly a facies fauna characteristic of shallow-water conditions along a rocky coast and at present is known from only three localities—one at the base of the Franconia at Taylors Falls, Minn., the other two at the base of the Davis in Missouri.

<sup>5</sup> Ulrich, E. O., Notes on new names in table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin: Wisconsin Acad. Arts, Sci., and Letters Trans., vol. 21, pp. 72-94, 1924.

<sup>6</sup> Dake, C. L., and Bridge, Josiah, Faunal correlation of the Ellenburger limestone of Texas: Geol. Soc. America Bull., vol. 43, pp. 725-741, 1932.

The presence of the *Camaraspis* fauna in the base of the Davis is another reason for assuming that the non-fossiliferous portion of the Bonneterre may represent the *Crepicephalus* and *Aphelaspis* zones.

Overlying the Davis are two thin dolomitic formations—the Derby and Doe Run dolomites—which have yielded practically no fossils. Their position in the upper Mississippi Valley and Texas sections is therefore doubtful, but they are believed to represent the upper half of the Wilberns formation and the upper half of the Franconia, either wholly or in part. There is one tie with the Texas section which of itself is of no great value but which when taken with the general sequence of faunas is at least significant. Near the base of the upper half of the Wilberns formation, in what was called the "Fort Sill faunal equivalent," there are several layers of limestone filled with small spherical bodies which show traces of structure and have been provisionally identified as *Girvanella* sp.<sup>7</sup> These bodies occur above the *Billingsella* zone and beneath the *Prosaukia* zone. In Missouri small spherical bodies of approximately the same size are found at a definite horizon in the Derby dolomite, but dolomitization has destroyed all traces of structure. These bodies occur above the *Taenicephalus* zone, but as previously stated the *Prosaukia* zone has not been recognized in Missouri.

A further reason for correlating the Derby and Doe Run formations with the upper part of the Franconia (Hudson and Bad Axe members of the Conference classification) and with the upper half of the Wilberns is found in the presence of the *Scaevoxyra* fauna in the overlying formation in all three areas. This fauna is characterized by various species of the gastropod *Scaevoxyra* and the trilobites *Plethometopus* and *Platycolpus*. It occurs in the St. Lawrence dolomite member of the Trempealeau formation of the Conference classification, in the Potosi dolomite of Missouri, and in the basal portion of the Ellenburger limestone in sections along the Colorado River, Tex., thus serving to correlate the beds in these three areas. This same fauna has been found about 500 feet beneath the top of the Copper Ridge dolomite in eastern Tennessee.

The Trempealeau of the Conference classification is the youngest of the three formations recognized in that classification. It contains several lithologic units, many of which have been accorded formation rank by others. Most of these units contain distinctive faunas. The various classifications in current use are indicated in table 2.

<sup>7</sup> See The geology of Texas, vol. 1: Texas Univ. Bur. Econ. Geology Bull. 3232, 1932.

TABLE 2.—Various classifications of the late Upper Cambrian strata in the upper Mississippi Valley

| Kansas Geol. Soc. Conference, 1935<br>(K. G. S. Guidebook, fig. 2) |                              | Ulrich, 1935 (personal communication) | U. S. Geol. Survey (present classification) |                          | Minnesota, 1935<br>(K. G. S. Guidebook, fig. 2)  |
|--|------------------------------|---------------------------------------|---|--------------------------|--|
| Trempealeau formation  | Madison sandstone member     | Madison sandstone                     | Madison sandstone                           |                          |  |
|  | Jordan sandstone member      | Jordan sandstone                      | Jordan sandstone                            | Sandstone                | Jordan sandstone   |
|  |                              | Norwalk sandstone                     |   | Norwalk sandstone member |  |
|  | Lodi shale member            | Lodi shale                            | St. Lawrence formation                      | Lodi shale member        |  |
|  | St. Lawrence dolomite member | St. Lawrence dolomite                 |   | Mendota dolomite member  |  |
| Franconia formation  | Bad axe sandstone member     | Mazomanie formation                   |   | Shale                    | St. Lawrence formation<br>(includes at base shales and sandstones placed in underlying formations in other classifications). |

Overlying the St. Lawrence dolomite member of the Conference classification is the Lodi shale member, which carries the *Dikelocephalus* fauna, "universally (but with little justification) held to be the type fossil for the Upper Cambrian of the Pacific province."<sup>8</sup> Beds carrying this fauna are not known in Missouri and Texas. Some ascribe this absence to nondeposition of a Lodi equivalent, or to deposition and subsequent erosion, although neither region shows conclusive evidence of a hiatus between the beds carrying the pre- and post-*Dikelocephalus* faunas. An alternative interpretation is that the *Dikelocephalus* fauna is made up of forms that lived in the mud and are restricted to areas in which the deposits are shales. This explanation receives additional support from the upper Mississippi Valley, where at some places, according to Raasch,<sup>9</sup> the shales and siltstones of the Lodi shale member grade laterally into coarser clastic deposits, which have been called "Norwalk" by Ulrich, and "Jordan" by the Conference; and where this occurs the characteristic *Dikelocephalus* fauna is replaced by other forms. There are no shales in this part of the section in either Missouri or Texas, and this would explain the absence or scarcity of this fauna.

The Norwalk or lower Jordan faunas are still imperfectly known, and more detailed studies must be made before exact correlations are possible. However, Raasch<sup>9</sup> claims that all the genera described from the Eminence dolomite of Missouri<sup>10</sup> occur in the Jordan and Madison of Wisconsin. Characteristic genera among the trilobites are *Eptychaspis*, *Triarthropsis*, *Calvinella*, *Stenochilina*, and *Stenopilus*. The gastropod *Sinuopea* is sparingly represented in the Eminence and is abundant at one horizon in the Jordan; these two occurrences mark the first appearance of that genus in these two regions. Near the top of the

Eminence is a zone characterized by several large species of *Plethopeltis* and *Calvinella*, which may correspond to the Madison. Raasch records the unique trilobite *Entomaspis* from the Madison, and the same genus occurs in both the Eminence and Proctor dolomites of Missouri. The Proctor is a unit which some consider to be a distinct formation but which the writer considers to be the upper part of the Eminence formation in certain areas.

The correlation of the Eminence with a zone in the Ellenburger limestone lying above the *Scaevoxyra* zone has been established by the presence of several Eminence species in the Ellenburger, among them *Eptychaspis typicalis* Ulrich and various species of *Stenopilus* and *Plethopeltis*.<sup>11</sup>

In Wisconsin the Madison sandstone is overlain by the Oneota dolomite, of Lower Ordovician age. This formation carries a large molluscan fauna which can be divided into several faunules. It is a widespread fauna and has been recognized in practically every important area of early Ordovician rocks in North America. By means of this fauna the equivalence of the Oneota dolomite with the Gasconade dolomite of Missouri and with beds at a horizon near the middle of the Ellenburger of Texas (the so-called Gasconade faunal equivalent) has been definitely established. All stratigraphers familiar with this portion of the section agree with this correlation.

Among the characteristic gastropods that occur in the three areas under consideration are *Gasconadia putilla* (Sardeson), *Helicotoma uniangulata* (Hall), *Pelagiella paucicostata* (Calvin), and many species of *Ophileta*. The cephalopods are represented by several genera, among them *Clarkeoceras* and *Cameroceras*, and many species are common to all three areas.

Beneath the Gasconade in Missouri is another formation of Lower Ordovician age, the Van Buren, which

<sup>8</sup> Raasch, G. O., Paleozoic strata of the Baraboo area: Kansas Geol. Soc. Guidebook, Ninth Annual Field Conference, p. 407, 1935.

<sup>9</sup> Raasch, G. O., personal communication.

<sup>10</sup> See Missouri Geol. Survey, vol. 24, ch. 6, 1930.

<sup>11</sup> Dake, C. L., and Bridge, Josiah, Faunal correlation of the Ellenburger limestone of Texas: Geol. Soc. America Bull., vol. 43, pp. 730-732, 1932.

carries a fauna related to but different from that of the overlying formation. It is composed primarily of gastropods and cephalopods. Among the gastropods are numerous species of *Sinuopea* and *Schizopea*.<sup>12</sup> Among the cephalopods which appear in this formation in great abundance, various species of *Burenoceras* and *Dakeoceras* are especially characteristic. For this reason it is termed the "*Burenoceras* zone." Strata carrying this fauna are unknown in the upper Mississippi Valley and at present are only doubtfully known from Texas, though there now seems to be reason for believing that this fauna occurs in the Ellenburger limestone in strata lying between beds carrying the Eminence and Gasconade faunas. It is known to occur in the Arbuckle limestone beneath beds carrying the Gasconade fauna. The strata carrying this fauna were probably the initial deposits of the advancing early Ordovician submergence, which did not reach the upper Mississippi Valley.

The correlation of these early Ordovician zones is well established, and the chief innovation of the present correlation is the placing of the Eminence and Potosi of Missouri and their Ellenburger equivalents as correlatives of the Trempealeau formation of the Conference classification.

It has been claimed that correlations based on similar associations of genera are of little or no value, and that the only correlations that can be trusted are those founded on a comparison of finely discriminated species. It is also assumed by some that a fauna, once developed, becomes practically universal in the sea in which it lives, and that it should be present in all the strata deposited in this sea during the time this particular fauna was living. However, there are many examples on record in which strata carrying faunas far more strikingly dissimilar than the ones that are considered to be homotaxial in this paper are correlated with one another because of their stratigraphic position between strata carrying cosmopolitan faunas. Also it is well known that the sea bottom today is not uniformly and universally populated, but that it contains areas which

are crowded with living forms and other areas which are practically barren of life. It is just as logical to assume that two faunas which are for the most part specifically and even generically dissimilar can exist a few hundred miles apart in the same epeiric sea under slightly different environmental conditions as it is to invoke crustal warpings and erosion or nondeposition in order to make two very similar faunas occur in one area at one time and recur in another area at a later time. It is difficult to imagine a sea invading the continent from the southwest, as the Upper Cambrian seas are believed to have done, which would leave a series of deposits such as the Trempealeau formation (Conference classification) in the upper Mississippi Valley and at the same time fail to leave any record of its presence in any of the Cambrian areas to the south of it. It is also equally difficult to imagine how a second sea could come in from the same quarter (it must have done so, because it contains so many identical genera) and leave a second set of deposits in all the areas from which the first set were either eroded or never deposited and at the same time fail to leave a well-defined record in the one area where these earlier deposits remain. Yet these are the assumptions that must be made if the Potosi and Eminence formations of Missouri and the beds of pre-Gasconade age in the Ellenburger of Texas are to be considered as being younger than the Jordan sandstone of the upper Mississippi Valley. No one today questions the practical equivalence of the *Cedaria*, *Crepicephalus*, *Aphelaspis*, *Camaraspis*, *Eoorthis*, *Taenicephalus*, *Ptychaspis*, *Prosaukia*, lower *Dikelocephalus*, and *Gasconadia* faunas in the three areas under consideration. In view of this striking parallelism it seems more logical to the writer to regard the four known occurrences of the *Scaevogyra* fauna as a single zone instead of making the occurrence in the St. Lawrence of the Conference classification older than the other three. Similarly it seems best for the present to consider the occurrence of similar forms in the Jordan and Madison of the upper Mississippi Valley, in the Eminence of Missouri, and in the lower part of the Ellenburger of Texas as representing a single horizon instead of placing the upper Mississippi Valley forms in an earlier zone and the others in a later one.

<sup>12</sup> Butts, Charles, Geology of Alabama: Alabama Geol. Survey Special Rept. 14, p. 88, pl. 14, figs. 23, 24, 1926. The name *Schizopea* Ulrich, 1926, takes precedence over *Rhachopea* Ulrich and Bridge (Missouri Bur. Geology and Mines, vol. 24, pp. 190-193, 1930), and *S. washburnei* Butts must be regarded as the genotype.



# A REDESCRIPTION OF FERDINAND ROEMER'S PALEOZOIC TYPES FROM TEXAS

By JOSIAH BRIDGE and GEORGE H. GIRTY

## ABSTRACT

This paper presents a redescription of the types of the Paleozoic fossils from the Central Mineral Region of Texas originally described by Ferdinand Roemer in 1849 and 1852, which have long been inaccessible to American students. These descriptions are accompanied by new figures which include the type specimens, topotypes now in the United States National Museum, and the types of several other species that are now considered to be synonyms. The localities that furnished the original specimens have been reestablished within fairly narrow limits, and the stratigraphic horizons have been accurately determined. The type material has been compared with material from other parts of the United States, and the geographic range of several of the forms has been greatly extended.

## ACKNOWLEDGMENTS

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The relocation of some of the type localities and the collection of some of the topotype material was done by Josiah Bridge in 1934 in the course of an investigation aided by a grant from the Penrose Bequest of the Geological Society of America.

## HISTORY

In 1845, 1846, and 1847 Dr. Ferdinand Roemer, a noted German geologist and paleontologist, spent about 17 months traveling in the then newly annexed State of Texas, gathering scientific data, and also visiting the various German settlements to obtain information of general interest to emigrants. The greater part of this time was spent in the Coastal Plain and the Edwards Plateau, which at that time were the settled portions of the State. In the course of this trip he spent about a month in the Central Mineral Region, which was then Indian country, and he seems to have been the first geologist to recognize and describe the Paleozoic rocks in that region.<sup>1</sup>

Roemer's first account of the geology of Texas, contained in a letter written from the field to the editor of

the American Journal of Science,<sup>2</sup> makes no mention of Paleozoic rocks, but he comments on specimens of granite which had been brought to him from outcrops north of Fredericksburg.

A second preliminary paper, written after his return to Europe,<sup>3</sup> gives a brief account of his trip to the San Saba River, describes the route traveled, notes the occurrence of granite, Lower Silurian (so designated by him) and Carboniferous rocks, and gives brief descriptions of them. He mentions the occurrence of *Asaphus*, *Bronteus*, *Euomphalus*, *Spirifer*, *Productus*, and *Terebratula* but gives no descriptions. In 1849 he published a comprehensive report on his travels in Texas,<sup>4</sup> a popular account intended primarily for German emigrants. The greater portion of the book consists of the journal of his trip, together with many observations about the country, its resources and inhabitants. Chapters 19 to 22 describe his journey into the Central Mineral Region. Besides the narrative, there is an introductory chapter which gives a brief summary of the history of the State, an account of its geography, climate, agricultural and mineral resources, the history of the German settlements within the State, and a bibliography of books and other published articles relating to Texas.<sup>4a</sup>

At the end of the book there is a scientific appendix in which his geologic, zoologic, and botanic observations are collected and summarized. The Paleozoic strata of the Central Mineral Region and 11 species of fossils found in them are described. This constitutes the first published report on the Paleozoic stratigraphy and paleontology of Texas. He lists the following Paleozoic species, and describes those preceded by an asterisk. The age designations in this list are his.

1. \**Lingula acutangula*, n. sp. Silurian.
2. *Orthis*, sp. ind. Silurian.
3. *Orthis umbraculum* L. v. Buch. Carboniferous.
4. *Terebratula pugnus* Sowerby. Carboniferous.
5. \**Spirifer meusebachianus*, n. sp. Carboniferous.
6. \**Productus*, sp. ind. Carboniferous.
7. \**Productus*, sp. ind. Carboniferous.
8. \**Euomphalus polygyratus*, n. sp. Silurian.

<sup>1</sup> See Hill, R. T., The present condition of knowledge of the geology of Texas: U. S. Geol. Survey Bull. 45, pp. 15-18, 1887. Comstock, T. B., Texas Geol. Survey 1st Ann. Rept., pp. 240-241, 1889 [1890].

<sup>2</sup> Roemer, F., A sketch of the geology of Texas: Am. Jour. Sci., 2d ser., vol. 2, pp. 358-365, 1846.

<sup>3</sup> Roemer, F., Contributions to the geology of Texas: Am. Jour. Sci., 2d ser., vol. 6, pp. 21-28, 1848.

<sup>4</sup> Roemer, F., Texas, mit besonderer Rücksicht auf deutsche Auswanderung und die physischen Verhältnisse des Landes, xiv, 464 pp., Bonn, 1849.

<sup>4a</sup> In 1935 a translation of these portions of the work, by Oswald Mueller, was published in San Antonio.

9. \*Euomphalus sanctisabae, n. sp. Silurian.
10. \*Pterocephalia sanctisabae, n. sp. Silurian.
11. \*Pygidium of a trilobite, gen. and sp. unknown. Silurian.

The report is accompanied by a hand-colored reconnaissance map, which shows his interpretation of the geology of the State and also his approximate route from Fredericksburg to the San Saba River and return.<sup>4b</sup>

In 1852 Roemer's monumental work on the Cretaceous formations of Texas was published.<sup>5</sup> Although devoted primarily to the description of the Cretaceous rocks and fossils, it contains an appendix in which, among other things, are descriptions of the Paleozoic strata and fossils. In all, he describes 12 species from the Lower Silurian (so designated by him) and Carboniferous. He redescribes the five new species of the previous report and adds a sixth, assigns four forms to previously described species, and describes two trilobites without referring them to a genus. These descriptions are accompanied by a lithographed plate on which all the species described, except *Terebratula pugnus* Sowerby and *Productus cora* D'Orbigny, are illustrated. The list of species, with Roemer's age designations, is as follows:

1. \*Spirifer meusebachanus. Carboniferous.
2. \*Orthis arachnoidea Phillips. Carboniferous.
3. Terebratula pugnus Sowerby. Carboniferous.
4. \*Productus flemingii Sowerby = no. 7 in preceding list. Carboniferous.
5. Productus cora D'Orbigny = no. 6 in preceding list. Carboniferous.
6. \*Lingula acutangula Roemer. Silurian.
7. \*Euomphalus polygyratus Roemer. Silurian.
8. \*Euomphalus sanctisabae Roemer. Silurian.
9. \*Euomphalus gyroceras, n. sp. Silurian.
10. \*Pterocephalia sanctisabae Roemer. Silurian.
11. \*Cephalon and pygidium of a trilobite, genus unknown. Silurian.
12. \*Pygidium of a trilobite, genus unknown = no. 11 of preceding list. Silurian.

All these forms except no. 3 are described in detail, and those preceded by an asterisk are illustrated on the accompanying plate.

This portion of the report was promptly reviewed by Barrande,<sup>6</sup> who noted at once the twofold division of the Lower Silurian of Roemer, a fact which seemed to have escaped Roemer.

Barrande had previously examined the works of Owen and Hall and had concluded that the oldest faunas which they had obtained from the Lake Superior and New York regions were approximately the same and that they represented his Primordial (Cambrian) fauna.

<sup>4b</sup> The map is reproduced in Mueller's translation, but the text of the appendix is omitted. The existence of this translation was not known to the authors until after this paper had gone to press. All translations from "Texas" included herein are from the appendix, and all references to "Texas" apply to the original work.

<sup>5</sup> Roemer, F., Die Kreidebildungen von Texas und ihre organischen Einschlüsse, mit einem die Beschreibung von Versteinerungen aus paläozoischen und tertiären Schichten enthaltenden Anhange, und mit 11 von C. Hohe nach der Natur auf Stein gezeichneten Tafeln, 100 pp., Bonn, 1852.

<sup>6</sup> Barrande, J., Silur-Gebilde in Texas und am oberen See: Neues Jahrb., 1853, pp. 446-447.

He now compared the trilobites and the *Lingula* described by Roemer with those figured by Owen and Hall, noted the similarity of their stratigraphic position, and concluded that Roemer had found the Primordial fauna in Texas and that it was the equivalent of the lowermost Paleozoic in Wisconsin and New York. He also observed that the various species of *Euomphalus* which Roemer had described had not been found in association with the trilobites and correctly concluded that they indicated a younger fauna.

Roemer's two reports have been of great value to students of Texas geology, but they are among the rarities of early American geologic literature. As the types of the Cretaceous and Paleozoic species described in them are preserved in the Geological and Paleontological Museum of the University of Bonn and are therefore not readily accessible to American students, the precise identification of many of the species has long been a difficult matter. Notwithstanding these difficulties, the satisfactory identification of most of the Cretaceous species has long since been accomplished, but there are very few references to the Paleozoic forms except bibliographic citations. This may be due in part to the fact that, being attached to a report entitled "The Cretaceous formations of Texas," the Paleozoic species have escaped general notice, but it is largely because very little stratigraphic and paleontologic work has been done on the early Paleozoic strata of the State.

During the second half of the nineteenth century the Central Mineral Region was visited at various times by parties from the Texas Geological Survey, but, with the single exception of the work done by Shumard, no new paleontologic data were acquired. The results of these investigations have been summarized in the papers by Hill and Comstock already cited.

Actual identification of Roemer's species has been made by only a few paleontologists. Shumard, while State geologist of Texas, published a brief notice of the region in 1860<sup>7</sup> and a more detailed account the following year. In this second paper<sup>8</sup> he described the Paleozoic rocks of Burnet County in considerable detail, gave several measured sections, and described nine new species of fossils, all Cambrian. One of Roemer's unnamed trilobites was named *Dikelocephalus roemeri* by Shumard, but none of his other species were mentioned. No illustrations accompanied these figures. The types are thought to have been deposited in the Texas State collection and, if so, were destroyed when the capitol burned in 1881. In 1914 Walcott<sup>9</sup> referred *Dikelocephalus roemeri* to *Ptychoparia* without discussion, and later he made it the type species of his new

<sup>7</sup> Shumard, B. F., [On Lower Silurian in Burnet County, Tex.]: St. Louis Acad. Sci. Trans., vol. 1, pp. 672-673, 1860.

<sup>8</sup> Shumard, B. F., The Primordial zone of Texas, with descriptions of new fossils: Am. Jour. Sci., 2d ser., vol. 32, pp. 213-221, 1861.

<sup>9</sup> Walcott, C. D., *Dikelocephalus* and other genera of the *Dikelocephalinae*: Smithsonian Misc. Coll., vol. 57, no. 13, p. 352, 1914.

genus *Elvinia*.<sup>10</sup> The name was derived from the town of Elvins, St. Francois County, Mo., where the species also occurs, furnishing another example of the close geologic relationship of the two areas.

Hall and Whitfield<sup>11</sup> and Walcott<sup>12</sup> described species of *Pterocephalia* from the Eureka district, and Walcott also described additional species from China.<sup>13</sup> He also identified Roemer's type species, *P. sanctisabae*, from material collected in Burnet County, Tex., and included this identification in faunal lists without further description.<sup>14</sup> He redescribed and figured *Lingula acutangula*, the only early Paleozoic brachiopod which Roemer described.<sup>15</sup>

The foregoing references appear to be the only published identifications of Roemer's species based on specimens, and none of the authors had access to the types. In 1931 the type specimens were loaned to the United States Geological Survey through the courtesy of Dr. N. Tilman, curator of the Museum of Geology and Paleontology at the University of Bonn, and for the first time it was possible to make comparisons. These specimens and the notes accompanying them have been of great assistance, and it has been possible to identify nearly every one of Roemer's species in the National Museum and Geological Survey collections. The study of the matrix in which the types are preserved has aided materially in assigning the type specimens to their proper stratigraphic horizons.

For the various reasons stated on the preceding pages, it seems desirable to publish translations of the original descriptions and to accompany these by notes based not only on the types but also on collections in the United States National Museum and elsewhere. A translation of Roemer's remarks about the Paleozoic stratigraphy is also included, partly as a matter of general interest and partly because they contain more precise information regarding the exact localities from which his collections were made. An effort has been made to fix each locality as accurately as the statements in Roemer's text, supplemented by personal knowledge of the region, will permit.

#### ROEMER'S LOCALITIES

Roemer collected his Paleozoic fossils at five localities. Four of these are in the San Saba Valley, and the fifth is somewhere on the great limestone plateau that

forms the north border of the granite area in Llano County. An effort has been made by Bridge to reestablish these localities in order to secure topotype material. A study of Roemer's narrative, followed by field investigations in the fall of 1934, has enabled this to be done with a reasonable degree of certainty for four of the localities.

It is a fairly safe assumption that the present roads were established along former Indian trails, and that many of them have not been materially relocated. This is particularly true of the principal crossings of the larger rivers, the greater number of which are still unbridged.

Roemer states that his party traveled northwestward from Fredericksburg a distance of about 80 miles to reach the San Saba River. In so doing, it seems fairly certain that he followed the approximate course of the present Fredericksburg, Mason, and Brady highway to a point near Mason and then took a more northerly direction, reaching the San Saba Valley in the vicinity of Voca. The distance which he gives is somewhat greater than that of the present route, but it must be remembered that all of his mileage is estimated, and also that he must have done considerable meandering to and fro to get over some of the rougher parts of the country. His brief descriptions of the geology along this route tally very well with present observations. He speaks of passing directly from the Cretaceous rocks onto a sandstone (Trinity or Hickory, or both), and from this onto the granite, without noting the presence of the "Silurian" (Cap Mountain, Wilberns, and Ellenburger) limestones, before reaching the Llano River. These conditions exist along the general course of the Fredericksburg-Mason road. The Cambrian limestones, though not entirely missing, are strongly overlapped by the Cretaceous rocks and are easily overlooked.

Roemer states that after crossing the Llano River his party traveled over granite for about 20 miles and then crossed a long, narrow, steep-sided eastward-trending ridge of limestone<sup>16</sup> which rested upon the granite, and that in another 12 miles they reached the San Saba River. This ridge is plainly the long tongue of Cambrian and Cretaceous rocks that crosses the present highway about 6 miles north of Mason. He makes no comment about the age of the limestones in this ridge at this point in the narrative, but in another place<sup>17</sup> he states that the first Silurian limestones were observed on the journey between the Llano and San Saba Rivers; he notes they were full of trilobite remains but does not state that any of his specimens came from this place. He does not mention the overlying Cretaceous rocks at this point, but he probably observed them. About the only place where he could

<sup>10</sup> Walcott, C. D., Cambrian and Lower Ozarkian trilobites: Smithsonian Misc. Coll., vol. 75, no. 2, p. 56, 1924; vol. 75, no. 3, pp. 88, 89, 1925.

<sup>11</sup> Hall, James, and Whitfield, R. P., U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 221, pl. 2, figs. 4-7, 1877.

<sup>12</sup> Walcott, C. D., Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, pp. 58, 59, pl. 9, fig. 21, 1884.

<sup>13</sup> Walcott, C. D., Cambrian faunas of China: U. S. Nat. Mus. Proc., vol. 29, pp. 67, 68, 1905; Smithsonian Misc. Coll., vol. 57, no. 4, p. 80, pl. 14, fig. 12, 1911; Carnegie Inst. Washington Pub. 54, vol. 3, pp. 146, 147, pl. 14, figs. 4, 5, 8, 1913.

<sup>14</sup> Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, p. 212, 1912.

<sup>15</sup> Walcott, C. D., Cambrian Brachiopoda, *Obolus* and *Lingulella*, with description of new species: U. S. Nat. Mus. Proc., vol. 21, no. 1152, pp. 392-394, pl. 28, 1898; Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 474-476, pl. 17, figs. 1, 1a-o, 1912.

<sup>16</sup> Roemer, F., Texas, p. 289, 1849.

<sup>17</sup> Idem, p. 388.

have found Cambrian limestones along this route between the Llano and San Saba Rivers is on the south side of this ridge where the present Mason-Katemcy road crosses it. Elsewhere along this same ridge the Cretaceous rests on granite, so that it seems fairly certain that he crossed it at about this point. After crossing the ridge, the party seems to have turned slightly east of north, reaching the San Saba River somewhere between Voca and the mouth of Lost Creek. After halting here for a day they crossed the river, made two short marches along the north bank, and made their third camp in the San Saba Valley at a point said to be about 14 miles upstream from the point at which they had first reached the river. They were probably close to Camp San Saba, although the distance that Roemer gives is too great. All the Cambrian species which Roemer describes were collected while at this camp. The greater part of these Cambrian fossils come from the *Camaraspis* zone, which occurs in the lower portion of the Wilberns formation. This zone is exposed along the San Saba River about a mile east of the present highway crossing, at a ford, and as this is the only place in this part of the San Saba Valley where this zone is exposed, it seems certain that Roemer must have obtained his fossils from this particular belt of outcrop. In 1934 Bridge collected *Pterocephalia sanctisabae*, *Elvinia roemeri*, and other characteristic species from beds exposed at water level on the north side of the San Saba River just below the ford half a mile northeast of Camp San Saba and 1 mile east of the new bridge on United States Highway 385 (pl. 66, B). Five or six feet above this zone are beds carrying *Eoorthis remnichia texana* in great abundance, which may be the "form similar to *Orthis*" that he mentions. The lithology of the beds carrying *Pterocephalia* is identical with that of the fragment containing Roemer's types.

The expedition continued along the north bank of the river until it reached the old Spanish mission and fort near the present town of Menard (pl. 66, A) and after spending a day or so in that neighborhood crossed the river and returned along the south bank. Roemer noted the occurrence of Carboniferous strata about 15 to 20 miles downstream from the fort and one Carboniferous species, *Spirifer meusebachanus*, was collected here from beds now placed in the Canyon group.<sup>18</sup> He also obtained two "Silurian" species, *Eccyliomphalus gyroceras* and *Ophileta polygyrata*, from this same general locality.

In 1934 Bridge collected *Eccyliomphalus gyroceras* and *Ophileta polygyrata* from the white limestone that forms the base of the Ellenburger limestone in this area, in a small ravine on the south side of the San Saba River half a mile east of the north-south highway that parallels the Mason-Menard County line. These species are abundant at this place and were found at

several places between this ravine and the ford at the Blockhouse ranch, about a mile farther east (downstream), and the lithology of the strata containing them is similar to the matrix of Roemer's specimens. These are the most westerly exposures of this part of the Ellenburger in the San Saba Valley, and, as they are at about the proper distance downstream from Menard, it would seem that Roemer's specimens came from this general locality.

The remaining "Silurian" specimen, *Lecanospira sanctisabae*, was collected on the first day of the return journey from the San Saba Valley. The party had followed the river downstream, past the point where they first reached it, until the valley reentered the Carboniferous rocks. They seem to have reached a point a few miles west of the present town of San Saba. Here they turned almost due south and returned to Fredericksburg. Although Roemer describes the route fairly well, there are no conspicuous landmarks along it which enable it to be located exactly. However, they must have crossed the great plateau formed by the Ellenburger limestone, which bounds the granite area on the north, on about the line of the present Pontotoc-San Saba road. *Lecanospira sanctisabae* is a characteristic fossil in beds of Roubidoux age in the Ellenburger, and specimens have been collected at this horizon along the above-mentioned road on the divide at the headwaters of Wallace Creek, latitude 31°06', longitude 98°51'.<sup>19</sup> This is probably the belt from which Roemer's specimens came, but the exact locality is of course uncertain. The fifth locality, which is the one from which the greater number of Carboniferous specimens came, has not been definitely located. The narrative places it near the site of their last camp in the San Saba Valley, about 35 miles downstream from the spot where the Cambrian collections were made. This would place it somewhere in the vicinity of San Saba. It is described as being in a small tributary valley on the left bank of the river.

#### ROEMER'S OBSERVATIONS ON THE PALEOZOIC STRATIGRAPHY OF TEXAS

Roemer's observations on the Paleozoic stratigraphy of Texas are brief. In the following translations, page references in parentheses refer to other portions of the original text, and phrases in brackets are interpolations by the present writers that are necessary in order to clarify certain statements:

##### THE OLDER OR PALEOZOIC ROCKS

In this broad region, the northwestern portion of which is covered by Cretaceous rocks, there is a relatively small area on the right bank of the Colorado River between the Pedernales and San Saba Rivers in which ancient stratified and massive crystalline rocks occur. Rocks of this type were first observed on the journey northward from the Llano to the San Saba River. These are impure, crumbly, partly crystalline gray limestones

<sup>18</sup> Roemer, F., Texas, pp. 314, 420, 421, 1849; Kreidebildungen, pp. 7, 88, 1852.

<sup>19</sup> See soil map of San Saba County, U. S. Dept. Agr., Bur. Soils, 1916.

in horizontal or gently tilted strata. They are surrounded by [rest on] granite. They are full of organic remains, the most abundant and characteristic of which are various species of trilobites. A few specimens of *Orthis* were also noted.

This same impure gray crystalline limestone was also observed in the valley of the San Saba River about 40 English miles below the old Spanish fort (p. 299). Here [also] trilobites are the most abundant fossils. One of these in particular (*Pterocephalia sanctisabae*, n. sp.) is readily distinguished from all known trilobite genera by broad leaf-like expansion [of the margins] of the cephalon and pygidium. The trilobites, although differing from known genera, are more closely related to Silurian types than to those of any other period of the Paleozoic. Associated with these trilobites are an *Orthis* and a species of *Lingula* (*L. acutangula*, n. sp.).

Farther upstream in the San Saba Valley a hard yellowish-gray limestone was found overlying [the trilobite beds]. From the few fossils which were obtained from it, it must also be of Silurian age.

Rocks that must be of Silurian age were also found downstream from the first-mentioned locality. This is a very tough, cherty limestone, filled with small quartz druses, and at this locality it forms barren, stony heights on both sides of the river (p. 317). Almost no fossils were observed, except a form of *Euomphalus* (*E. sanctisabae*, n. sp.), and this is different from most of the known Silurian species.

Another division of Paleozoic rocks was also found in association with the Silurian rocks in the San Saba Valley.

About 60 English miles below the old Spanish fort, in a small valley tributary to the San Saba, are strongly upturned ledges of a hard, black, massive limestone which contain large kidney-shaped masses of dark chert. This limestone is profusely fossiliferous, and the fossils show plainly that it is of Carboniferous age (p. 318). The most abundant fossil is a small species of *Productus* which, if not identical with, is at least very closely related to a form found abundantly in the Carboniferous limestone of Illinois. Associated with this species is *Orthis umbraculum* L. v. Buch (*Spirifera crenistriata* Sowerby), *Terebratula pugnus* Sowerby, and a finely striated *Productus* closely related to *P. cora* D'Orbigny. A single hand specimen of this limestone which I brought back with me resembles the black limestone of Visé so closely in its outward appearance as to be easily confused with it.

About 20 miles below the old Spanish fort a gray limestone containing large masses of black chert was found on the right bank of the river. From this several specimens of a *Spirifer* (*S. meusebachanus*, n. sp.) were collected. This species with its many divided and fasciculated ribs is a distinctive Carboniferous form and in many ways is most closely related to *Spirifer tasmani* Morris,<sup>20</sup> from Van Diemen's Land [Tasmania].

This universal distribution of species of the Carboniferous period even to the remotest portions of the earth furnishes a new illustration of the lack of climatic differences in the ancient geologic periods.

Not a trace of Devonian strata was found, and this is in complete accord with other observations. For example, as far as is known, there are no strata of Devonian age in that portion of North America which is west of the Mississippi River. This is particularly true along the Meramec River in Missouri, where, without a single exception, the Carboniferous limestone rests directly on Silurian strata. This is proved by the faunas of the two series of ancient rocks, which contain nothing that could be interpreted as the equivalent of the Devonian period.

The most westerly point at which rocks of the Devonian period are definitely known is at the Falls of the Ohio at Louis-

ville. At this place they are so thin and so closely related to the underlying Silurian by rocks which from their fossil content may be regarded as a transition series that their complete disappearance farther west is already indicated to a certain degree.—Texas, pp. 388-390, 1849.

#### OLDER OR PALEOZOIC ROCKS

No rocks belonging to the periods immediately preceding the Cretaceous are known in Texas. This applies in particular to the Jurassic formations, whose absence throughout the entire continent of North America was pointed out many years ago by Leopold von Buch, and of which not a trace has been definitely reported as a result of several investigations since that time. [A long footnote summarizes the results of these investigations.]

Just a little is definitely known of the occurrence of Triassic strata in Texas. The single observation on the rocks on the upper course of the Red River, in Falconer's journal,<sup>21</sup> indicates that possibly these rocks belong to this period. On the upper course of the Red River and westward from the Wichita River this traveler found strata of red sandstone interbedded with fibrous gypsum covering a broad area. Later on, in going westward from Cross Timbers, he observed the deep-red color of the water and the sand in all the rivers and brooks which he crossed, also a noticeable salt content in all standing and running water. The red color and salt and gypsum content of the rocks on the upper part of the Red River, which undoubtedly owes its name and color to them, may also serve to show its equivalence with the Bunter sandstone of Europe. However, such correlations, based entirely on lithologic observations and without knowledge of stratigraphic relationship and contained fossils, are always untrustworthy.

On the other hand, rocks of the older or Paleozoic period are definitely known in Texas. Not only Silurian strata but also those belonging to the Carboniferous have been definitely recognized by their paleontologic character. The older rocks are found in the mountainous portion of Texas, particularly in the region between the Llano and San Saba Rivers. They occur here together with massive crystalline rocks in a few comparatively small areas and appear to be completely encircled by Cretaceous rocks.<sup>22</sup>

1. In the region between the Llano and San Saba Rivers the first Silurian rocks were seen about 70 English miles northwest of the German settlement of Fredericksburg, on the Pedernales. At this place they are completely surrounded by granite and occur in a very narrow tongue of land extending from west-southwest to east-northeast. The rock is an impure, partly crystalline, much weathered and decomposed limestone in slightly dipping or almost horizontal layers. It is completely filled with the head and tail shields of characteristic trilobites. This same impure limestone was also found in the San Saba Valley about 40 miles below the old Spanish fort (Texas, p. 299). Here also the strata are essentially horizontal. The limestone contains many green grains of iron silicate. Although firm and compact while in the ledge, the strong crystalline structure of the rock causes the surface of broken fragments to crumble readily. The entire mass of the limestone is filled with countless detached trilobite shields, almost to the total exclusion of other organic remains. These trilobites appear to belong to genera and species which, while different from known forms, most closely resemble Silurian types. From the confused mass of fragments the following species can be separated:

<sup>20</sup> See Buch, L. v., Die Bäreninsel, nach Keilhau geognostisch beschrieben, p. 11, figs. 3a, b, Berlin, 1847.

<sup>21</sup> Falconer, Thomas, Notes on a journey through Texas and New Mexico in the years 1841 and 1842: Royal Geog. Soc. London Jour., vol. 13, p. 210, 1842.

<sup>22</sup> The distribution of these older rocks is shown on the geologic map that accompanies the general report on Texas. The boundary between the Carboniferous and Silurian strata is not shown, the few poor observations available not being sufficient to permit this being done.—J. B.

(1) *Pterocephalia sanctisabae*, n. sp. A species that is readily distinguished from other trilobites by the remarkable leaflike expansion of the cephalon and pygidium.

(2) Pygidium of an otherwise unknown form which is remarkable because of the great height of the axis.

(3) Pygidium and cephalon of a species which resembles *Calymene* in the lateral notching of the glabella but which, however, belongs to an entirely different genus.

The only other fossils found here were a *Lingula* (*L. acutangula*, n. sp.) related in shape to *L. cuneata* Hall, from the Medina sandstone of Silurian age at Lockport, N. Y., and an *Orthis* closely resembling *Orthis testudinaria* Dalman.

Lastly, there is another stratigraphic series which is to be classified as Silurian. This is a white or bright-gray, tough, cherty limestone containing many small quartz druses. It forms the barren rock-strewn uplands that are found along both sides of the San Saba River in the middle portion of its course (Texas, p. 317). The only fossil that was observed in great abundance was a species of *Euomphalus* (*E. polygyratus*, n. sp.)<sup>23</sup> but this does not definitely determine the Silurian age of these rocks, because, on the one hand, the *Euomphalus* shows great differences from known Silurian species, and, on the other hand, the petrographic character of the rock gives no suggestion that they belong to any other portion of the older rocks.

2. Carboniferous limestone was definitely recognized at two places in the San Saba Valley. The first locality was about on the right bank of the river about 20 miles below the old Spanish fort (Texas, p. 314). In this locality it consists of a well-stratified tough yellowish-gray limestone which contains large masses of black chert. Its identification as Carboniferous is determined particularly by the presence of a *Spirifer* (*S. meusebachanus*, n. sp.) which belongs to a group of Carboniferous species distinguished by the fasciculate arrangement of the ribs and which is very closely related to another *Spirifer* (*S. tasmani* Morris) from Van Diemen's Land.

The Carboniferous was just as definitely identified at a second locality farther down the valley and about 60 miles below the old Spanish fort (Texas, p. 389). In a small tributary valley on the west side of the San Saba River are heavy, steeply dipping ledges of tough black limestone containing streaks of dark chert a foot in thickness. This limestone is rich in fossils, among which the following species were recognized:

*Productus flemingii* Sowerby, especially abundant.

*Productus cora* D'Orbigny.

*Terebratula pugnus* Sowerby.

*Orthis arachnoidea* Phillips.

These fossils leave no doubt as to the age of this rock. A single fossiliferous fragment of this limestone which I brought back with me resembles hand specimens of European Carboniferous limestones and is hardly to be distinguished from those from Visé, on the Maas. \* \* \*—Kreidebildungen, pp. 86–87, 1852.

#### DESCRIPTION OF SPECIES

The material received from Bonn consists of 20 lots, numbered 1 to 20. These numbers have nothing to do with the numbers assigned to the specimens in either of Roemer's papers. Each lot consists of a single fragment of rock containing one or more fossils, except lot 4, which contains two fragments. Each lot is accompanied by a label giving the name and many of them other information about the specimen. These

<sup>23</sup> Evidently a misprint. *E. sanctisabae* is elsewhere said to be abundant here. *E. polygyratus* was said to have been collected some 40 miles or so farther southwest, and Roemer notes that only a single specimen was obtained. (See Texas, pp. 314, 421; also Kreidebildungen, pp. 91, 339.)—J. B.

notes show which specimens served as the principal sources of the original illustrations, which were used to supply supplementary details, and which were considered by Roemer to be the types. This information has been incorporated in the revised descriptions.

#### CAMBRIAN SPECIES

By JOSIAH BRIDGE

#### BRACHIOPODA

##### *Lingulepis acutangula* (Roemer)

Plate 67, figures 10a, b; plate 68, figures 1–6

1849. *Lingula acutangula* Roemer, Texas, p. 420.  
 1852. *Lingula acutangula* Roemer, Die Kreidebildungen von Texas, p. 90, pl. 11, figs. 10a, b.  
 1852. *Lingula pinnaformis* Owen, Geological Survey of Wisconsin, Iowa, and Minnesota, p. 583, pl. 1b, figs. 4, 6, 8. (For synonymy of *Lingulepis pinnaformis* see Walcott, U. S. Geol. Survey Mon. 51, pp. 545–546, 1912. The following citations refer only to Roemer's types and to forms identified as *L. acutangula*.)  
 1889. *Lingula acutangula*. Miller, North American geology and paleontology, p. 349.  
 1897. *Lingulepis acutangulus*. Schuchert, U. S. Geol. Survey Bull. 87, p. 259 (generic reference).  
 1933. *Lingulella acutangula*. Bridge, in Sellards, Adkins, and Plummer, Texas Univ. Bull. 3232, p. 231, pl. 2, fig. 9 [not fig. 8]. (No description; fig. 9 is the holotype.)  
 Not 1898. *Obolus* (*Lingulella*) *acutangulus*. Walcott, U. S. Nat. Mus. Proc., vol. 21, pp. 392, 394, pl. 27, fig. 6, pl. 28, figs. 1, 2.  
 Not 1912. *Lingulella acutangula*. Walcott, U. S. Geol. Survey Mon. 51, p. 474, pl. 17, figs. 1, 1a–1o.  
 Not 1931. *Lingulella acutangula*. Dake, Missouri Bur. Geology and Mines, 2d ser., vol. 23, pp. 61, 86, 87, 96 (cited in faunal lists).

#### ORIGINAL DESCRIPTIONS

1. *Lingula acutangula*, n. sp. Shell ovate, subtriangular, produced anteriorly into an acute beak, posteriorly rounded.<sup>24</sup> Allied to *L. cuneata* Conrad (see Hall, Geology of New York, pt. 4, pl. 1, no. 2, fig. 5), from the Medina sandstone at Lockport. From the gray Silurian limestone with abundant trilobite remains at the locality described on page 299.—Texas, p. 420.

##### 6. *Lingula acutangula*

Plate 11, figures 10, 10a, 10b

*Lingula acutangula* F. Roemer, Texas, p. 420.

Length 8", width 6"

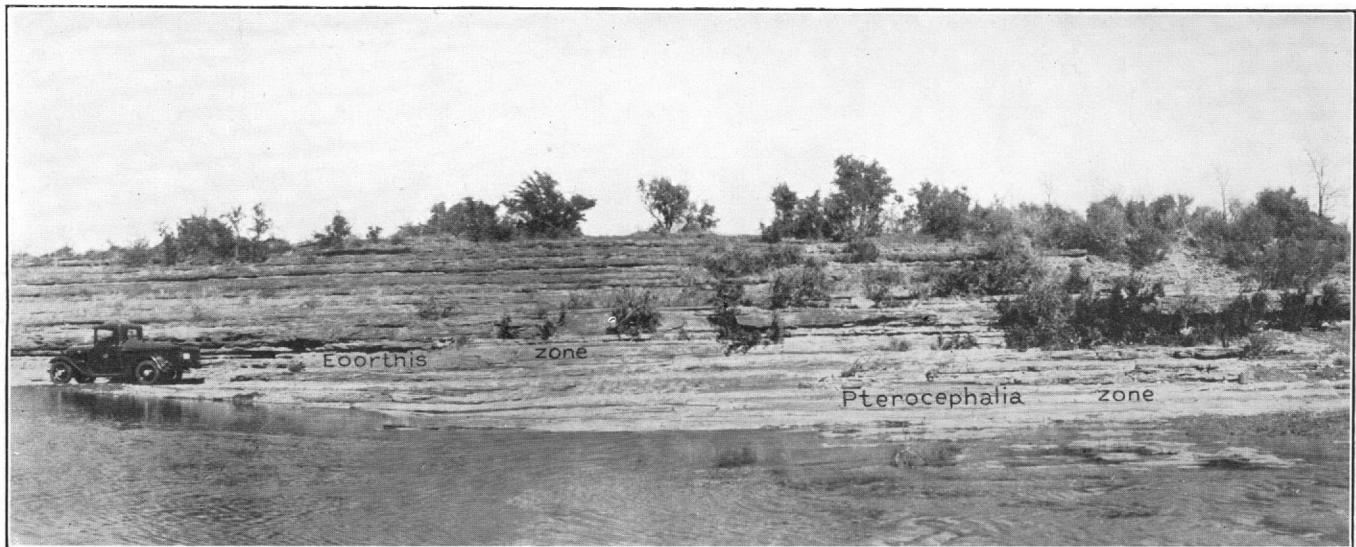
Shell ovate, subtriangular, short, slightly convex, the posterior end rounded, the anterior end produced into a narrow beak. The shell is oval, almost triangular, short, slightly convex, posteriorly rounded, the anterior end drawn out into a sharply pointed beak.

At a few places on the upper surface of damaged shells one can plainly see the laminated structure of the shell, which is made up of thin plates laid one above the other. The chitinous condition, which is characteristic of the genus and which is usually well preserved, is less commonly shown.

<sup>24</sup> In all descriptions the portions in italics are in Latin in the original texts. Phrases in brackets indicate additions and interpretations by the translator.



A. RUINS OF THE MISSION SAN SABA, "THE OLD SPANISH FORT" OF ROEMER, ABOUT A MILE WEST OF MENARD, TEX.



B. LOWER PART OF THE WILBERNS FORMATION ON NORTH BANK OF SAN SABA RIVER AT FORD HALF A MILE EAST OF HIGHWAY BRIDGE AT CAMP SAN SABA.



In its outward appearance this form resembles *Lingula cuneata* Conrad (see Hall, Geology of New York, pt. 4, pl. 1, no. 2, fig. 5), from the Medina sandstone at Lockport. However, when compared with specimens of the New York form which are before me, it is to be distinguished by its much sharper beak.

**Occurrence:** Common in the gray, brightly crystalline Silurian limestone, with abundant trilobites in the San Saba Valley.

**Description of the figures:** Figure 10a, view of the outer surface; figure 10b, profile view.—Kreidebildungen, p. 90.

#### NOTES ON THE TYPE SPECIMEN

A comparison of the type specimen with the types of the well-known *Lingulepis pinnaformis* (Owen) shows plainly that they are the same species, and as Roemer's name has priority, *L. pinnaformis* (Owen) becomes a synonym of *L. acutangula* (Roemer).

Roemer's material consists of a single imperfect specimen (no. 20) on a fragment of gray, coarsely crystalline glauconitic limestone. The matrix is identical with that in which the trilobites are preserved. It also contains a few fragments of trilobite tests, none of which are complete enough for identification.

The specimen is a somewhat exfoliated ventral valve, which lacks the extreme tip of the beak and most of the anterior and left anterolateral margin. In its present condition it is 16 millimeters long and 13 millimeters wide, but when complete its dimensions must have been approximately 19 by 16 millimeters. These measurements agree very closely with Roemer's (8 by 6 lines) and constitute additional evidence in support of the idea that this was his type specimen.

The original figure (pl. 67, fig. 10a), is much narrower than the type specimen and shows a sharp angulation at the junction of the anterolateral and posterolateral margins, which does not exist on the type specimen. In view of these differences it is not at all surprising that this species has been misidentified by subsequent workers. The convexity of the valve is 2.8 millimeters.

The anterior end of the shell, to judge from the course of the growth lines, was evidently rather blunt and broadly rounded, the anterior margin passing into the anterolateral margins without any sharp angulation.<sup>25</sup> The posterolateral margins are slightly concave and meet at the beak in an angle of 78°. Where the outer surface is preserved, it is ornamented by fine, concentric, somewhat irregular growth lines.

The shell itself is about 0.2 millimeter thick and is composed of white crystalline calcite. The inner surface, where exposed by the exfoliation of the shell, is marked by strong radiating ribs, crossed by heavier, widely spaced concentric lines. In the middle of the shell about three of the ribs occur in the space of 1 millimeter, whereas the concentric lines are spaced about 1 millimeter apart. Both sets become more closely spaced toward the beak. The muscle scars are not exposed.

<sup>25</sup> In Roemer's description the terms "anterior" and "posterior" are used in the opposite sense from present usage.

When compared with the types of *Lingulepis pinnaformis* the similarity of form and size is at once apparent. The outline of the valve and the relative proportions are practically identical. Roemer's specimen is slightly larger than the largest of Owen's types (pl. 68, fig. 6), but specimens of this size are common in areas where the species is abundant. The measurements of three ventral valves among Owen's types are, length, 16, 15.5, and 13 millimeters; width, 12.5, 13, and 11 millimeters; convexity, 2.2, 2.2, and 2 millimeters. These specimens also display the faint radial internal markings which show so plainly on Roemer's specimen.

The surprising thing about this identification is the fact that *Lingulepis pinnaformis* has not been recorded from Texas. Walcott records *L. acuminata* (which he considered to be the same as *L. pinnaformis*) from four localities in the Central Mineral Region and also from El Paso.<sup>26</sup> None of these appear to belong to *L. acutangula*; in fact, they are all narrower and more sharply acuminate than the forms which he referred to this species. Nor does the species appear in any of the collections made by Dake and the writer.

The species has been identified in a collection from the Hickory (?) sandstone<sup>27</sup> at a point about a quarter of a mile east of Sandy post office, Blanco County. Most of the material from this locality is fragmentary, but several good specimens that agree very closely with Roemer's specimen were obtained. The species is evidently not common over the entire area, but it may be locally abundant, as in this locality.

#### COMPARISON WITH OTHER SPECIMENS REFERRED TO LINGULEPIS ACUTANGULA

There have been few references to this species. Schuchert changed the generic reference to *Lingulepis* but did not discuss the species. In 1898 Walcott referred to the species and published illustrations of a Texas form which he identified as *Lingulella acutangulus*. In his monograph on Cambrian Brachiopoda Walcott describes this species in detail and illustrated it with a plate containing not only the illustrations of his previous paper but also many others. All these specimens came from three localities in the Central Mineral Region, and it is extremely abundant in these localities and many others in that area.

The most obvious difference between this form and Roemer's specimen is in the proportion of length to width. In Roemer's specimen this is approximately 10 : 8.5, but in Walcott's specimens it averages 10 : 6.75. All of Walcott's specimens, both figured and unfigured, are smaller than Roemer's. The largest specimen (Mon. 51, pl. 17, fig. 1e) is 14.5 millimeters long. Another specimen (pl. 17, fig. 1) is nearly as large, but

<sup>26</sup> Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 544-550, pl. 42, figs. 1k-1o, 1912.

<sup>27</sup> These outcrops have not been visited, and it is not definitely known whether they are actually Hickory or the Lion Mountain sandstone member of the Cap Mountain.

the average length of the ventral valve is between 9 and 10 millimeters.

Edwards,<sup>28</sup> who has restudied nearly all of Walcott's material in preparation of a monograph on the Cambrian brachiopods of Wisconsin, refers *Lingulella acutangula* Walcott to *L. arguta* Walcott, and this seems to be the correct assignment. The various references to *L. acutangula* subsequent to the publication of Walcott's monograph (with the exception of fig. 9, pl. 2, Texas Univ. Bull. 3232, 1933) are also assignable to *L. arguta*.

It is entirely possible that the very broad forms which are here designated *Lingulepis acutangula* represent the extremely mature stage of a form that is somewhat narrower in the normal adult stage, for the successive growth increments tend to increase the width of the shell more rapidly than the length. If this is true, both types should be found more or less intimately associated at all localities. This is not the case. *Lingulepis acutangula* is not a common form. It is not common at any of the Cambrian localities in central Texas that have been examined, and as yet it has not been found in association with a narrow form such as *L. arguta*. On the other hand, where it is extremely abundant, as for example in the Eau Claire formation of southern Wisconsin, it fills certain strata to the almost total exclusion of other forms. A certain amount of individual variation is observable when large numbers of specimens belonging to this species are compared, and it is quite possible to divide them into several groups that might be termed species or varieties, but such a course would serve no useful purpose, as it would have neither stratigraphic nor geographic significance.

#### OCCURRENCE

The type specimen came from the San Saba Valley at a point about half a mile east of Camp San Saba, McCulloch County. The horizon is basal Wilberns. The species also occurs in a sandstone thought to be the Hickory in the valley of Hickory Creek about a quarter of a mile east of Sandy post office, Blanco County.

"*Orthis*" sp. undet.

#### ORIGINAL DESCRIPTION

2. *Orthis* sp. ind. Related to *O. testudinaria* Dalman. Found in association with the foregoing species [*L. acutangula*].—Texas, p. 420.

#### REMARKS

This form was neither described nor figured in the Kreidebildungen, although it is mentioned at several places. No specimens answering to its description were included in the shipment from Bonn. Roemer evidently had in mind one or more of the coarsely ribbed brachiopods such as *Billingsella coloradoensis*,

<sup>28</sup> Edwards, Ira, unpublished manuscript.

*Eoorthis Wichitaensis*, *E. indianola*, or *E. remnichia texana*, all of which are more or less abundant in the Upper Cambrian of this area. According to Walcott's faunal lists, *B. coloradoensis* is almost invariably associated with *Lingulella arguta*,<sup>29</sup> whereas the other forms occur at a higher horizon, in the base of the Wilberns formation. *Eoorthis remnichia texana* is extremely abundant at the locality east of Camp San Saba in a bed about 5 feet above the beds carrying *Pterocephalia*.

#### TRILOBITA

##### Genus PTEROCEPHALIA Roemer

###### *Pterocephalia sanctisabae* Roemer

Plate 67, figures 1a-d; plate 68, figures 7-43

- 1849. *Pterocephalia sanctisabae* Roemer, Texas, p. 421.
- 1852. *Pterocephalia sanctisabae* Roemer, Die Kreidebildung von Texas, p. 92, pl. 11, figs. 1a-d.
- 1877. *Conocephalites (Pterocephalus) laticeps* Hall and Whitfield, U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 226, pl. 2, fig. 37.
- 1884. *Ptychoparia (Pterocephalus) laticeps*. Walcott, Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, p. 59.
- 1889. *Pterocephalia laticeps*. Miller, North American geology and paleontology, p. 564.
- 1889. *Pterocephalia sanctisabae*. Miller, idem, p. 564.
- 1933. *Pterocephalia sanctisabae*. Bridge, in Sellards, Adkins, and Plummer, Texas Univ. Bull. 3232, p. 232, pl. 2, figs. 26, 27. (Types refigured without description.)

#### ORIGINAL DESCRIPTIONS

10. *Pterocephalia sanctisabae*, n. sp. This species undoubtedly belongs to a new genus which I here name *Pterocephalia* on account of the remarkable extremely thin, leaf-like expansion of the cranidium. The diagnosis of this form is as follows: Head expanded in a leaf-like plate in front and on both sides of the glabella. Glabella with four incised furrows on each side; tail bordered by a broad, rounded, leaf-like depressed margin.

The thorax is not known, and therefore association of this pygidium and cranidium is questionable; however, on account of the analogous structure of the two it is extremely probable.

This species is widely separated from all other known trilobites by this leaf-like expansion of the cranidium and pygidium. It is common in a gray Silurian limestone at the locality previously described on page 299.—Texas, p. 421.

This preliminary description was greatly expanded in the "Kreidebildungen" and was accompanied by several excellent illustrations.

###### 10. *Pterocephalia sanctisabae*

Plate 11, figures 1a-d

*Pterocephalia sanctisabae* F. Roemer, Texas, p. 421.

Certain weathered layers of gray limestone outcropping in the San Saba Valley are filled with trilobite remains to the almost total exclusion of other types of animal life. Noteworthy among these is a cephalon which appears here for the first time and which does not seem to be related to any known genus of trilobites. It differs especially in the very wide, leaf-like, thin expansion of the

<sup>29</sup> Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 212-213, 1912.

anterior portion of the cephalon. A careful examination has made it possible to determine the generic characters of the trilobite to which this head belongs. A pygidium is also referred to the same genus with a considerable degree of certainty. The reason for including this pygidium in the genus lies in the analogous broad, leaf-like expansion which it possesses, in the large number of pygidia which are found, and in the absence of any other cephalon in these strata with which it could be associated.

The cephalon figured on plate 11, figures 1a and 1b, which is one of four identical specimens now before me, will be described first. On the whole it is very flat, in the anterior portion somewhat concave. The length is somewhat greater than the width, but in regard to this statement it should be borne in mind that the free cheeks which lie outside of the facial suture are missing on all the examples before me. The glabella narrows anteriorly and is not half as long as the cephalon. On the sides it is separated from the fixed cheeks by a clearly defined furrow. At the anterior end it is separated from the broad winglike anterior expansion of the cephalon by a shallow furrow, ornamented with many small, delicate radial wrinkles. The occipital furrow is well developed and is deeper on the sides than in the middle. On each side are two sharp glabellar furrows directed posteriorly, which do not join across the center but which occupy about one-third the width of the glabella. There is also a third pair, which are weaker, shorter, and almost horizontal. The center of the occipital ring is raised into a short blunt knob.

The fixed cheeks on each side of the glabella are strongly arched from the margin of the glabella to the facial suture. The course of the facial suture is not as plain as is indicated in the figure. A somewhat elevated and prominent portion of the border is to be considered as the palpebral lobe—that is, that portion of the cranidium which carries the eye tubercles. The free cheeks are not known, but from the shape of the cranidium and the width of the pygidium assigned to it they are thought to be narrow and do not essentially affect the shape of the cranidium. The occipital furrow on the fixed cheeks is plainly visible but is not as deep as it is upon the glabella. The broad, flat, leaf-like expansion on the anterior portion of the cranidium is almost plane but is slightly concave from the anterior to the posterior end. The semicircular anterior margin has a fine raised line parallel to it at a distance of about one line. The upper surface of this leaf-like expansion as ordinarily preserved is smooth, but in a single specimen in which the outer shell layer is largely destroyed the surface is covered with very fine, sharp, anastomosing raised lines, similar in character to those which are found in many other trilobite genera—for example, *Bronteus*. No traces of the dorsal furrow that bounds the glabella are to be found on this leaf-like expansion. When the cephalon just described is compared with the typical trilobite head, it appears that the entire leaf-like expansion of the anterior portion of the cephalon must be regarded as an extraordinary widening of the frontal border (*limbus*), for there is nothing else except the frontal border in front of the sharply defined glabella.

The pygidium assigned to the cephalon just described possesses the following characteristics. It is semicircular, with the anterior corners rounded, the anterior and central portions strongly elevated, while the lateral and posterior edges are extended into a smooth, broad, paper-thin lamella. The axis, which is small in comparison to the entire pygidium, narrows posteriorly and terminates slightly beyond the half-length of the pygidium. It is strongly elevated, almost half-cylindrical, and carries 9 to 10 well-marked annulations. The upper surface of the pygidium slopes away from both sides of the axis gradually at first and then descends steeply to the flat marginal expansion. The elevated lateral slopes of the pygidium lying next to the axis are ornamented with slightly raised, gently curving pleurae, one for each segment of the axis. They

flatten out and vanish when they reach the flat marginal expansion. This flattened marginal border of the pygidium is ornamented with extremely fine, sharp, raised lines similar to those found on the anterior border of the cephalon. It is otherwise smooth.

Little is known of the thorax, at least in association with either the cephalon or the pygidium. In one piece of rock a single incomplete segment which probably belongs to this form has been found lying close to the cephalon. It is thin, very smooth, 1.5 lines wide, weakly arched, and the ends are blunt and obliquely truncate.

From the foregoing description, the generic characters may be summed up as follows:

*Pterocephalia*,<sup>30</sup> n. gen.

*Head semicircular, thin, almost plane, the portion lying in front of the glabella expanded into a long thin lamina.*

*Glabella subtriangular, narrowest anteriorly; circumglabellar furrow continuous; glabellar furrows in three pairs, of which two are longer and obliquely directed, and one, the anterior pair, horizontal and shorter, not continuous.*

*Facial suture widely separated anteriorly, forming an almost straight line from the frontal to the occipital margin.*

*Thoracic segments smooth, obliquely truncated on each end, number (?).*

*Pygidium semicircular, convex, bordered by a wide, thin plate which is especially produced posteriorly; axis elevated, narrow, composed of 9 to 10 segments; pleura distinctly incurved, becoming short and disappearing posteriorly.*

*One species: *Pterocephalia sanctisabae*.*

Common in the crystalline gray limestone carrying abundant trilobite remains which occurs in the San Saba Valley.

Description of figures: Figure 1a, view of cephalon from above; figure 1b, view of cephalon in profile; figure 1c, view of pygidium from above; figure 1d, view of pygidium in profile.—Kreidebildung, p. 92.

NOTES ON THE TYPE SPECIMENS

The type material consists of a fragment of grayish-white, coarsely crystalline limestone containing two cranidia (no. 1); and four other fragments of the same type of rock containing incomplete pygidia (nos. 2, 3, 4). The label accompanying lot 1 bears the following note: "Probably the original of plate 11, figure 1b; certainly the original of plate 11, figure 1a, explicitly mentioned by Roemer." The smaller cranidium is practically complete, and its measurements agree very well with those of the original illustration. Inasmuch as Roemer based his genus and species on the cranidium, these cranidia should be considered syntypes, and the associated pygidia may be considered paratypes. According to Roemer's statement there should be four cranidia, hence four syntypes, but there were only two heads in the material received from Bonn.

The most obvious differences between the original specimens and the figures are the conspicuous eye lines, which are neither illustrated nor mentioned in the descriptions. These lines rise opposite the anterior pair of glabellar furrows and are directed outward and slightly backward, terminating at the anterior ends of the palpebral lobes. They are a conspicuous feature

<sup>30</sup> Etymol.: πτερόν, a wing; κεφαλή, a head.

of all specimens that have been examined and are also present in other species referred to this genus.

In the original figure the glabella and brim are drawn slightly wider than they are in the specimen, and the facial suture is too sharply indented at the anterior end of the fixed cheek. Both of the type cranidia are more or less imperfect at this point, but the course of the suture is well shown on other specimens in the collections of the United States National Museum. The remaining important difference is that the posterior lateral lobes of the fixed cheeks are about 1.5 millimeters longer than the figure indicates.

At first sight the four fragmentary pygidia appear to belong to two or three distinct species, but on closer study the differences are found to be due chiefly to conditions of preservation and are therefore more apparent than real. The two large specimens are evidently adult forms, and the smaller ones probably represent immature individuals. The label accompanying the large specimen (no. 3), shown on plate 68, figure 8, bears the following note: "Designated by Roemer as the original of figure 1c." On the label accompanying the other large specimen (no. 2), plate 68, figure 9, is written, "Probably the original of plate 11, figure 1d." Neither specimen, however, conforms exactly to the illustrations.

The dimensions of the type specimens are included in the table facing page 248.

A single fragmentary pleural segment included in the type material marked "San Saba \* \* \* 10" may be the specimen mentioned by Roemer, but it differs in several particulars. It is about 23 millimeters long and 8 millimeters wide. Neither end is preserved, but the direction and curvature of the furrow indicate that it came from the right side of an individual. There is no way of telling whether this is the specimen mentioned by Roemer or not, as it was not figured, but its general size and shape seem to preclude it from belonging to *Pterocephalia*.

#### NOTES ON ADDITIONAL MATERIAL REFERRED TO THIS SPECIES

About 36 cranidia, all more or less fragmentary, have been compared with the types, and detailed measurements of most of these are plotted in the table facing page 248. The table also shows measurements of several pygidia, but these are much less abundant in the collections available. By this means it has been possible to compare specimens of all sizes from 11 localities in Texas, Oklahoma, Missouri, South Dakota, and Nevada with the types. The most striking result of these measurements is the very close agreement of the proportions of each specimen regardless of size or of geographic source. For example, if the ratio of the length of the cephalon to the length of the glabella in the type specimen is compared with this ratio in the other specimens, it will be found that the differences

between them are so slight as to be well within the probable error of measurement, and also within the limits of individual variation.<sup>31</sup> Comparisons of the ratio of other combinations of measurements on the type with the ratio of the same combinations on other specimens give equally close results.

Comparisons may also be made by establishing the ratio of a certain measurement on the type to the same measurement on the specimen to be compared, and then comparing this ratio with the ratio of other measurements on the same pair of specimens.

This very close agreement of relative proportions, regardless of size or geographic source (see table), is one of the strongest reasons for considering all these forms to be a single species.

The pygidia from the Black Hills average somewhat wider than those from other localities but agree in all other respects. As they are preserved in a shale and are considerably flattened, whereas all the other specimens are preserved uncrushed in limestone, this extra width is interpreted as a result of the flattening, which, from the original shape of the pygidium, should be more transversely than longitudinally.

#### COMPARISON WITH OTHER SPECIES NOW REFERRED TO PTEROCEPHALIA SANCTISABAE

1. An examination of the type material of *Pterocephalia laticeps* (Hall and Whitfield) leaves no doubt that it is synonymous with *P. sanctisabae* Roemer. The species was described from the lowest limestones on Pogonip Mountain, White Pine district, Nev., now known to be of Upper Cambrian age. The cranidium as illustrated differs from *P. sanctisabae* in its narrower, more elongate, and somewhat angular glabella. The specimen from which Hall and Whitfield's illustration (pl. 68, fig. 40) was made shows all these characters, but not as strongly as the illustration would indicate. Associated with the type cranidium is the mold of a second cranidium which has almost exactly the size and proportions of the larger of the two type cranidia of *P. sanctisabae*. (See table, columns 2 and 32.) A clay squeeze taken from this second Nevada specimen and subjected to slight lateral compression developed the same peculiar combination of features which characterizes the figured cranidium of *P. laticeps*, and this, together with the fact that the rock in which this specimen is preserved shows traces of compression, indicates that *P. laticeps* was founded on a distorted specimen (pl. 68, figs. 40-42). An additional bit of evidence that favors this interpretation is found in a small collection from the Secret Canyon

<sup>31</sup> These comparisons are most easily made by setting the two measurements which are to serve as the basis of comparison opposite each other on a slide rule and noting the difference between the proportional and actual measured dimension of the corresponding measurements on other specimens. In making these comparisons, naturally the more accurate of the two measurements to be compared should govern. In the table doubtful and obviously incomplete measurements are indicated by a query (?), and the figure given is usually less than what it should be.

*Comparative measurements, in millimeters, of 36 crania and 14 pygidia of *Pterocephalia sanctisabae* Roemer, from various localities in the central and western United States*

[Measurements followed by a query (?) are estimates and for the most part are too low.

<sup>1</sup> Crushed.



shale south of the Hamburg mine, near Eureka, Nev. This collection contains six fragmentary cranidia, all of which have been identified as *P. laticeps* but which actually resemble *P. sanctisabae* far more closely. (See table, columns 34-36.) This relationship of *P. sanctisabae* and *P. laticeps* is easily demonstrated by comparing the cranidia of the types of these forms by the method outlined above. When the ratio of two measurements of length or of width on the type is compared with the same ratio based on measurements of *P. laticeps*, the agreement is found to be remarkably close.

For example, if the ratio of length of cranidium to length of glabella of the type of *P. sanctisabae* (24:10) is taken as the standard of comparison, it will be found that a cranidium 30 millimeters long should have a glabella 12.5 millimeters long, whereas the glabella of *P. laticeps* has a length of 12.25 millimeters. This is a discrepancy of only 2 percent, and it can certainly be charged to individual variation, or to error in measurement, or to both.

Similarly, if the ratio of width of cranidium to width of glabella of the type is taken as a standard (22:8.5), a cranidium which is 21 millimeters wide should have a glabella which is 8.1 millimeters wide. These last two measurements are those of the type of *P. laticeps* and show practically no discrepancy.

However, if the ratio of length of cranidium to width of cranidium (24:22) is taken as the standard, a cranidium 30 millimeters long should be 27.5 millimeters wide, whereas the cranidium of *P. laticeps* is only 21 millimeters wide. This is a discrepancy of nearly 24 percent, and the difference between the two measurements (6.5 millimeters) furnishes a measure of the amount of compression which the specimen has undergone.

The pygidium assigned to *P. laticeps* is figured as having a strong notch at the center of the posterior margin, whereas that of *P. sanctisabae* has only a shallow emargination at this point, but an examination of the specimen from which the figure of *P. laticeps* was drawn strongly suggests that this notch is due to a fracture of the posterior margin. No other pygidium assigned to *P. laticeps* preserves this margin, and the point cannot be settled at this time. The measurements of the pygidium of *P. laticeps* indicate that it has the same proportions as the pygidia of *P. sanctisabae*. (See table, columns 1, 2, and 31.)

2. *Dicellocephalus multicinctus* Hall and Whitfield,<sup>32</sup> later referred by Walcott<sup>33</sup> without discussion to *Apatocephalus*, appears to have been founded on a fragmentary pygidium of *Pterocephalia sanctisabae* which lacks the entire posterior margin. The specimen is so broken that it gives a slight suggestion of

possessing five blunt spines, which were accepted as real by Hall and Whitfield and were sketched in on the original figure, though regarding this feature the authors themselves were none too certain. A careful examination of the specimen shows that this suggestion of spines is entirely accidental, the part of the margin which is indicated as being preserved being the result of a fracture that probably healed during the life of the animal (pl. 68, fig. 37). In all other respects the specimen agrees perfectly with other pygidia of *P. sanctisabae*. (See table, column 32.)

#### DISTRIBUTION

Roemer's specimens were collected on the north bank of the San Saba River about half a mile east of Camp San Saba. (See p. 242.) An examination of the collections in the United States National Museum shows that the species is represented in collections from the Wilberns formation of Texas, the Honey Creek formation of the Wichita and Arbuckle Mountains, the Davis formation of the Ozark region, the Deadwood formation in the Black Hills, and the Secret Canyon shale of the Eureka district, Nev. It was also collected on Pogonip Mountain, in the White Pine district, Nev., from beds whose exact age is not known, but from the very narrow vertical range of the species elsewhere it would seem safe to refer these strata to the Secret Canyon. In every geographic province in which it has been found and at almost every locality within these provinces the species is associated with *Elvinia roemeri* (Shumard), and at most places with species of the genus *Camaraspis*.

In Texas the *Camaraspis* zone occurs in the Wilberns formation about 0 to 50 feet above the heavy sandstone which Paige mapped as the top of the Cap Mountain (Lion Mountain sandstone member). In the Wichita Mountains it is about 135 feet above the top of the Reagan sandstone at one locality, but in the West Timbered Hills of the Arbuckle Mountains it is about 100 feet above the Reagan sandstone, according to measurements by C. E. Decker. In the St. François Mountains of Missouri the zone is about 10 to 15 feet thick and occurs in the Davis formation about 20 to 25 feet above the top of the Bonneterre dolomite. The exact position of the zone in the Secret Canyon shale of Nevada is not known at present.

In the Black Hills of South Dakota *Pterocephalia sanctisabae*, associated with *Elvinia roemeri* and other characteristic forms, has been found in a greenish-gray shale about 175 feet above the base of the Deadwood formation in Whitewood Canyon in the northern part of the town of Deadwood. These specimens were collected by Ed Barragy, of the University of Iowa, and have been made available for comparison by Dr. A. K. Miller, of that institution. In Wisconsin the *Camaraspis* zone occurs in the Ironton member of Franconia formation. *Elvinia* is fairly common in this

<sup>32</sup> U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 226, pl. 2, fig. 37, 1877.

<sup>33</sup> Walcott, C. D., Smithsonian Misc. Coll., vol. 57, p. 352, 1914.

zone, but *Pterocephalia* is extremely rare, although it has recently been found at one or two localities by Raasch.<sup>34</sup>

#### COMPARISON WITH OTHER SPECIES ASSIGNED TO PTEROCEPHALIA

*Pterocephalia occidens* Walcott<sup>35</sup> appears to be a valid species. All the known specimens came from a single locality south of the Hamburg mine, in the Eureka district, Nev. The formation is probably the Secret Canyon shale, although the original description states that they came from the "Hamburg" (Dunderberg) shale. The type cranium is very small, being only 6.5 millimeters long. The largest approximately complete cranidium in the collection is 17 millimeters long, and other fragments indicate a maximum length of 20 millimeters. From this it would seem that the species is somewhat smaller in average size than *Pterocephalia sanctisabae*. The two anterior pairs of glabellar furrows are wanting or very faintly developed in *P. occidens*, and the last three segments of the pygidium are much fainter.

*Pterocephalia asiatica* Walcott<sup>36</sup> is a valid species. The type is fragmentary, but enough of the cranium is preserved to show the essential generic characters. In most respects it is very similar to *P. sanctisabae*. The associated pygidium is too fragmentary for exact determination and probably does not belong to the same genus.

*Dicellocephalus* (*Pterocephalia*) *bilobatus* Hall and Whitfield,<sup>37</sup> afterward referred by Walcott to *Platycopus*<sup>38</sup> and still later to *Anomocare*,<sup>39</sup> does not appear to belong to *Pterocephalia* but on the contrary seems best referred to some division of the Saukinae. The species is founded on a pygidium with a deeply cleft posterior margin which at first sight somewhat resembles *Pterocephalia*. However, the axis contains but 6 segments, as against 10 to 11 in *Pterocephalia*. In addition, the marginal expansions are proportionately narrower, and the pleural furrows extend almost to the margin.

*Pterocephalia busiris* Walcott, described in the same reports as the preceding species, is based on two pygidia that show none of the essential characters of *Pterocephalia*. It is a well-marked form and has been doubtfully assigned to *Lioparia* by Kobayashi.<sup>40</sup>

*Pterocephalia? liches* Walcott, the third Chinese species, is likewise not a member of the genus and has been made the type of the new genus *Kolpura* by Resser and Endo.<sup>41</sup>

As a result of these comparisons it appears that the genus as now known contains three species—namely, *Pterocephalia sanctisabae* Roemer, the genotype, which is widely distributed in the basal Wilberns and its equivalents in the Upper Cambrian of the Central and Western United States; *P. occidens* (Walcott), associated with *P. sanctisabae* in the Eureka district; and *P. asiatica* Walcott, from the Upper Cambrian of the Shantung district of China.

#### SYSTEMIC POSITION

Roemer stated that *Pterocephalia* differed from all known genera of trilobites in certain particulars but made no attempt to show its relationships. Shumard<sup>42</sup> considered it "to be related, if not identical with *Conocephalites* of Zenker," but did not discuss it further. Hall and Whitfield<sup>43</sup> made it a subgenus of *Conocephalites* without discussion. Walcott<sup>44</sup> at first considered it to be a subgenus of *Ptychoparia*, but in his later papers he gave it full generic rank. He never described the genus nor discussed its affinities. It was listed and described in Miller's "North American geology and paleontology" but is not mentioned in the English editions of Zittel's textbook nor in Grabau and Shimer's "North American index fossils."

Ulrich<sup>45</sup> listed the genus from Missouri, and Ulrich and Resser<sup>46</sup> mentioned it in a discussion of the genetic relationships of the dikelcephalids. In their paper they suggested that *Pterocephalia* should be placed in Raymond's subfamily Hungaiinae, but at the same time they removed this group from the Dikelcephalidae and suggested that it represents a distinct family which might also include Walcott's genera *Burnetia* and *Elkia*. This assignment was doubtless suggested by the broadly expanded margins of the cephalon and pygidium, but to the writer it seems more probable that this is a case of homeomorphy, and that the similarity is more apparent than real. Nor does *Pterocephalia* seem to be closely related either to *Hungaia* or to *Burnetia* or *Elkia*.

In none of these forms is the expansion of the brim at all comparable with that of *Pterocephalia*. In the Dikelcephalinae and presumably in *Burnetia* and *Elkia* also the facial suture remains on the dorsal surface in crossing the median line, whereas in *Pterocephalia* it becomes marginal or submarginal directly in front of the eyes. The eye lines, which are conspicuous in

<sup>34</sup> Raasch, G. O., personal communication, 1935.

<sup>35</sup> Walcott, C. D., Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, pp. 58, pl. 9, fig. 21, 1884.

<sup>36</sup> Walcott, C. D., U. S. Nat. Mus. Proc., vol. 39, p. 67, 1905; Research in China: Carnegie Inst. Washington Pub. 54, vol. 3, p. 146, pl. 14, figs. 5, 5a, 5b, 1913.

<sup>37</sup> U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 227, pl. 2, fig. 37, 1877.

<sup>38</sup> Walcott, C. D., Smithsonian Misc. Coll., vol. 57, p. 349, 1914.

<sup>39</sup> Idem, p. 366.

<sup>40</sup> Kobayashi, T., The Cambro-Ordovician formations and faunas of south Chosen: Tokyo Imp. Univ., Fac. Sci., Jour., sec. 2, vol. 4, pt. 2, p. 231, 1935.

<sup>41</sup> Resser, C. E., and Endo, R., in Kobayashi, T., op. cit., pp. 90, 231.

<sup>42</sup> Shumard, B. F., The Primordial zone of Texas, with descriptions of new fossils: Am. Jour. Sci., 2d ser., vol. 32, p. 214, 1861.

<sup>43</sup> Hall, James, and Whitfield, R. P., U. S. Geol. Expl. 40th Par. Rept., vol. 4, pp. 221-223, 1877.

<sup>44</sup> Walcott, C. D., Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, pp. 58, 59, 1884; Cambrian faunas of China: U. S. Nat. Mus. Proc., vol. 29, no. 1415, pp. 67-68, 1905; Cambrian faunas of China: Smithsonian Misc. Coll., vol. 57, no. 4, p. 80, 1911; Research in China: Carnegie Inst. Washington Pub. 54, vol. 3, pp. 146, 147, 1913.

<sup>45</sup> Ulrich, E. O., in Weller, Stuart, and St. Clair, Stuart, The geology of Ste. Genevieve County, Mo.: Missouri Bur. Geology and Mines, 2d ser., vol. 22, p. 51, 1928.

<sup>46</sup> Ulrich, E. O., and Resser, C. E., The Cambrian of the upper Mississippi Valley, pt. 1: Milwaukee Pub. Mus. Bull., vol. 12, no. 1, pp. 12-15, 1930.

*Pterocephalia*, are not developed in the other forms. The head is thus truly ptychoparian, differing from other genera in that family chiefly in the great development of the brim.

In *Pterocephalia* the axis of the pygidium contains 10 or 11 segments, twice the number characteristic of the Dikelocephalidae and Hungaiidae. The pygidia of *Burnetia* and *Elkia* are not definitely known, and hence no comparisons are possible.

Kobayashi<sup>47</sup> places the genus in the family Ptychopariidae and proposes a new subfamily, the Pterocephaliinae, to contain *Pterocephalia*, *Amecephalus*, *Amecephalina*, and possibly *Alokistocare* and *Coosia*.

#### Elvinia roemeri (Shumard)

Plate 67, figures 2a, b, 3a, b; plate 69, figures 1-22

- 1849. Pygidium of a trilobite of unknown genus and species, Roemer, Texas, p. 422, Nr. 11.
- 1852. Pygidium of a generically undetermined trilobite, Roemer, Die Kreidebildungen von Texas, p. 94, pl. 11, figs. 3a, b.
- 1852. Cephalon \* \* \* of a trilobite belonging to an unknown genus, Roemer, Die Kreidebildungen von Texas, p. 93, pl. 11, figs. 2a, b (not 2c, d).
- 1861. *Dikelocephalus roemeri* Shumard, Am. Jour. Sci., 2d ser., vol. 32, pp. 220, 221.
- 1877. *Crepicephalus (Loganellus) unisulcatus* Hall and Whitfield, U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 216, pl. 2, fig. 22 (not fig. 23).
- 1884. *Ptychoparia unisulcatus*. Walcott, Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, p. 58.
- 1889. *Dicellocephalus roemeri*. Miller, North American geology and paleontology, p. 544.
- 1912. *Ptychoparia matheri*. Walcott, Smithsonian Misc. Coll., vol. 57, no. 9, p. 268, pl. 44, figs. 15-17.
- 1914. *Ptychoparia roemeri*. Walcott, Smithsonian Misc. Coll., vol. 57, no. 13, p. 352 (generic reference).
- 1924. *Elvinia roemeri*. Walcott, Smithsonian Misc. Coll., vol. 75, no. 2, p. 56, pl. 11, fig. 3.
- 1925. *Elvinia roemeri*. Walcott, idem, no. 5, pp. 88, 89, pl. 17, figs. 9-13.
- 1928. *Elvinia roemeri*. Ulrich, in Weller and St. Clair, Missouri Bur. Geology and Mines, 2d ser., vol. 22, pl. 51 (cited in faunal list).
- 1931. *Elvinia roemeri*. Dake, Missouri Bur. Geology and Mines, 2d ser., vol. 23, p. 88 (cited in faunal list).
- 1933. *Elvinia roemeri*. Bridge, in Sellards, Adkins, and Plummer, Texas Univ. Bull. 3232, p. 232, pl. 2, figs. 17-19.

#### ORIGINAL DESCRIPTIONS

11. Pygidium of a trilobite of unknown genus and species. This is recognized by its very strongly elevated, half-cylindrical axis, which distinguishes it from other [known] trilobites.—Texas, p. 422.

12. Pygidium of a generically undetermined trilobite. Plate 11, figs. 3a, b. (See F. Roemer, Texas, p. 422, no. 11.)

This pygidium is almost semicircular, arched, bordered by an upturned rim. The axis is thick and broad and is raised in the form of a hemicylinder high above the lateral sides of the shield. The width and height remain the same to the posterior margin of the shield, where it is abruptly truncated. The axis, aside from the anterior bordering ring, shows four annulations, the last one

of which is more or less divided into two parts by a depression. Only the three anterior rings continue on to the strongly arched sides as broad, flattened pleurae.

The outstanding character of this pygidium is the thick axis, which maintains the same width throughout its length. The flattened, short pleurae indicate affinities with certain trilobite genera such as *Ceraurus* Green (*Cheirurus* Beyrich) and particularly *Sphaerexochus* Beyrich. However, in these last-named genera the outer margin is serrate, while in this specimen it is entire and plainly rounded.

Occurrence: Several complete examples of this pygidium, one of the largest of which is figured, were found in association with the other trilobites in the Silurian limestone in the San Saba Valley.

Description of the figures: Figure 3a, from above; figure 3b, profile view.

Besides the trilobites which have been described, the same rock contains three or four other forms, but the specimens before me are so incomplete that it is impossible to describe them adequately.—Kreidebildungen, p. 94.

11. Cephalon \* \* \* of a trilobite belonging to an unknown genus. Plate 11, figures 2a, b.<sup>48</sup>

The material pertaining to this trilobite which is now before me shows clearly that it belongs to a distinct genus, but it is not sufficient to allow me to determine all of its generic characters.

The cephalon is elevated, semicircular in section, the anterior end with a broad, abruptly deflected border. The posterior end is bordered by an occipital ring which is set off by a well-marked occipital furrow. The glabella is bounded on all sides by a distinct furrow and rises to the same height as the fixed cheeks. It shows two faint, slanting glabellar furrows on each side. The course of the facial suture—in other words, the lateral edges of the cranidium—is not as plainly shown in the examples before me as in the illustration. However, one can readily see that in general it agrees with the facial suture in the genus *Calymene* in that the two lines are widely separated from each other at the anterior end and run in an oblique direction to the posterior corners of the cephalon. The free cheeks are missing in all known specimens. \* \* \* No thoracic segments which might belong to this cranidium and pygidium are known. The relationship of the parts which have been described to other trilobite genera is not clear. The cephalon, on the one hand, shows a few similarities in structure with *Calymene*, but the pygidium, on the other hand, shows an entirely different type of structure.

Occurrence: Associated with the preceding [*P. sanctisabae*] in the crystalline Silurian limestone of the San Saba Valley.

Explanation of figures: Figure 2a, view of cephalon from above: 2b, the same in profile \* \* \*.—Kreidebildungen, pp. 93, 94.

From the foregoing descriptions it will be seen that Roemer did not suggest any relationship between the cranidium and pygidium which are here classed as a single species. On the contrary, he considered a fragmentary cranidium of *Idahoia* to be a pygidium and associated it "very doubtfully" with the cranidium.

In 1861 Shumard published descriptions of several Cambrian species from the Central Mineral Region, among them *Dikelocephalus roemeri*. In his description of this species he says: "An excellent figure of this head is given by Dr. Roemer in his 'Kreidebildungen von Texas' (Taf. XI, fig. 2a), but the author proposes

<sup>47</sup> Kobayashi, T., op. cit., pp. 230, 231.

<sup>48</sup> The portions of the description which are omitted refer to another specimen which Roemer assumed to be the pygidium of this species but which is actually a fragmentary cranidium referred to *Idahoia*. (See p. 256.)—J. B.

no name for the species." Inasmuch as Shumard's specimens were never figured, and as his types appear to be lost, the specimen upon which Roemer's figure was based and which Shumard explicitly referred to his species is the nearest thing to a type that exists. In one sense, it might be considered a paratype, as it is a specimen mentioned in addition to the types in the original description, even though the author had only the figure available for comparison.

Shumard described a pygidium which he thought belonged to this species and also noted that the so-called pygidium which Roemer had assigned to it was actually the head of another form and referred it to *Arionellus*.

In 1924 Walcott<sup>49</sup> established the genus *Elvinia*, with *Dikelocephalus roemeri* as the genotype. The description was very brief, and the following year he published a second and somewhat more extended description.<sup>50</sup> In the second paper he stated that the pygidium assigned to *Elvinia roemeri* is not the same as the one described by Shumard, but he did not note that it is one of the unidentified forms described and figured by Roemer.

#### REVISED DESCRIPTION

Cranidium strongly convex, the length slightly more than half the greatest width; width of the frontal margin between the angles of the facial suture at the rim about half the width across the posterior lateral lobes; the angle between the axial plane and a line passing through the extremities of the rim and the posterior lateral lobes about 30°.

Glabella cuneiform, the sides converging anteriorly at an angle of 30°; abruptly truncated anteriorly, moderately elongated; sharply set off from the remainder of the cranidium by a strong circumglabellar furrow and slightly elevated above it. Width of the glabella at the posterior end approximately one-third the total width, and its length about seven-tenths that of the cranidium.

The anterior pair of glabellar furrows are extremely faint and cannot be detected on most specimens, especially those which preserve the test. They originate about opposite the eye lines and are directed posteriorly at an angle of 30°; second pair also faint but much more commonly observable, directed posteriorly at an angle of about 45°; third pair (first pair in Walcott's description) strongly defined, directed posteriorly at the same angle as the preceding pair for about one-third the width of the glabella, their inner ends connected by a strong transverse furrow. The course of this furrow is the distinguishing generic character cited by Walcott in his original description of *Elvinia*.

Occipital furrow rather strongly defined, narrowest along the axial plane and becoming wider and shallower toward the margins of the glabella.

Frontal border broad, convex, and abruptly deflected; divided into two very unequal portions by the marginal furrow; the width of the brim approximately three times that of the rim. Rim prominent, narrow, strongly rounded, broadly triangular.

Fixed cheeks rather narrow, about two-thirds the width of the glabella, and only slightly broadened at the palpebral lobes, which are not noticeably elevated above the surface of the cheek. Posterior lateral lobes broad and long, curved strongly downward, the extremities bluntly rounded.

Eye lines prominent, directed posteriorly at an angle of about 10°.

Facial suture cutting the frontal margin in front of the anterior corners of the glabella and extending laterally across the rim until it reaches a position in front of the posterior end of the palpebral lobe, thus giving the portion of the rim that is attached to the cranidium its triangular outline. In crossing the marginal furrow the facial suture bends abruptly inward to the anterior end of the palpebral lobe, curves gently around it, and then swings off at an angle of about 35°, cutting the posterior margin a short distance inside the genal angle.

None of the cranidia in the collections of the United States National Museum have the free cheeks attached. However, the cheek described here is associated with the cranidia at almost every locality from which the species has been collected, and it is the only one in the collections that can be logically assigned to this form. The outline is approximately that of a quarter ellipse, with the width slightly greater than the height. Marginal furrow strong and well defined anteriorly, becoming shallower and fainter as it approaches the genal angle. Occipital furrow broad and shallow. Rim strong and smoothly rounded, the anterior end produced into a spine by the course of the facial suture across it. Genal angle carrying a short, slender spine, which is directed outward at an angle of about 35° from the axial line. Surface of the cheek smoothly rounded.

Eyes not well preserved on any of the material at hand. They are about one-third the length of the cheek, crescentic, narrow, and not strongly elevated.

Doublure, hypostoma, and thoracic segments unknown.

Pygidium semicircular, about twice as wide as long. Anterior margins curving slightly back from the axis, strongly rounded at the outer angles. Posterior and lateral margins forming a semicircle, the edge rather strongly upturned, thickened, and rounded as if it were rolled about a wire. In many specimens this upturned margin is broken away, and the pygidium assumes

<sup>49</sup> Walcott, C. D., Smithsonian Misc. Coll., vol. 75, no. 2, p. 56, pl. 11, fig. 3, 1924.

<sup>50</sup> Idem, no. 3, p. 88, pl. 17, figs. 9-13, 1925.

a triangular shape which at first sight causes it to be regarded as a distinct form.

Axis stout, about one-third the width of the pygidium, its sides parallel, strongly elevated, extending nearly to the posterior margin, the posterior end blunt, rounded, and standing high above the rim. Annulations four, not including the articulating ring, the terminal one double.

Lateral slopes moderately convex, becoming concave near the posterior and lateral margins. Each slope with three rounded pleural ridges, one opposite each of the three anterior annulations of the axis; the ridges separated by broad, shallow grooves.

Surface of the entire test smooth.

#### NOTES ON ROEMER'S SPECIMENS

Roemer's material contains two cranidia and two pygidia referable to this species. There is also a third cranidium in the type lot, but it belongs to a different genus. (See p. 255.) The cranidia are numbered 6 and 7, the pygidia 9 and 10. The labels accompanying the cranidia bear the following inscription: "Trilobite genus? *caput*. F. Roemer, Kr. v. Texas, Taf. XI, fig. 2a. Silurian, San Saba, Texas." On the back of the label of no. 6 is the following note: "On the back of the board to which this specimen was fastened is a note by Roemer stating definitely that this is the original (of fig. 2a)." On the back of the specimen itself is a notation in ink "I, 2, a." The "I" is very close to the margin and is evidently a portion of the Roman numeral XI. The other cranidium has no supplementary notes on either the label or the specimen.

The two cranidia are of medium size. Both specimens lack the outer half of the brim and the extremities of the posterolateral lobes. The occipital and posterior glabellar furrows are clearly defined; the anterior pair shows faintly in specimen no. 6. The eye lines are also indicated faintly in this specimen; in the other the surface of the test is flaked off at this point. The outlines of the glabella and fixed cheeks agree fairly well with the illustration, but the brim was evidently added from the third cranidium, which, as has already been noted, belongs to a different genus.

The two pygidia show a considerable variation in size, one being at least a third larger than the other. In both, the posterior and lateral margins are more or less incomplete. Both are referred to the same species. They conform to the descriptions, and no additional notes are necessary.

The label attached to the larger of the two specimens (no. 9) bears the following notation: "Trilobite genus? pygidium, F. Roemer, Kr. v. Texas, Pl. XI, figs. 3a, b, San Saba, Texas, Silurian." On the reverse is the following statement: "Definitely designated by Roemer as the original." The label accompanying the smaller specimen (no. 10) has practically the same notation on its face and the following on the reverse side: "Has

probably served to supplement fig. 3a." Roemer's figures 2a and 2b give a fair idea of the cranidium but are incorrect in many of the details. The facial suture is incorrectly drawn, the eye lobes are too small and too prominent, the posterior lateral lobes are too short, and the rim is too thin and too sharply curved. His illustrations of the pygidium, figures 3a and 3b, are much better.

#### NOTES ON OTHER TYPES

Walcott's type cranidium (plesiotype) selected "as most nearly representing Shumard's description of the species" is about one-fourth larger than Roemer's specimens and is much more nearly complete. At first sight, Walcott's specimen appears to be sufficiently different to be regarded as another species. It appears to be flatter and to have a less abruptly deflected brim, but a comparison of the profiles shows that this is largely an optical illusion caused by the lack of part of the brim and all of the rim in Roemer's specimens. Such minor differences as do exist, such as the slight flattening of the cranidium, are those which are conceivably due to age. The greater part of the cranidium is exfoliated, traces of the skin remaining at the corners of the brim and along the posterior margin. The deep notch in the brim is due to an injury that healed during the life of the animal, for the chitinous skin is rolled around the edges of the fracture.

The pygidium figured by Walcott is identical in size and proportions with the larger of Roemer's specimens, and it shows the details of the upturned rim better than either of them.

The cranidium of *Crepicephalus unisulcatus* Hall and Whitfield is unquestionably an *Elvinia*, but the associated pygidium belongs to a different genus.

The type lot, the figured cranidium and pygidium on a fragment of limestone (U. S. Nat. Mus. 24574), came from the Eureka district, Nev., exact horizon and locality unknown. Associated with this specimen are two other lots from limestones in the Secret Canyon shale, Eureka district (localities 61 and 63), bearing the same number (24574) but collected at much later dates. Cranidia and free cheeks in these later collections were identified as *C. unisulcatus* by Walcott. Hall and Whitfield's original locality is very poorly described, and there is no way of determining whether either of Walcott's collections came from it, but there is a strong probability that all three collections came from the same horizon. The type cranidium is slightly smaller than Roemer's smaller specimen (no. 7). The margins of the fixed cheeks are broken away or buried in the matrix, and the posterior lateral lobes are missing, all of which tends to give the cranidium a narrow and more elongate appearance. The glabella appears to be squarer than the average, and the brim is more strongly arched and more sharply deflected. These characters seem to be peculiar to this specimen, the

cranidia in other collections from the Eureka district agreeing more closely with the Middle Western types. The anterior pair of glabellar furrows are not preserved, and the second pair are very faint on the holotype but much more distinct on the paratype. *Elvinia unisulcata* has been considered to be a distinct species, but the type specimen is very poor, and most of the forms that have been referred to it agree better with *E. roemeri*. The writer considers *E. unisulcata* a synonym of *E. roemeri*.

*Ptychoparia matheri* Walcott is considered to be a synonym of *Elvinia roemeri*. *Ptychoparia matheri* was founded on several imperfect cranidia, a few free cheeks, and a single imperfect and very small pygidium from the top of the Potsdam sandstone near Whitehall, N. Y. The largest and most nearly complete cranidium, the one figured by Walcott and refigured on plate 69, figure 11, is slightly larger than Walcott's plesiotype of *Elvinia roemeri*. The relative proportions of the glabella and of such other parts of the two cranidia as may be compared are practically identical, with the exception of the width across the anterior end of the brim, which is relatively narrower in the New York specimen. The only other cranidium in this lot that is complete enough to permit this comparison to be made shows the same proportions as the Texas specimens, and this variation in width has been noted in collections from other localities. There is no fixed amount of variation, and the specimens cannot be divided into two sharply contrasted groups on this basis. In general, it may be said that the width across the brim is commonly slightly more than the length of the glabella, but it may narrow until it equals or is slightly less than this length. Moreover, this distinction does not appear to have either stratigraphic or geographic significance, and for these reasons it is not considered to be of specific importance. The free cheeks agree very well with cheeks from other localities. The pygidium is very small and very poorly preserved. It may not belong to the genus—in fact, according to Resser, it belongs to *Dunderbergia*. At one time the Potsdam sandstone was thought to be much younger than the beds carrying the *Camaraspis* fauna in the Mississippi Valley, but at present practically all stratigraphers agree that they are equivalent.

The genus *Moosia*, proposed by Walcott in the same paper with *Elvinia*, is now considered to be a synonym of it.<sup>51</sup> The genus was founded on a small lot of badly

crushed specimens from the Goodsir formation in British Columbia. Both cranidium and pygidium show the typical characters of *Elvinia*, and the writer agrees with Resser and Kobayashi in placing them in the same genus. The material now available is so scanty and so badly crushed that it is not possible to make detailed comparisons of the type species *E. grandis* with *E. roemeri*. There seem to be a number of rather striking differences, and for the present it is regarded as a distinct species. The lower few hundred feet of the Goodsir formation carry the typical *Camaraspis* fauna.

#### REMARKS

At first glance it would seem possible to divide the specimens here grouped under the name *Elvinia roemeri* into three or four species, and in fact this has been done, although some of them have never been published. Most of these species were described from a single locality, and in many of the descriptions the author did not have other material available for comparison. It is only within the last few years that enough specimens have been brought together to permit detailed studies to be made. In all, some 40 cranidia and a smaller number of free cheeks and pygidia have been used in making these comparisons. This material came from 18 localities scattered through the States of New York, Wisconsin, South Dakota, Missouri, Oklahoma, Texas, Utah, and Nevada.

The most striking result of this comparison is that while certain variations which have been called species exist, they have neither geographic nor stratigraphic significance. For example, *Elvinia roemeri*, originally described from Texas, has been listed from Oklahoma, Missouri, Wisconsin, and South Dakota. "*Elvinia unisulcata*" (type locality Nevada) has been reported from Utah, South Dakota, Missouri, and Texas, and "*E. matheri*" (type locality New York) has also been identified in Wisconsin and Missouri.

In his second description of *Elvinia roemeri* Walcott states that "it will be necessary to make several species from among the numerous specimens from Texas," and this was done in the collections, although the distinctions were never published. Some of these forms had a similarly wide distribution. Actually, there is as much or more variation between the individuals assigned to one or another of these so-called species as there is between the types of the various forms, and many specimens cannot be placed satisfactorily in any one of them. (See table on p. 255.)

<sup>51</sup> Resser, C. E., Nomenclature of some Cambrian trilobites: Smithsonian Misc. Coll., vol. 93, no. 5, p. 42, 1935. Kobayashi, T., The Cambro-Ordovician formations and faunas of south Chosen: Tokyo Imp. Univ., Fac. Sci., Jour., sec. 2, vol. 4, pt. 2, p. 282, 1935.

Comparative measurements, in millimeters, of 12 cranidia of *Elvinia roemeri*

[Measurements followed by plus sign are incomplete because of fracturing. Width of brim is an unreliable measurement, partly because of individual variations and partly because corners are often deeply buried or lost. Large specimens are relatively less convex than smaller ones.]

|   | Texas                              |                                    |   |  | New York | Nevada   |   | Utah   | South Dakota   |                         | Missouri   | Oklahoma           |
|---|------------------------------------|------------------------------------|---|--|----------|--|---|--|--|-------------------------|--|--------------------|
|   | Para-type A<br>(pl. 69,<br>fig. 1) | Para-type B<br>(pl. 69,<br>fig. 4) | Plesio-type,<br>locality<br>70,<br>U. S.<br>N. M.<br>70259<br>(pl. 69,<br>fig. 9) | Locality 68,<br>U. S. N. M.<br>93013<br>(pl. 69,<br>fig. 15) |          | <i>P. "matheri"</i> ,<br>holotype, U. S.<br>N. M. 55858<br>(pl. 69, fig. 11) | <i>E. "unisulcata"</i> ,<br>U. S. N. M. 24574 | Locality<br>32-t,<br>U. S.<br>N. M.<br>93026<br>(pl. 69,<br>fig. 32) | Plesio-type<br>(pl. 69,<br>fig. 18),<br>locality<br>63 | Locality 88-a, Deadwood | Locality<br>11-k,<br>Flat<br>River,<br>U. S.<br>N. M.<br>93024<br>(pl. 69,<br>fig. 16) | Pl. 69,<br>fig. 14 |
| Length of cranium                           |                                    |                                    | 25.6  | 16.6   | 28+      | 14   | 16.5  | 23   | 17   | 27.5                    | 23.6   | 28+                |
| Width of cranium at posterior lateral lobes | 27+                                | 25+                                | 46  | 24+  |          | 15+  | 30  | 40   | 27.6   | 40+                     | 41   | 52                 |
| Length of brim                              |                                    |                                    | 7.7   | 4.4  |          | 7  | 3.8   | 4.2  | 7  | 5                       | 8  | 7.2                |
| Width of brim                               | 15                                 |                                    | 22.5  | 12.5   | 22.5+    | 11   | 12.4  | 17.5   | 12.2   | 20.5+                   | 19.5   |                    |
| Length of glabella                          | 13                                 | 11.5                               | 17.9  | 12.3   | 21       | 10.2   | 12.3  | 16   | 12   | 19.5                    | 16.4   | 20.4               |
| Width of glabella                           | 10.5                               | 9                                  | 15  | 10   | 17       | 8.3  | 9.8   | 13.5   | 9.5  | 17.5                    | 13.4   | 17                 |
| Width of glabella at anterior end           | 6                                  | 5                                  | 7.5   | 5.2  | 8.7      | 4.7  | 5   | 8  | 5.1  | 9                       | 7.6  | 10                 |
| Width of fixed cheek at palpebral lobes     | 4.1                                | 4                                  | 7   | 4.3  | 8.5      | 3.5  | 5   | 6.6  | 4.8  |                         | 7  | 7.3                |
| Width of cranium at palpebral lobes         | 18                                 | 15.5                               | 26  | 17.2   | 31       | 14   | 18  | 123  | 16   |                         | 22.2   | 28                 |
| Height of occipital ring                    | 4                                  | 3                                  | 5   | 3.7  | 5.2      | 2.6  | 4.2   | 5  | 3.5  | 5+                      | 5.5  | 6.5                |
| Height of cranium                           | 5.8?                               | 5.1?                               | 10.4  | 6  | 12       | 5.8  | 7   | 11   | 8.5  | 9+                      | 13   | 9                  |
| Angle of glabella                           | 30°                                | 30°                                | 30°   | 30°  | 30°30'   | 29°  | 30°   | 30°  | 30°  | 30°30'                  | 30°  | 30°                |

<sup>1</sup> Presence or absence of test seriously affects certain measurements, especially width across palpebral lobes.

## OCCURRENCE

Roemer's specimens were collected on the San Saba River at the same locality and from the same beds that yielded *Pterocephalia*. Shumard's specimens were collected at the head of Clear Creek, Burnet County. His statement that it is associated with *Tricrepicephalus texanus* is an error, for although the *Tricrepicephalus* horizon is present at this locality, it is at least 100 feet lower in the section. Walcott's specimens came from two localities in the Central Mineral Region. He gives the horizon as Cap Mountain, but later work has shown that the correct horizon is the basal part of the Wilberns formation. It has been found at several other localities in the Central Mineral Region and is invariably associated with *Pterocephalia sanctisabae*. The same association is found in the Honey Creek limestone in the Arbuckle and Wichita Mountains of Oklahoma, in the basal part of the Davis formation of Missouri, at a certain horizon in the Deadwood formation in the Black Hills, and in the Secret Canyon shale in the Eureka district of Nevada. It also occurs in the Ironton member of the Franconia formation in Wisconsin, where it is associated with *Camaraspis*, *Idahoia*, *Irvingella*, and other genera characteristic of the Wilberns, Honey Creek, and Davis. It occurs also in the top of the Potsdam sandstone in the Lake Champlain region, in beds in the Dugway Range in Utah which are presumably the equivalent of the upper portion of the Orr formation in the adjacent House Range, in Upper Cambrian limestones in the southwestern part of Sublette County, Wyo., and in lime-

stones in the lower portion of the Pogonip limestone of the White Pine district of Nevada. It has a somewhat greater vertical range than *P. sanctisabae*, for it is also found sparingly in the *Irvingella major* zone, which immediately overlies the *Camaraspis* zone in many areas.

Specimens of *Elvinia roemeri* from the Ore Hill limestone of Pennsylvania agree in all respects with the forms just described and serve to correlate the Ore Hill with the lower Franconia. The species has recently been found in collections from southwestern Wyoming.

The species has been recognized in collections from about 19 localities in 9 widely separated States, and in almost every locality it is associated with other equally characteristic forms. This association over so broad an area is of great value in interregional correlation.

*Aphelaspis depressa* (Shumard)

Plate 69, figures 23-26

1861. *Conocephalites depressus* Shumard, Am. Jour. Sci., 2d ser., vol. 32, pp. 219, 220.  
 1889. *Ptychoparia depressa*. Miller, North American geology and paleontology, p. 565.  
 1935. *Aphelaspis depressa*. Resser, Smithsonian Misc. Coll., vol. 93, no. 5, p. 11.

Among the Roemer specimens is a small fragment of limestone (no. 5) which bears the same label as those accompanying the cranidia of *Elvinia roemeri* (nos. 6 and 7). The label also carries the following notation: "Almost certainly used in filling out fig. 2c." The block contains several fragmentary cranidia, three of

which are fairly complete and all of which belong to the same species. The species is entirely different from *E. roemeri* and has been identified with one of Shumard's unfigured species, *Conocephalites depressus*. This species has recently been made the type of a new genus, *Aphelaspis*, by Resser, but it has never been figured. The best-preserved cranidium of Roemer's specimen is figured in plate 69, figures 23, 24. Other specimens from Texas selected by Walcott to replace Shumard's lost types are shown in plate 69, figures 25, 26.

The original description is sufficient and need not be repeated.

#### OCCURRENCE

This species is extremely abundant in the upper part of the Cap Mountain formation, in limestones immediately below the Lion Mountain sandstone member, and in limestone lenses in the base of that member. It occupies a zone about 40 feet thick, which, owing to the abundance of this form, has come to be known as the *Aphelaspis* zone.

This zone does not occur on the San Saba River at the ford half a mile east of Camp San Saba, or at any other point farther upstream. It is exposed on both sides of the river just west of Voca, and this particular specimen is believed to have come from that locality. The lithology is so very similar to that of the *Camaraspis* zone that they could easily be confused with one another.

#### *Idahoia?* sp.

Plate 67, figures 2c, d; plate 69, figures 27, 28

1852. \* \* \*<sup>52</sup> Pygidium of a trilobite belonging to an unknown genus, Roemer, Kreidebildungen, p. 93, pl. 11, figs. 2c-d.  
1861. *Arionellus* sp. Shumard, Am. Jour. Sci., 2d ser., vol. 32, p. 221.

#### ORIGINAL DESCRIPTION

The pygidium (figs. 2c, d) next to be described is very doubtfully associated with this cephalon. It was not observed joined to the cephalon by means of the thorax, but only as separate parts. The reason for considering them to be related is the fact that they are associated together and that both show about the same degree of rounding [elevation]. The pygidium in question is strongly elevated, almost triangular, and terminates posteriorly in a small, somewhat posteriorly directed spine. In the middle of the pygidium is an oval, strongly and evenly elevated area surrounded on all sides by a furrow. The posterior portion of the furrow that outlines this area appears to continue along the lateral margins of the shield on both sides. However, it is not a plane, as the drawing would indicate. The anterior portion of the furrow separates the oval area from the forward portion of the shield, which is bowed upward in a cross roll [transversely], and this in turn is separated from the upturned anterior margin by a broad furrow. \* \* \*

<sup>52</sup> Section omitted here is given in the description of *Elvinia roemeri*.

Occurrence: Associated with the preceding in the crystalline Silurian limestone in San Saba Valley.

Explanation of the figures: \* \* \* 2c, view of the pygidium from above; 2d, view of the pygidium in profile.

#### REMARKS

Roemer's material consists of a small fragment of limestone (no. 8) containing an imperfect cranidium. Only the occipital ring, the glabella, and a portion of the brim, retaining parts of the test, are preserved. All of the margin, except that of the occipital ring, is missing, so that from the specimen it is very difficult to form any idea of the original outline. The glabella has parallel sides and is evenly rounded anteriorly. It is rather strongly elevated. The circumglabellar furrow is distinct and strongly impressed. No glabellar furrows can be detected, but the lack of them may be due to conditions of preservation. Occipital furrow strong; occipital ring broadly triangular; the apex to the rear and terminated by a strong, posteriorly directed occipital spine. The brim is about equally divided into a strongly deflected, preglabellar area and a flat or slightly upturned rim. The preglabellar area bears markings that resemble radial striations, but this may be due to weathering.

The accompanying label bears the following notation: "(8) Trilobite genus? pygidium? F. Roemer, Texas, pl. 11, figs. 2c, d, Silurian, San Saba, Texas."

The general appearance of this specimen suggests that it should be placed in Walcott's genus *Idahoia*. The glabella of this specimen is more truly oval than in typical *Idahoia*. Moreover, *Idahoia* has never been found in beds as low as the *Camaraspis* zone but occurs somewhat higher in the section in the *Ptychaspis-Prosaukia* zone.<sup>53</sup>

Roemer's specimen could also be referred to the genus *Saratogia*, a form which is closely allied to *Idahoia* and which future work may show to be congeneric with it. In *Saratogia* the glabella is more rectangular in outline and more abruptly truncated anteriorly, the glabellar furrows show more distinctly, and the preglabellar area and rim are slightly different, but whether these differences are generic or specific is yet to be determined.

#### OCCURRENCE

The specimen is said to have been collected at the same locality that yielded the other trilobites. No other specimens referable to this form have been found in the collections from Texas, but an undescribed species believed to be identical with it occurs in the Ironton member of the Franconia formation in Wisconsin.

<sup>53</sup> Raasch, G. O., Stratigraphy of the Cambrian system of the upper Mississippi Valley: Kansas Geol. Soc., Ninth Ann. Field Conference, Guidebook, p. 303, 1935.

## ORDOVICIAN SPECIES

By JOSIAH BRIDGE

## GASTROPODA

*Ophileta polygyrata* (Roemer)

Plate 67, figures 4a, b; plate 69, figures 29-34, 36, ?35

1849. *Euomphalus polygyratus* Roemer, Texas, p. 421.  
 1852. *Euomphalus polygyratus* Roemer, Die Kreidebildungen von Texas, p. 91, pl. 11, figs. 4a, b.  
 1889. *Euomphalus polygyratus*. Miller, North American geology and paleontology, p. 404.  
 1900. *Pleurotomaria hunterensis* Cleland, Bull. Am. Paleontology, vol. 4, no. 18, pl. 16 (42), pl. 4, fig. 2 (not fig. 1).  
 1903. *Polygyrata polygyratus*. Weller, New Jersey Geol. Survey, Paleontology, vol. 3, Paleozoic faunas, p. 130.  
 1903. *Polygyrata sinistra* Weller, idem, p. 130.  
 1903. *Polygyrata hunterensis*. Weller, idem, p. 130.  
 1915. *Polygyrata hunterensis*. Bassler, U. S. Nat. Mus. Bull. 92, p. 1020.  
 1915. *Polygyrata polygyrata*. Bassler, idem, p. 1020.  
 1915. *Polygyrata sinistra*. Bassler, idem, p. 1020.  
 1919. *Ophileta complanata* Bassler, Maryland Geol. Survey, Cambrian and Ordovician, p. 302, pl. 31, figs. 2-5.  
 1932. *Ophileta polygyrata*. Bridge, in Dake and Bridge, Geol. Soc. America Bull., vol. 43, p. 741, pl. 12, fig. 10 (type refigured).  
 1933. *Ophileta polygyrata*. Bridge, in Sellards, Adkins, and Plummer, Texas Univ. Bull. 3232, p. 233, pl. 3, fig. 10 (type refigured).

## ORIGINAL DESCRIPTIONS

8. *Euomphalus polygyratus*. n. sp. Shell 1'3" in diameter, convex, with numerous whorls, 9-10, narrow, subequal, appressed, [the upper surface] of each one lying in the same plane and forming a low cone above.

This species resembles *E. gualteriatus* Goldfuss (*Helicites gualteriatus* Schlotheim) in that the upper surface of all the whorls forms a blunt conical surface, but it differs from this form in the much greater number of whorls [which it possesses].

A single specimen was found in gray (Silurian?) limestones about 20 English miles below the old Spanish fort.—Texas, p. 421.

7. *Euomphalus polygyratus*

Plate 11, figures 4a, b

*Euomphalus polygyratus* F. Roemer, Texas, p. 421.

Diameter 1'3", height 5"

Shell coiled dextrally, convex above, bluntly conical, concave below; with numerous (9-10) narrow, almost equal, appressed whorls, the same forming a blunt, conical surface; with the section across the whorls subrhomboidal.

The shell is convex above, obtusely conical, concave below; whorls numerous (9-10), narrow, very slowly increasing in width, thus forming almost equal whorls which are pressed closely on one another with the upper surface in the same obtuse conical plane without interruption. The cross section of the whorl is almost rhomboidal.

This form is particularly distinguished by two characters—by the obtusely conical upper surface, which is formed by the edges of the whorls meeting without interruption, and by the significant number of the whorls. It has the first of these characters in common with *Euomphalus gualteriatus* Goldfuss (*Helicites gualteriatus* Schlotheim), from the Silurian strata of Sweden and Russia, which [species], on the other hand, differs from it in the much lower number of whorls (3-4) and in the much more rapid manner in which they enlarge.

Occurrence: The single specimen that serves as the basis of the preceding description is an internal mold found in a gray limestone in San Saba Valley about 20 miles below the site of the old Spanish fort. The relationship of this species with a Silurian form indicates that the limestone which contains it is itself a part of the Silurian system and probably of the older Silurian.

Description of figures: Figure 4a, view from above; figure 4b, apertural view.—Kreidebildungen, p. 91.

## NOTES ON THE TYPE SPECIMEN

The holotype (no. 11) is an internal mold preserved in a fine-grained gray, slightly magnesian limestone. Only the dorsal surface is shown, the umbilicus being concealed by the matrix. The outer whorls are broken at several places, allowing good cross sections of the whorl to be obtained. The upper surface is deeply weathered, so that all surface markings are obliterated, and the whorls forming the summit of the spire are eroded away. Seven whorls may be definitely counted, and the extremely slow rate of increase in diameter of these indicates that there were at least four more in the spire. The ratio of increase is about 6:5.

What appears to be the aperture is shown in the upper right-hand corner as the specimen is figured. The small projections in the extreme upper and lower right-hand corners fail to show cross sections of the whorl and are considered to be matrix.

The whorl is rhomboidal in cross section, wider than high, the upper and lower outer slopes meeting the slightly supramedian peripheral keel at an angle of about 65°. The upper surface is so badly corroded that no traces of the sigmoid profile of the shoulder remain.

The dimensions of the fragment are, actual diameter 31 millimeters, restored diameter 35 millimeters, actual height 12 millimeters, restored height 15 millimeters, diameter of umbilicus approximately 29 millimeters, height of body whorl near aperture 4 millimeters, width at same point 7.7 millimeters (estimated), apical angle 125°.

The shell agrees very closely in size and general proportions with the large syntype of *Pleurotomaria hunterensis* Cleland. (See table, p. 258.) The most noticeable difference is in the apical angle, which is 115° in Cleland's specimen<sup>54</sup> and between 120° and 125° in Weller's. The latter figure agrees almost exactly with the apical angle of the small, incomplete specimen shown in Cleland's figures 7 and 8.

## COMPARISON WITH OTHER FORMS

The great similarity between *Euomphalus polygyratus* Roemer, *Pleurotomaria hunterensis* Cleland, and *Polygyrata sinistra* was originally pointed out by Weller,<sup>55</sup> who assigned all three forms to his genus *Polygyrata*.

<sup>54</sup> Cleland, H. F., The Calciferous of the Mohawk Valley: Bull. Am. Paleontology, vol. 3, no. 13, p. 12 (124), pl. 17, figs. 7, 8, 1900.

<sup>55</sup> Weller, Stuart, The Paleozoic faunas: New Jersey Geol. Survey, Paleontology, vol. 3, p. 130, 1903.

but retained them as distinct species. Later Ulrich and Bridge,<sup>56</sup> after comparing the types of the three species, concluded that *Polygyrata sinistra* Weller was a synonym of *Ophileta hunterensis* (Cleland). They also noted the great similarity between these forms and Roemer's specimen but provisionally considered them to be distinct. As *P. sinistra* was the type of Weller's genus, and *Ophileta* was the older name, *Polygyrata* was made a synonym of *Ophileta*. The restudy of Weller's type showed that he was mistaken in interpreting his species as a sinistrally coiled form. The growth lines, which are faintly preserved on the outer whorl (pl. 69, fig. 34), show plainly that the shell coiled to the right in the normal manner and not to the left as shown in Weller's figure.<sup>57</sup>

The basis of Weller's interpretation is to be seen in a small healed fracture, a minute scissors fault which has displaced the shell on each side of the break to the extent indicated by the depth of the whorls in his figure 2. At the same time, there was also a slight amount of lateral displacement, and it was this fact which caused him to interpret the shell as sinistral. The growth lines on the specimen (pl. 69, figs. 33, 34) show that this is not the case.

The differences between these New York and New Jersey forms and Roemer's specimen are very slight, the latter being slightly smaller, with slightly narrower whorls and a wider suture line. It is an internal mold, which preserves no traces of the outer shell. These are present in the other specimens, and this is believed to account for the difference, for the shell is invariably thickened along the peripheral keel, and this thickening broadens the whorls and narrows the suture line. In the autumn of 1934 the writer collected several specimens referable to this species at two localities in the western part of the Central Mineral Region. One of these was on the San Saba River in the general vicinity of the locality that furnished Roemer's specimen (p. 242), and the other was on Honey Creek southwest of Mason. Some of these specimens preserve the outer shell (pl. 69, fig. 36). The agreement between these forms and those from New York and New Jersey is so close that the writer regards them as conspecific, and as *Ophileta polygyrata* has many years' priority, *O. hunterensis* (Cleland) (including *Polygyrata sinistra* Weller) is regarded as a synonym.

The measurements of the various specimens used in this comparison are given below:

#### Measurements, in millimeters, of specimens of *Ophileta*

[An asterisk indicates that the measurement has been computed to allow for a portion of the specimen which is not preserved]

|   | O. polygyrata holotype | O. hunterensis holotype | O. hunterensis fragment | O. sinistra |
|---|------------------------|-------------------------|-------------------------|-------------|
| Diameter-----   | *35                    | 38                      | 15                      | 36          |
| Altitude-----   | *15                    | *19                     | 5                       | 7—          |
| Apical angle-----   | 125°                   | 115°                    | 115°                    | 125°        |
| Diameter of umbilicus-----                                  | 29—                    | 30?                     | 5. 5                    | 29?         |
| Width of body whorl near aperture, suture to periphery----- | 3. 2?                  | 4. 4                    | —                       | 4           |

#### OCCURRENCE

According to Roemer the holotype was collected in the San Saba Valley about 20 miles downstream from the old Spanish fort (Menard). This is all the information given in his description, but from a study of his narrative<sup>58</sup> it seems fairly certain that the specimen was collected on the return journey, and that it came from the south bank of the river about 5 miles below the point where the Paleozoic strata disappear beneath the Cretaceous rocks in the bed of the river. This locality is probably in Mason County somewhere near the Menard County line.

As noted above, the writer has collected *Ophileta polygyrata* at two localities. In both it occurs in association with *Eccyliomphalus gyroceras* (Roemer) in dense white limestone of Gasconade age that forms the base of the Ellenburger throughout most of the western part of the Central Mineral Region. This limestone is the one which Dake and Bridge<sup>59</sup> called the *Eccyliomphalus gyroceras* zone and which they considered to be the middle division of their Gasconade faunal equivalent. This is now known to have been an error, as recent work has shown conclusively that their so-called lower member of the Gasconade faunal equivalent is merely the down-faulted upper member. Thus the Gasconade faunal equivalent as now known consists of two members—a lower white limestone carrying *Eccyliomphalus gyroceras* and *Ophileta polygyrata* and an upper dolomitic zone carrying the more common Gasconade assemblage.

#### *Eccyliomphalus gyroceras* (Roemer)

Plate 67, figures 6a, b; plate 70, figures 6–10

1852. *Euomphalus gyroceras*. Roemer, Die Kreidebildungen von Texas, p. 91, pl. 11, figs. 6a, b.  
 1889. *Eccyliomphalus gyroceras*. Miller, North American geology and paleontology, p. 403.

<sup>56</sup> Ulrich, E. O., and Bridge, Josiah, *Ophileta, Polygyrata, and Lecanospira* [abstract]: Geol. Soc. America Bull., vol. 43, no. 1, p. 278, 1932.

<sup>57</sup> Weller, Stuart, op. cit., pl. 4, fig. 1.

<sup>58</sup> Roemer, F., Texas, p. 314, 1849.

<sup>59</sup> Dake, C. L., and Bridge, Josiah, Faunal correlation of the Ellenburger limestone of Texas: Geol. Soc. America Bull., vol. 43, p. 735, fig. 2, 1932.

1898. *Phanerotinus gyroceras*. Weller, U. S. Geol. Survey Bull. 153, p. 420.
1915. *Eccyliomphalus gyroceras*. Bassler, U. S. Nat. Mus. Bull. 92, p. 467.
1932. *Eccyliomphalus gyroceras*. Bridge, in Dake and Bridge, Geol. Soc. America Bull., vol. 43, p. 740, pl. 12, fig. 6.
1933. *Eccyliomphalus gyroceras*. Bridge, in Sellards, Adkins, and Plummer, Texas Univ. Bull. 3232, p. 233, pl. 2, fig. 6.

## ORIGINAL DESCRIPTION

9. *Euomphalus gyroceras*, n. sp.

Plate 11, figures 6a, b

Diameter 1" 1"'; height 2"

*Shell an incomplete spiral in one plane, with whorls completely separate, with less than two [whorls]. Cross section of the whorl a compressed oval.* The shell is an incomplete spiral, coiled in the same plane, forming less than two complete volutions, often scarcely one, in which case it appears hook-shaped. The whorls free, separated by a wide interval. The cross section of the whorl is oval, somewhat compressed dorsoventrally.

This form is most closely related to those in the Devonian limestones at Paffrath am Rhein and in the Harz Valley. It also resembles *Euomphalus serpula* De Koninck (*Serpularia centrifuga* A. Roemer), which occurs in the Carboniferous limestone of Belgium and which also differs from the typical form of the genus in its free whorls, which do not touch each other. The Texas species, however, differs from the European forms in the compressed, oval cross section of the whorl, which is circular in *Euomphalus serpula*, and in the coiling of the whorls in the same plane, while the European forms for the most part are more or less plainly conically coiled. In addition, the number of whorls in the latter species is greater.

The generic designation of this form is doubtful, because all the Texas specimens agree in the wide separation and small number of the whorls—characters not attributed to the genus *Euomphalus*. A great number of Texas specimens were examined, and all agree in these particulars, so that it is plainly the normal habit of the species. Moreover, although a single specimen with free whorls is occasionally found in other gastropod genera that have the whorls in close contact—for example, *Helix*—the close-coiled condition is the normal one, while here the opposite is the case. In addition, the small number of volutions constitute a form which is very different from that of the true *Euomphalus*. In case more detailed studies should justify the removal of this and similar forms from this genus (*Euomphalus*), it might be placed in the new genus *Serpularia*,<sup>60</sup> which my brother, A. Roemer, has named.

Finally, it is to be noted that these shells, which for the most part are preserved as natural longitudinal sections, show no internal cross partitions or septa, similar to those possessed by many true species of *Euomphalus*.

Occurrence: Many specimens with partly preserved shells were collected from a compact bright yellowish-gray limestone (Carboniferous limestone?) occurring in the valley of the San Saba River about 20 English miles below the old Spanish fort.

Description of figures: Figure 6a, view from above; figure 6b, cross section of the last whorl.—Kreidebildungen, p. 91.

## REMARKS

The type material consists of two specimens (nos. 13 and 14), both of which are natural, longitudinal sections preserved in a limestone matrix. The original figure is evidently based on the specimen illustrated in plate 70, figure 6, and a note on the back of the label confirms this conclusion. The specimens must be considered syntypes.

Syntype A (the specimen just mentioned) shows a longitudinal section as seen from the ventral side (on the assumption that the direction of coiling is dextral) and consists of about 1½ volutions. The inner end of the whorl tapers to a fine point, and there is no trace of a more closely coiled inner portion, but the lack of this is probably due to weathering. No section of the whorl is obtainable on this specimen. The ventral side appears to have been smoothly rounded, with the maximum convexity slightly toward the inside of the center. The ventral side of the aperture seems to have been entire or very slightly sinuate.

Syntype B (pl. 70, fig. 7) also shows a natural longitudinal section, but in this specimen it is seen from the dorsal side. It is not as well preserved, only about one-half of the final whorl remaining, and it is quite evident that the inner whorls have been eroded away, for at one point there is a faint suggestion of one of them. The apertural end intersects the margin of the fragment of rock and affords a good cross section of the ventral half of the whorl, which agrees very well with the section postulated for syntype A.

Neither specimen shows any trace of surface markings or gives any clue to the profile of the dorsal side. In neither one is there any definite trace of the septa that are so noticeable in certain species of this genus, notably in *Eccyliomphalus multiseptarius* Cleland.

Examples of this species collected by C. L. Dake and the writer show additional characters not shown by the types. Several show the initial spiral, and these indicate that the shell consists of about 1½ volutions and that the whorls are nowhere in contact. Other fragmentary specimens show that the whorl is oval in cross section, slightly flattened on the inner side, with the longer diameter parallel to the plane of coiling. None of the specimens observed show any trace of surface markings or of septa.

The dimensions of the types are, syntype A, diameter 31 millimeters, width of whorl near aperture 8 millimeters, width of whorl one-half volution from aperture 3.5 millimeters; syntype B, slightly larger, diameter 36 millimeters, width of whorl near aperture 8.5 millimeters, width of whorl one-half volution from aperture 5 millimeters.

Most of the specimens in the United States National Museum are somewhat smaller, but some of them attain the size of Roemer's specimens. The diameters of the

<sup>60</sup> Name preoccupied by *Serpularia* Münster, 1840 (Vermes). *Serpularia* A. Roemer, 1843 (Mollusca)=*Serpulospira* Cossman, 1915, genotype *Serpularia centrifuga* A. Roemer, 1843, according to information furnished by J. B. Knight. The genotype is a Devonian form, but future work may show that many of the early Paleozoic American species now referred to *Eccyliomphalus* should be placed here.—J. B.

whorl of a large fragment are 7 and 8.5 millimeters; those of a smaller specimen are 5 and 6 millimeters.

#### OCCURRENCE

The types came from the locality on the San Saba River about 20 miles below the old Spanish fort which has already been discussed in connection with *Ophileta polygyrata*, and in 1934 the writer collected both species in this same general locality (p. 242). The matrix is a dense fine-grained creamy-white to yellowish, almost lithographic limestone which is known to occur at three horizons, at least, in the Ellenburger.

The limestone carrying *E. gyroceras* is the lowest of the three white limestones above noted. It is the basal portion of the Gasconade division of the Ellenburger. Several specimens were collected near the top of this zone along the Mason-Brady highway about 1.45 miles north of the bridge at Camp San Saba. In this section it is about 100 feet above limestone carrying an Upper Cambrian fauna.

The species has also been collected in the extreme southwestern part of the Llano uplift from outcrops along the White ranch road about 7 miles southwest of the bridge across the Llano River. At this locality these white limestones are the oldest rocks exposed and are directly overlain by the Trinity sand, although the Roubidoux beds of the Ellenburger are exposed along this road in the vicinity of the Llano River.

*Eccyliomphalus gyroceras* appears to be fairly common and seems to mark a very definite horizon in the Ellenburger limestone; it should therefore prove to be an extremely valuable index fossil in the Llano region.

#### Lecanospira sanctisabae (Roemer)

Plate 67, figures 5a, b; plate 70, figures 1-5

- 1849. *Euomphalus sanctisabae* Roemer, Texas, p. 421.
- 1852. *Euomphalus sanctisabae* Roemer, Die Kreidebildungen von Texas, p. 91, pl. 11, figs. 5a, b.
- 1889. *Straparollus sanctisabae*. Miller, North American geology and paleontology, p. 426.
- 1915. *Straparollus sanctisabae*. Bassler, U. S. Nat. Mus. Bull. 92, p. 1198.
- 1932. *Lecanospira sanctisabae*. Bridge, in Dake and Bridge, Geol. Soc. America Bull., vol. 43, p. 741, pl. 12, figs. 13, 14.
- 1933. *Lecanospira sanctisabae*. Bridge, in Sellards, Adkins, and Plummer, Texas Univ. Bull. 3232, p. 234, pl. 2, figs. 13, 14.

#### ORIGINAL DESCRIPTIONS

9. *Euomphalus sanctisabae*, n. sp. Shell 1"2" in diameter, flat on the upper surface, whorls about six, increasing perceptibly in width, convex above, vertical cross section of the whorl oval.

Common in the white cherty Silurian limestone that forms the barren uplands on both sides of the San Saba River in the middle portion of its course. (See p. 339.)—Texas, p. 421.

#### 8. *Euomphalus sanctisabae*

Plate 11, figures 5a, b

*Euomphalus sanctisabae* F. Roemer, Texas, p. 421.

Diameter 1"8", height 3"

Shell flat above, discoidal, sinistrally coiled, whorls about six, gradually enlarging, slightly rounded, vertical section of whorl ovate, subrectangular; spire not elevated, concave beneath.

The shell is disk-shaped, sinistrally coiled, almost plane above. The whorls separated by a furrow, moderately numerous (about six), increasing slowly in breadth, on the upper side flat-arched, almost plane, in cross section oval, almost rectangular.

The single example before me is in the form of an internal mold and shows only traces of the enclosing shell in the form of white silica rings. In the specimen under discussion only the upper side is visible, but from the cross section of the whorl it is plainly seen that the under side is shallowly concave.

The almost plane upper side of the shell and the slowly increasing [diameter] of the whorl does not allow this form to be confused with any other.

Occurrence: The described specimen was found in bright-gray cherty limestone which contains many small cavities lined with druses composed of quartz crystals that glitter in the sun. [The limestone is] probably of Silurian age and forms the barren cliffs on both sides of the San Saba River in the middle portion of its course. (See above, p. 7.) In this limestone the species is not uncommon.

Explanation of the figures: Figure 5a, view from above; figure 5b, view seen from side opposite the aperture.—Kreidebildungen, p. 91.

#### REMARKS

The type specimen (no. 12) is an internal mold preserved in the dense white lithographic limestone that occurs in at least three well-defined zones in the Ellenburger limestone. The shell itself was partly silicified, and traces of it remain. The base of the shell (dorsal side of Roemer) is exposed and shows seven whorls coiled in a plane. Two sections are broken out from the final half of the body whorl, but enough remains to determine the position of the aperture with a fair degree of certainty. The opposite side of the specimen is almost completely covered by the white-limestone matrix, but the dorsal keel of the body whorl is plainly visible for about one-third of the length of the whorl. Some of the matrix was removed, revealing the keel of the penultimate whorl and showing plainly that the spire is depressed, but it was not advisable to attempt to clean the entire specimen. This keel is median. The cross section of the whorl, which is well exposed where the final whorl is fractured, is pentangular, with all the angles rounded except the one formed by the dorsal keel. The whorls are in contact to about one-half of the height of the outer one and about three-fourths of the height of the inner one. The whorls do not overlap sufficiently to form a smooth concave spire, the summit of each whorl being separated from

adjoining whorls by a sharp V-shaped groove, which carries the suture.

There is a very perceptible and regular increase in the width of the whorls, the ratio being 3:2 in any adjoining pair.

The surface markings and aperture are not preserved.

The depressed spire with its elevated dorsal keel and the flat or gently concave base are all characteristic of the genus *Lecanospira*, and this species is referred to it without question.

The maximum measurable diameter of the holotype is 40 millimeters; the computed diameter of the restored specimen is at least 47 millimeters; the diameters of the body whorl at the point where the first fracture occurs are, width 9 millimeters, height 10 millimeters; the diameters of the triangular fragment of the body whorl at a point estimated to be 20 millimeters from the aperture are, width 11 millimeters, height 12 millimeters.

The species appears to be intermediate between *Lecanospira compacta* (Salter) and *L. biconcava* Ulrich and Bridge. The dorsal keel is median as in *L. compacta*, but the whorls are narrower and enlarge more slowly than in that species. They are broader and more rapidly expanding than those of *L. biconcava*, and the base is flat, not slightly concave as in *L. biconcava*.

#### OCCURRENCE

The locality from which the holotype was obtained is not at all definite, but from the narrative it was collected on the return trip from the San Saba River. As nearly as can be determined from his map, Roemer's route lay close to the meridian 98°50'. This meridian crosses the great plateau underlain by the Ellenburger limestone, which bounds the north edge of the Llano uplift at about the line of the present road from Pottotoc to San Saba. At several places along this road, particularly on the plateau around the headwaters of Wallace Creek, the present writer found ledges of dense white lithographic limestone carrying fragmentary specimens of *Lecanospira sanctisabae*, and it may well be that the holotype came from this general locality.

Several poorly preserved examples of what appears to be the same species were collected in 1931 by C. L. Dake on the high bluff on the north side of the Llano River about half a mile northwest of the concrete ford on the White ranch road. At this locality the first specimens were found in a prominent ledge on the south-east face of the hill about 165 feet above the flood plain of the Llano River, and above this point scattered specimens were found ranging through a zone at least 100 feet thick. In the upper part of this zone they are associated with a species of *Rouibidouxia*.

The white limestone containing these fossils is the middle one of three such zones in the Ellenburger limestone and is to be correlated with the Roubidoux sandstone of Missouri, with the Longview limestone and Nittany dolomite of the Appalachian Valley, and with an unnamed bed in the Arbuckle limestone of Oklahoma.

#### CARBONIFEROUS SPECIES

By GEORGE H. GIRTY

Roemer cited five species from rocks of Carboniferous age. Four of these (*Orthis arachnoidea*, *Terebratula pugnus*, *Productus flemingii*, and *Productus cora*) were identified with described species; the fifth (*Spirifer meusebachanus*) was described as new. *Terebratula pugnus* and *Productus cora* were not figured, and there was, effectively, no text for *Terebratula pugnus*.

As regards geologic horizon, the four species first mentioned are stated to have been found in association. The horizon is undoubtedly in the Bend group, but whether it is Smithwick or Marble Falls is not so certain. Among the numerous collections from those formations at my disposal there is one especially (station 2602) which seems to have the same fauna and the same rock characters as Roemer's specimens. The horizon of this collection is given as Smithwick(?). *Spirifer meusebachanus* appears to have been found at a different locality and a different horizon from the rest. Bridge informs me that the rocks at the locality where he believes that specimen to have been collected are mapped as Canyon by the Texas Geological Survey.

The material examined as representing Roemer's collection comprises (1) the holotype of *Spirifer meusebachanus*, a free specimen (pl. 70, figs. 18-21); (2) a small slab purporting to contain the specimen figured as *Productus flemingii* (pl. 70, figs. 14 and 15); (3) another small slab purporting to contain the same original (pl. 70, figs. 16 and 17); (4) a large slab containing at one end the original of one of the figures of *Orthis arachnoidea*, together with specimens of *Terebratula pugnus* and more specimens of *Productus flemingii* (pl. 70, fig. 12); (5) a small slab split off from the large one last mentioned, which contains on its upper or outer surface a fragment from which was drawn the enlargement showing the surface characters of *Orthis arachnoidea* (pl. 70, fig. 13) and on its under side the reverse of the other specimen illustrated as *Orthis arachnoidea*.

Roemer's original plate is reproduced as plate 67 of this report; photographic reproductions of his original material are given on plate 70 as just described. As regards text, the species are taken up in the same order as in Roemer's report, and his text is reproduced in full (translations by Bridge), followed by such comment and discussion as seem suitable.

***Spirifer meusebachanus Roemer***

Plate 67, figures 7a-c; plate 70, figures 18, 19, 20, 21

**ORIGINAL DESCRIPTION***Spirifer meusebachanus* F. Roemer, Texas, p. 420.Width 2<sup>1</sup>/<sub>2</sub>" 3<sup>1</sup>/<sub>2</sub>", thickness 1<sup>1</sup>/<sub>2</sub>" 5<sup>1</sup>/<sub>2</sub>", length 1<sup>1</sup>/<sub>2</sub>" 9<sup>1</sup>/<sub>2</sub>"

Shell large, inflated, transverse, scarcely alate, radially plicate; with numerous plications, rounded, arranged in bundles; with the dorsal [ventral] valve ornamented with a deep median sinus and two lateral depressions; with the beak sharply incurved; with an area 3<sup>1</sup>/<sub>2</sub>" in height, with distinct vertical striations; with the ventral [dorsal] valve ornamented by a high median plication.

The shell is large, inflated, wider than high, almost triangular, slightly winged; the outer surface ornamented with many rounded branching costae, which are grouped into bundles containing three or four. These are crossed by widely spaced growth lines which occur only near the margins of the shell.

The dorsal [ventral] valve is provided with a broad, deep median sinus, as wide as the side [lateral slope] of the valve. Its broad, rounded, tonguelike point extends deeply into the ventral [dorsal] valve. On each side of the valve is a broad, shallow depression, which, when taken with the median sinus, causes the latter to appear to be bordered by a broad rounded ridge. The ventral [dorsal] valve is likewise strongly arched and is elevated in the middle into a high rounded fold, which is also ornamented with costae. The anterior margin is deeply notched for the reception of the tongue-shaped lobe of the dorsal [ventral] valve. The hinge line shows a moderately high area with plainly defined vertical striations.

The foregoing description and the figures are of a single, very beautiful and entirely complete specimen which was collected and presented to me by Mr. O. von Meusebach, the former general commissioner of the Association for the Protection of German Immigrants in Texas. He collected it while on our joint expedition in the San Saba Valley in the spring of 1847, from gray Carboniferous limestone at a locality about 20 miles below the old Spanish fort. (See F. Roemer, Texas, p. 314: ante, p. 7.)

I name this species for its discoverer, who had made scientific contributions before his emigration to America, as is witnessed by the collections of fossils from the glacial drift of the Mark of Brandenburg and Pomerania, which he has deposited in the Mineralogical Museum at Berlin, and who later on most cheerfully and unselfishly assisted me in pursuit of my geologic journey's goal in Texas.

Besides the specimen in question, which was used by preference as the basis for the description, there are before me a number of imperfect specimens which I collected at the same locality and which correspond [to it] in all respects.

The inequality and strong branching of the costae shows plainly that this is one of the Carboniferous species which is characterized by the fasciculate arrangement of the costae on the outer surface.

A comparison with similar species in the genus shows a close relationship to *Spirifer tasmani* Morris,<sup>61</sup> from Van Diemen's Land [Tasmania]. This last resembles the Texan species in the fasciculate arrangement of the costae and the general outward form of the shell but differs in the finer costae which ornament the sinus and fold and in the more limited depth of the sinus. *Spirifer condor* D'Orbigny,<sup>62</sup> from Bolivia, is very close to the

Texas species according to D'Orbigny's figure; but according to De Koninck, who has examined the original specimen, it is indistinguishable from *Spirifer striatus* Sowerby.

Explanation of the figures: Figure 7a, View of the outer surface of the dorsal [ventral] valve; figure 7b, view of the outer surface of the ventral [dorsal] valve; figure 7c, view from the side.—Kreidebildungen, p. 88.

**REMARKS**

The holotype is a fine specimen, and though it is somewhat idealized in the figures, a good idea of its characters can be had from them. Imperfections are present which are glossed over in the illustrations but are brought out in the photographs—for instance, the top of the fold and part of the sides are decorticated and also the arches that enclose the sinus. The dorsal view (fig. 7b) is somewhat misleading, for the fold is narrower, higher, and more strongly rounded on top than one would judge from the figure.

The surface markings are not well shown. They seem to consist of fine sublamellose incremental lines, some of which are stronger than the rest. These stronger lines vary in size and spacing; apparently only those that are especially pronounced are mentioned by Roemer. No fine radial striations have been observed, but if they were very fine they may originally have been present.

Roemer has mentioned the fasciculation of the costae, a feature which is in fact conspicuous. The fascicles are but slightly prominent, even near the hinge line, and farther forward they are essentially flat. They catch the eye because they are outlined by striae stronger than the rest.

*S. meusebachanus* has commonly been cited as a synonym of *S. cameratus* Morton. It is so treated by both Schuchert and Weller. At that time, however, *S. cameratus* was also made to include *Spirifer triplicatus* Hall. If the characters shown by the holotype are constant, *S. meusebachanus* is probably distinct from both the species mentioned. *S. triplicatus* is not so gibbous; it has finer and more numerous costae, and the fascicles are arched or subangular. Compared with *S. cameratus* (for example, the specimens which I figured from Putnam Hill, Ohio), *S. meusebachanus* is larger and much more gibbous, and it has a much more strongly developed fold and sinus. Large size, high convexity, and strength of fold and sinus are characters that are likely to accompany each other in specimens of any species, and it may be that smaller and younger specimens of *S. meusebachanus* would not be readily distinguished from *S. cameratus*.

The suggestion is carried on another page that the horizon of *S. meusebachanus* is probably higher than the Bend group, supposedly the Canyon group. As bearing upon this point, Spirifers of this general character are abundant in the Bend group, but none of those which I have seen are comparable to the

<sup>61</sup> Physical description of New South Wales and Van Diemen's Land, by Count Strelczecki, p. 250, pl. 15, fig. 2. Leopold von Buch, Die Bären-Insel nach Keilbau geognostisch beschrieben, p. 11, figs. 3a, b (a beautiful illustration of a specimen now in the Berlin Museum).

<sup>62</sup> Voyage dans l'Amérique méridionale, par A. D'Orbigny, tome 3, 4ème partie, Paléontologie, p. 46, pl. 5, figs. 11-14.

holotype of *S. meusebachanus* in perfection of preservation. They commonly occur as disconnected valves and are likely to be much exfoliated. They are more of the character of *S. cameratus* and regularly differ from Roemer's species in being much less gibbous. This evidence, for what it is worth, would suggest either that *S. meusebachanus* was not a Bend group species or else that the holotype is not really a representative specimen. Furthermore, some of the matrix still remaining in the cardinal area is a yellowish earthy rock—another piece of evidence that should be weighed cautiously.

#### *Orthis arachnoidea* Phillips

Plate 67, figures 9a, b; plate 70, figures 11, 12, 13

#### ORIGINAL DESCRIPTION

*Orthis arachnoidea* Phillips, Paleozoic fossils, p. 67, pl. 27, fig. 114.  
*Spirifera arachnoidea* Phillips, Geology of Yorkshire, vol. 2, pl. 11, fig. 4.

The illustration shows the dorsal valve of a young specimen. The outline and the size and number of the branching, radiating, granular costae agree in all respects with those in specimens of *Orthis arachnoidea* Phillips, from the Carboniferous of England. However, I do not consider this identification to be indisputable, because there are not a sufficient number of specimens showing the various growth stages available [to make detailed comparisons].

Occurrence: In black, indubitable Carboniferous limestone, which also contains *Productus flemingii* Sowerby, *Productus cora* D'Orbigny, and *Terebratula pugnus* Sowerby, occurring in a tributary valley of the San Saba Valley.—Texas, p. 318; ante, p. 7.

Explanation of the figures: Figure 9a, View of a dorsal valve from above; figure 9b, a portion of the outer surface greatly enlarged.—Kreidebildungen, p. 89.

#### REMARKS

Synonymists have placed this citation under *Derbyia crassa*, and such are its general but not, probably, its precise relations. Roemer has given us two figures of the species—one showing a valve in full, the other an enlargement of the surface. These two figures are based on different specimens. In one of the foregoing paragraphs it was remarked that the collection comprised two slabs that fit together, one small and one relatively large (pl. 70, figs. 11, 12). The specimen figured in full is on the large slab and is an internal mold of a brachial valve. It is nearly flat over most of its surface, but it is warped rather strongly downward near the lower right-hand margin. It was brought to light by breaking off the small slab, which on its lower side contains the interior of the same specimen, but its upper side exposes the specimen from which was drawn the enlargement to show the surface characters. The latter specimen, which is also a dorsal valve, is considerably larger than the other (nearly 30 millimeters in length), gently but irregularly convex, and in a poor state of preservation, being rather fragmentary and partly exfoliated.

As both specimens are dorsal valves, the generic position of the species is indeterminable, though the probabilities point to *Derbyia*, or possibly *Orthotetes*. I have a pedicle valve, probably of the same species, from station 2902 (see p. 264), which shows the interior and affords evidence that the generic relations are in fact with *Derbyia*. My specimen occurs in the same fauna as Roemer's, but this fact is not decisive. If Roemer's species can be referred to *Derbyia* on these grounds, it differs from *D. crassa* in being more finely striated, and other differences may come to light when a more varied assortment of specimens representing both valves is brought together. The difference in the striation is conspicuous between Roemer's fossil and most specimens, possibly the more characteristic specimens, of *D. crassa*, but that species varies materially in the details of its surface sculpture, and the difference is not noticeable if some of the more finely striated specimens of *D. crassa* are used. Until the species from Texas is better known it would more prudently be cited as *Derbyia crassa* var.

#### *Terebratula pugnus* Sowerby

Plate 70, figure 12

A small but indubitable example of this widely distributed Carboniferous species frequently occurs in the Carboniferous limestone of the San Saba Valley in association with the preceding species.—Kreidebildungen, p. 89.

As Roemer does not figure the species so designated nor give any of its characters save that it is small, I question whether his citation is a fit subject for inclusion in synonymy. Schuchert omits it; Weller cites it under *Pugnax utah*. Although it seems desirable to say a little more about the species in this place, the present citation also would probably best be ignored.

Roemer's material contains several specimens evidently representing the species which he identified as *Terebratula pugnus*, all fragmentary or partly buried in matrix. I have hesitated to take the necessary steps to determine the relations of this form, for that could not be accomplished without ascertaining its internal characters. The likelihood of any definite result in that direction seemed poor, and it is deemed wiser, at the present time, to leave the species in much the same state in which it comes from Roemer, except, of course, that any close relation to *Terebratula pugnus* cannot be admitted.

The best specimen is a dorsal valve, partly covered by matrix. It is strongly transverse and probably about 15 millimeters in width. The fold bears four plications and the lateral slopes about four each. The plications are large, rounded, and not traceable to the beak, the one nearest the hinge on each side being very faint. Internally the dorsal valve has a median septum which is short but of unknown height.

Presumably this species belongs in the genus *Wellerella*, if that genus is worth recognizing, but as com-

pared with *W. osagensis* (the *Pugnax utah* of former days), it is materially larger and somewhat more numerously plicated, the normal arrangement in *W. osagensis* being three on the fold and three on each side.

#### *Marginifera roemerii* Girty, n. sp.

Plate 67, figures 8a, b; plate 70, figures 12, 14, 15, 16, 17

##### ORIGINAL DESCRIPTION

*Productus flemingii* Sowerby, Min. Conch., vol. 1, p. 154, pl. 68, fig. 1.

De Koninck, Monographie des genres *Productus* et *Chonetes*, p. 95, pl. 10, figs. 2a-1, fig. 3h.

*Productus* sp. ind. F. Roemer, Texas, p. 421, no. 7.

I have at hand several well-preserved specimens, none of which differ markedly in size from the one figured and which are therefore smaller than the customary size of this European species. According to De Koninck's own study of the Texas specimens, there is no doubt that they are conspecific with *Productus flemingii* Sowerby, the synonymy of which has been carefully worked out by De Koninck. Moreover, there is a great similarity of outward form to young specimens of *Productus semireticulatus* Fleming—in fact, these two species, which are the most widely distributed [members] of the whole genus, are very closely related. The shell is comparatively thick, and on the inner surface [there are] deep small pits, which appear as coarse grains on the surface of internal molds. The dorsal [ventral] valve of a single specimen shows a sudden upward bending such as frequently occurs in *Productus semireticulatus*. Well-defined spine bases are scattered singly over the entire surface of the dorsal [ventral] valve, especially over the lateral slopes.

Occurrence: Several examples were found in association with the foregoing species in a tributary valley of the San Saba Valley, in black Carboniferous limestone in which this species seems to be the most abundant fossil.

Explanation of the figures: Figure 8a, external surface of the dorsal [ventral] valve; figure 8b, [the same] from the side.—Kreidebildungen, p. 89.

##### REMARKS

Roemer's two figures of this species are presumably different views of the same specimen, but some doubt surrounds the determination of the original. The species is obviously abundant, for it is represented by several specimens on each of the two small slabs and by a number of specimens on the large slab already mentioned several times. Accompanying labels indicate that both of the small slabs contain the specimen figured. One slab (pl. 70, figs. 14, 15) contains a specimen which is uncovered (though partly by me) and agrees closely with the figures. It is, however, very slightly smaller and is imperfect at one side, whereas the figure shows an unbroken specimen. The other slab (pl. 70, figs. 16, 17) contains three specimens, two of which can be rejected as subjects of the illustrations. One (fig. 17, upper left) is too small, too finely striated, and in fact may belong to a different species; the other (fig. 17, lower left) is compressed and partly covered by matrix. The third specimen is on the edge of the slab and is not shown by figure 17, but a

posterior view is shown by figure 16. It is almost the counterpart of the specimen on the other small slab, but it is slightly wider and so in more exact agreement with the original figure. It is, however, partly concealed by matrix, and its surface characters are not so clearly shown as those of the other specimen. If either specimen alone is the original of the drawing, it is this one, but more probably the drawing is a composite picture of both. The broken specimen clearly shows evidence of *Marginifera* structure.

Schuchert includes Roemer's citation in the synonymy of *Productus longispina*, but with it he also includes *Productus (Marginifera) splendens* and *Productus (Marginifera) wabashensis*. Weller, too, includes Roemer's citation in the synonymy of *Productus longispina* and with it *Productus (Marginifera) splendens*. *Productus (Marginifera) wabashensis* he recognizes as a distinct species. The affinities of Roemer's form prove to be nearer to *M. wabashensis* than to *M. splendens*, but I regard it as distinct even from *M. wabashensis* and have it described in manuscript as *Marginifera roemerii* on specimens from my own collection (station 2602, 11 miles west of San Saba, Tex.). These specimens are to be regarded as the types of this new species. The associated fauna appears to be the same as that in which "*Productus flemingii*" occurs, and my specimens, which are numerous, agree with Roemer's.

#### *Productus cora* D'Orbigny

##### ORIGINAL DESCRIPTION

*Productus cora* D'Orbigny, Voyage dans l'Amérique méridionale, Paléontologie, p. 55, pl. 5, figs. 8, 9, 10 (male).

De Koninck, Monographie des genres *Productus* et *Chonetes*, p. 50, pl. 4, figs. 4a, b; pl. 5, figs. a-d.

*Productus* sp. ind. F. Roemer, Texas, p. 421 (no. 6).

As a result of the investigations in western Texas, an entirely new locality is established for this well-known and widely distributed species,<sup>63</sup> which in North America is often confused with *Productus scoticus* Sowerby and *Productus comoides* Sowerby. According to D'Orbigny, who named the species, it was found at several places in the highlands of Bolivia. E. de Verneuil<sup>64</sup> has observed it at many places in the States of Kentucky, Ohio, Illinois and in New Scotland. The Texas specimens, so far as their incomplete preservation permits comparisons to be made, agree perfectly with specimens from Illinois, and in particular, the very fine costae that ornament the outer surface are the same in both. Moreover, the specimens are just as close to the European forms in size as those from Illinois, in that they are all scarcely more than 1 inch wide.

Occurrence: Common in association with the previously described species in the black Carboniferous limestone in a valley tributary to the San Saba Valley.—Kreidebildungen, p. 90.

##### REMARKS

Roemer does not figure the species which he refers to *P. cora*, and he does not describe it sufficiently for any

<sup>63</sup> See De Koninck, op. cit., pp. 52, 53.

<sup>64</sup> Note sur le parallélisme des dépôts paléozoïques de l'Amérique septentrionale avec ceux de l'Europe (extrait du Bull. de la Soc. géol. de France, 2ème série, tome 4), p. 61.

one to verify his identification. It is doubtful, therefore, whether his citation is substantial enough for synonymic recognition. In this respect it stands upon essentially the same plane as his citation of *Terebratula pugnus*. Accordingly, Roemer's citation is omitted by Schuchert but is placed in the synonymy of *P. cora* by Weller. It is true that Roemer discusses the relations of *P. cora* at considerable length, but if perchance the different forms that he mentions (including the one from Texas) do not prove to belong to the same species, his discussion only contributes to confuse the subject.

I am in a measure estopped from commenting upon the *P. cora* of Roemer because among his fossils there

is none which by any possibility could be referred to that species. I may say, however, that the faunas of Pottsville age in both Arkansas and Texas contain specimens of "*Linoprotuctus*" in more or less abundance, but I doubt whether *P. cora* is represented among them. Certainly the great majority of specimens where a decision could be reached do not belong to that species; they are more nearly allied to *P. ovatus*. Careful work may disclose grounds for distinguishing them from *P. ovatus* also, but as between that species and *P. cora*, the identification would lie with *P. ovatus*. These remarks are presumably applicable to the form that Roemer cited as *P. cora*.



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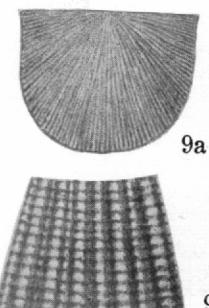
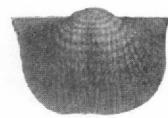
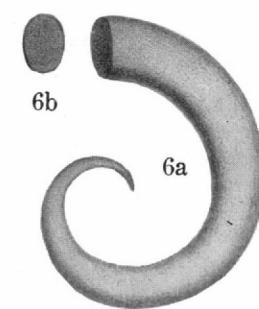
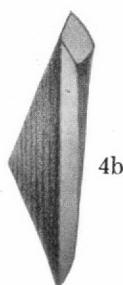
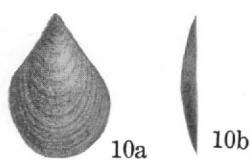
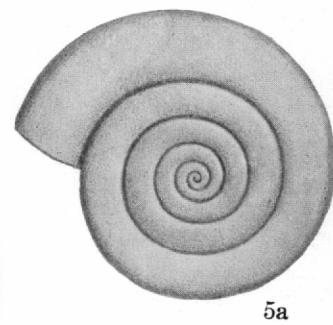
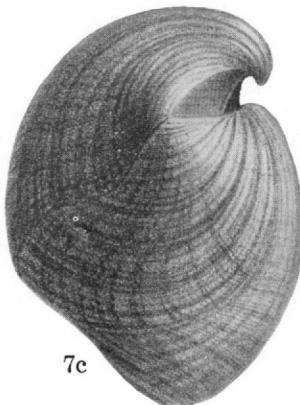
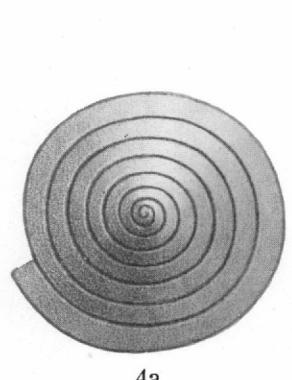
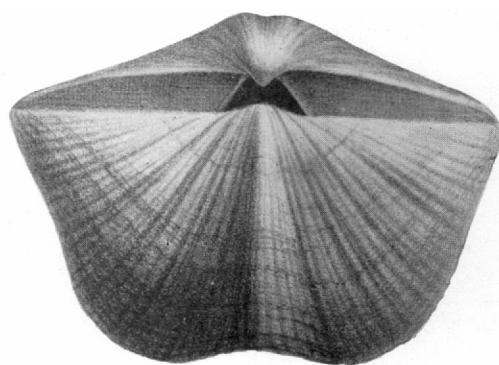
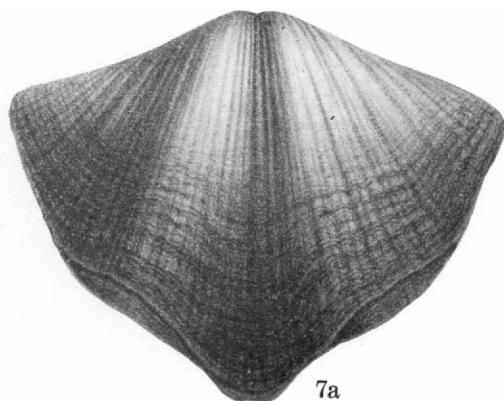
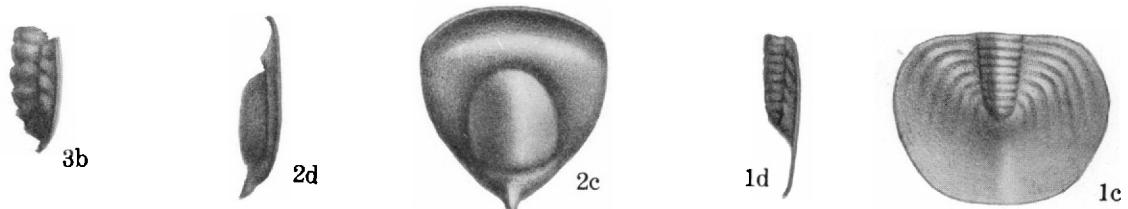
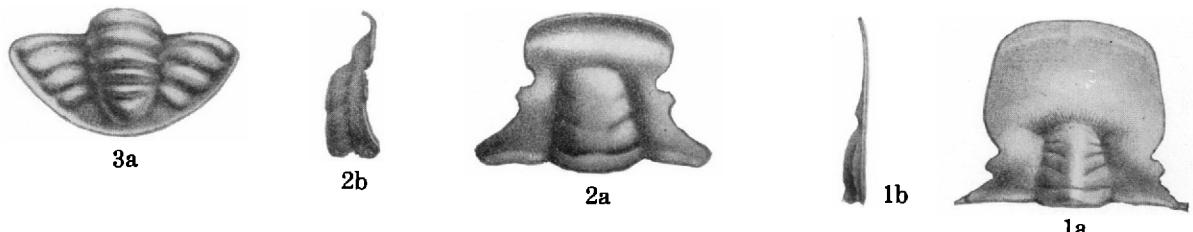
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**PLATES 67-70**

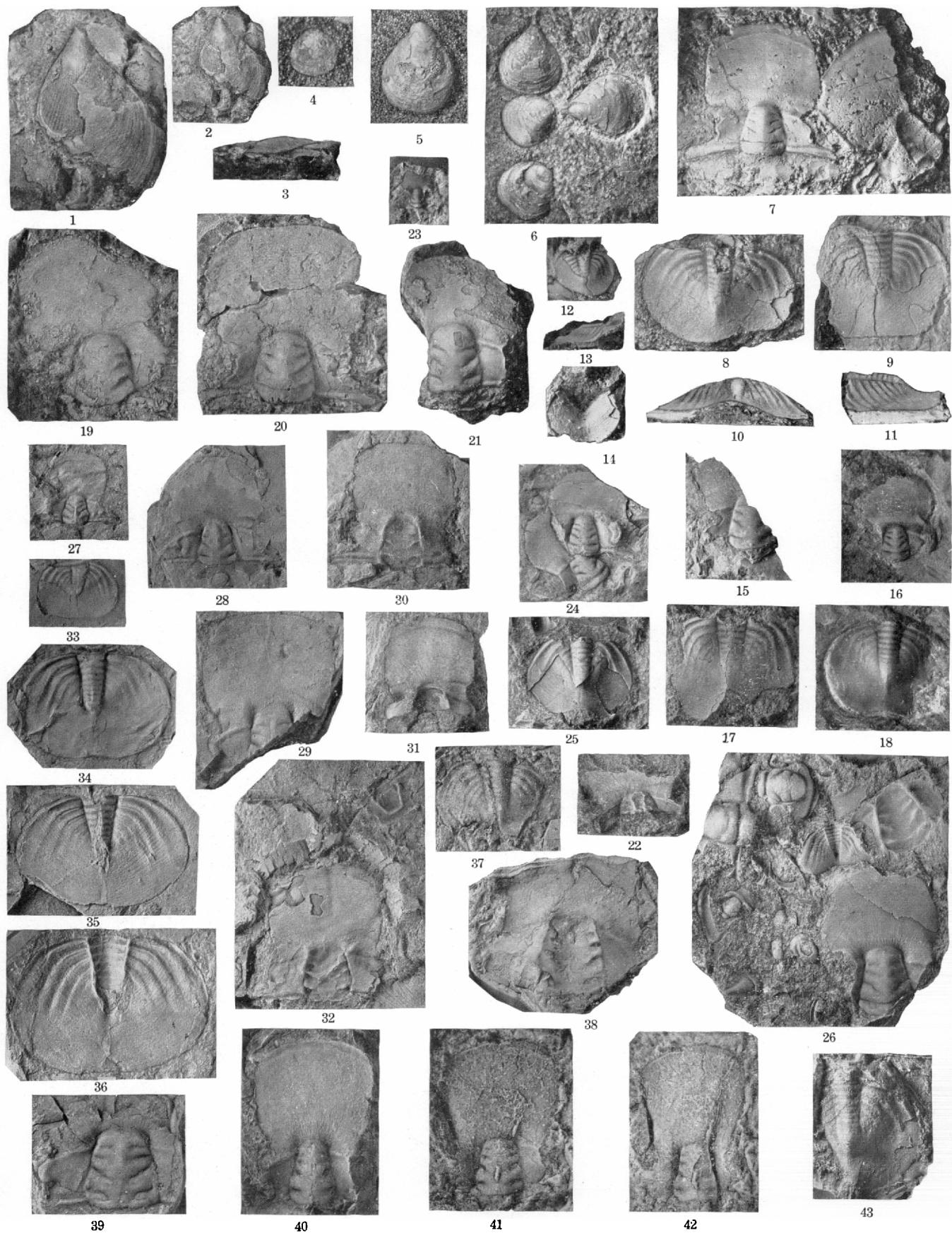
## PLATE 67

Reproduction of plate 11, Kreidebildungen von Texas, 1852. Numbering of figures as in the original plate; page references refer to the present paper.

- FIGURE 1. *Pterocephalia sanctisabae* Roemer (p. 246): a, Cranidium seen from above, the free cheeks wanting; b, cranidium in profile seen from the side; c, pygidium seen from above; d, pygidium in profile seen from the side.
- FIGURE 2. *Elvinia roemeri* (Shumard) (p. 251): a, Cranidium seen from above; b, cranidium in profile seen from side. *Idahoia?* sp. (p. 256): c, pygidium (cranidium) seen from above; d, pygidium (cranidium) in profile seen from the side.
- FIGURE 3. *Elvinia roemeri* (Shumard) (p. 251): a, Pygidium seen from above; b, same in profile from the side.
- FIGURE 4. *Ophileta polygyrata* (Roemer) p. 257): a, Shell seen from above; b, apertural view.
- FIGURE 5. *Lecanospira sanctisabae* (Roemer) (p. 260): a, Shell seen from above [below]; b, apertural view.
- FIGURE 6. *Eccyliomphalus gyroceras* (Roemer) (p. 258): a, Shell seen from above; b, cross section of the whorl.
- FIGURE 7. *Spirifer meusebachanus* Roemer (p. 262): a, View of the dorsal [ventral] valve; b, view of the ventral [dorsal] valve; c, profile seen from the side.
- FIGURE 8. *Marginifera roemeri* Girty (p. 264): a, View of the dorsal [ventral] valve from above; b, same from the side.
- FIGURE 9. *Orthis arachnoidea* (Phillips) (p. 263): a, View of the dorsal valve; b, a portion of the surface enlarged.
- FIGURE 10. *Lingulepis acutangula* (Roemer) (p. 244): a, View from above; b, same from the side.



FERDINAND ROEMER'S PALEOZOIC TYPES FROM TEXAS AND SPECIMENS COMPARED WITH THEM.



FERDINAND ROEMER'S PALEOZOIC TYPES FROM TEXAS AND SPECIMENS COMPARED WITH THEM.

## PLATE 68

FIGURES 1-6. *Lingulepis acutangula* (Roemer) (p. 244):

1. Ventral valve, the holotype,  $\times 4$ .
- 2, 3. Ventral and profile views of the holotype, natural size. Locality 353, Wilberns formation, near Camp San Saba, Tex. Museum of Geology and Paleontology, University of Bonn, Germany.
- 4, 5. Dorsal and ventral valves from the Hickory (?) sandstone one-fourth mile east of Sandy post office, Blanco County, Tex. U. S. Nat. Mus. 93009.
6. Owen's types of *Lingulepis pinnaformis*. Eau Claire formation, St. Croix Falls, Wis. U. S. Nat. Mus. 17860.

FIGURES 7-43. *Pterocephalia sanctisabae* Roemer (p. 246):

7. Exterior and interior of two cranidia, the syntypes.
  - 8, 9. Dorsal views of two large pygidia, paratypes A and B.
  - 10, 11. Posterior and lateral views of paratype A.
  - 12, 13. Dorsal and lateral views of a small pygidium, paratype C.
  14. Under surface of another small pygidium, paratype D.
- Specimens shown in figures 7-14 are Roemer's types, from locality 353, *Camaraspis* zone of the Wilberns formation, from the San Saba River near Camp San Saba, Tex. Originals in the Museum of Geology and Paleontology, University of Bonn, Germany.
- 15, 17. Cranidium and pygidium from Wilberns formation. Locality 70, near Morgans Creek, Burnet County, Tex. Plesiotypes. U. S. Nat. Mus. 93010.
  - 16, 18. Cranidium and pygidium from Wilberns formation. Locality 353, San Saba River, half a mile east of highway bridge at Camp San Saba (pl. 1, B), McCullough County, Tex. Topotypes. U. S. Nat. Mus. 93012.
  19. Cranidium from the Honey Creek formation, locality 9-1-2, northeast of Big Baldy Mountain, Wichita Mountains, Okla. U. S. Nat. Mus. 93014.
  20. Cranidium from the Honey Creek limestone, locality 91-a, West Timbered Hills, Arbuckle Mountains, Okla. U. S. Nat. Mus. 93015.
  21. Cranidium from the Honey Creek formation, locality 9-q, Blue Creek Canyon, 15 miles northwest of Fort Sill, Wichita Mountains, Okla. U. S. Nat. Mus. 93016.
  22. Fragmentary cranidium showing the eye lines and the radial markings on the brim. Honey Creek formation, locality 89-v, West Timbered Hills, NE $\frac{1}{4}$  sec. 9, T. 1 S., R. 1 W., Murray County, Okla. U. S. Nat. Mus. 93017.
  23. Small cranidium from the Davis formation, locality 11-e, southwest of Potosi, Washington County, Mo. U. S. Nat. Mus. 93018.
  - 24-26. Cranidia and pygidia from the Davis formation, locality 11-k, near shaft of Federal No. 4 mine, Flat River, St. François County, Mo. U. S. Nat. Mus. 93019. Figure 26 shows association with *Elvinia roemeri* (upper left).
  - 27-30, 32, 39. A series of cranidia from shale in the Deadwood formation, north wall of Whitewood Canyon in the northern part of Deadwood, S. Dak. 27, 29, 30, 39, Museum of the Department of Geology, University of Iowa; 28, 32, U. S. Nat. Mus. 93020. Figure 32 shows characteristic association with *Elvinia roemeri*.
  31. Counterpart of figure 22, with an unusually well preserved brim. U. S. Nat. Mus. 93017.
  - 33-36. A series of pygidia from shale in the Deadwood formation; same locality as figures 27-30, 32. 33, 34, Museum of Department of Geology, University of Iowa; 35, 36, U. S. Nat. Mus. 93020.
  37. Cast of the pygidium of *Dikelocephalus multicinctus* Hall and Whitfield. Upper Cambrian, Eureka district, Nev. U. S. Nat. Mus. 24640. (The original specimen is a natural mold.)
  38. Cast of natural mold of fragmentary cranidium, locality 60, across canyon from dump of Old Richmond mine, Eureka district, Nev. U. S. Nat. Mus. 93021.
  40. Cranidium of *Pterocephalia "laticeps"* Hall and Whitfield. Upper Cambrian, lowest beds on west side of Pogonip Mountain, White Pine district, Nev. U. S. Nat. Mus. 24562.
  41. Cast of a cranidium in the type lot of *Pterocephalia laticeps* which agrees in all respects with syntype B (fig. 7). The original specimen is a natural mold. U. S. Nat. Mus. 24562.
  42. The same cast after slight lateral compression, showing the development of the characters of *P. laticeps*.
  43. Cast of pygidium of *P. laticeps*. The original is a natural mold. Same locality as figures 40-42. U. S. Nat. Mus. 24561.

## PLATE 69

**FIGURES 1-21.** *Elvinia roemeri* (Shumard) (p. 251):

- 1-8. Roemer's types. All specimens from the Wilberns formation, locality 353, San Saba Valley, near Camp San Saba, McCullough County, Tex. Originals in the Museum of Geology and Paleontology, University of Bonn, Germany.
- 1-3. Dorsal, frontal, and profile views of the larger cranium, paratype A.
- 4, 5. Dorsal and profile views of the smaller cranium, paratype B.
- 6, 7. Dorsal and profile views of the larger pygidium.
8. Dorsal view of the smaller pygidium.
9. Large cranium selected by Walcott to replace Shumard's lost type. Wilberns formation, locality 70, near Morgans Creek, Burnet County, Tex. Plesiotype, U. S. Nat. Mus. 70259.
10. Pygidium, assigned to this species by Walcott. Wilberns formation, locality 68, top of west peak of Packsaddle Mountain, Llano County, Tex. U. S. Nat. Mus. 70261.
11. Cranium figured as the type of *E. "matheri"* (Walcott), upper part of Potsdam sandstone, locality 110, near Whitehall, N. Y. U. S. Nat. Mus. 58585.
- 12, 13. Dorsal and profile views of cranium from the Davis formation, locality 11-k, near shaft of Federal No. 4 mine, Flat River, St. Francois County, Mo. U. S. Nat. Mus. 93011.
- 14, 16. Two cranidia from limestones about 100 feet above the sandstones at the base of the Deadwood formation, locality 88-a, in the northern part of the town of Deadwood, S. Dak. The larger specimen preserves much of the test and consequently appears to be broader across the glabella than other specimens of equal size (figs. 9, 11, 12, 18) from which the test has been removed. U. S. Nat. Mus. 93024.
15. Cranium from the Wilberns formation, locality 68, top of the west peak of Packsaddle Mountain, Llano County, Tex. U. S. Nat. Mus. 93013.
17. Type of *Crepicephalus unisulcatus* Hall and Whitfield. This is the specimen from which the original figure was drawn. From "limestone in the Potsdam group, Eureka, Nev." Unfortunately, the occipital ring was cut off when the print was mounted. U. S. Nat. Mus. 24574.
18. Cranium identified as *Crepicephalus unisulcatus* by Walcott. Secret Canyon shale, locality 63, northeast of Adams Hill, Eureka district, Nev. U. S. Nat. Mus. 24574.
- 19-21. Cranium and two pygidia from the Honey Creek limestone, locality 89-v, NE $\frac{1}{4}$  sec. 9, T. 1 S., R. 1 W., West Timbered Hills, Arbuckle Mountains, Okla. U. S. Nat. Mus. 93025. Figure 20 shows a mold of the outer surface.
22. Cranium doubtfully referred to this species, locality 32-t, Upper Cambrian limestone in Fandango Spring Canyon, east side of Dugway Range, Tooele County, Utah. U. S. Nat. Mus. 93026.

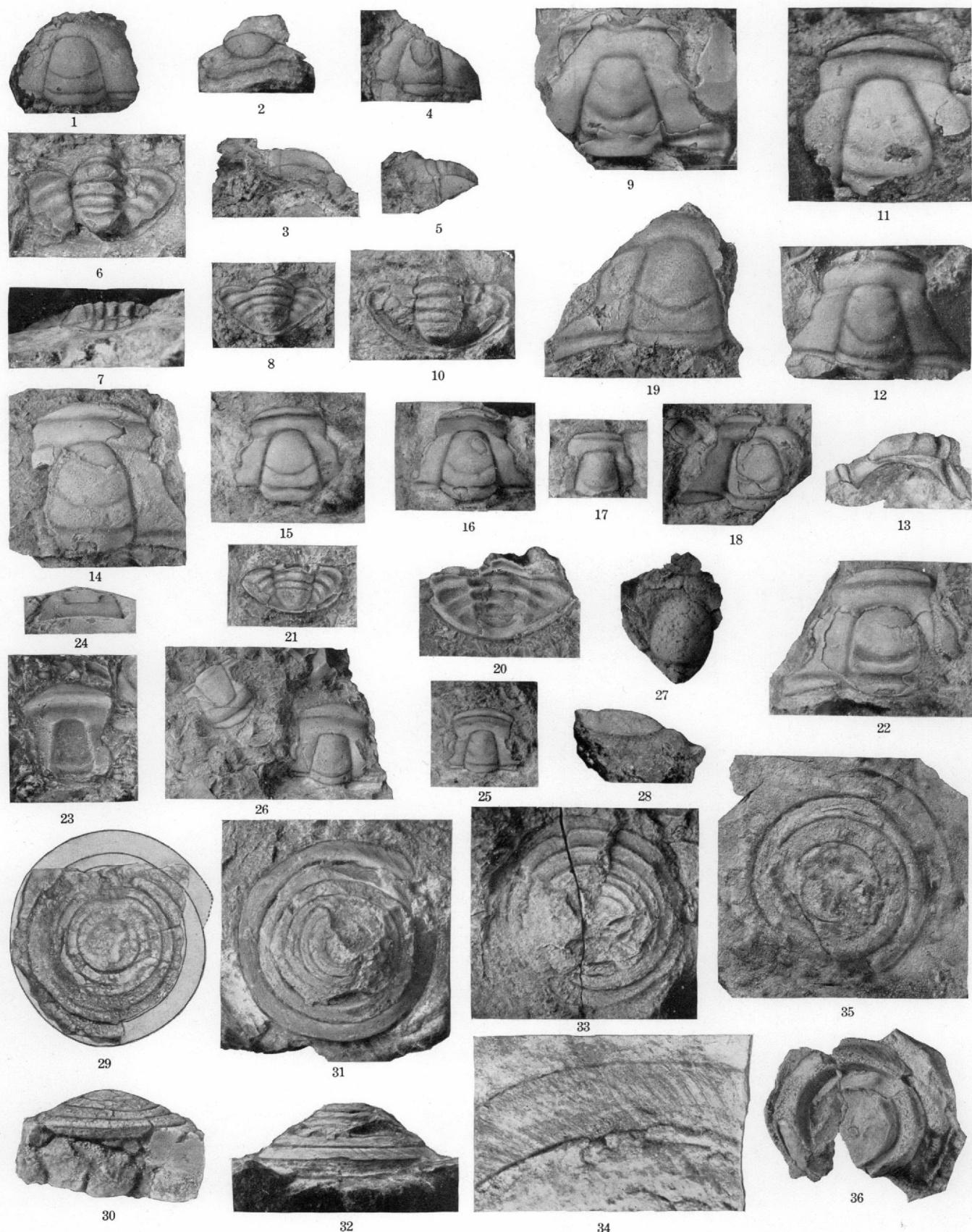
**FIGURES 23-26.** *Aphelaspis depressa* (Shumard) (p. 255):

23. Roemer's specimen, a mold of a cranium. Top of Cap Mountain formation, San Saba Valley, somewhere between Voca and Camp San Saba, McCullough County, Tex.
24. Frontal view of a squeeze made from the preceding.
- 25, 26. Cranidia selected by Walcott to replace Shumard's lost type. Locality 67, near Potatotop, Burnet County, Tex. U. S. Nat. Mus. 90172.

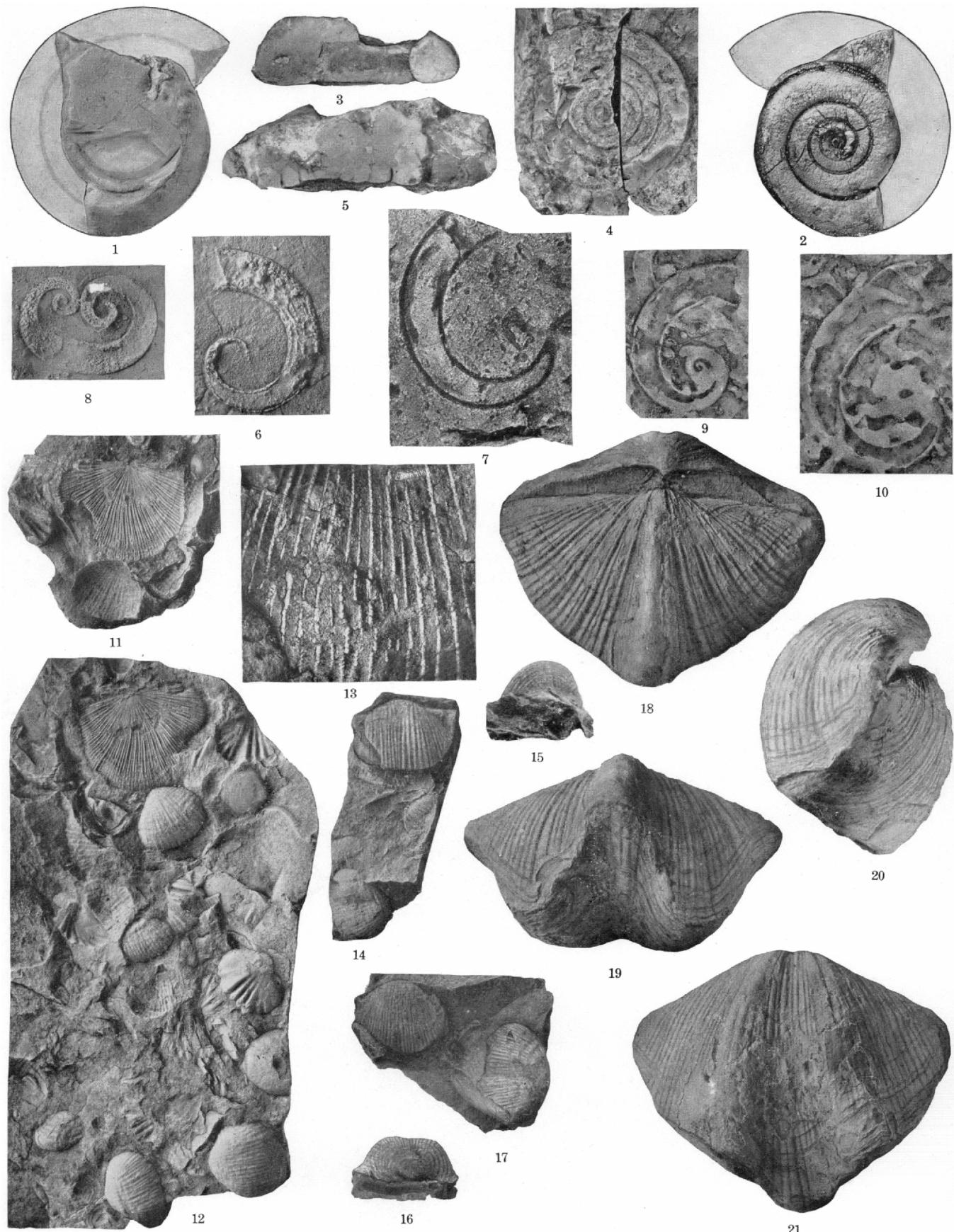
**FIGURES 27, 28.** *Idahoia?* sp. (p. 256). Dorsal and profile views of Roemer's specimen. Wilberns formation, locality 353, San Saba River, about half a mile east of highway bridge at Camp San Saba, McCullough County, Tex. Original in the Museum of Geology and Paleontology, University of Bonn, Germany.

**FIGURES 29-34, 36, ?35.** *Ophileta polygyrata* (Roemer) (p. 257):

- 29, 30. Dorsal and profile views of the holotype. Limestone of Gasconade age near base of Ellenburger limestone, on San Saba River about 20 miles east of Menard, presumably about half a mile east of the Mason-Menard County line, Mason County, Tex. Original in the Museum of Geology and Paleontology, University of Bonn, Germany.
- 31, 32. Dorsal and profile views of the type of "*Pleurotomaria hunterensis*" Cleland. Tribes Hill formation, Fort Hunter, N. Y. Original in Museum of Cornell University, Ithaca, N. Y.
33. Dorsal view of the type of *Polygyrata sinistra* Weller. The healed fracture (p. 258) shows in the figure and intersects a recent fracture near the apex of the shell. The growth lines are best shown at the bottom of the figure to the right of the recent fracture. Specimen from the Kittatinny limestone, Columbia, N. J. Original in the New Jersey State Museum, Trenton, N. J.
34. Portion of the outer whorl of specimen shown in figure 33,  $\times 4$ , to show growth lines. This is the same portion mentioned in the description of figure 33, but it has been rotated 180°. The irregular right-hand margin is the artificial fracture. Photograph by J. Brookes Knight.
35. A large fragmentary specimen doubtfully referred to this species. White limestone of Gasconade age, near the base of the Ellenburger limestone, in side valley on south side of San Saba River about half a mile east of the Mason-Menard County line, Mason County, Tex. U. S. Nat. Mus. 93027.
36. Another specimen from the same locality. U. S. Nat. Mus. 93027.



FERDINAND ROEMER'S PALEOZOIC TYPES FROM TEXAS AND SPECIMENS COMPARED WITH THEM.



FERDINAND ROEMER'S PALEOZOIC TYPES FROM TEXAS AND SPECIMENS COMPARED WITH THEM.

## PLATE 70

FIGURES 1-5. *Lecanospira sanctisabae* (Roemer) (p. 260):

- 1-3. Dorsal, ventral, and lateral views of the holotype. Figure 3 shows the cross section of the whorl at the bottom of figure 2. Original from beds of Roubidoux age in the Ellenburger limestone from southwestern part of San Saba County, Tex. Specimen in the Museum of Geology and Paleontology, University of Bonn, Germany.
4. Ventral view of a specimen from the same horizon, location 469-b, north side of Llano River, 1½ miles west of the mouth of Honey Creek and 265 feet above river level, Mason County, Tex. U. S. Nat. Mus. 93022.
5. Cross section of the specimen shown in figure 4, showing the outline of the whorls, the depressed spire, and the slightly concave base.

FIGURES 6-10. *Eccyliomphalus gyroceras* (Roemer) (p. 258):

- 6, 7. Roemer's types. His figure was clearly drawn from the specimen shown in figure 6. White limestone of Gasconade age at the base of the Ellenburger limestone in the San Saba Valley a short distance east of the Mason-Menard County line, Texas. Originals in the Museum of Geology and Paleontology, University of Bonn, Germany.
8. Two specimens from the same horizon, locality 471-e, 1½ miles north of Camp San Saba, McCullough County, Tex. U. S. Nat. Mus. 86949.
- 9, 10. Two specimens from the lower part of the Ellenburger limestone, west bank of Honey Creek, 2 miles south of the Mason-London road. U. S. Nat. Mus. 93023.

FIGURES 11-13. *Orthis arachnoidea* (Phillips) (p. 263). The specimen at the top of the slab (fig. 12) is an internal mold of a dorsal valve, the original of figure 9a in Roemer. The slab shown by figure 11 was split off from the large slab and on its under surface, here in view, shows the interior of the same specimen. A large, imperfect dorsal valve on the upper surface of the same slab is the original of Roemer's figure 9b, an enlargement showing sculpture. Figure 13 of this plate is a photographic enlargement ( $\times 4$ ) of part of the same shell.

FIGURES 11-17. *Marginifera roemeri* Girty, n. sp. (p. 264). Specimens of this species are seen on all the four slabs represented by figures 11, 12, 14-17, but Roemer's figures (8a, 8b) are probably a composite representation of specimens on the slabs shown by figures 14 and 17 of this plate. One of these is the upper specimen of figure 14, of which a side view is shown by figure 15. The other specimen is situated on the side of the slab represented by figure 17, and it does not appear in that figure. Figure 16 is a posterior view of this specimen. Roemer's figures, on the other hand, may represent either of these specimens singly, supplying the broken part if the original of figure 14 of this plate was used, or the part covered by matrix if the original of figure 17 of this plate was used. The specimen shown at the left in figure 17, though partly covered by matrix, is in good condition. It does not enter into this question, however. It is too small, too finely striated, and may not belong to the same species.

FIGURE 12. *Terebratula pugnus* (Sowerby) (p. 263). Roemer does not figure the species which he referred to *T. pugnus*, but several specimens are represented on the slab shown by this figure. The dorsal valve midway on the right side of the slab is the subject of Girty's comments.

FIGURES 18-21. *Spirifer meusebachanus* Roemer (p. 262). Four views of the holotype. Roemer did not give an anterior view corresponding to figure 19.



# RELATION OF SALINITY TO THE CALCIUM CARBONATE CONTENT OF MARINE SEDIMENTS

By PARKER D. TRASK

## ABSTRACT

The calcium carbonate content of sediments is influenced by many factors, such as temperature, depth, salinity, hydrogen-ion concentration of the water, degree of saturation of the water with calcium carbonate, activity of living organisms, and proportion of terrigenous debris in the sediments. Many of the factors are interrelated. The temperature, for example, affects the solubility of calcium carbonate in sea water; it influences the growth of living organisms, it varies the salinity because of its effect on evaporation, and it modifies the action of several other factors. Most of the factors that affect the formation and deposition of calcium carbonate operate simultaneously, and the relative importance of the effects of the individual factors varies in different parts of the ocean. It is difficult, therefore, to isolate a single factor and ascertain the magnitude of its effect in comparison with the effect of some other factor. This paper, however, is an attempt to discuss the relation of the calcium carbonate content of marine sediments to the salinity of the water, with particular reference to the surface layers.

The problem is approached in three ways—(1) by a discussion of the effect of the salinity upon the solubility of calcium carbonate in sea water (because of the dominant influence of the solubility on the formation of solid calcium carbonate in the sea); (2) by a statistical study of the relation of the salinity to the calcium carbonate content of sediments in many parts of the world; and (3) by the preparation of a map showing the distribution of calcium carbonate on the floor of the ocean with respect to the salinity of the surface water. In each of these lines of attack the effect of temperature is also considered, so that the influence of salinity may be compared with the effect of a factor whose influence is generally recognized.

The studies of the solubility relations indicate that in the upper layers of water, in which presumably most of the solid calcium carbonate is formed, an increase in salinity from 34 to 35 parts per thousand raises the degree of saturation of the water with respect to calcium carbonate 8.4 percent, and that an increase in temperature from  $20^{\circ}$  to  $21^{\circ}$  C. raises the degree of saturation 4.6 percent. That is, a rise of 1 part per thousand in salinity affects the solubility of calcium carbonate approximately as much as an increase of  $2^{\circ}$  in temperature. In many parts of the ocean the salinity of the surface water changes 1 part per thousand in roughly the same distance as the temperature of the surface water changes  $2^{\circ}$ . The surface temperature, however, varies more during the course of a year than the surface salinity, and the temperature decreases greatly with depth, but the salinity does not. It would seem, therefore, that in several parts of the ocean salinity has as great an effect as temperature on the solubility of calcium carbonate, but that the total effect of salinity on the solubility is less than that of temperature.

In the statistical part of the investigation the relation of the calcium carbonate content of the sediments to the surface salinity, surface temperature, and depth was ascertained by a series of averages, by graphs based on these averages, and by coefficients of correlation of the data represented by these averages. The surface salinity and surface temperature were con-

sidered because of the importance of the upper layers of water in the formation of solid calcium carbonate. However, subsequent to the compilation of the statistical results, it has been shown by other workers that the upper 200 meters of water probably represents the zone in which most of the solid calcium carbonate is formed. Consequently the results might have been more reliable if the average salinity and average temperature in this zone had been considered instead of surface salinity and temperature. The surface salinity indicates the average salinity in this zone better than the surface temperature indicates the average temperature. This difference may account for the better relation that was found between calcium carbonate and surface salinity than between calcium carbonate and surface temperature.

The series of averages and the accompanying graphs indicate that the calcium carbonate content of the sediments increases as the surface salinity rises. The rate of rise in calcium carbonate content is greatest between salinities of 34 and 36 parts per thousand. Sediments in areas in which the salinity of the surface water is less than 34 parts per thousand in general contain less than 5 percent of calcium carbonate, and those in areas in which the salinity is more than 36 parts as a rule contain more than 50 percent of calcium carbonate. The critical salinity seems to be about 35 parts per thousand, which is approximately the average for the ocean. The calcium carbonate content of the sediments likewise increases as the temperature increases and as the depth decreases.

The relation for the surface temperature is less well defined than that for salinity or that for depth. The critical depth with respect to calcium carbonate content of the sediments seems to be about 1,500 fathoms, as the calcium carbonate content of sediments in water less than 1,500 fathoms deep is much more nearly constant than that of sediments in water more than 1,500 fathoms deep, particularly for sediments that were laid down near the shore.

The results of the determination of the coefficients of correlation are similar to those based on the averages. (The coefficient of correlation is a mathematical expression of the degree of relationship between two variables, such as calcium carbonate content of sediments and surface salinity.) The coefficients of correlation indicate that the calcium carbonate content is fairly definitely related to surface salinity for both pelagic and near-shore deposits and to depth for pelagic deposits. It is less distinctly related to depth for near-shore deposits and to temperature for both near-shore and pelagic deposits.

The areal distribution of calcium carbonate on many parts of the sea floor varies in sympathy with the surface salinity and to a smaller extent with surface temperature, but on several parts, notably in the South Atlantic, it does not. The results of an empirical investigation of this type are naturally attended by a certain amount of ambiguity due to the effect of other factors, such as the proportion of clastic material, that mask the effect of salinity; but they are sufficiently reliable to indicate that the surface salinity is definitely related to the calcium carbonate content of the sediments and that its effect is similar in order

of magnitude to the effect of surface temperature. The empirical relations of the calcium carbonate content of the sediments thereby agree with the solubility relations of calcium carbonate in sea water in indicating that salinity is an important factor in the deposition of calcium carbonate.

The relation between the calcium carbonate content of sediments and the salinity, however, may in part not be a cause and effect relation. It is possible that the surface salinity may be a rough index of the degree of saturation of the water with calcium carbonate. Thus, areas of high salinity may be supersaturated, with the result that they favor the precipitation of calcium carbonate.

Two geologic applications of the results are considered—one relating to the deposition of red clay, the other to past climates. An increase in degree of saturation of the deep water in the ocean, due to an increase in temperature, may result in less calcium carbonate being dissolved from particles as they fall to the sea floor, thus causing the calcium carbonate content of the sediments to be increased. As red clay is characterized by a small calcium carbonate content, the quantity of red clay on the sea floor under such conditions would be less than at present. Consequently, the scarcity of red clay among ancient sediments may be accounted for by increases in the degree of saturation of the water in the past.

As the calcium carbonate content of sediments in areas of high salinity is generally large, and as an arid climate would favor the development of high salinity in the sea water, it is suggested that some alternations between limestone and calcareous shale or between calcareous shale and noncalcareous shale may be indicative of changes in climate. The more calcareous layers would represent more arid periods, when evaporation was high and influx of terrigenous debris was small, and the less calcareous layers would represent more humid periods, when evaporation was low and influx of terrigenous debris was great.

#### INTRODUCTION

The object of this report is to show that the salinity of the sea water is a factor influencing the calcium carbonate content of marine sediments. In order to ascertain the relative importance of salinity, the effect of salinity on the deposition of calcium carbonate is compared with the effect of other factors, chiefly temperature. The problem has been approached in three ways—(1) study of the factors influencing the deposition of calcium carbonate, with special emphasis on the effect of salinity and temperature upon the solubility of calcium carbonate in sea water; (2) statistical study of the relation of salinity, temperature, and depth to the calcium carbonate content of near-shore and pelagic sediments; and (3) preparation of a map showing the relation of the areal distribution of calcium carbonate on the sea floor to the surface salinity, surface temperature, and depth of water. The results obtained in all these lines of attack are in accord in indicating that salinity is definitely related to the calcium carbonate content of sediments.

I am indebted to Dr. Roger Revelle and Dr. E. G. Moberg, of the staff of the Scripps Institution of Oceanography, La Jolla, Calif., for assistance in calculating the effect of salinity and temperature on the solubility of calcium carbonate in sea water, and for their kindness in giving me access to unpublished data. I wish to thank Dr. T. Wayland Vaughan, director of the

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#### FACTORS INFLUENCING THE CALCIUM CARBONATE CONTENT OF SEDIMENTS

##### GENERAL FACTORS

The calcium carbonate content of sediments is affected by four main groups of factors—(1) the source of particles of calcium carbonate in the water, (2) the transportation of the particles while they are being deposited, (3) the changes that take place in the sediments after the particles have been deposited, and (4) the proportion of particles of clastic origin in the sediments. The source of calcareous particles in the water is the most influential of these four groups of factors and is discussed in detail below.

In the transportation of the particles the main considerations are the strength of the currents, the depth of water, the size and shape of the particles, the degree of saturation of the water with calcium carbonate, the rate of solution of calcareous particles, the shape of the ocean floor, and the buoyancy of the particles. The chief influence of salinity in the transportation of the particles is its effect on the degree of saturation of the water, which in turn controls the rate of solution of calcareous particles. Salinity influences the density of the water, and as the rate at which particles fall depends upon their buoyancy—that is, the difference in density between the particles and the liquid through which they fall—the salinity might have a very slight effect on the rate at which the particles sink. Moreover, in the ocean, currents such as the Gulf Stream are caused by the attempt of masses of water of different density to come to equilibrium, and as salinity is one of the main factors controlling density, it would therefore indirectly affect the transportation of particles.

The changes that take place in the sediments after the particles have been deposited are mainly connected with the processes of diagenesis—that is, lithification. The main factor with which salinity might be associated in the processes of diagenesis is the removal of calcium carbonate by solution of particles.

The chief factors governing the proportion of particles of clastic origin in the sediments are (1) distance from shore—near-shore sediments in general contain much clastic debris, and pelagic sediments contain relatively little; (2) climate—sediments deposited near arid regions consist of less clastic material than those near humid regions; (3) relief of land—sediments laid down near areas of low relief, like Florida, contain less clastic

material than those near areas of high relief, like California; (4) location with respect to the mouths of streams—sediments off the mouths of large streams contain much more clastic debris than those off small streams; and (5) the rate at which calcareous particles are added to the sediments. The salinity of the water, except for its effect on the rate at which calcareous particles are added to sediments, influences but slightly the quantity of clastic debris in the sediments.

Calcium carbonate gets into the water in a solid form in three ways—(1) by chemical precipitation, (2) as remains of living organisms, and (3) as detrital particles derived from limestone. The presence of limestone areas in the drainage basins of streams entering the sea may locally be the main source of calcium carbonate in sediments deposited near shore; but in general the calcium carbonate content of marine sediments is due chiefly to chemical precipitation or remains of organisms. The relative importance of these two sources is a controversial problem that has not yet been solved satisfactorily. In fact, so little is known about the processes by which organisms extract calcium carbonate from water for their bodily needs that it seems impracticable to attempt to discuss this phase of the subject in the present report. However, both chemical precipitation of calcium carbonate and the formation of calcareous material by organisms are favored by increased saturation of the sea water with calcium carbonate.

#### SOLUBILITY OF CALCIUM CARBONATE IN SEA WATER MAIN FACTORS

The solubility of calcium carbonate in sea water has been studied intensively in the past few years by several workers, among whom are Moberg, Revelle, and their associates at Scripps Institution; Buch, Gripenberg, and their associates at Helsingfors; and Wattenberg, who accompanied the *Meteor* expedition to the South Atlantic.<sup>1</sup> The discussion of the solubility relations of calcium carbonate in the present report is based on the work of these investigators. As their publications describe the problem in full and contain extensive bibliographies, only a summary of the features that relate to the question of salinity is included here.

The chemical precipitation of calcium carbonate depends upon the degree of saturation of the water with calcium carbonate. If the water is undersaturated, solid particles of calcium carbonate can pass into solution; if it is oversaturated, solid particles can be formed by precipitation from the water. Precipitation, how-

ever, does not necessarily take place as soon as the saturation point is reached. The water can become supersaturated to a considerable extent before beginning to produce solid calcium carbonate. The precipitation of calcium carbonate from solution is favored by the presence in the water of solid particles, either of calcium carbonate or of something else. The initiation of precipitation by such an action is called "seeding."

The saturation point depends upon the law of mass action. That is, the water is saturated when the product of the concentration of calcium and carbonate equals a constant, called the "apparent solubility product constant." The relation expressed symbolically is

$$[\text{Ca}^{++}][\text{CO}_3^{--}] = K'_{\text{CaCO}_3}$$

The apparent solubility product constant is practically independent of the quantity of calcium carbonate or the concentration of calcium and carbonate in the water, but it is not constant with respect to other variables, for if the temperature, salinity, pressure, or concentration or kinds of ions other than calcium or carbonate change, the apparent solubility product constant likewise changes.

If the concentration of calcium is high, a small concentration of carbonate will make the water saturated with respect to calcium carbonate, and if the concentration of calcium is low, a large concentration of carbonate is needed to make the water saturated. If the product of calcium and carbonate exceeds the apparent solubility product constant, calcium carbonate can be removed from solution by precipitation of solid calcium carbonate until the product of the calcium and carbonate ions equals the solubility product constant, but whether or not under any particular circumstances calcium carbonate will be precipitated in the sea depends on the laws governing supersaturation, which are not yet well understood.

According to the relations governing the solubility of calcium carbonate in the sea, three main factors, therefore, are concerned—(1) the concentration of calcium, (2) the concentration of carbonate, and (3) the apparent solubility product constant. The concentration of calcium at any given depth<sup>2</sup> depends almost entirely upon the salinity, because the salinity represents the concentration of total solids in solution, and if the salinity changes, then it follows that the concentration of all the salts, including those of calcium, likewise changes. The apparent solubility product constant is influenced by several factors, including temperature and salinity. It increases with rise in salinity and decreases with rise in temperature (table 1). The concentration of carbonate depends upon a large number of variables and is by far the most influential factor in the deposition of calcium carbonate.

<sup>1</sup> Moberg, E. G., Greenberg, D. M., Revelle, R., and Allen, E. C., The buffer mechanism of sea water: Scripps Inst. Oceanography Bull., Tech. ser., vol. 3, no. 11, pp. 231-278, 1934. Buch, K., Harvey, H. W., Wattenberg, H., and Gripenberg, S., Ueber das Kohlensäuresystem im Meerwasser: Conseil perm. expl. mer Rapports et procès-verbaux, vol. 79, pp. 1-70, 1932. Wattenberg, H., Kalziumkarbonat- und Kohlenstoffgehalt des Meerwassers: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925-27, Band 8, Teil 2, pp. 1-333, 1933. Revelle, R., and Fleming, R. H., The solubility product constant of calcium carbonate in sea water: 5th Pacific Sci. Cong., Victoria and Vancouver, Proc., vol. 3, pp. 2089-2092, 1933. Revelle, R., Physicochemical factors affecting the solubility of calcium carbonate in sea water: Jour. Sedimentary Petrology, vol. 4, pp. 103-110, 1934.

<sup>2</sup> Revelle, R., Physicochemical factors affecting the solubility of calcium carbonate in sea water: Jour. Sedimentary Petrology, vol. 4, p. 107, 1934.

## INFLUENCE OF CARBON DIOXIDE

Carbonate ions represent one of the three forms in which carbon dioxide occurs in sea water. The other two forms are bicarbonate ions and carbonic acid. For a strictly accurate discussion, carbonic acid and free carbon dioxide should be considered separately, but their effects are so nearly alike that for the purpose of this discussion they are treated as one variable.<sup>3</sup>

These three forms of carbon dioxide are related to one another according to definite laws, which are expressed symbolically as follows:

$$\frac{[\alpha H^+][HCO_3^-]}{[H_2CO_3]} = K_1' \quad (1)$$

$$\frac{[\alpha H^+][CO_3^{--}]}{[HCO_3^-]} = K_2' \quad (2)$$

$$B = [HCO_3^-] + 2[CO_3^{--}] \quad (3)$$

In these equations  $B$  is the equivalent concentration of titratable base;  $\alpha H$ , the activity or effective concentration of hydrogen ions as indicated by the pH;  $K_1'$  and  $K_2'$ , the respective apparent dissociation constants of the first and second steps in the ionization of carbonic acid; and the brackets denote molar concentration.<sup>4</sup>

The first equation indicates that the concentration of bicarbonate depends upon the concentration of hydrogen ions and undissociated carbonic acid and on a constant  $K_1'$ , called the "first apparent dissociation constant of carbonic acid." The second equation indicates that the concentration of carbonate depends upon the concentration of hydrogen and bicarbonate and upon a constant  $K_2'$ , called the "second apparent dissociation constant of carbonic acid." Thus if the concentration of any one of the three forms of carbon dioxide—namely, carbonate, bicarbonate, or carbonic acid—should change, the concentration of the other two forms must also change in order to satisfy the relations expressed in equations 1 and 2. The two apparent dissociation constants,  $K_1'$  and  $K_2'$ , similar to the apparent solubility product constant of calcium carbonate,  $K'_{CaCO_3}$ , are affected by external conditions, such as temperature, salinity, and the activity of the ions in the solution; but they are practically unaffected by the concentration of hydrogen, carbonate, and bicarbonate ions and by carbonic acid.

Sea water, being alkaline, contains an excess of base that can be balanced against a weak acid like carbonic acid. At a salinity of 34 parts per thousand the amount of carbon dioxide that can be balanced against this excess base is approximately 103 milligrams per liter.<sup>5</sup> As the carbonate radical has double the valence of the bicarbonate radical, only one-half as much carbon di-

<sup>3</sup> Moberg, E. G., Greenberg, D. M., Revelle, R., and Allen, E. C., The buffer mechanism of sea water: Scripps Inst. Oceanography Bull., Tech. ser., vol. 3, p. 238, 1934.

<sup>4</sup> For detailed explanation of these equations see Moberg, E. G., and others, op. cit., pp. 235-268.

<sup>5</sup> Moberg, E. G., and others, op. cit., p. 269.

oxide—that is, 51.5 milligrams per liter—in the form of carbonate is needed to balance the excess base. If the quantity of carbon dioxide were intermediate between 51.5 and 103 milligrams per liter, part of the base could be balanced by carbonate and part by bicarbonate. The relation is expressed symbolically in equation 3. This equation, however, is not strictly accurate, because part of the excess base is balanced by acids of boron<sup>6</sup> and perhaps by other acids as well. According to Revelle and Fleming, the influence of borate becomes greater as the hydrogen-ion concentration decreases—that is, as the pH increases. At a hydrogen-ion concentration of  $10^{-9}$ —that is, at a pH of 9—about 16 percent of the excess base is balanced by borates, but at a pH of 8.0 to 8.2, which is the general average for the surface of the sea, the proportion of excess base balanced by borates is less than 4 percent,<sup>7</sup> which indicates that nearly all the excess base is balanced by some form of carbonic acid.<sup>8</sup> Below the surface of the ocean the pH decreases to about 7.8,<sup>9</sup> and the influence of boron is insignificant. Equation 3, which shows the relation of carbonic acid to excess base, therefore seems to be approximately correct for the conditions that usually prevail in the sea, but to be strictly accurate it should include the effect of boron.

Similarly, to be strictly accurate the excess base should be corrected for the effect of hydrogen and hydroxyl ions, but according to Moberg and his associates<sup>9</sup> this effect is not great for conditions that ordinarily prevail in the sea. Consequently, in order to simplify the calculations, the effect of these ions on the excess base was not considered in connection with equation 3.

The distribution of the three forms of carbon dioxide in the water therefore depends on the three fundamental relations expressed by equations 1, 2, and 3. These three equations may be solved simultaneously and the total effect expressed as follows:

$$[HCO_3^-] = \frac{K_1'}{4K_2'} [H_2CO_3] \left( \sqrt{1 + \frac{8BK_2'}{K_1'[H_2CO_3]}} - 1 \right) \quad (4)$$

An expression for the concentration of carbonate instead of the bicarbonate could have been given, but it would be in a form that would make numerical computation difficult.

It follows from equations 1 to 4 and also from experimental work of Moberg and his associates<sup>10</sup> that the hydrogen-ion concentration increases—or, as generally

<sup>6</sup> Revelle, R., and Fleming, R. F., The solubility product constant of calcium carbonate in sea water: 5th Pacific Sci. Cong., Victoria and Vancouver, Proc., vol. 3, pp. 2089-2092, 1933.

<sup>7</sup> Buch, K., Der Borsäuregehalt des Meerwassers und seine Bedeutung bei der Berechnung des Kohlensäuresystems im Meerwasser: Conseil perm. expl. mer Rapports et procès-verbaux, vol. 85, pp. 71-75, 1933.

<sup>8</sup> Wattenberg, H., Kalziumkarbonat- und Kohlensäuregehalt des Meerwassers: Wiss. Ergeb. Deutschen Atlantischen Exped. Meteor, 1925-27, Band 8, Teil 2, pp. 268-308, 1933.

<sup>9</sup> Moberg, E. G., and others, op. cit., pp. 243-244.

<sup>10</sup> Idem, p. 269.

reported, the pH decreases—as the total content of carbon dioxide rises. Thus, at a pH of 8.5 the total content of carbon dioxide is about 83 milligrams per liter, of which about 20 milligrams is in the form of carbonate, 63 milligrams in the form of bicarbonate, and less than 1 milligram in the form of carbonic acid. At a pH of 8.1, which prevails at the surface of the ocean, the total content of carbon dioxide is about 93 milligrams, of which 10 milligrams occurs as carbonate, 83 milligrams as bicarbonate, and less than 1 milligram as carbonic acid; and at a pH of 7.5, the total content of carbon dioxide is about 104 milligrams, of which less than 1 milligram is carbonate, 103 milligrams bicarbonate, and about 1 milligram carbonic acid. As the pH falls below 7.5 the total content of carbon dioxide rises. This increase is almost entirely in the free carbon dioxide or carbonic acid. The content of carbon dioxide in the form of bicarbonate and carbonate remains about 103 milligrams and less than 1 milligram per liter, respectively.

The relationships expressed above indicate that between pH 7.5 and 8.5, which represents practically the entire range for the sea, each unit decrease in total quantity of carbon dioxide means a decrease of two units in bicarbonate and an increase of one unit in carbonate. That is, each decrease of 1 milligram in total content of carbon dioxide causes an increase of 1 milligram of carbon dioxide in the form of carbonate. The gain in carbonate, however, is slightly less than the loss in total content of carbon dioxide, because a decrease in total content of carbon dioxide causes an increase in the pH of the water, which in turn causes more of the excess base to be balanced by borates. Consequently, part of the base that would have to be balanced by carbonate if borates were not present is balanced by borates, and not so much carbon dioxide changes from bicarbonate to carbonate.

This relation of carbonate to total content of carbon dioxide is probably the most significant factor in the deposition of calcium carbonate, as it is most susceptible to change. The total content of carbon dioxide ranges chiefly between 90 and 95 milligrams per liter in the upper layers of the sea, where, as discussed below, most of the calcium carbonate seems to be formed.<sup>11</sup> The carbon dioxide in the form of carbonate under such conditions ranges between 8 and 12 milligrams per liter. Thus, a decrease of only 1 percent in the total content of carbon dioxide causes an increase of about 10 percent in the quantity of carbonate. It follows, therefore, that small changes in the total quantity of carbon dioxide in the water have a very pronounced influence on the solubility of calcium carbonate.

The relations governing the quantity of carbonate in the sea water, however, as indicated by the foregoing

discussion, are complicated. The controlling factors are the concentration of carbonic acid and bicarbonate, the total content of carbon dioxide, the hydrogen-ion concentration, and the two apparent dissociation constants of carbonic acid,  $K_1'$  and  $K_2'$ . These factors, in addition to being interrelated to some extent, are also influenced by other factors. The content of carbonic acid depends upon the content of free carbon dioxide, which in turn is directly affected by the solubility of carbon dioxide in sea water, by the carbon dioxide tension in the air above the water, and by the activity of the organisms in the water. The solubility of free carbon dioxide in the water and the two apparent dissociation constants,  $K_1'$  and  $K_2'$ , are influenced considerably by the temperature and salinity. The quantity of excess base in the water depends directly upon the salinity, but it is not affected significantly by small changes in temperature (table 1).

#### EFFECTS OF INDIVIDUAL FACTORS

The foregoing analysis shows that the deposition of calcium carbonate in the sea is affected by many factors and that several of these factors influence the deposition of calcium carbonate in different ways.

#### TEMPERATURE

The temperature of sea water affects the solubility of calcium carbonate in the water because of its influence on (1) the solubility of free carbon dioxide in the water, (2) the apparent solubility product constant,  $K'_{\text{caco}_3}$ , (3) the two apparent dissociation constants of carbonic acid,  $K_1'$  and  $K_2'$ , and (4) the hydrogen-ion concentration. It also influences the growth of living organisms, which in turn affect the deposition of calcium carbonate in several ways. Moreover, owing to its effect on evaporation, it influences the salinity of the water. As the temperature changes with depth, it also influences the relations for depth. Finally, it has some minor effects because of its influence on the viscosity and density of the water and because of its relation to the formation of detrital particles by the weathering of limestone.

#### SALINITY

The salinity of sea water influences the solubility of calcium carbonate in the water because of its relations to (1) the solubility of free carbon dioxide in the water, (2) the constants,  $K_1'$ ,  $K_2'$ , and  $K'_{\text{caco}_3}$ , (3) the hydrogen-ion concentration, and (4) the quantity of calcium and excess base in the water. Like the temperature, it affects the viscosity and density of the water and the growth of living organisms. Owing to its effect on the density of water, it influences the circulation of masses of water in the ocean, with the result that bodies of warm or cold water are moved from their places of formation; and thus the salinity indirectly affects the temperature of the water.

<sup>11</sup> Moberg, E. G., and others, op. cit., p. 269.

## ORGANISMS

Living organisms may remove calcium carbonate directly from the water to make shells and skeletal material. They may transport particles of calcium carbonate in their digestive tracts. Forms like bacteria may precipitate calcium carbonate directly,<sup>12</sup> or, as suggested by Revelle,<sup>13</sup> they may instigate the precipitation of calcium carbonate from supersaturated water by a seeding action induced by the presence of their bodies in the water. Living organisms may give off waste products, such as ammonia, which may affect the solubility of calcium carbonate.<sup>14</sup> The most important action of living things in the sea with respect to the precipitation of calcium carbonate, however, is their effect on the part played by carbon dioxide in the water.

The floating plants (phytoplankton) living in the surface layers of the water remove large quantities of carbon dioxide from the water for building organic compounds in their tissues by the aid of photosynthesis. The animals living in the sea, on the other hand, give off carbon dioxide as a waste product. The decomposition of the tissues of dead plants and animals as they fall to the bottom of the sea results in the addition of carbon dioxide to the water. The phytoplankton is confined chiefly to the upper 200 meters of water, in which light penetrates effectively for photosynthesis.<sup>15</sup> The animals are found at nearly all depths but are largely confined to the upper layers, in the zone of phytoplankton, which forms their basic source of food. Decomposition takes place at all depths, but its effect is more evident in the water beneath the zone of phytoplankton. In the upper 100 to 200 meters of water the removal of carbon dioxide by the phytoplankton is greater than the addition of carbon dioxide to the water by animals and by decomposition;<sup>16</sup> but below 200 meters the reverse is true. These phenomena cause the upper 200 meters of water to contain comparatively little carbon dioxide and the water below a depth of 200 meters to contain comparatively much carbon dioxide. Consequently, the surface layers are relatively rich and the lower layers relatively poor in carbonate. The upper layers, therefore, are more highly saturated with calcium carbonate than the lower layers.

Wattenberg<sup>17</sup> has prepared maps showing the degree of saturation of the water in the South Atlantic, which presumably apply in general to the other oceans as

<sup>12</sup> Bavendamm, W., Die Mikrobiologische Kalkfällung in der tropische See: Archiv Mikrobiologie, Band 3, pp. 205-276, 1932. This paper contains a good bibliography.

<sup>13</sup> Revelle, R., personal communication.

<sup>14</sup> Murray, J., On the deposits of the Black Sea: Scottish Geog. Mag., vol. 16, p. 684, 1900.

<sup>15</sup> Cf. Hentschel, E., Allgemeine Biologie des süd-Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925-27, Band 11, 1933.

<sup>16</sup> Wattenberg, H., op. cit., pp. 162, 236.

<sup>17</sup> Idem, pp. 194-205.

well. The surface water ranges from about 100 percent saturation in polar latitudes to about 150 percent saturation in equatorial latitudes. Below a depth of about 200 meters in polar latitudes and 500 meters in tropical latitudes the water everywhere is undersaturated with calcium carbonate, but in no place is the degree of saturation reported to be less than 90 percent.

Wattenberg's maps are based on a determination of the apparent solubility product constant that is about one-half as large as the determination by Revelle and Fleming,<sup>18</sup> made by a different method.

The solubility product constant of calcium carbonate in sea water has to be determined experimentally and is very difficult to measure. It represents the point of equilibrium at which no calcium carbonate will be dissolved and none will be precipitated from the water. The solubility of calcium carbonate in sea water is very small, and the water tends to become supersaturated before precipitation begins. Consequently, it is not surprising that the results of Wattenberg should differ by 50 percent from those of Revelle and Fleming. The gratifying feature is that they are as close to one another as they are. It would seem, therefore, that the proper order of magnitude of the apparent solubility product constant has been ascertained. However, because Revelle and Fleming's determination of this constant is distinctly greater than Wattenberg's, the estimates of the degree of saturation for the South Atlantic given by Wattenberg may be too high. It nevertheless seems probable that the upper layers of water in the ocean, especially in low latitudes, are saturated with calcium carbonate and that the water below 200 meters is undersaturated.

## DEPTH

The depth of water, therefore, is an important factor in the deposition of calcium carbonate. The upper layers of water, which appear to be saturated with calcium carbonate, represent the zone in which calcium carbonate is formed by chemical precipitation, and they also represent the zone in which most of the skeletal material, composed of calcium carbonate, is produced by the action of living organisms. The layers below a depth of 200 meters, where the water is undersaturated with calcium carbonate, represent a zone where calcium carbonate may be dissolved from particles as they sink to the sea floor.

Depth, because of its relation to pressure, also affects the solubility of calcium carbonate.<sup>19</sup> In addition, the temperature of the water decreases from the surface downward, with the result that the deep water can hold more calcium carbonate in solution than the surface layers. The salinity of the deep ocean water is remark-

<sup>18</sup> Revelle, R., and Fleming, R. F., op. cit., p. 2091.

<sup>19</sup> Wattenberg, H., op. cit., p. 209.

ably constant and differs but little from the general average of the ocean.<sup>20</sup> The influence of salinity on calcium carbonate because of changes in depth, therefore, is not great.

#### CALCULATION OF EFFECT OF CHANGE IN TEMPERATURE AND SALINITY ON SOLUBILITY OF CALCIUM CARBONATE

##### METHOD OF CALCULATION

The effect of changes in salinity and temperature on the solubility of calcium carbonate in sea water can be computed from the relations given in equations 1 to 4 and from the apparent solubility product constant. The quantity of carbonate in the water can be calculated from equations 3 and 4. The content of bicarbonate is determined from equation 4 by substitution of the figures for carbonic acid, excess base, and the two apparent dissociation constants,  $K_1'$  and  $K_2'$ . The carbonate content is then readily obtained by substitution of the figures for bicarbonate and excess base in equation 3.

In order to show the effect of increase in temperature and salinity, the solubility of calcium carbonate in sea water was calculated for three sets of conditions—(1) a standard condition in which the temperature was 20° C. and the salinity was 34 parts per thousand; (2) where

the temperature was 1° higher but the salinity was the same; and (3) where the salinity was 1 part per thousand higher but the temperature was the same (table 1). For the standard condition the carbonate content of a saturated solution was computed on the basis of a hydrogen ion concentration of  $10^{-8}$ , or a pH of 8.0 (which is determined mainly by the amount of carbonic acid in the water), a first apparent dissociation constant of  $1.07 \times 10^{-8}$  ( $pK_1' = 5.97$ ), a second apparent dissociation constant of  $8.9 \times 10^{-10}$  ( $pK_2' = 9.05$ ), and an excess base equivalent to 103 milligrams of carbon dioxide in the form of bicarbonate. The carbonate content for the conditions of increased temperature and salinity was likewise computed by substitution of the proper figures for carbonic acid,  $K_1'$ ,  $K_2'$ , and excess base in equations 3 and 4. The changes in  $K_1'$ ,  $K_2'$ , and carbonic acid (in reality, in the solubility of free carbon dioxide in saline solutions) corresponding to the changes in temperature and salinity were based on data presented by Buch and his associates.<sup>21</sup> The excess base was assumed to vary directly with the salinity and to be unaffected by temperature. The effect of boron was disregarded, but, as mentioned above, at a hydrogen ion concentration of  $10^{-8}$ , the effect of boron is slight.

TABLE 1.—Effect of a small rise in salinity and temperature on the solubility of calcium carbonate in sea water

|   | Standard | Rise in tem- |        | Rise in salinity |
|---|----------|--------------|--------|------------------|
|   |          | 20           | 21     |                  |
| Temperature.....  | 20       | 21           | 20     |                  |
| Salinity.....   | 34       | 34           | 35     |                  |
| Free $\text{CO}_2$ (assumed to be equivalent to $[\text{H}_2\text{CO}_3]$ ) - - - - -   | 1. 000   | 0. 974       | 0. 996 |                  |
| First apparent dissociation constant of carbonic acid $\frac{[\alpha\text{H}^+][\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} = K_1'$ - - - - - | 1. 000   | 1. 015       | 1. 008 |                  |
| Second apparent dissociation constant of carbonic acid $\frac{[\alpha\text{H}^+][\text{CO}_3^{--}]}{[\text{HCO}_3^-]} = K_2'$ - - - - -     | 1. 000   | 1. 023       | 1. 047 |                  |
| Reciprocal of hydrogen-ion concentration $\frac{1}{[\alpha\text{H}^+]}$ - - - - -   | 1. 000   | 1. 007       | 1. 016 |                  |
| Excess base (titration alkalinity), $B$ - - - - -   | 1. 000   | 1. 000       | 1. 029 |                  |
| Concentration of bicarbonate $[\text{HCO}_3^-]$ - - - - -   | 1. 000   | . 995        | 1. 020 |                  |
| Concentration of carbonate $[\text{CO}_3^{--}]$ - - - - -   | 1. 000   | 1. 025       | 1. 085 |                  |
| Concentration of calcium $[\text{Ca}^{++}]$ - - - - -   | 1. 000   | 1. 000       | 1. 029 |                  |
| Apparent solubility product constant of calcium carbonate in sea water $K'_{\text{CaCO}_3}$ - - - - -                                       | 1. 000   | . 978        | 1. 030 |                  |
| Degree of saturation of sea water with calcium carbonate $\frac{[\text{Ca}^{++}][\text{CO}_3^{--}]}{K'_{\text{CaCO}_3}}$ - - - - -          | 1. 000   | 1. 046       | 1. 084 |                  |

#### RESULTS

The results of the calculations are presented in table 1. The computations are given in the ratio form so that percentage changes in the size of the different variables will be readily apparent. For a rise in temperature of 1° C. the carbonate content increases 2.5 percent, and for a rise in salinity of 1 part per thousand the carbonate content increases 8.5 percent.

<sup>20</sup> Defant, A., Die vertikale Verteilung von Temperatur und Salzgehalt im Weltmeere: Gesell. Erdkunde Berlin Zeitschr., Jahrg. 1930, pp. 28-42. Wüst, G., Schichtung und Tiefenzirkulation des Pazifischen Ozeans: Inst. Meereskunde Veröffentl., A, Heft 20, 1929. Sverdrup, H. W., The deep water of the Pacific, according to the observations of the Carnegie: Internat. Geod. and Geophys. Union, Repts. Stockholm meeting, pp. 87-93, Carnegie Inst. Washington, Dept. Terrestr. Magnetism, 1930.

The content of calcium ions was assumed to vary proportionately with the salinity and to be unaffected by the rise in temperature. As the salinity increased 2.9 percent, the calcium content likewise increased 2.9 percent. The changes in the apparent solubility product constant were computed from data given by Wattenberg.<sup>22</sup> For the increased temperature the apparent solubility product constant was lowered 2.2 percent, and for the increased salinity it was raised 3.0 percent.

As the sea water is completely saturated with calcium carbonate when the product of the calcium and car-

<sup>21</sup> Buch, K., and others, op. cit. (1932), pp. 46, 54, 63.

<sup>22</sup> Wattenberg, H., op. cit., pp. 199, 203.

bonate equals the apparent solubility product constant, the degree of saturation of the water with calcium carbonate can be expressed by a ratio  $\frac{[\text{Ca}^{++}][\text{CO}_3^{--}]}{K'_{\text{CaCO}_3}}$ .

If the ratio is greater than 1.0 the water is oversaturated; if less than 1.0 it is undersaturated; and if equal to 1.0 it is exactly saturated.

The degree of saturation of the water for the three chosen sets of conditions can therefore be calculated by the substitution of the proper figures for  $[\text{Ca}^{++}]$ ,  $[\text{CO}_3^{--}]$ , and  $K'_{\text{CaCO}_3}$  in this ratio. In the standard condition the ratio is unity and the water is exactly saturated. Where the temperature is  $1^{\circ}$  higher the water is 4.6 percent oversaturated, and where the salinity is 1 part per thousand higher the water is 8.4 percent oversaturated. That is, according to this table, at a temperature of  $20^{\circ}$ , a salinity of 34 parts per thousand, and a pH of 8.0, a rise of  $1^{\circ}$  in temperature increases the degree of saturation 4.6 percent, and a rise of 1 part per thousand in salinity increases the degree of saturation 8.4 percent.

These determinations of the effect of temperature and salinity on the solubility of calcium carbonate should be classed as estimates. They are believed to indicate the proper order of magnitude, but some of the variables on which they depend, especially the apparent solubility product constant of calcium carbonate, have not yet been worked out completely. Consequently the determinations may be modified in the future. Wattenberg,<sup>23</sup> using a different method of calculation, reports a rise in degree of saturation of the water of about 3.5 percent, instead of 4.6 percent, for an increase of  $1^{\circ}\text{C}$ . in temperature; and Revelle,<sup>24</sup> by a still different method in which a correction was made for boron, finds a rise of 5.2 percent for an increase of  $1^{\circ}\text{C}$ .

Wattenberg does not calculate the effect of salinity on the degree of saturation, but Revelle<sup>25</sup> reports a rise of 5.0 percent, instead of 8.4 percent, for an increase in salinity of 1 part per thousand. Revelle, though having assisted me in calculating the effect of salinity on the solubility, when he came to make his own determination took more factors into consideration and in part used different data. According to current concepts of the solubility of calcium carbonate, his estimate is therefore presumably more accurate than mine; but the greater effect of salinity indicated by my calculations is more nearly in agreement with the relation of the calcium carbonate content of sediments to the surface salinity indicated by the statistical studies described below. The two determinations, however, are of the same general order of magnitude and demonstrate that the degree of saturation of the water with calcium carbonate increases as the salinity rises.

## SIGNIFICANCE

It is evident from the data given in table 1 that the salinity definitely affects the solubility of calcium carbonate in the sea and therefore influences the deposition of calcium carbonate. The magnitude of the change in degree of saturation for an increase in salinity of 1 part per thousand, compared with the magnitude of the change for a rise of  $1^{\circ}$  in temperature, demonstrates that salinity ranks with temperature as a factor controlling the solubility of calcium carbonate.

However, it is difficult to ascertain whether or not the effect of salinity on the solubility of calcium carbonate in sea water is as great as that of temperature. In the upper 200 meters of water, in which most of the solid calcium carbonate seems to be formed, the rate of change in solubility of calcium carbonate with respect to lateral changes in salinity and temperature is of the same order of magnitude. This feature is illustrated by figure 19, which shows the lines of equal temperature and salinity on the surface of the ocean. The maximum rate of change in salinity on the surface of the open ocean is about 0.4 part per thousand in 100 miles; in temperature, about  $0.7^{\circ}$  in 100 miles. The effect of this change in salinity on the solubility is  $0.4 \times 8.4 = 3.3$  percent, and the effect of this change in temperature is  $0.7 \times 4.6 = 3.2$  percent—that is, the effects are about the same. The relation of the areal distribution of calcium carbonate in sediments to surface temperature and to salinity, illustrated by plate 71, also supports this inference. It would seem, therefore, that in some parts of the ocean salinity would influence the solubility as much as the temperature. However, the seasonal variations of temperature on the surface of the ocean during the course of a year are relatively greater than those of salinity. Moreover, the temperature decreases greatly with depth, but the salinity does not. Consequently the total effect of salinity on the solubility of calcium carbonate in the ocean presumably is less than the effect of temperature.

## STATISTICAL STUDY OF RELATIONS

### METHOD OF STUDY

The relation of the salinity to the calcium carbonate content of marine sediments may also be studied statistically. In a previous investigation<sup>26</sup> I compiled a table which suggested strongly that the calcium carbonate content of marine sediments is definitely related to the salinity of the surface water. In this table the average calcium carbonate content of the sediments in 100 environments of deposition from many parts of the world was plotted against the salinity of the surface water. Table 2 is a modification of this previous table.

<sup>23</sup> Wattenberg, H., op. cit., p. 207.

<sup>24</sup> Revelle, R., Physicochemical factors affecting the solubility of calcium carbonate in sea water: *Jour. Sedimentary Petrology*, vol. 4, pp. 103-110, 1934.

<sup>25</sup> *Idem*, p. 207.

<sup>26</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., *Origin and environment of source sediments of petroleum*, p. 103, Houston, Tex., Gulf Publishing Co., 1932.

TABLE 2.—*Relation of calcium carbonate content of marine sediments to salinity of surface water, as indicated by individual environments of deposition*

| Average (median) CaCO <sub>3</sub> content of region (percent)        | Salinity (parts per thousand) |       |       |     |
|---|-------------------------------|-------|-------|-----|
|   | <34                           | 34-35 | 35-36 | 36+ |
|   | Number of regions             |       |       |     |
| 0 to 2  | 40                            | 4     | —     | —   |
| 3 to 10   | 8                             | 6     | —     | —   |
| 11 to 20  | 9                             | 4     | 3     | 2   |
| 21 to 50  | —                             | 1     | 6     | 6   |
| 51 to 88  | —                             | —     | 6     | 5   |
| Average (median) CaCO <sub>3</sub> content for given salinity percent | 1                             | 5     | 45    | 45  |

According to this table, the sediments in areas in which the surface salinity is less than 35 parts per thousand contain little calcium carbonate, and those in areas in which the salinity is more than 35 parts contain much calcium carbonate. This relationship, however, might be more apparent than real, because the effects of other factors, such as temperature and depth of water, the degree of saturation of the water with calcium carbonate, the action of organisms, or the proportion of clastic detritus in the sediments, were not considered. The salinity might happen to vary in the same way as some of these other factors and thus not be definitely related to the calcium carbonate content of the sediments.

If the effect of the other factors could be considered and if the salinity were then still found to vary with the calcium carbonate content, it would be evident that the relation is definite. The ideal way to undertake such an investigation would be to make all the factors except salinity constant, and then examine the relationship between salinity and calcium carbonate. Unfortunately, it is impossible to make all the other factors constant, but the effect of some of them can be determined to a certain extent by means of a statistical study of a large number of samples.

#### CONTROL OF EXTRANEous FACTORS

The sea floor can be divided into several areal groups representing different conditions of temperature, depth of water, and distance from shore; and the relation of the salinity to the calcium carbonate content of the sediments in each group can then be examined. The size of the groups into which it is practicable to divide the sea floor depends upon the number of samples available. If the number of samples is large, the size of the groups can be small; but if the number of samples is small, the size of the groups must be large, because each group should be represented by enough samples to counterbalance the effects of factors not considered in the selection of the groups. About 2,000

samples were available for study, and the most practicable number of groups into which the sea floor could be divided seemed to be 32. The average number of samples in each group, therefore, was about 60, which should be sufficient to counterbalance to a considerable extent the effect of the factors that were not evaluated, such as the degree of saturation of the water with calcium carbonate.

If there are 32 groups, the most practicable grouping seems to be to divide the sea into 4 temperature groups; divide each of these temperature groups into 4 depth groups, making 16 groups; and then divide each of these depth groups into 2 groups according to distance from shore, making 32 groups in all.

The mean annual temperature of the surface of the sea ranges chiefly between 0° and 30° C., but over a large area it ranges mainly between 20° and 30°. Consequently, instead of making four equal groups based on surface temperature, it seemed better to make the areal distribution of the groups more nearly equal and have the limits of the groups 0°-10°, 10°-20°, 20°-25°, and 25°-30°. The limits of the four depth groups were 0 to 1,000, 1,000 to 2,000, 2,000 to 3,000, and 3,000 to 4,000 fathoms. In reference to distance from shore, the samples were divided into near-shore and pelagic groups. All the samples in the near-shore group were obtained less than 500 miles from shore and most of them within 200 miles of shore. For the most part they represent "terrigenous deposits" in the Murray classification.<sup>27</sup> The pelagic samples represent sediments far from land and are characterized by material of chemical and organic origin, in contrast with the near-shore deposits, which contain considerable material of clastic origin in addition to that of chemical and organic origin. The effect of detrital particles on the proportion of calcium carbonate in the sediments is compensated to some extent by means of this division of the sediments into near-shore and pelagic deposits, but it would be better if it had been practicable to make more than two divisions of the sediments with respect to distance from shore, because of the possibility that variations in the proportion of detrital particles within either the near-shore or the pelagic group might obscure the effect of other variables, such as temperature or salinity.

In fact, in the entire grouping of the samples the limits of the individual groups are so wide that variations within any one of them may mask the relation of salinity to calcium carbonate. Ordinarily, variations in calcium carbonate arising from variations within a group will tend to counterbalance one another, but if the effect of some particular factor, such as temperature, or proportion of clastic material, or degree of saturation of the water with calcium carbonate,

<sup>27</sup> Murray, J., and Renard, A. F., *Challenger Rept.*, Deep-sea deposits, pp. 228-240, 1891.

should vary in some of the individual groups in the same way as the salinity, the relation of salinity to calcium carbonate might be completely obscured. For example, in certain parts of the sea, notably in latitudes greater than 40°, the surface temperature and salinity vary in the same way with respect to latitude (fig. 19). If within the areal confines of a temperature group the salinity should be found to vary with respect to horizontal distance in the same way as temperature, and if a relation between salinity and calcium carbonate of the sediments were found, it would not follow necessarily that the variations in calcium carbonate were due to variations in salinity. They might be due in part or wholly to variations in temperature within the group. A similar degree of indefiniteness would arise in areas where the salinity increases away from shore, because it would not be certain whether the increase in calcium carbonate in the sediments were due to the increased salinity or to the smaller proportion of clastic material in the sediments.

The possibility of sympathetic variations of this type is an inevitable result of a system of grouping in which the range within the individual groups is considerable. The conclusions obtained from a study of such groups, however, though not completely satisfactory, are certainly more definite than if no grouping had been made. Moreover, it is evident from plate 71 and figure 19 that surface salinity in most parts of the ocean does not vary in the same way in a horizontal direction as surface temperature, depth of water, or distance from shore. Furthermore, each of the 32 individual groups represents several different parts of the sea in which the conditions are not everywhere the same. The number of samples in the individual groups is fairly large, and the samples are distributed over many parts of the sea. Therefore, according to the laws of probability, the chances are against the possibility that the relation of surface salinity to the calcium carbonate content of the sediments might be obscured by the effect of variations of other factors in any individual group, and still more in a large number of groups. Consequently, if a consistent relationship between salinity and calcium carbonate is found for nearly all the groups, the chances are much in favor of its being a true relationship, though not necessarily one of cause and effect.

It seems evident, therefore, that if there is such a relationship for salinity, its existence will be indicated by a statistical study of this type, but it does not necessarily follow that the true degree of the relationship will be indicated. For example, as pointed out below, the extent to which the water is saturated with calcium carbonate may possibly be related to the surface salinity and thus may have influenced in part the relation between salinity and calcium carbonate content of the sediments brought out by the statistical study.

#### METHOD OF COMPARING SALINITY AND CALCIUM CARBONATE CONTENT

In the determination of the relation of salinity to calcium carbonate, the samples likewise were classed according to groups. Each of the 32 groups for temperature, depth, and distance from shore was divided into 4 groups based on salinity and into 8 groups based on calcium carbonate content. The limits of the salinity groups, in parts per thousand, were less than 34, 34 to 35, 35 to 36, and more than 36. This type of grouping was adopted because of the suggestion indicated by table 1 that the critical salinity was about 35 parts per thousand and that salinities of less than 34 or more than 36 parts did not seem to affect appreciably the calcium carbonate content of sediments. The limits of the calcium carbonate groups, in percent, were 0 to 2, 2 to 5, 5 to 10, 10 to 20, 20 to 30, 30 to 50, 50 to 75, and more than 75. The object of this grouping was to separate the samples into varying grades of content of calcium carbonate, ranging from carbonate-free to limestone-forming sediments. The subsequent calculations, however, would have been simpler if the limits of the groups had been geometric instead of arbitrary.

It would also probably have been better if the average salinity and average temperature in the upper 200 meters of water had been considered instead of the surface salinity and temperature. The statistical part of this report was prepared in 1931, primarily for the purpose of ascertaining whether or not the relationship expressed by table 2 was real. The papers of Wattenberg,<sup>28</sup> Buch and others,<sup>29</sup> and Moberg and others,<sup>30</sup> which emphasize the importance of the upper 200 meters of water with respect to the formation of calcium carbonate, had not yet appeared, and at that time there was no reason to presume that the average salinity or temperature of any particular depth zone would be better to consider than the surface salinity or temperature. In many parts of the sea—notably in low latitudes—the surface salinity represents the average salinity in the upper 200 meters of water more closely than the surface temperature represents the average temperature of that zone.<sup>31</sup> The conditions in the upper 200 meters of water depend largely upon the circulation of water in the ocean. Heat derived from the sun raises the temperature of the surface water

<sup>28</sup> Wattenberg, H., Kalziumkarbonat- und Kohlensäuregehalt des Meerwassers: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925-27, Band 8, Teil 2, pp. 1-333, 1933.

<sup>29</sup> Buch, K., Harvey, H. W., Wattenberg, H., and Gripenberg, S., Ueber das Kohlensäuresystem im Meerwasser: Conseil perm. expl. mer Rapports et procès-verbaux, vol. 79, pp. 1-70, 1932.

<sup>30</sup> Moberg, E. G., Greenberg, D. M., Revelle, R., and Allen, E. C., The buffer mechanism of sea water: Scripps Inst. Oceanography Bull., Tech. ser., vol. 3, no. 11, 231-278, 1934.

<sup>31</sup> Defant, A., Die systematische Erforschung des Weltmeeres: Gesell. Erdkunde Berlin Zeitschr., Sonderband zur Hundertjahrfeier der Gesellschaft, p. 485, 1928. Wüst, G., Der Ursprung der Atlantischen Tiefenwässer: Idem, p. 520; Schichtungen und Tiefezirkulation des Pazifischen Ozeans: Meereskunde Veröffentl., A, Heft 20, 1929. Schott, G., Geographie des Atlantischen Ozeans, p. 144, Hamburg, C. Boysen, 1928. Schott, G., and Schu, F., Die Wärmeverteilung in den Tiefen des Stilles Ozeans: Annalen der Hydrographie, Band 38, pls. 2, 3, p. 48, 1910.

more readily than it raises the salinity of the surface water by means of its effect on evaporation. These features may account in part for the apparently closer relation of the calcium carbonate content of the sediments to the surface salinity than to the surface temperature.

#### SOURCE OF DATA

About 3,000 samples were considered, of which 1,953 were selected for study. The samples are described in Murray's *Challenger*,<sup>32</sup> Pacific,<sup>33</sup> and Atlantic<sup>34</sup> reports and in my report on source beds.<sup>35</sup> These publications give the calcium content, the depth, and the position of the samples. Pratje<sup>36</sup> and Correns<sup>37</sup> have published maps of the distribution of calcium carbonate in the South Atlantic, but the data from these maps were not used for the statistical study, because they were not presented in a form readily applicable to the statistical groups that were used.

The data for salinity were derived from Schott's map<sup>38</sup> showing the mean annual salinity of the surface of the oceans; and the data for temperature from maps by Schott,<sup>39</sup> Schott and Schu,<sup>40</sup> Krümmel,<sup>41</sup> and Shokalsky,<sup>42</sup> showing the mean annual isotherms of the surface water.

The samples available for study cover the world more or less satisfactorily. The Pacific and Atlantic Oceans are fairly well represented, but the Indian and Antarctic Oceans are not. No pelagic samples from the Arctic Ocean were available, but several samples were procured off the northern coast of Canada and Alaska. Most of the inland and semienclosed seas are represented—namely, the Arabian, Baltic, Bering, Black, Caribbean, Japan, Java, Mediterranean, Red, and Yellow Seas and the Gulfs of California, Maine, Mexico, Panama, and Venezuela. The near-shore samples came from many parts of the Arctic, Atlantic, and Pacific coasts of North and South America, the entire west coast of Africa, and the coasts of parts of Arabia, Antarctica, Australia, Europe, India, Japan, Java, and the Philippine Islands.

<sup>32</sup> Murray, J., and Renard, A. F., *Challenger Rept.*, Deep-sea deposits, pp. 34-147, 1891.

<sup>33</sup> Murray, J., and Lee, G. V., The depth and marine deposits of the Pacific: Harvard Coll. Mus. Comp. Zoology Mem., vol. 38, pp. 40-148, 1909.

<sup>34</sup> Murray, J., and Chumley, J., The deep-sea deposits of the Atlantic Ocean: Royal Soc. Edinburgh Trans., vol. 54, pp. 1-216, 1924.

<sup>35</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., Origin and environment of source sediments of petroleum, pp. 249-273, Houston, Tex., Gulf Publishing Co., 1932.

<sup>36</sup> Pratje, O., Geologische Tiefseeforschungen auf der Deutschen Atlantischen Expedition: Deutsche geol. Gesell. Monatsber., Band 79, p. 202, 1927.

<sup>37</sup> Correns, C. W., Mineralogisch-geologische Arbeiten der Deutschen Atlantischen Expedition: Gesell. Erdkunde Berlin Zeitschr., Jahrg. 1928, Ergänzungsheft 3, p. 127.

<sup>38</sup> Schott, G., Die Verteilung des Salzgehaltes im Oberflächerwasser der Ozeane: Annalen der Hydrographie, Band 56, Heft 5, p. 184, 1928.

<sup>39</sup> Schott, G., Geographie des Atlantischen Ozeans, pl. 10, p. 144, Hamburg, C. Boysen, 1926.

<sup>40</sup> Schott, G., and Schu, F., Die Wärmeverteilung in den Tiefen des Stillen Ozeans: Annalen der Hydrographie, Band 38, Heft 1, pp. 2-25, 44, 1910.

<sup>41</sup> Krümmel, O., Handbuch der Ozeanographie, Band 1, pp. 400-406, 1907 (for Indian Ocean).

<sup>42</sup> Shokalsky, J., Oceanography [in Russian], pp. 134, 135, Petrograd, 1917.

Some areas were represented by many samples, and others by few. In order to make the results of the statistical study of these areas comparable, the number of samples from areas represented by many samples was reduced. In this process of reduction, an attempt was made to select samples proportionately with respect to area, so that the sediments chosen for study would represent an approximately equal distribution. This process of elimination lowered the number of samples to 1,953, of which 928 were typically pelagic deposits and 1,035 were near-shore sediments or deposits from inland seas or lakes.

About 4 percent of the near-shore sediments represent samples of fresh-water and saline lakes that had been studied previously.<sup>43</sup> The sediments of saline lakes contain considerable calcium carbonate, but those from nearly all the fresh-water lakes contain less than 2 percent. It is probable, however, that the proportion of fresh-water lakes characterized by calcareous deposits is greater than was indicated by the previous work, which was based on relatively few lakes; and it is also probable that the calcium carbonate content of lacustrine sediments is ordinarily influenced more by other factors than it is by the salinity of the water.<sup>44</sup>

The relation of the salinity to the calcium carbonate content of lacustrine sediments is not discussed in this paper, but in order to make the study of the effect of salinity representative of general conditions, a few lacustrine samples were included in the statistical study. As this paper is restricted mainly to the discussion of marine conditions, it might be better if this had not been done. The lacustrine samples, however, form so small a proportion of the total number of samples, and the relationships they exhibit are so similar to those indicated by marine sediments, that the statistical results are not significantly different from what they would have been if the lacustrine samples had been omitted.

#### METHOD OF COMPILING DATA

The method of recording the data was to use 32 cards, 16 for near-shore sediments and 16 for pelagic deposits. The 16 cards in each of these groups were divided into 4 series of temperature groups and 4 series of salinity groups. For example, there were 4 cards for the salinity group of less than 34 parts per thousand, 1 for each of the 4 temperature subgrades. Similarly there were 4 cards for the salinity group of 34 to 35 parts per thousand, 1 for each temperature grade; and so on. On each card the depth was plotted against the calcium carbonate content. Each of the 1,953 samples was placed in the proper category on one of these cards. Table 3 illustrates the manner of plotting.

<sup>43</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., op. cit., pp. 100, 281.

<sup>44</sup> Naumann, E., Die Bodenablagerungen der Seen: Internat. Ver. theor. u. angew. Limnologie Verh., Band 4, 1929. Pia, J., Die rezente Kalksteine; Min. pet. Mitt., Ergänzungsband, 1933.

TABLE 3.—*Relation of calcium carbonate content of pelagic deposits to depth of water in areas in which the surface water has a salinity greater than 36 parts per thousand and a temperature higher than 25° C.*

| CaCO <sub>3</sub> (percent)          | Depth (fathoms)   |              |                |                |                |                |                |                | Total number of samples |
|--------------------------------------|-------------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------------|
|                                      | 0 to 500          | 500 to 1,000 | 1,000 to 1,500 | 1,500 to 2,000 | 2,000 to 2,500 | 2,500 to 3,000 | 3,000 to 3,500 | 3,500 to 4,000 |                         |
|                                      | Number of samples |              |                |                |                |                |                |                |                         |
| 0 to 2                               |                   |              |                |                |                | 1              | 9              | 1              | 11                      |
| 2 to 5                               |                   |              |                |                |                | 6              | 4              |                | 10                      |
| 5 to 10                              |                   |              |                |                | 1              | 2              | 3              | 1              | 7                       |
| 10 to 20                             |                   |              |                |                | 1              | 5              | 1              |                | 7                       |
| 20 to 30                             |                   |              |                | 1              | 1              | 8              | 1              |                | 11                      |
| 30 to 50                             |                   |              | 1              | 5              | 9              | 4              | 2              |                | 21                      |
| 50 to 75                             | 2                 | 1            | 8              | 7              | 22             | 7              |                |                | 47                      |
| 75+                                  | 2                 | 6            | 3              | 7              | 12             |                |                |                | 30                      |
| Total                                | 4                 | 7            | 12             | 20             | 46             | 33             | 20             | 2              | 144                     |
| Average percent of CaCO <sub>3</sub> | 77                | 79           | 66             | 62             | 60             | 28             | 9              | 4              | 47                      |

The cards could just as well have been arranged in a form in which the salinity or the temperature instead of the depth was plotted against the calcium carbonate content of the sediments, but the depth was used because of the time saved thereby in compilation.

In order to study the relationship of surface salinity and surface temperature to the calcium carbonate content of the sediments the figures on these cards were rearranged on 64 other cards—32 for salinity and 32 for temperature. The salinity and temperature groups were subdivided into near-shore and pelagic groups, and these in turn were segregated into four depth groups, each representing an interval of 1,000 fathoms. That is, for salinity there were 32 cards to cover all possible variations of two groups based on distance from shore, four temperature groups, and four depth groups. Similarly there were 32 cards for surface temperature, representing all possible combinations of two groups based on distance from shore, four depth groups, and four salinity groups. These 64 cards, together with the 32 cards that showed the relation of depth to calcium carbonate content, formed the basis for the statistical study of the problem.

#### ARITHMETIC MEANS

##### METHOD OF PRESENTING DATA

It is not practicable to present in this paper the 96 size distributions<sup>45</sup> represented by these cards. Instead, the significant features are summarized in three ways—first, in tables 4 to 6, which show the average<sup>46</sup> calcium carbonate content for different combinations of depth, surface salinity, and surface temperature; second, in figures 12 to 18, which show graphically the relation of the average calcium carbonate content of the sediments for given surface salinity, surface temperature, and depth; and third, in table 7, which indicates for each of the 96 subgroups the coefficients of correlation between the calcium carbonate content of the sediments and the salinity, the temperature, and the depth.

<sup>45</sup> A "size distribution" is a numerical classification of items according to a number of groups of different sizes. Table 3 represents the size distribution of calcium carbonate and depth for a particular temperature and salinity. It shows the distribution of the samples with respect to calcium carbonate and depth on the basis of the number of samples in each of several categories.

<sup>46</sup> "Mean" and "average" unless otherwise stated are used interchangeably in the present report to indicate the arithmetic mean.

TABLE 4.—*Mean calcium carbonate content of marine sediments for different salinity and temperature of the surface water and for different depth of water; data arranged to show relation for depth*

[Figures in italic are averages based on 5 samples or less; figures without indication of probable error represent single samples]

## Near-shore sediments

| Salinity (parts per thousand) | Temperature (°C.) | Depth (fathoms)                      |            |            |              |                |                |                |                |
|-------------------------------|-------------------|--------------------------------------|------------|------------|--------------|----------------|----------------|----------------|----------------|
|                               |                   | 0 to 100                             | 100 to 250 | 250 to 500 | 500 to 1,000 | 1,000 to 1,500 | 1,500 to 2,000 | 2,000 to 3,000 | 3,000 to 4,000 |
|                               |                   | Mean percentage of calcium carbonate |            |            |              |                |                |                |                |
| <34                           | 0 to 10           | 6±4                                  | 7±4        | 4±1        | 3±1          | 3±2            | 10±8           | 1±0            | 1±0            |
|                               | 10 to 20          | 7±4                                  | 10±8       | 8±8        | 15±10        | 20±5           | 1±?            | 6±3            | 1±?            |
|                               | 20 to 25          | 3±3                                  |            | 62±5       | 62±5         | 62±?           |                |                |                |
|                               | 25 to 30          | 19±13                                | 24±8       | 13±7       | 12±6         | 20±6           | 19±14          | 13±8           |                |
|                               | 0 to 10           | 3±2                                  | 1±1        | 1±?        | 14±6         | 26±6           | 17±4           |                |                |
|                               | 10 to 20          | 3±3                                  | 15±?       | 16±5       | 17±6         | 20±10          | 5±1            | 4±2            |                |
|                               | 20 to 25          | 13±7                                 | 1±?        | 12±8       | 12±9         |                | 3±2            | 4±2            |                |
|                               | 25 to 30          | 14±18                                | 16±13      | 26±18      | 18±10        | 28±18          | 10±8           | 9±7            |                |
|                               | 0 to 10           |                                      | 20±3       | 12±3       | 17±7         |                | 25±?           |                |                |
|                               | 10 to 20          | 30±4                                 | 41±13      | 27±14      | 24±9         | 18±6           | 19±11          | 11±6           |                |
| 34 to 35                      | 20 to 25          | 45±21                                | 62±?       | 39±15      | 35±12        | 23±8           | 20±9           | 9±4            |                |
|                               | 25 to 30          | 53±31                                | 60±19      | 82±?       | 38±10        | 51±15          | 19±11          | 16±6           |                |
|                               | 0 to 10           |                                      |            |            |              |                |                |                |                |
|                               | 10 to 20          | 37±30                                | 46±22      | 27±9       | 32±11        | 33±12          | 29±5           | 29±5           |                |
|                               | 20 to 25          | 28±9                                 |            | 15±?       | 13±7         | 16±6           | 16±4           |                |                |
|                               | 25 to 30          | 46±28                                | 62±10      | 57±18      | 49±26        | 41±24          | 37±12          | 24±9           |                |
|                               | Mean              | 23±13                                | 25±10      | 24±10      | 23±9         | 26±9           | 16±8           | 12±5           | 1±0            |

## Pelagic deposits

| Salinity (parts per thousand) | Temperature (°C.) | Depth (fathoms)                      |              |                |                |                |                |                |                |
|-------------------------------|-------------------|--------------------------------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                               |                   | 0 to 500                             | 500 to 1,000 | 1,000 to 1,500 | 1,500 to 2,000 | 2,000 to 2,500 | 2,500 to 3,000 | 3,000 to 3,500 | 3,500 to 4,000 |
|                               |                   | Mean percentage of calcium carbonate |              |                |                |                |                |                |                |
| <34                           | 0 to 10           |                                      | 40±?         | 36±23          | 12±9           | 1±0            | 1±0            | 1±?            |                |
|                               | 10 to 20          |                                      | 72±7         | 38±25          | 11±8           | 1±0            |                |                |                |
|                               | 20 to 25          |                                      |              |                | 21±14          |                |                |                |                |
|                               | 25 to 30          |                                      |              |                |                |                |                |                |                |
|                               | 0 to 10           |                                      | 62±?         | 62±5           | 77±6           | 33±20          | 49±11          |                |                |
|                               | 10 to 20          |                                      | 51±7         | 62±?           | 71±12          | 38±33          | 2±1            | 1±0            | 1±0            |
|                               | 20 to 25          |                                      |              | 25±?           | 2±1            | 1±0            | 1±0            | 1±?            |                |
|                               | 25 to 30          | 54±19                                | 48±8         | 48±10          | 43±10          | 51±19          | 21±20          |                | 1±?            |
|                               | 0 to 10           |                                      | 57±6         |                | 40±?           |                |                |                |                |
|                               | 10 to 20          | 82±4                                 | 65±6         | 60±8           | 67±10          | 50±15          | 28±24          | 1±0            |                |
| 34 to 35                      | 20 to 25          | 82±?                                 |              | 82±?           | 56±7           | 40±30          | 39±30          |                | 1±?            |
|                               | 25 to 30          | 77±5                                 | 74±7         | 76±6           | 57±14          | 40±19          | 18±11          |                |                |
|                               | 0 to 10           |                                      |              |                |                |                |                |                |                |
|                               | 10 to 20          | 63±13                                | 62±15        | 68±12          | 68±11          | 45±17          | 40±?           |                |                |
|                               | 20 to 25          | 75±6                                 | 74±6         | 76±6           | 63±12          | 58±11          | 32±21          | 4±2            |                |
|                               | 25 to 30          | 77±8                                 | 77±5         | 66±8           | 62±16          | 60±14          | 28±18          | 9±4            | 4±2            |
|                               | Mean              | 73±9                                 | 63±7         | 62±10          | 53±10          | 44±15          | 25±15          | 9±4            | 2±1            |

The mean calcium carbonate content of each depth group for all combinations of surface salinity and temperature is shown in table 4. The figures for the probable error<sup>47</sup> given after the figure for the mean represent the semi-interquartile range<sup>47</sup> when more than 10 samples were averaged, and two-thirds the standard deviation<sup>47</sup> when less than 10 samples were averaged.

<sup>47</sup> For detailed discussion of these statistical terms, see Chaddock, R. E., Principles and methods of statistics, pp. 153-163, 235-238, New York, Houghton Mifflin Co., 1925.

The probable errors obtained in this way indicate only the order of magnitude of the scatter<sup>48</sup> of the items averaged. For example, in table 4 the mean representing the column for the depth group of 2,500 to 3,000 fathoms in table 3 is given as 28±18 percent, which indicates that the calcium carbonate content of

<sup>48</sup> The "scatter" is a measure of the deviation of the samples from the mean. For example, if the items in a size distribution range between 28 and 32 percent the maximum deviation from the mean (30 percent) is 2 percent, which is small; but if the items range between 10 and 50 percent the mean is still 30 percent, but the maximum deviation from the mean is 20 percent, which is large. The scatter in the first case would be small and in the second large.

one-half the samples that were averaged lies within a range of  $2 \times 18 = 36$  percent, distributed on both sides of the mean of 28 percent. Actually, one-half the samples have a calcium carbonate content ranging between 8 and 44 percent. This average of  $28 \pm 18$  in table 4 is not to be confused with the average of  $25 \pm 15$  just below, which refers to the general average for all pelagic samples in the depth interval 2,500 to 3,000 fathoms, regardless of temperature or salinity.

#### RESULTS

It is evident from table 4 that the calcium carbonate content of the sediments in general decreases with increase in depth of water, especially below 2,000 fathoms. The amount of scatter, however, is high, which indicates that for this group of sediments the relationship is not close or that factors which have not been considered mask the effect of depth.

The relationship of surface temperature to the calcium carbonate content is illustrated better by table 5. This table was compiled from the 32 cards for temperature. The probable error was obtained in the same way as in table 4. The table indicates that the calcium carbonate content rises as the surface temperature increases. However, the amount of scatter, as shown by the figures for probable error, is high, which indicates that the relationship is to a certain extent indefinite.

A similar table for surface salinity could be compiled by a rearrangement of the items in table 5, and it would show a rise in calcium carbonate content for rise in salinity. However, as the relations for salinity are expressed in detail by figures 12 to 16, a table especially arranged to illustrate the effect of salinity was not prepared.

TABLE 5.—*Mean calcium carbonate content of marine sediments for different salinity and temperature of the surface water and for different depth of water; data arranged to show relation for temperature*

[Italic figures represent averages based on 5 samples or less. Numbers without indication of probable error represent single samples]

| Salinity (parts per thousand)        | Depth (fathoms) | Temperature (°C.)   |              |              |              |                  |              |              |              |
|--------------------------------------|-----------------|---------------------|--------------|--------------|--------------|------------------|--------------|--------------|--------------|
|                                      |                 | Near-shore deposits |              |              |              | Pelagic deposits |              |              |              |
|                                      |                 | 0 to 10             | 10 to 20     | 20 to 25     | 25 to 30     | 0 to 10          | 10 to 20     | 20 to 25     | 25 to 30     |
| Mean percentage of calcium carbonate |                 |                     |              |              |              |                  |              |              |              |
| <34                                  | 0 to 1,000      | <i>5±2</i>          | <i>9±6</i>   | <i>17±16</i> | <i>17±8</i>  | <i>40±0</i>      | <i>47±22</i> |              | <i>21±14</i> |
|                                      | 1,000 to 2,000  | <i>8±7</i>          | <i>16±5</i>  | <i>62±?</i>  | <i>20±12</i> | <i>21±15</i>     | <i>1±0</i>   | <i>7±4</i>   |              |
|                                      | 2,000 to 3,000  | <i>1±0</i>          | <i>6±3</i>   |              | <i>13±8</i>  |                  |              |              |              |
|                                      | 3,000 to 4,000  | <i>1±0</i>          | <i>1±?</i>   |              |              | <i>1±?</i>       |              |              |              |
|                                      | 0 to 1,000      | <i>5±2</i>          | <i>11±6</i>  | <i>12±8</i>  | <i>21±15</i> | <i>62±?</i>      | <i>51±7</i>  |              | <i>49±14</i> |
| 34 to 35                             | 1,000 to 2,000  | <i>21±6</i>         | <i>16±10</i> | <i>8±2</i>   | <i>22±13</i> | <i>71±6</i>      | <i>68±12</i> | <i>6±5</i>   | <i>45±10</i> |
|                                      | 2,000 to 3,000  |                     |              | <i>4±2</i>   | <i>9±7</i>   | <i>42±19</i>     | <i>18±9</i>  | <i>1±0</i>   | <i>37±26</i> |
|                                      | 3,000 to 4,000  |                     |              |              |              |                  | <i>1±0</i>   | <i>1±?</i>   | <i>1±?</i>   |
|                                      | 0 to 1,000      | <i>14±5</i>         | <i>30±10</i> | <i>40±16</i> | <i>53±29</i> | <i>57±6</i>      | <i>68±6</i>  | <i>82±?</i>  | <i>77±5</i>  |
| 35 to 36                             | 1,000 to 2,000  | <i>25±?</i>         | <i>19±8</i>  | <i>22±9</i>  | <i>44±13</i> |                  | <i>65±10</i> | <i>57±10</i> | <i>75±6</i>  |
|                                      | 2,000 to 3,000  |                     |              | <i>11±6</i>  | <i>9±4</i>   | <i>16±6</i>      | <i>40±?</i>  | <i>43±21</i> | <i>40±30</i> |
|                                      | 3,000 to 4,000  |                     |              |              |              |                  | <i>1±0</i>   | <i>1±?</i>   | <i>18±11</i> |
|                                      | 0 to 1,000      |                     | <i>33±11</i> | <i>22±7</i>  | <i>50±25</i> |                  | <i>63±13</i> | <i>75±6</i>  | <i>77±6</i>  |
| 36+                                  | 1,000 to 2,000  |                     | <i>32±9</i>  | <i>16±6</i>  | <i>44±20</i> |                  | <i>65±13</i> | <i>66±11</i> | <i>63±13</i> |
|                                      | 2,000 to 3,000  |                     | <i>29±5</i>  |              | <i>24±9</i>  |                  | <i>55±17</i> | <i>44±22</i> | <i>47±18</i> |
|                                      | 3,000 to 4,000  |                     |              |              |              |                  | <i>40±?</i>  | <i>4±2</i>   | <i>8±4</i>   |
|                                      | Mean            |                     | <i>9±4</i>   | <i>17±7</i>  | <i>20±9</i>  | <i>28±14</i>     | <i>40±9</i>  | <i>45±11</i> | <i>36±11</i> |
| <i>46±13</i>                         |                 |                     |              |              |              |                  |              |              |              |

A comparison of the relations for surface salinity, surface temperature, and depth is presented in table 6. Each number representing the percentage of calcium carbonate in this table is the average of two or more numbers in tables 4 and 5. In the process of averaging, in order to make the data in table 6 as comparable as possible, numbers in tables 4 and 5 based on five to two samples were weighted one-half and numbers based on only one sample were weighted one-fourth. The means shown at the bottom of each of the three main divisions of table 6 represent the average of all the numbers given for the particular grouping in tables 4 and 5, not the average of the four or less averages repre-

senting the particular grouping in table 6. For example, the general average of the calcium carbonate content of the pelagic sediments in areas in which the surface salinity is less than 34 parts per thousand is given as  $22 \pm 12$  in table 6. This is not the mean of the two numbers ( $31 \pm 18$  and  $5 \pm 3$ ) given for this grouping in table 6; it is the mean of the seven numbers representing this grouping in table 5. It was hoped by this process of averaging to minimize irregularities caused by the small number of samples in some subgroups. However, because of the large probable error the averages indicated in tables 4 to 6 are to be considered as indicating only the order of magnitude.

TABLE 6.—Comparison of the relation of the calcium carbonate content of marine sediments to the salinity of the surface water, the temperature of the surface water, and the depth of water, as indicated by arithmetic means

[Italic figures represent averages based on less than 5 samples. Numbers without indication of probable error represent single samples]

| Temperature (°C.)                    | Depth (fathoms)  | Salinity (parts per thousand) |                |                |                |                  |                |                |                |
|--------------------------------------|--|-------------------------------|----------------|----------------|----------------|------------------|----------------|----------------|----------------|
|                                      |  | Near-shore deposits           |                |                |                | Pelagic deposits |                |                |                |
|                                      |  | <34                           | 34 to 35       | 35 to 36       | 36+            | <34              | 34 to 35       | 35 to 36       | 36+            |
| Mean percentage of calcium carbonate |  |                               |                |                |                |                  |                |                |                |
| 0 to 30                              | { 0 to 1,000<br>1,000 to 2,000<br>2,000 to 3,000<br>3,000 to 4,000 | 13±9                          | 12±8           | 34±15          | 37±14          | 53±12            | 69±6           | 72±9           |                |
|                                      |  | 18±9                          | 17±9           | 28±10          | 33±13          | 31±18            | 47±8           | 66±9           | 65±12          |
|                                      |  | 7±4                           | 6±4            | 12±5           | 27±7           | 5±3              | 22±13          | 43±24          | 49±19          |
|                                      |  | 1±0                           |                |                |                |                  | 1±0            | 11±7           | 10±3           |
| Mean                                 |  | 12±7                          | 13±7           | 28±11          | 33±14          | 22±12            | 35±11          | 50±12          | 51±12          |
| Temperature (°C.)                    | Salinity (parts per thousand)                                      | Depth (fathoms)               |                |                |                |                  |                |                |                |
|                                      |  | Near-shore deposits           |                |                |                | Pelagic deposits |                |                |                |
|                                      |  | 0 to 1,000                    | 1,000 to 2,000 | 2,000 to 3,000 | 3,000 to 4,000 | 0 to 1,000       | 1,000 to 2,000 | 2,000 to 3,000 | 3,000 to 4,000 |
| Mean percentage of calcium carbonate |  |                               |                |                |                |                  |                |                |                |
| 0 to 10                              | { 0 to 10<br>10 to 20<br>20 to 25<br>25 to 30                      | 9±3                           | 15±7           | 1±0            | 1±?            | 54±6             | 46±10          | 25±10          |                |
|                                      |  | 21±8                          | 21±9           | 14±4           |                | 63±9             | 61±14          | 31±13          | 9±?            |
|                                      |  | 23±12                         | 21±6           | 7±3            |                | 77±7             | 43±9           | 34±17          | 3±2            |
|                                      |  | 35±19                         | 33±15          | 15±7           |                | 66±9             | 56±10          | 44±22          | 12±8           |
| Mean                                 |  | 23±11                         | 22±10          | 12±5           | 1±?            | 66±7             | 57±11          | 35±17          | 7±4            |
| Depth (fathoms)                      | Salinity (parts per thousand)                                      | Temperature (°C.)             |                |                |                |                  |                |                |                |
|                                      |  | Near-shore deposits           |                |                |                | Pelagic deposits |                |                |                |
|                                      |  | 0 to 10                       | 10 to 20       | 20 to 25       | 25 to 30       | 0 to 10          | 10 to 20       | 20 to 25       | 25 to 30       |
| Mean percentage of calcium carbonate |  |                               |                |                |                |                  |                |                |                |
| 0 to 4,000                           | { <34<br>34 to 35<br>35 to 36<br>36+                               | 4±3                           | 9±5            | 26±16          | 17±9           | 17±10            | 27±13          |                | 21±14          |
|                                      |  | 13±4                          | 10±6           | 8±5            | 17±12          | 62±10            | 37±8           | 3±3            | 40±16          |
|                                      |  | 16±5                          | 22±8           | 26±10          | 42±16          | 49±6             | 50±11          | 47±20          | 52±12          |
|                                      |  | 31±9                          | 19±7           | 39±18          |                |                  | 58±14          | 47±11          | 49±10          |
| Mean                                 |  | 9±4                           | 17±7           | 20±9           | 28±14          | 40±9             | 45±11          | 36±11          | 46±13          |

Table 6, like tables 4 and 5, exhibits a rise in calcium carbonate content of the sediments as the surface salinity and surface temperature increase and as the depth decreases. Because the averages are based on more samples than in tables 4 and 5, the respective relationships of salinity, temperature, and depth to calcium carbonate content are more regular.

#### GRAPHIC PRESENTATION

##### METHOD OF PLOTTING

Although most of the essential features of the statistical study of the data are presented in tables 4 to 6, the general relations are illustrated more clearly by diagrams. Figures 12 to 18 represent the main features given in these tables. Figures 12 to 15 show the relation of surface salinity to the calcium carbonate content of the sediments for different combinations of

depth of water and surface temperature. These figures are based on the means shown in table 5. Size groups in which the mean was based on only one sample are not represented in the figures. In the preparation of the figures, the averages of the groups representing salinities less than 34 and more than 36 parts per thousand were arbitrarily taken as 33.5 and 36.5, respectively.

##### RELATION FOR SALINITY

Figure 12 shows the relations for salinity in areas in which the surface temperature ranges between 0° and 10° C., for two depth intervals of both near-shore and pelagic deposits. The number of samples was insufficient to illustrate the relation for the other depth intervals in this temperature group. The calcium carbonate content for each depth interval represented

on this figure rises with increase in salinity. In the near-shore deposits in the depth interval 0 to 1,000 fathoms the mean calcium carbonate content rises from 5 percent for salinities less than 34 parts per

carbonate content for each depth interval, except the interval 3,000 to 4,000 fathoms, which is represented by only a few samples, rises with increase in surface salinity. However, in the pelagic sediments from intervals of 0 to 1,000 and 1,000 to 2,000 fathoms the calcium carbonate content is approximately constant for a salinity in excess of 35 parts per thousand. It is greater for the pelagic group than for the near-shore group, and it is greater for depth intervals of less than 2,000 fathoms than for intervals of more than 2,000 fathoms. The calcium carbonate content of the sediments in the interval 0 to 1,000 fathoms is approximately equal to that in the interval 1,000 to 2,000 fathoms for both the near-shore and the pelagic groups, but in both depth intervals it is distinctly greater in the pelagic than in the near-shore group.

FIGURE 12.—Relation of calcium carbonate content of marine sediments to the salinity of the surface water for temperatures of  $0^{\circ}$  to  $10^{\circ}$  C. In this and the next four figures the lines represent mean calcium carbonate content of the sediment for the given salinity of the surface water, for water of different depths. The depths are classified into four groups of 1,000 fathoms each, and each depth group is represented by one line—for example, the dashed line for the 0-1,000 fathom group refers to all areas in which the water ranges in depth between 0 and 1,000 fathoms. This figure represents all areas in which the mean annual temperature of the surface water is between  $0^{\circ}$  and  $10^{\circ}$  C.; figures 13, 14, and 15 refer respectively to areas in which the temperature is  $10^{\circ}$  to  $20^{\circ}$ ,  $20^{\circ}$  to  $25^{\circ}$ , and  $25^{\circ}$  to  $30^{\circ}$  C.; and figure 16 refers to the average of the four temperature groups—that is, to all areas, regardless of temperature.

thousand to 14 percent for salinities ranging between 35 and 36 parts; and in the interval 1,000 to 2,000 fathoms from 8 percent for salinities less than 34 parts per thousand to 21 percent for salinities ranging between 34 and 35 parts. In the pelagic group, for the depth interval of 1,000 to 2,000 fathoms, the mean calcium carbonate content rises from 21 percent for salinities less than 34 parts per thousand to 71 percent for salinities between 34 and 35 parts; and in the interval 2,000 to 3,000 fathoms it rises from 1 to 42 percent between these salinity limits.

The pelagic deposits contain more calcium carbonate than the near-shore deposits. In the near-shore group the sediments in the interval 1,000 to 2,000 fathoms have a greater calcium carbonate content than those in the interval 0 to 1,000 fathoms, thus presumably reflecting the effect of masking on the calcium carbonate content by terrigenous detritus. In the pelagic group the sediments in the interval 1,000 to 2,000 fathoms contain more calcium carbonate than those in the interval 2,000 to 3,000 fathoms, thus presumably representing the effect of solution of particles as they fall to the bottom in deep water.

The same phenomena apply to the temperature group  $10^{\circ}$  to  $20^{\circ}$ , illustrated by figure 13. The calcium

carbonate content of pelagic sediments is slight as the salinity rises above 35 parts per thousand. The decrease with increasing depth is well illustrated by this temperature interval, for both near-shore and pelagic sediments.

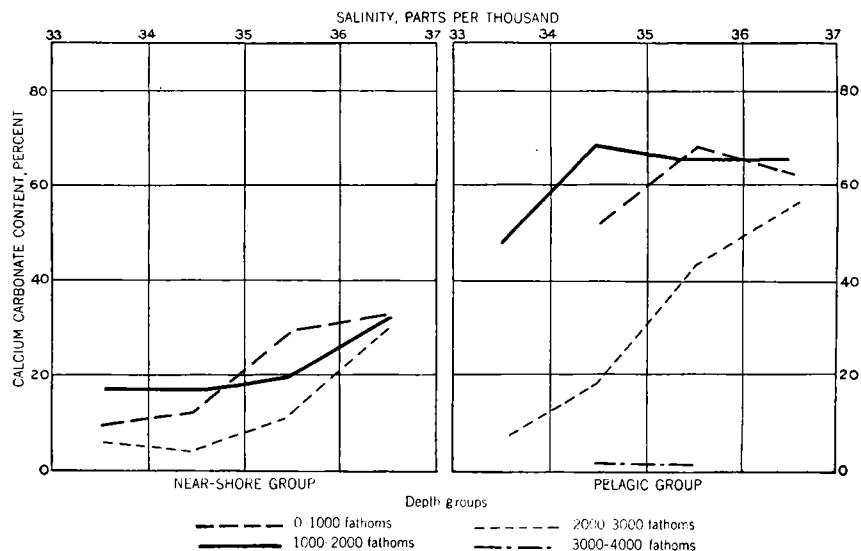
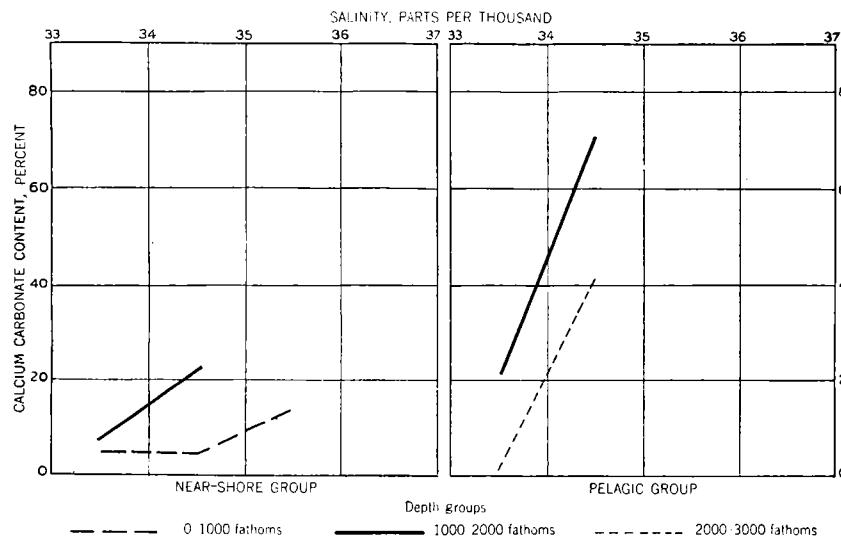


FIGURE 13.—Relation of calcium carbonate content of marine sediments to the salinity of the surface water for temperatures of  $10^{\circ}$  to  $20^{\circ}$  C. (See fig. 12 for explanation.)

The calcium carbonate content of sediments of the temperature group  $25^{\circ}$  to  $30^{\circ}$ , illustrated by figure 15, in general increases as the salinity rises. The increase here, as in the lower-temperature groups, is small above a salinity of 35 parts per thousand. In fact, in two of

the seven groups shown in figure 15, the mean calcium carbonate content decreases significantly as the salinity rises above 35 parts.

This figure illustrates well the loss in calcium carbonate content with increase in depth. The decrease is small above 2,000 fathoms and large below 2,000 fathoms. The pelagic deposits contain more calcium carbonate than the near-shore sediments.

The calcium carbonate content of all groups above 3,000 fathoms, represented in figures 12 to 15, rises with increase in salinity, but in one of the two groups for the interval 3,000 to 4,000 fathoms it decreases as the salinity rises above 35 parts per thousand, and in the other it is constant between salinities of 34 and 36 parts per thousand, which represent the limits of the samples available. This rise in calcium carbonate content for increased salinity for depths less than 3,000 fathoms is so consistent in so many different groups of temperature and depth that it seems evident that surface salinity is definitely related to the calcium carbonate content of the sediments.

A summary of all the temperature groups illustrated by figures 12 to 15 is presented in figure 16, which is based on table 6. The heavy broken line in this figure represents the average of all the depth groups shown

The rate of increase of calcium carbonate with respect to salinity apparently decreases as the salinity rises above 35 parts per thousand, as indicated by the flattening of the general curves for both the near-shore and pelagic groups for salinities greater than 35 parts.

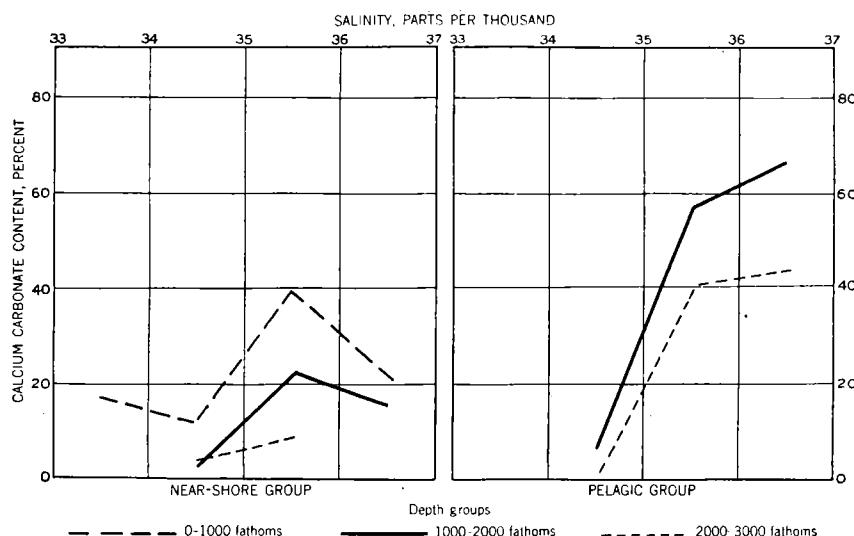


FIGURE 14.—Relation of calcium carbonate content of marine sediments to the salinity of the surface water for temperatures of 20° to 25° C. (See fig. 12 for explanation.)

The increase in calcium carbonate between salinities of 34.5 and 35.5 parts per thousand is 15 percent, compared with 5 percent between 35.5 and 36.5 parts in the near-shore sediments and with 1 percent for the same interval in the pelagic sediments.

#### RELATION FOR DEPTH

Figure 16 shows also the decrease in calcium carbonate content of the sediments as the depth increases. The two lines for the depth intervals above 2,000 fathoms are close together, and those for the depth intervals below 2,000 fathoms are relatively far apart. This feature indicates that the loss in calcium carbonate with increasing depth is greater below than above 2,000 fathoms.

The loss with increasing depth is illustrated better by figure 17, which shows the relation of depth to calcium carbonate for various salinities. Each salinity curve in this figure represents the average of the four temperature groups for the particular salinity and is based on data presented in table 4.

In the pelagic sediments the rate of

decrease of calcium carbonate with respect to depth is fairly regular for all depths, although it is slightly less above 2,000 fathoms than below 2,000 fathoms. In the near-shore deposits, however, the rate of decrease with respect to depth is distinctly less above 1,500 fathoms than below 1,500 fathoms. This feature is indicated by the increase in the slope of the curve for the general average at a depth of about 1,500 fathoms.

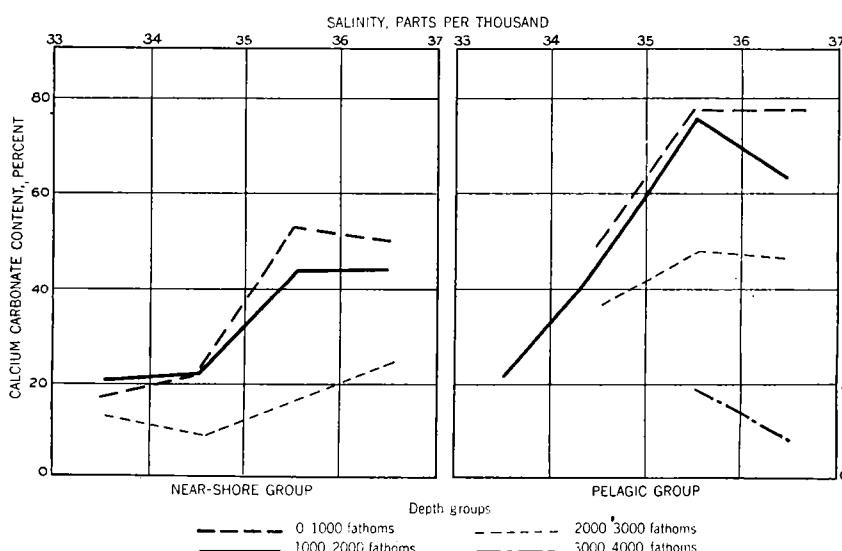


FIGURE 15.—Relation of calcium carbonate content of marine sediments to the salinity of the surface water for temperatures of 25° to 30° C. (See fig. 12 for explanation.)

and is based on the general means given for salinity in table 6. This figure shows the general increase in calcium carbonate content with rise in salinity. The average calcium carbonate content for all temperatures and all depths, in the near-shore group, increases from 12 to 33 percent with the increase from low to high salinity, and in the pelagic group it increases from 22 to 51 percent.

In fact, in the near-shore group the mean calcium carbonate content for all salinities and temperatures is nearly constant between depths of 0 and 1,500 fathoms. The average calcium carbonate content for

carbonate content of the sediments is less closely related to surface temperature than to surface salinity. In the near-shore group, however, as indicated by figures 16 and 18, the relation for surface temperature seems to be about as definite as the relation for surface salinity.

#### COEFFICIENTS OF CORRELATION

The curves in figures 12 to 18 represent means, but they do not show the amount of scatter. The scatter, however, is indicated in tables 4 to 6 by the figures representing the probable error. In general the scatter is high, which suggests that the relationship may not be as definite as is indicated by the averages shown in figures 12 to 18. The Pearsonian coefficient of correlation  $r^{49}$  takes into consideration the amount of scatter and gives an objective value of the degree of relationship, or more properly the degree of association,<sup>50</sup> between two components of a size distribution.

The coefficient of correlation is a ratio ranging between -1.0 and +1.0. If it is

FIGURE 16.—Relation of calcium carbonate content of marine sediments to the salinity of the surface water; average for all temperatures. (See fig. 12 for explanation.)

depth intervals of 0 to 1,000, 1,000 to 2,000, 2,000 to 3,000, and 3,000 to 4,000 fathoms for the near-shore sediments is 23, 22, 12, and 1 percent, respectively; for the pelagic deposits, 66, 57, 35, and 7 percent. The curves shown in figure 17 illustrate also the large calcium carbonate content for high salinity in pelagic deposits compared with near-shore deposits.

#### RELATION FOR SURFACE TEMPERATURE

The relation of the surface temperature to the calcium carbonate content of sediments is illustrated by figure 18, which is based on data presented in tables 5 and 6. The figure shows that the calcium carbonate content of the sediments in general increases as the temperature rises. The rate of increase, however, is more regular for near-shore than for pelagic deposits. In the near-shore sediments the general average for all depths and salinities increases from 9 percent in the temperature group  $0^{\circ}$  to  $10^{\circ}$  to 28 percent in the group  $25^{\circ}$  to  $30^{\circ}$ , and in the pelagic deposits it rises from 40 to 46 percent between these two temperature groups. The rate of increase in the near-shore sediments is fairly regular, but in the pelagic sediments it is irregular, and the curve showing the relationship is W-shaped. The average calcium carbonate content of the four temperature groups  $0^{\circ}$  to  $10^{\circ}$ ,  $10^{\circ}$  to  $20^{\circ}$ ,  $20^{\circ}$  to  $25^{\circ}$ , and  $25^{\circ}$  to  $30^{\circ}$  for the pelagic sediments is 40, 45, 36, and 46 percent, respectively. It would seem, therefore, that in the pelagic group the calcium

more than 0.7 the degree of association is very good; if it is between 0.5 and 0.7 the degree of association is good; if it is between 0.3 and 0.5 the degree of association is fair; and if it is below 0.3 the degree of association is poor. Negative coefficients indicate inverse relationships.

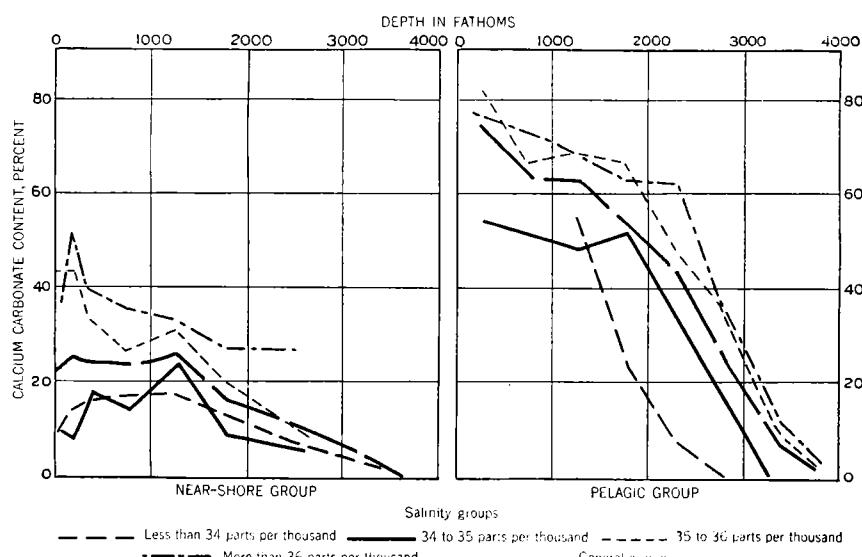


FIGURE 16.—Relation of calcium carbonate content of marine sediments to the salinity of the surface water; average for all temperatures. (See fig. 12 for explanation.)

The coefficient of correlation is determined with a certain amount of unreliability, which is called the probable error. The probable error is greatest when the coefficient is 0, and it decreases in magnitude as the

<sup>49</sup> Chaddock, R. E., Principles and methods of statistics, pp. 286-305, New York, Houghton Mifflin Co., 1925.

<sup>50</sup> The term "association" seems better than "relationship", because it implies no cause and effect relation.

coefficient approaches 1.0 or -1.0. It also decreases as the number of samples increases. A coefficient of correlation ordinarily is not regarded as significant unless it is at least four times as great as the probable

error. Thus if the coefficient and the probable error are  $0.30 \pm 0.10$  the relation may not be significant, but if they are  $0.30 \pm 0.04$ , the relation, or rather the degree of association, though not particularly good, is significant.

TABLE 7.—Comparison of the relation of the calcium carbonate content of marine sediments to the salinity of the surface water, the temperature of the surface water, and the depth of water, as indicated by coefficients of correlation

| Near-shore deposits |  |  |                   |                                |                                   |  |                        |                 |                               |  |                          |
|---------------------|--|--|-------------------|--------------------------------|-----------------------------------|--|------------------------|-----------------|-------------------------------|--|--------------------------|
| Salinity            |  |  |                   | Depth                          |                                   |  |                        | Temperature     |                               |  |                          |
| Temperature (° C.)  | Depth (fathoms)                                      | Coefficient of correlation             | Number of samples | Temperature (° C.)             | Salinity (parts per thousand)     | Coefficient of correlation                           | Number of samples      | Depth (fathoms) | Salinity (parts per thousand) | Coefficient of correlation                         | Number of samples        |
| 0-10                | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | 0.31 ± 0.04<br>.45 ± .08<br>-.45 ± .08 | 190<br>48<br>11   | 0-10<br>34-35<br>35-36<br>36+  | <34<br>34-35<br>35-36<br><34      | -0.07 ± 0.05<br>.75 ± .06<br>.09 ± .12<br>-.21 ± .07 | 184<br>23<br>31<br>96  | 0-1,000         | <34<br>34-35<br>35-36<br><34  | 0.36 ± 0.03<br>.17 ± .06<br>.45 ± .04<br>.40 ± .07 | 317<br>131<br>144<br>150 |
| 10-20               | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | .56 ± .03<br>.37 ± .08<br>.76 ± .06    | 234<br>55<br>24   | 10-20<br>34-35<br>35-36<br>36+ | <34<br>34-35<br>35-36<br><34      | -.29 ± .08<br>.31 ± .07<br>.14 ± .07<br>.84 ± .04    | 36<br>78<br>79<br>24   | 1,000-2,000     | 34-35<br>35-36<br>36+         | .02 ± .09<br>.50 ± .07<br>.20 ± .11                | 55<br>56<br>36           |
| 20-25               | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,009-4,000 | .28 ± .07<br>.38 ± .11<br>.50 ± .18    | 85<br>29<br>8     | 20-25<br>34-35<br>35-36<br>36+ | <34<br>34-35<br>35-36<br>38 ± .12 | .26 ± .13<br>.27 ± .09<br>.03 ± .08                  | 24<br>44<br>22<br>76   | 2,000-3,000     | 34-35<br>35-36<br>36+         | .31 ± .13<br>.18 ± .20<br>.31 ± .17                | 23<br>11<br>12           |
| 25-30               | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | .48 ± .03<br>.39 ± .06<br>.39 ± .11    | 233<br>78<br>26   | 25-30<br>34-35<br>35-36<br>36+ | <34<br>34-35<br>35-36<br><34      | .02 ± .07<br>.21 ± .09<br>.09 ± .07                  | 103<br>47<br>85        | 3,000-4,000     | 34-35<br>35-36<br>36+         | .00 ± .34  | 4                        |
| General average     |  | .44 ± .02                              |                   | 1,025                          |                                   | .01 ± .06  |                        | 952             |                               | .32 ± .04  |                          |
| Pelagic deposits    |  |  |                   |                                |                                   |  |                        |                 |                               |  |                          |
| 0-10                | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | 0.47 ± 0.21<br>.79 ± .07<br>.65 ± .12  | 6<br>15<br>11     | 0-10<br>34-35<br>35-36<br>36+  | <34<br>34-35<br>35-36<br><34      | 0.48 ± 0.14<br>.35 ± .17<br>0                        | 14<br>12<br>1          | 0-1,000         | <34<br>34-35<br>35-36<br>36+  | -0.18 ± 0.20<br>.58 ± .10<br>.18 ± .10             | 1                        |
| 10-20               | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | .04 ± .12<br>.19 ± .06<br>.58 ± .03    | 33<br>133<br>165  | 10-20<br>34-35<br>35-36<br>36+ | <34<br>34-35<br>35-36<br>36+      | .62 ± .08<br>.49 ± .07<br>.48 ± .05<br>.32 ± .05     | 26<br>50<br>117<br>113 | 1,000-2,000     | <34<br>34-35<br>35-36<br>36+  | .30 ± .15<br>.55 ± .07<br>.30 ± .06<br>.04 ± .06   | 17<br>50<br>95<br>135    |
| 20-25               | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | .24 ± .21<br>.63 ± .05<br>.32 ± .05    | 9<br>63<br>135    | 20-25<br>34-35<br>35-36<br>36+ | <34<br>34-35<br>35-36<br><34      | .59 ± .10<br>.35 ± .08<br>.68 ± .03                  | 18<br>54<br>134<br>2   | 2,000-3,000     | <34<br>34-35<br>35-36<br>36+  | .28 ± .06<br>.13 ± .05<br>.10 ± .05                | 24<br>99<br>172<br>216   |
| 25-30               | 0-1,000<br>1,000-2,000<br>2,000-3,000<br>3,000-4,000 | .67 ± .08<br>.50 ± .05<br>.05 ± .05    | 23<br>86<br>200   | 25-30<br>34-35<br>35-36<br>36+ | <34<br>34-35<br>35-36<br><34      | .36 ± .07<br>.52 ± .05<br>.71 ± .03                  | 76<br>107<br>133       | 3,000-4,000     | <34<br>34-35<br>35-36<br>36+  | .00 ± .25<br>.47 ± .15<br>.21 ± .12                | 1<br>7<br>12<br>29       |
| General average     |  | .45 ± .06                              |                   | 928                            |                                   | .50 ± .03  |                        | 857             |                               | .13 ± .05  |                          |

\* Total number of samples.

<sup>b</sup> Depths greater than 2,000 fathoms excluded.

<sup>c</sup> Depths less than 1,000 fathoms excluded.

The coefficient of correlation was determined for each of the 96 original size distributions except for a few that were represented by a small number of samples. The results are shown in table 7. The coefficients varied so much that in the determination of the general averages, four types of averages—the mean, the median, a weighted mean, and a weighted median—were averaged together to determine the general average. In the computation of the weighted averages the coefficients were weighted inversely as the probable error. The probable error of the averages represents the semi-interquartile range divided by the square root of the number of groups averaged.

The average coefficient of correlation of the 11 near-shore groups showing the relation of surface salinity to calcium carbonate content is  $.44 \pm .02$ . The range is from  $.28 \pm .07$  to  $.76 \pm .06$ . These data indicate a definite but not particularly close association between the calcium carbonate content of near-shore sediments and the salinity of the surface water. The average coefficient of correlation between surface salinity and calcium carbonate content of the 15 groups of pelagic sediments is  $.45 \pm .06$ . The range is from  $-.24 \pm .21$  to  $.79 \pm .07$ . The numerical value of the average coefficient of correlation is nearly the same as for the near-shore deposits, but the larger probable error for

the pelagic group indicates that the degree of association is less certain for pelagic deposits than for near-shore deposits.

The average coefficient of correlation between depth and calcium carbonate content for the 15 groups of near-shore deposits is  $.01 \pm .06$ , and for the 12 groups of pelagic deposits it is  $.50 \pm .03$ . The smallness of the coefficient for the near-shore deposits indicates that they show no apparent relationship between depth and calcium carbonate content, but the figure for the pelagic deposits indicates a fairly good degree of asso-

relationship between depth and calcium carbonate content in near-shore deposits, where the quantity of terrigenous detritus may obscure the effect of depth. A large coefficient, on the other hand, suggests strongly that there is a relationship.

The relation between the surface salinity and the calcium carbonate of sediments seems to be fairly definite, because the average coefficient for all the groups is about .45. The relation, however, is more definite for near-shore than it is for pelagic deposits because of the larger probable error for the pelagic deposits.

The relation between depth and calcium carbonate content for pelagic deposits, but not for near-shore deposits, likewise is fairly definite. The relation for surface temperature, on the other hand, seems to be less certainly established. The apparent lack of relationship between surface temperature and the calcium carbonate content of the sediments, however, does not necessarily indicate a poor relation for temperature in general, because calcium carbonate is presumably formed chiefly in the upper 50 or 100 meters of water in the sea, and lateral variations in temperature in this zone do not necessarily occur in the same way as in the surface water above.

The statistical data therefore must be interpreted as not demonstrating the existence of a relationship between temperature and calcium carbonate content of the sediments; but they most certainly do not indicate that no relationship exists. In fact, the averages represented by figure 18, although associated with a large amount of scatter, suggest that the calcium carbonate content of marine

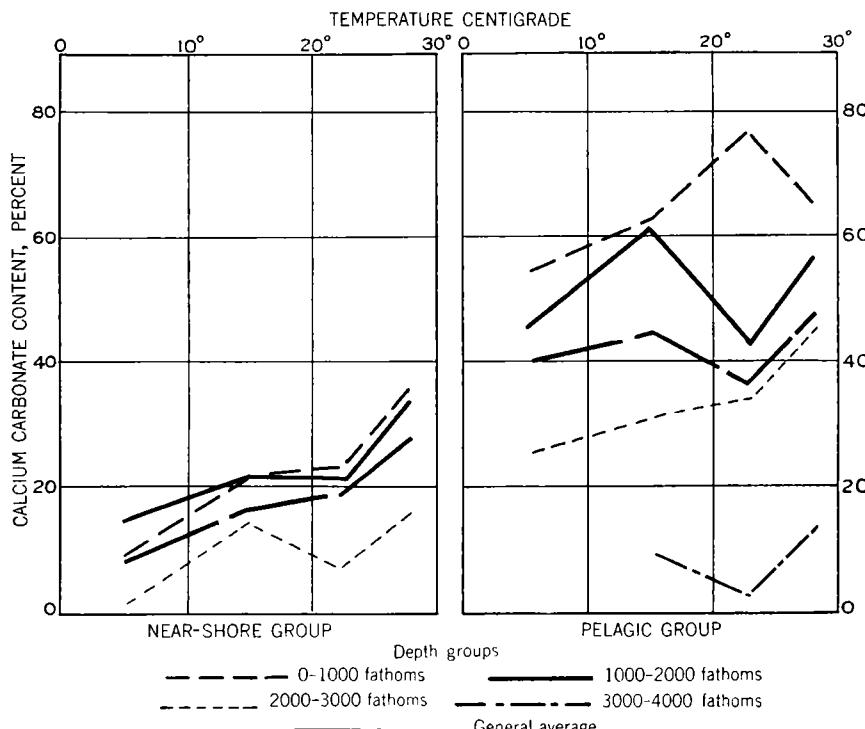


FIGURE 18.—Relation of calcium carbonate content of marine sediments to the temperature of the surface water. The lines in this figure represent mean calcium carbonate content of the sediments for the given temperature of the surface water in water of different depths. The depths are classified according to four depth groups, as in figures 12 to 16. The salinity is not considered in this figure; each line represents the average for all salinities in each particular depth group.

ciation between depth and calcium carbonate content. The average coefficient of correlation between surface temperature and calcium carbonate content for the 13 near-shore groups is  $.32 \pm .04$ , which indicates at best only a slight degree of association; for the 14 pelagic groups it is  $.13 \pm .05$ , which indicates very little association.

#### SIGNIFICANCE OF STATISTICAL DATA

The coefficient of correlation does not demonstrate a cause and effect relationship. Neither does a low coefficient necessarily indicate lack of relationship, as a small coefficient may be due to the effect of variables other than the two variables upon which the coefficient is based—that is, the real relationship may be masked by the effect of other factors. Such, for instance, might be the cause of the apparent poor

sediments increases as the surface temperature of the overlying water rises.

The most definite conclusion derived from this statistical study is that the calcium carbonate content of the sediments seems to be definitely related to the salinity of the overlying surface water; the calcium carbonate content of the sediments increases with the surface salinity.

The increase in calcium carbonate content of the sediments is greatest between salinities of 34 and 36 parts per thousand. Sediments in areas where the salinity is less than 34 parts in general contain less than 5 percent of calcium carbonate, and those in areas in which the salinity is more than 36 parts as a rule contain more than 50 percent of calcium carbonate. The calcium carbonate content increases but slightly as the salinity rises above 36 parts. The critical salinity seems to be about 35 parts per thousand, which is approximately the average salinity of the ocean.

## AREAL RELATIONS OF CALCIUM CARBONATE CONTENT OF SEDIMENTS

### PREPARATION OF MAP

In order to ascertain the extent to which the relationships of calcium carbonate to surface salinity, surface temperature, and depth might be affected by extraneous factors, a map was prepared showing the distribution of calcium carbonate in marine sediments throughout the world with respect to depth of water and surface salinity (pl. 71). The surface temperature should also be shown on this map, but in order to make the map clearer the temperature was indicated on another map (fig. 19). The surface salinity was also shown on figure 19, so that the relation of the temperature to the calcium carbonate content of the sediments could be ascertained easily by comparison with the salinity lines on the two maps.

### SOURCE OF DATA

The salinities shown on plate 71 and figure 19 are taken from Schott,<sup>51</sup> and the temperatures shown on figure 19 from Shokalsky.<sup>52</sup> The depths are taken from Murray and Hjort,<sup>53</sup> except those in the south Atlantic, which are based largely on Wüst.<sup>54</sup> The depth contours on Wüst's map are given in kilometers, which, although roughly equal to multiples of 500 fathoms, cause difficulty in the construction of a map based on fathoms, especially in regions such as the ocean off southern Brazil, where a large area lies between a depth of 2,000 fathoms and 4 kilometers.

The distribution of calcium carbonate was compiled from three sources—(1) the calcium carbonate content of nearly 4,000 samples reported by several workers;<sup>55</sup> (2) maps of the areal distribution of calcium carbonate in the Pacific Ocean by Murray and Lee,<sup>56</sup>

<sup>51</sup> Schott, G., Die Verteilung des Salzgehaltes im Oberflächenwasser der Ozeane: *Annalen der Hydrographie*, Band 56, Heft, 5, p. 184, 1928.

<sup>52</sup> Shokalsky, J., Oceanography [in Russian], pp. 134-135, Petrograd, 1917. See also Schott, G., Geographie des Atlantischen Ozeans, pl. 10, p. 144, Hamburg, C. Boysen, 1926. Schott, G., and Schu, F., Die Wärmeverteilung in den Tiefen des Stillen Ozeans: *Annalen der Hydrographie*, Band 38, Heft 1, p. 44, 1910. Krümmel, O., Handbuch der Ozeanographie, Band 1, pp. 400-406, 1907.

<sup>53</sup> Murray, J., and Hjort, J., The depths of the ocean, p. 128, New York, Macmillan Co., 1912.

<sup>54</sup> Wüst, G., Schichtung und Zirkulation des Atlantischen Ozeans: *Wiss. Ergeb. Deutschen Atlantischen Exped. Meteor*, 1925-27, Band 6, Lieft. 1, p. 84, 1933.

<sup>55</sup> Von Gimbel, Geologisch-mineralogische Untersuchung der Meeresgrundproben aus der Nordsee: *Ergebn. Untersuchungsfahrten S. M. Knbt. Drache* in der Nordsee, 1881, 1882, 1884, pp. 23-47, Berlin, 1886. Murray, J., and Renard, A. F., *Challenger Rept.*, Deep-sea deposits, pp. 34-147, 1891. Murray, J., and Philippi, E., Die Grundproben der Deutschen Tiefsee Expedition: *Wiss. Ergeb. Deutschen Tiefsee Exped. Valdivia*, 1899-1900, pp. 98-136, 1908. Murray, J., and Lee, G. V., The depth and marine deposits of the Pacific: *Harvard Coll. Mus. Comp. Zoology Mem.*, vol. 38, pp. 40-148, 1909. Philippi, E., Die Grundproben der Deutschen Südpolar-Expedition: *Deutschen Südpolar-Exped.*, 1901-3, Repts., vol. 2, pp. 437-557, 1910. Spethmann, H., *Studien über die Bodenzusammensetzung der Baltischen Depression vom Kattegat bis zur Insel Gotland*: *Wiss. Meeresuntersuchungen*, neue Folge, Band 12, Abt. Kiel, pp. 309-312, 1910. Murray, J., and Chumley, J., The deep-sea deposits of the Atlantic Ocean: *Royal Soc. Edinburgh Trans.*, vol. 54, pp. 1-216, 1924. Samoiloff, J. V., and Gorshkova, T. I., The deposits of the Barents and Kara Seas [in Russian, with English summary]: *Trudy Plovuchnevo Morskovo Nauchno Inst. Vyp. 14*, pp. 36-39, 1924. Pratje, O., Die Sedimente der Deutschen Bucht: *Wiss. Meeresuntersuchungen*, neue Folge, Band 18, Abt. Helgoland, Heft 6, p. 126, 1931. Trask, P. D., Hammar, H. E., and Wu, C. C., Origin and environment of source sediments of petroleum, pp. 249-273, Houston, Tex., Gulf Publishing Co., 1932.

<sup>56</sup> Murray, J., and Lee, G. V., op. cit., map 3, p. 169.

in the north Atlantic south of latitude 25° by Correns,<sup>57</sup> and in the south Atlantic by Pratje;<sup>58</sup> and (3) maps of the distribution of the deep-sea deposits in the Atlantic and Indian Oceans by Murray and Philippi,<sup>59</sup> in the Pacific Ocean by Murray and Lee,<sup>60</sup> and in the northwest Pacific by Hanzawa.<sup>61</sup> The data from all these sources were placed on a single map, and the lines of equal calcium carbonate content shown on plate 71 were drawn upon the basis of the data so plotted.

### CLASSIFICATION OF DATA

On plate 71 the calcium carbonate content of the sediments is separated into three groups—50 to 100 percent, 10 to 50 percent, and 0 to 10 percent. If sufficient data were available it would be desirable to make more subdivisions, but as several large areas were represented only by a few bottom samples it seemed practicable to make only three groups. Furthermore, in many areas the calcium carbonate content of the sediments changes from high to low within a short distance; consequently, because of the relatively small scale of the map, it would be confusing to increase the number of subdivisions in these areas.

The threefold classification presented here separates the sediments into groups of rich, intermediate, and poor calcium carbonate content, or, in terms of rocks which the sediments would form when lithified, into (1) limestones, (2) calcareous shales or sands, and (3) slightly calcareous or noncalcareous shales or sands.

### RELIABILITY OF MAP

The distribution of calcium carbonate has been indicated over the entire map, but as many areas are represented by only a few data the map should be interpreted with an understanding of the conditions under which it was made.

In the Atlantic Ocean the mapping is based on a large number of samples and is fairly reliable between 40° N. and 40° S. In the Pacific, however, it is based on fewer samples than in the Atlantic. Murray and Lee present a map of the distribution of calcium carbonate in the Pacific, but their map contains large areas unrepresented by samples. Hanzawa<sup>62</sup> and I<sup>63</sup> present additional data, but still several large areas are represented by only a few samples—notably north of 40° N., south of 50° S., and in the southwest Pacific south of 20° S.

<sup>57</sup> Correns, C. W., Mineralogisch-geologische Arbeiten der Deutschen Atlantischen Expedition: *Gesell. Erdkunde Berlin Zeitschr.*, Jahrg. 1928, Ergänzungsheft 3, p. 127.

<sup>58</sup> Pratje, O., Geologische Tiefseeforschungen auf der Deutschen Atlantischen Expedition: *Deutsch. geol. Gesell. Zeitschr.*, Monatsber., Band 79, p. 202, 1927.

<sup>59</sup> Murray, J., and Philippi, E., op. cit., maps 1 and 2, p. 206.

<sup>60</sup> Murray, J., and Lee, G. V., op. cit., map 2, p. 169.

<sup>61</sup> Hanzawa, S., Preliminary report on marine deposits from the southwestern North Pacific Ocean, in *Records of oceanographic works in Japan*, pp. 59-77, Nat. Research Council Japan, 1928.

<sup>62</sup> Hanzawa, S., op. cit.

<sup>63</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., op. cit.

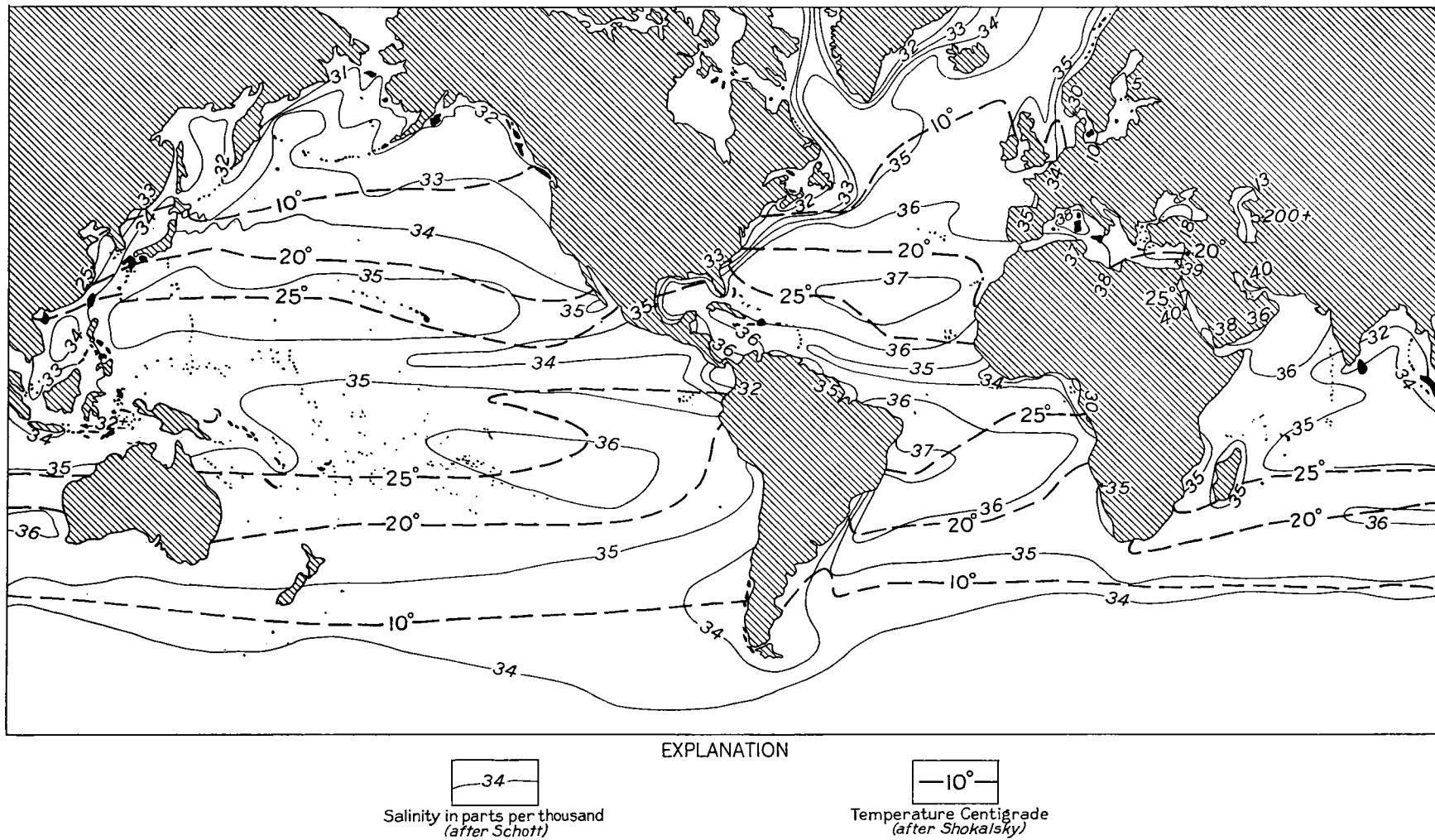
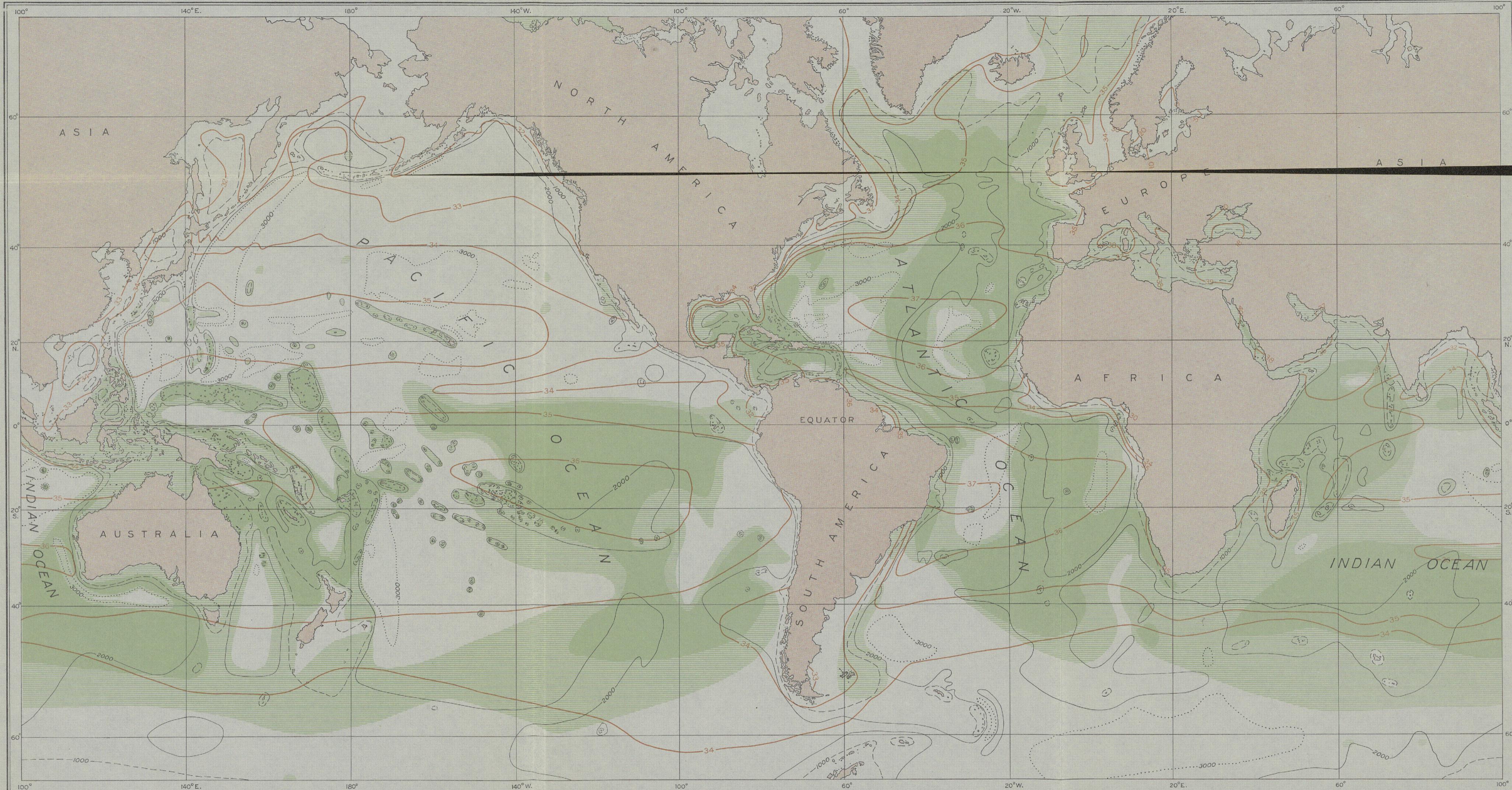


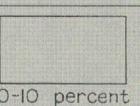
FIGURE 19.—Map of the ocean showing the mean annual salinity and temperature of the surface water. (After Schott and Shokalsky.)



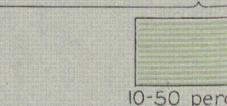
Compiled from various sources by  
Parker D. Trask

MAP OF THE OCEAN SHOWING THE CALCIUM CARBONATE CONTENT OF THE SEDIMENTS, THE SALINITY OF THE SURFACE WATER, AND THE DEPTH OF THE WATER

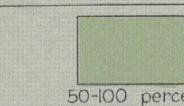
CALCIUM CARBONATE CONTENT OF SEDIMENTS



0-10 percent

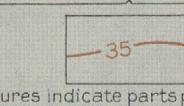


10-50 percent

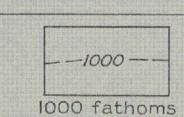


50-100 percent

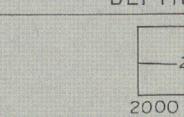
EXPLANATION  
SALINITY OF SURFACE WATER



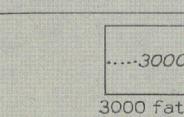
35  
Figures indicate parts per thousand



1000  
—1000—  
1000 fathoms



2000  
—2000—  
2000 fathoms



3000  
...3000...  
3000 fathoms



Murray and Lee<sup>64</sup> show three lines of equal calcium carbonate content—namely, 25, 50, and 75 percent. On plate 71 the 50-percent line in the Pacific Ocean is based largely on Murray and Lee's 50-percent line, but the 10-percent line lies within the limits of Murray and Lee's 25-percent line. In general, deposits classified by Murray<sup>65</sup> as red clay contain less than 10 percent of calcium carbonate. He places the upper limit at 30 percent and states that the average calcium carbonate content of red clay in the Atlantic Ocean is about 8 percent and in the Pacific 5.3 percent.<sup>66</sup> Consequently, unless there were data to the contrary, the line for 10-percent calcium carbonate on plate 71 is placed slightly within the limits for red clay shown by Murray and Lee.<sup>67</sup> Similarly, in the south Atlantic the line for 10 percent is drawn within Pratje's line for 30 percent.<sup>68</sup>

Some parts of the map are based on very little information. The Indian Ocean, in latitudes south of 50°, and the area off the west coast of France are not well represented by samples. Maps of the distribution of bottom deposits by Murray and his coworkers were the main guides for these parts of plate 71. In the China Sea some deposits may contain more than 10 percent of calcium carbonate, and in the East Indies and the Mediterranean Sea some sediments contain more than 50 percent. The calcium carbonate content indicated in the vicinity of the islands of the western Pacific should be considered only rough estimates.

## RESULTS

### AREAS IN WHICH RELATIONS ARE DEFINITE

The data presented on plate 71 show that the calcium carbonate content of the sediments in many parts of the sea is related to surface salinity, surface temperature, and depth. The calcium carbonate content, the surface salinity, and the surface temperature in general increase from the poles toward the Equator. However, in large areas on both sides of the Equator the calcium carbonate content is more closely related to the surface salinity than to the surface temperature.

In the north Pacific the surface salinity and the calcium carbonate content of the sediments are low. The area of maximum salinity in the Pacific is in the southeastern part, which likewise is characterized by deposits rich in calcium carbonate. The western part of the south Pacific has a lower surface salinity than the eastern part and the sediments contain less calcium carbonate in the west than in the east, except for an area east of the northern part of Australia, where the water in general is less than 2,000 fathoms deep. In

the northern part of the Indian Ocean, the western part is more saline than the eastern part, and its sediments have a greater content of calcium carbonate. The Mediterranean and Red Seas have a high salinity and the sediments are rich in calcium carbonate. The tongue of high calcium carbonate extending southward from Brazil is in an area of high salinity. The salinity of the north Atlantic is relatively high even in areas where the temperature of the surface water is less than 20° C., and the sediments in general are rich in calcium carbonate. The deposits along the west coast of Africa contain considerable calcium carbonate in the higher latitudes, but little in the vicinity of the Equator. The sediments in the Bay of Panama likewise contain little calcium carbonate. In both the Bay of Panama and off the west coast of equatorial Africa the surface salinity is comparatively low. The surface salinity in these areas, therefore, is fairly closely related to the calcium carbonate content of the sediments.

The map also shows clearly the influence of depth of water on the calcium carbonate content of the sediments. Almost every area having a depth of more than 3,000 fathoms is characterized by deposits containing less than 10 percent of calcium carbonate, and no area of this depth contains deposits having more than 50 percent of calcium carbonate.

### AREAS IN WHICH RELATIONS DO NOT SEEM TO HOLD

However, though this map indicates that the relation of calcium carbonate content of the sediments to the surface salinity, surface temperature, and depth seems to hold for many areas in the sea, it also shows that the relation does not hold for all areas. The relation for surface temperature, for example, does not apply very well to low latitudes. It is evident also that deposits of equal depth differ considerably in content of calcium carbonate. In most of the Pacific Ocean, except the southeastern part, the sediments lying between depths of 2,000 and 3,000 fathoms contain little calcium carbonate, whereas in most of the Atlantic and in the southeastern Pacific the sediments in that depth interval contain much calcium carbonate. The sediments in the northwestern part of the Indian Ocean are richer in calcium carbonate than the deposits of equal depth in the northeastern part. The sediments on the east side of the mid-Atlantic ridge in general are richer than those lying at similar depth on the west side.

The relation for salinity likewise does not apply to areas near the mid-Atlantic ridge. The surface salinity is greater on the west side than on the east side of the ridge in the south Atlantic and equal on the two sides in the north Atlantic. Wüst's concept that the Antarctic bottom current causes a low content of calcium carbonate in the sediments<sup>69</sup> may account for

<sup>64</sup> Murray, J., and Lee, G. V., The depth and marine deposits of the Pacific. Harvard Coll. Mus. Comp. Zoology Mem., vol. 38, map 3, p. 169, 1909.

<sup>65</sup> Murray, J., and Renard, A. F., *Challenger Rept.*, Deep-sea deposits, pp. 192, 213, 1891. Murray, J., and Hjort, J., *The depths of the ocean*, p. 166, New York, Macmillan Co., 1912.

<sup>66</sup> Murray, J., and Lee, G. V., op. cit., p. 20.

<sup>67</sup> Idem, map 2, p. 169.

<sup>68</sup> Pratje, O., op. cit., p. 202.

<sup>69</sup> Wüst, G., Schichtung und Zirkulation des Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925-27, Band 6, Lief. 1, pp. 59-64, 1933.

the distribution of calcium carbonate among the deposits of the Atlantic Ocean, as he suggests, but it does not seem to apply to the Pacific Ocean, where the sediments in southern latitudes contain more calcium carbonate than those in northern latitudes.

It would also seem that if the surface salinity influenced the deposition of calcium carbonate, the sediments underlying the Atlantic equatorial current, which is composed of water of relatively low surface salinity, should contain comparatively little calcium carbonate. The map does not indicate any such low calcium carbonate content in this area. The equatorial current in the Pacific, however, though likewise characterized by relatively low surface salinity, is underlain by sediments low in calcium carbonate. The deposits north of the Pacific equatorial current, underlying the area having a salinity of 35 parts per thousand, are represented by very few samples, but the data available suggest that the sediments are slightly richer in calcium carbonate in this area than in the vicinity of the equatorial current. However, if the calcium carbonate content of the sediments is related to the surface salinity, it would seem as if the sediments in the north Pacific in the area underlain by water having a salinity of 35 parts per thousand should contain more calcium carbonate than they do.

The calcium carbonate content of the deposits off southern California and Baja California is about 15 percent, which is higher than usual for areas having a salinity as low as in this region. These sediments are fairly rich in bottom-living Foraminifera, which may be a contributing cause to the somewhat greater calcium carbonate content than would be expected. The sediments off the Mackenzie Delta, in northern Canada, contain about 12 percent of calcium carbonate or dolomite. As a considerable proportion of the carbonate in these sediments seems to be dolomite,<sup>70</sup> it is probable that much of the carbonate is derived from particles of limestone or dolomite transported from adjacent land areas. The sediments of the Black Sea are fairly rich in calcium carbonate, but the surface salinity is low, being only 18 parts per thousand.

It would seem, therefore, that the relations of surface salinity, surface temperature, and depth to the calcium carbonate content of the sediments are not demonstrated definitely by the areal relations shown on plate 71. However, as explained above, the deposition of calcium carbonate is a very complicated process and is affected by a large number of factors, many of which operate simultaneously. The individual factors vary in their effect in different parts of the ocean. In some areas the influence of any particular factor may be obscured by the effect of some other factor. A relation between the calcium carbonate content of the sediments

and the salinity therefore would not be apparent for all areas in the ocean. The surprising feature is that a relation is found for so many areas.

#### COMPARISON WITH RESULTS OF OTHER LINES OF ATTACK

The relation of the areal distribution of calcium carbonate content to surface salinity accords fairly satisfactorily with the relation indicated by the statistical study of the individual samples. The relation indicated by both of these empirical lines of attack agrees with the relation indicated by the study of the solubility of calcium carbonate in sea water. It seems evident, therefore, that the calcium carbonate content of the sediments is definitely related to the salinity of the water. Areas of high salinity are associated with sediments rich in calcium carbonate, and areas of low salinity are associated with sediments poor in calcium carbonate.

#### EXPLANATION OF RELATIONSHIPS

The relation of salinity to the calcium carbonate content of sediments may be only in part a cause and effect relation. The notable increase in calcium carbonate content of sediments as the surface salinity rises from 34 to 36 parts per thousand is considerably greater than would be indicated by the increase in degree of saturation of the water caused by such a rise in salinity. The salinity associated with the greatest change in calcium carbonate content of the sediments is about 35 parts per thousand, which is approximately the average salinity of the ocean. It is possible that the surface isohalines of 35 parts per thousand may roughly mark the line between oversaturation and undersaturation of calcium carbonate in the upper layers in the sea. That is, areas in which the salinity is more than 35 parts per thousand are likely to be supersaturated, thus favoring the precipitation of calcium carbonate, and areas in which the salinity is less than 35 parts are likely to be undersaturated, thus inhibiting the precipitation of calcium carbonate. The salinity would thus be only an index of the degree of saturation of the water—that is, the relation between the salinity and calcium carbonate content of the sediments might to a considerable extent be a relation that was not one of cause and effect.

Similarly, it is possible that as the salinity rises above 35 parts per thousand it affects the activity of organisms in a manner not yet known, thus indirectly influencing the deposition of calcium carbonate; for, as explained above, living organisms, because of their effect on the carbon dioxide content of the water, constitute one of the most influential factors affecting the deposition of calcium carbonate in the sea.

Furthermore, though the salinity in different parts of the ocean remains fairly constant from year to year, the water in any particular area, in the course of time,

<sup>70</sup> Trask, P. D., Hammar, H. E., and Wu, C. C., Origin and environment of source beds of petroleum, p. 104, Houston, Tex., Gulf Publishing Co., 1932.

moves to another area in which the salinity is different—that is, the water in the ocean circulates in a more or less definite way. The salinity tends to increase in certain areas because of evaporation and tends to decrease in other areas because of influx of water from land or from the sky. The water in areas in which evaporation prevails is relatively dense and strives to move to areas where the water is less saline and therefore less dense. The sea water, consequently, is constantly but in general very slowly moving in its effort to maintain equilibrium; but because of the effects of evaporation and precipitation equilibrium is never attained.<sup>71</sup> However, a sort of balance is obtained which causes the salinity in different parts of the ocean to remain nearly constant, even though the water in those areas continues to move.

Consequently, in areas of high salinity, where the degree of saturation presumably is greater than 100 percent, precipitation of calcium carbonate can continue more or less indefinitely, thus favoring the deposition of calcareous sediments. If the water did not move, only a comparatively small quantity of calcium carbonate could be precipitated, because the degree of saturation of the water would soon be lowered to 100 percent and no more calcium carbonate could be precipitated until the degree of saturation increased again. However, because of this slow circulation of the water, the physical conditions in any one area remain more or less constant, and calcium carbonate can be precipitated continually from areas in which the degree of saturation of the water is greater than 100 percent. The relation of calcium carbonate content of sediments to salinity therefore may to a considerable extent be influenced by the effect of salinity on oceanic circulation.

The relation of the salinity to the calcium carbonate content of sediments may also be due in part to the relation of salinity to time. Experimental data of investigators at the Scripps Institution of Oceanography seem to indicate that the precipitation of calcium carbonate from sea water is influenced by the length of time the water has remained in a state of supersaturation.<sup>72</sup> Salinity is a rough index of the length of time water has remained at or near the surface, because the basic way in which water becomes saline is through evaporation, and the higher the salinity the longer the water has been in a position where it could evaporate. Therefore if the length of time that the water remains in a state of supersaturation is a factor, salinity may be an indirect index of the precipitation of calcium carbonate.

These possible explanations of the relation of the calcium carbonate content of marine sediments to salinity are offered as working hypotheses in an attempt

to account for the closer relation of the calcium carbonate content of the sediments to the salinity of the water than is indicated by the solubility of calcium carbonate in sea water.

#### GEOLOGIC APPLICATION OF RELATIONSHIPS

The sediments the geologist encounters in the field leave clues about the conditions under which they were deposited. The proper interpretation of these clues depends largely upon knowledge of the conditions under which sediments now accumulate. As Bigelow<sup>73</sup> mentions repeatedly, our knowledge of the processes and conditions that prevail in the ocean is handicapped greatly by paucity of observations. The field is so big and the science is so young that many problems are far from being solved satisfactorily. The problem of deposition of sediments is no exception to this statement. The conditions of deposition of calcium carbonate have probably been investigated as fully as any other problem of sedimentation, but, as is evident from this paper, much is yet to be learned about the manner in which calcium carbonate is deposited in sediments. Consequently it is hazardous at this time to reason backward from the calcium carbonate content of ancient sediments and infer the conditions under which the sediments were deposited. However, to illustrate the possibilities afforded by studies of the calcium carbonate content of ancient sediments, two subjects—the deposition of red clay and inferences about past climates—may be discussed briefly here.

#### FORMATION OF RED CLAY

Wattenberg<sup>74</sup> states that below a depth of 500 meters in the south Atlantic the saturation of the water with calcium carbonate ranges between 90 and 100 percent. The degree of saturation of the water in these parts of the ocean is influenced strongly by the temperature and by the production of carbon dioxide, either by decomposition of organisms after death or by the metabolic processes of living organisms. The lower temperature and the higher carbon dioxide content of the deep water increase the solubility of the water for calcium carbonate, with the result that the degree of saturation of the water becomes less. If the degree of saturation decreases, there is a greater tendency for particles of calcium carbonate to be dissolved as they fall through the water, and the quantity of calcium carbonate deposited in the sediments becomes smaller. Conversely, if the temperature of the water were increased or if the rate of formation of carbon dioxide were lessened, the saturation of the water with calcium carbonate would be increased and the calcium carbonate content of the sediments should become larger.

<sup>71</sup> Cf. Johnstone, J., An introduction to oceanography, 2d ed., pp. 256-303, Liverpool, 1928.

<sup>72</sup> Gee, H., Calcium equilibrium in the sea, V, Preliminary experiments on precipitation by removal of carbon dioxide under aseptic conditions: Scripps Inst. Oceanography Tech. ser., vol. 3, no. 7, p. 183, 1932. Moberg, E. G., Greenberg, D. M., Revelle, R., and Allen, E. C., The buffer mechanism of sea water: Scripps Inst. Oceanography Tech. ser., vol. 3, no. 11, p. 247, 252, 1934.

<sup>73</sup> Bigelow, H. B., Oceanography, New York, Houghton Mifflin Co., 1931.

<sup>74</sup> Wattenberg, H., Kalziumkarbonat- und Kohlensäuregehalt des Meerwassers: Wiss. Ergeb. Deutschen Atlantischen Exped. Meteor, 1925-27, Band 8, Teil 2, p. 222, 1933.

According to data presented by Wattenberg<sup>75</sup> for temperatures ranging between 0° and 10° C., an increase of 3° would decrease the solubility of calcium carbonate in the water about 10 percent—that is, the degree of saturation would increase about 10 percent. If all the water before the temperature was raised was more than 90 percent saturated, which according to Wattenberg<sup>76</sup> now holds for the subsurface water of the south Atlantic, and presumably for other oceans as well, an increase of 10 percent in the degree of saturation would cause the water everywhere to be more than 100 percent saturated. Particles of calcium carbonate therefore would not dissolve as they fell to the sea floor, with the result that calcareous sediments instead of red clay would be deposited in the ocean. Although Wattenberg's data may be subject to correction, they certainly indicate the order of magnitude. The absence or scarcity of red clay among ancient sediments might therefore be explained by the greater degree of saturation of the deep water in the ocean in the past than at present. The increase in degree of saturation of the water could have been caused by an increase in temperature, but it could also have been caused by the water remaining at the same temperature long enough to become saturated by solution of calcareous particles as they fell to the sea floor, or by a decrease in carbon dioxide content of the water.

The cold water that now occupies the lower part of the ocean is derived largely from polar regions. It is probable that if the polar ice caps were removed the water at the bottom of the ocean would become warmer, the capacity of the water to hold calcium carbonate in solution would become less, and there would be a tendency for the sediments to have a greater content of calcium carbonate.

If it is assumed that essentially all the water from the surface to the bottom was saturated with calcium carbonate at the end of the Pliocene epoch, the advent of the ice age would have lowered the temperature of most of the ocean, and the degree of saturation of the water, particularly of the subsurface layers, would have become less. The sediments deposited during Pleistocene time in general should therefore contain relatively little calcium carbonate.

At the end of the Pleistocene epoch, or perhaps even during the warm interglacial intervals, the temperature of the ocean would gradually rise and the calcium carbonate content of the sediments accordingly should increase. That is, the calcium carbonate content of sediments such as *Globigerina* ooze would diminish progressively downward from the surface of the deposits until a zone of pre-Pleistocene (or interglacial) sediments was reached. Such a downward diminution of

calcium carbonate is reported by Pratje<sup>77</sup> and Iselin<sup>78</sup> in *Globigerina* oozes in the Atlantic. These authors regard this downward decrease in carbonate as due to progressive upward leaching of the calcium carbonate; but the phenomenon is perhaps explained more plausibly by the progressive increase in saturation of the overlying water since Pleistocene time.

The same condition would result also if the water remained at the same temperature for considerable time. If the temperature remained constant for a sufficiently long period, the water would eventually become saturated, because of solution of calcareous particles falling through the water, with the result that the calcium carbonate content of the sediments would become relatively high. Presumably red clay would not be deposited under such conditions until the overlying water again became undersaturated with calcium carbonate. A general lowering of the temperature of the deeper layers of water seems the simplest way to decrease the degree of saturation of the water, but increased production of carbon dioxide by any cause would have the same effect.

It is evident from this discussion that the depth at which red clay now forms in the sea is influenced strongly by the degree of undersaturation of the water with calcium carbonate, and that in other geologic periods the depths at which it could form would probably be different from the present depths.

#### RELATION OF CALCIUM CARBONATE CONTENT OF ANCIENT SEDIMENTS TO CLIMATE

The average salinity of the surface of the ocean is about 35 parts per thousand. The sediments in regions in which the surface salinity is greater than 35 parts in general contain considerable calcium carbonate, and the sediments in areas in which the salinity is less than 35 parts, particularly in areas in which it is less than 34 parts, contain relatively little calcium carbonate. (See table 1.) That is, the sediments in areas in which the salinity is above the average are likely to be rich in calcium carbonate, and those in areas in which the salinity is below the average are likely to be poor in calcium carbonate.

This relationship is subject to many exceptions. The calcium carbonate content of sediments is influenced by several factors in addition to salinity, particularly by the proportion of terrigenous constituents, which in many areas masks the effects of other factors; for even though the rate of deposition of calcium carbonate is constant, the sediments off the mouths of large rivers contain little calcium car-

<sup>75</sup> Pratje, O., Geologische Tiefseeforschungen auf der Deutschen Atlantischen Expedition: Deutsch. geol. Gesell. Zeitschr., Monatsber., Band 79, p. 203, 1927.

<sup>76</sup> Iselin, C. O., Recent work on the dynamic oceanography of the North Atlantic: Am. Geophys. Union Trans. 10th Ann. Meeting, pp. 88-89, Nat. Research Council, 1930.

bonate compared with the sediments off arid coasts. Consequently it is not safe to generalize backward and infer that if a sediment contains little calcium carbonate it necessarily was deposited in water of sub-normal salinity, or that if it contains much calcium carbonate it was deposited in water having a salinity greater than normal. The data presented in this paper indicate, however, that there is a significant chance that the calcium carbonate content of some sediments reflects the climate, particularly with respect to rainfall, at the time the sediments were deposited.

Therefore, some alternations between limestone and calcareous shale or between calcareous shale and non-calcareous shale may represent fluctuations in climate. The more calcareous layers might have been deposited

during dry periods, which would favor the evaporation of water and tend to increase the salinity in the basin of deposition and which at the same time would decrease the quantity of detritus transported to the basin of deposition. The less calcareous layers might have been deposited during wet periods, in which the water had a low salinity and the quantity of detritus transported by rivers was large.

It would be presumptuous to advocate that alternations between limestone and shale should in general be interpreted in this way. However, the possibility should be mentioned that some alternations between limestone and shale or between calcareous and non-calcareous shale might have resulted largely from alternate changes in climate.



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