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GEOLOGICAL SURVEY

PRELIMINARY REPORT ON THE STRATIGRAPHY OF THE PARK CITY AND PHOSPHORIA FORMATIONS AND AN ANALYSIS OF THE DISTRIBUTION OF PHOSPHATE IN UTAH*

By

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Trace Elements Investigations Report 627

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PRELIMINARY REPORT ON THE STRATIGRAPHY OF THE PARK CITY AND PHOSPHORIA FORMATIONS AND AN ANALYSIS OF THE DISTRIBUTION OF PHOSPHATE IN UTAH

By Thomas M. Cheney

ABSTRACT

The Phosphoria formation of Permian age contains the major phosphate deposits in the western United States. It consists mostly of phosphatic shale, chert, and cherty shale, but in Utah the Phosphoria formation intertongues with the carbonate rocks and cherty carbonate rocks of the Park City formation. The Phosphoria is well developed in northeastern Utah, but it thins southward and eastward. The Park City formation also thins southward and eastward and intertongues with and passes into red and greenish-gray and tawny beds that are northward and northwestward extending tongues of the Woodside formation.

The only economically important phosphate deposits in Utah are those in the Meade Peak phosphatic shale member of the Phosphoria formation. The Meade Peak contains both acid-grade and furnace-grade deposits in the northern Wasatch Mountains and Crawford Mountains, Utah, and it contains large reserves of low-grade rock amenable to strip-mining on the southern flank of the Uinta Mountains near Vernal, Utah.

Phosphate deposits are also present in a phosphatic shale unit, 25 to 150 feet thick, at the base of the Deseret limestone of Mississippian age in the Tintic, Oquirrh, and southern and central

Wasatch Mountains, Utah, and at the base of its partial equivalent the Brazer limestone in the northern Wasatch Mountains, Utah. As now known, these phosphate deposits are not rich, thick, nor extensive enough to be minable at the present time.

INTRODUCTION

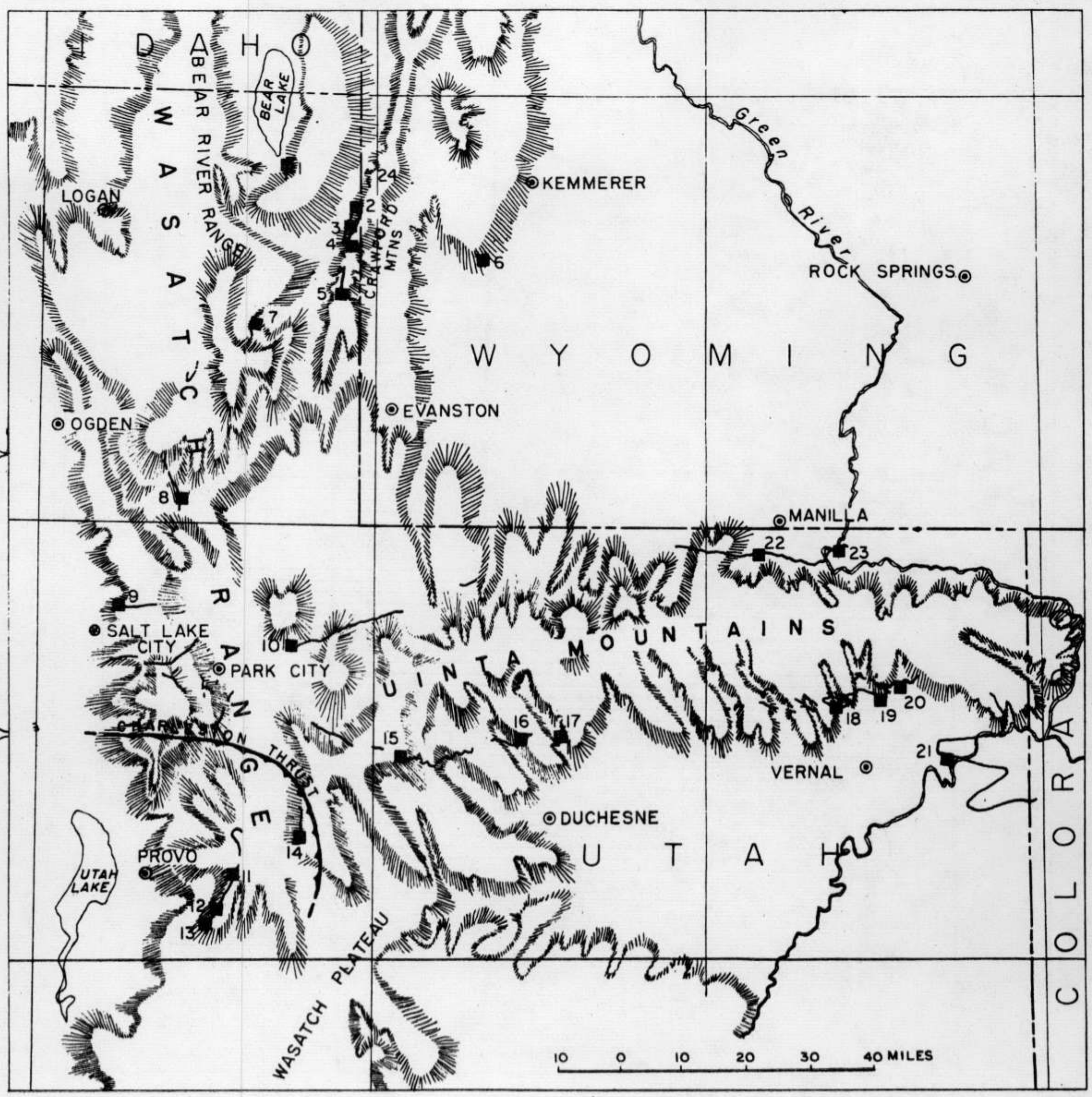
The purpose of this paper is to present a preliminary discussion of the stratigraphy of the Park City and Phosphoria formations with special emphasis on the phosphatic parts, and to discuss the distribution of phosphate in Utah. The Mississippian deposits are discussed only briefly because of the lack of new data concerning them.

The sedimentary rocks that comprise the Park City and Phosphoria formations and equivalent strata of Permian age in the western states have been the subject of recent investigations by the U. S. Geological Survey because of the large reserves of phosphate and minor elements in the phosphatic members of the Phosphoria formation. The sediments that formed these two intertonguing formations and their equivalents were deposited over a large area in Montana, Idaho, Wyoming, Nevada, Colorado, and Utah during part of Permian time. Phosphate deposits are known in the Phosphoria formation in all of these states except Colorado, but the largest reserves are in the Meade Peak phosphatic shale member of the Phosphoria formation in southeastern Idaho and adjacent parts of Utah and Wyoming.

Acid-grade phosphate deposits in Utah are known only in the northern Wasatch Mountains and Crawford Mountains (fig. 1), and they are being mined today in a few places. Large reserves of furnace-grade phosphate rock lie on the southeast flank of the Uinta Mountains near Vernal, but these deposits apparently are not minable at the present price of phosphate rock. Phosphate deposits of low grade and probably local extent also occur at the base of the Brazer and Deseret limestones of Mississippian age.

FIELD WORK

The U. S. Geological Survey's recent investigation of the phosphate deposits of Utah has been underway since 1947. During the course of this investigation, all or, at least, the most phosphatic parts of the Meade Peak phosphatic shale member have been measured and sampled at 25 localities (fig. 1) in Utah. Because the phosphatic beds are generally in non-resistant, poorly exposed parts of the formation, it was necessary to make artificial exposures either by hand trenching or more commonly by digging with a bulldozer. Individual rock units were then measured, described, and sampled (McKelvey and others, 1953, p. 3-6). The Park City and the non-phosphatic parts of the Phosphoria were measured and described at several localities and sampled at a few.



MEASURED SECTIONS OF THE PHOSPHORIA AND PARK CITY FORMATIONS

Laketown	1	Little Diamond Creek	13
North Crawford	2	Strawberry Valley	14
Brazer Canyon	3	Wolf Creek	15
Upper Brazer	4	Dry Canyon	16
South end Crawford Mountains	5	Lake Fork	17
Cumberland	6	Rock Canyon	18
Sugar Pine Creek	7	Brush Creek	19
Devils Slide	8	Little Brush Creek	20
Fort Douglas	9	Split Mountain	21
Franson Canyon	10	Sols Canyon	22
Right Fork Hobble Creek	11	Horseshoe Canyon	23
Wanrhodes Canyon	12	Leefe	24

FIGURE I. Index map showing area of this report, localities where sections were measured and sampled, and the four areal subdivisions discussed in this report. Location of Charleston fault after Baker (Baker, et al., 1949, p.1196) and Crittenden (Crittenden, et al., 1952, p.24).

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ACKNOWLEDGMENTS

Many geologists have contributed to this paper either by field work or by suggestions and criticisms concerning the analyses of the data and writing of this report. Special thanks are due to V. E. McKelvey who supervised most of the work and made many suggestions that have been incorporated in this paper. Among those who have contributed to the field work special mention should be made of D. M. Kinney, J. W. Huddle, and L. E. Smith, who supervised the field parties in 1947; and to R. P. Sheldon, R. G. Waring, R. A. Smart, and M. A. Warner who, together with the author, were responsible for all field work during 1951. Alvin F. Holzle ably assisted in the field for a short time during 1953. The Division of Raw Materials of the U. S. Atomic Energy Commission contributed to the financial support of this work.

During preparation of this report, many helpful criticisms and suggestions concerning the interpretation of the data have been made by R. P. Sheldon, E. R. Cressman, L. D. Carswell, and R. A. Gulbrandsen.

Several members of the U. S. Forest Service, the U. S. Army at Fort Douglas, Utah, the City of Salt Lake Engineering Office, and phosphate companies, as well as local residents, granted access to property or gave information which has been greatly appreciated.

STRATIGRAPHY OF UPPER PALEOZOIC AND TRIASSIC ROCKS IN NORTHEASTERN UTAH

The sedimentary rocks of northern Utah range in age from Precambrian to Recent. The general lithologic character, thickness, and the nomenclature applied to the upper Paleozoic sedimentary rocks are illustrated in figure 2.

In the upper Paleozoic rocks of northern Utah carbonate rock and sandstone are the dominant rock types, and cherty carbonate rock and black, generally phosphatic, carbonaceous shale are the characteristic minor rock types. The vertical sequence of strata in the central Wasatch Mountains (Baker, and others, 1949) is, in ascending order: the carbonate rock of the Madison limestone, black shale (carbonaceous and slightly phosphatic) generally considered to be basal Deseret limestone, and somewhat cherty carbonate rock of the Deseret, sandstone and carbonate rock of the Humbug formation, and black shale of the "Doughnut" formation/ of Crittenden, and others, (1952, p. 10), all of Mississippian age; cherty limestone of the Morgan formation, and sandstone of the Weber quartzite of Pennsylvanian age; and carbonate rock and cherty carbonate rock of the lower member of the Park City formation; black phosphatic shale of the Meade Peak phosphatic shale member of the Phosphoria formation; and chert, cherty carbonate rock, and sandstone of the Franson member of the Park City formation of Permian age.

/ Great Blue(?) formation of Granger (1953).

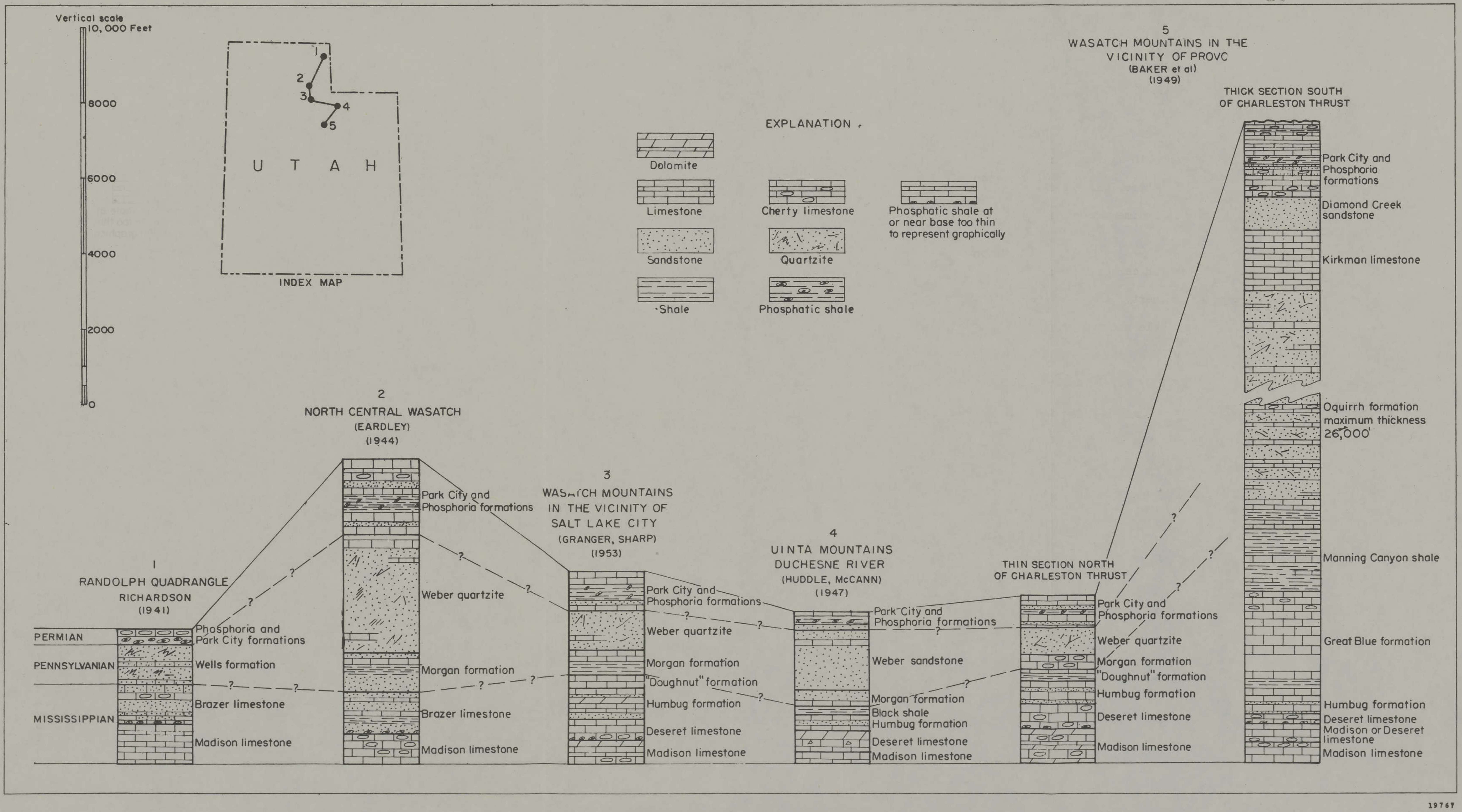


FIGURE 2. Columnar sections showing lithology and nomenclature of upper Paleozoic rocks in northern Utah. Modified after Granger (1953)

This vertical sequence of black shale, carbonate rock (generally cherty) and sandstone which, with minor exception, is repeated three times in the upper Paleozoic rocks of northern Utah, has been pointed out by V. E. McKelvey (oral communication) as one in which black and particularly phosphatic shales characteristically occur the world over; a similar sequence within the Phosphoria formation and associated rocks in western Wyoming has been described in some detail by R. P. Sheldon, (1957). All of the major units thin gradually to the east, and some pinch out in eastern Utah and western Colorado.

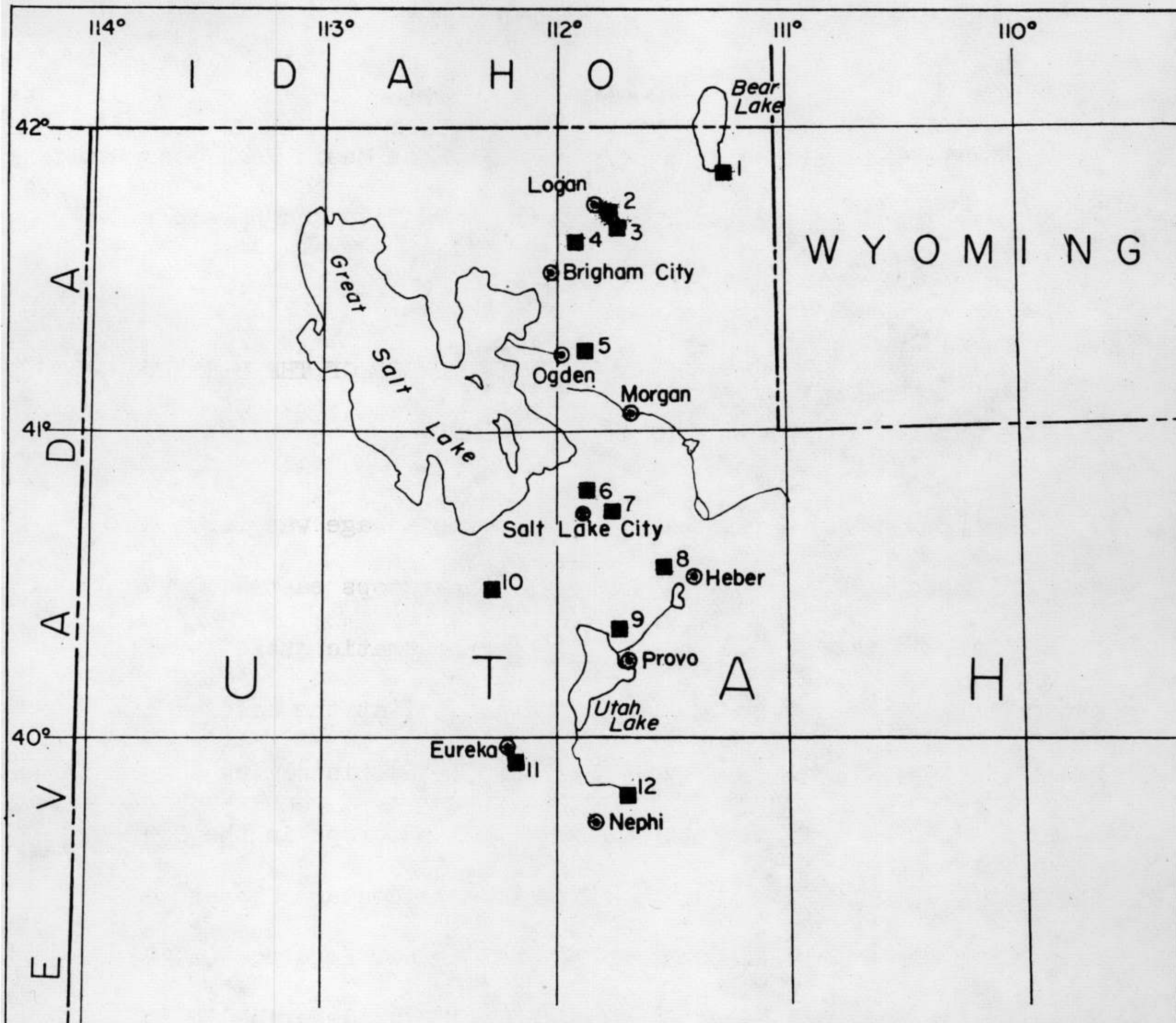
The rocks of Permian age are overlain by the red beds of the Woodside formation of Triassic age in the central and southern Wasatch Mountains and in the western Uinta Mountains. In the eastern part of the Uinta Mountains both red beds and greenish-gray shale intertongue with and overlie the Park City formation; these beds were identified as the Woodside formation by Thomas (1939) and Thomas and Kreuger (1946, p. 1263-1270) but have recently been assigned to the Moenkopi formation by Kinney and Rominger (1947) and Kinney (1955, p. 56). In the northern Wasatch Mountain area the rocks of Permian age are overlain by the light brown and gray siltstones and limestones of the Triassic Dinwoody formation (Kummel, 1954).

In northern Utah the only notably phosphatic units are the black shale at the base of the Brazer and Deseret limestones of Mississippian age and the Meade Peak phosphatic shale member of the Phosphoria formation of Permian age. The stratigraphy of the phosphatic shale of Mississippian age is reviewed briefly, but most of the emphasis in this report is placed on a discussion of the Meade Peak phosphatic shale member and associated rocks of the Park City and Phosphoria formations of Permian age.

STRATIGRAPHY OF THE PHOSPHATIC SHALE MEMBER OF THE DESERET AND BRAZER LIMESTONES

Phosphatic shale in rocks of Mississippian age was first described by Blackwelder (1910, p. 543) from outcrops east of Ogden, Utah. Richardson (1913) also found this phosphatic shale zone in outcrops near Laketown, Utah (loc. 1, fig. 3), at the base of the Mississippian Brazer limestone. Gilluly (1932), in naming the Deseret limestone of Mississippian age from outcrops in the Oquirrh Mountains (loc. 10, fig. 3), placed the basal contact beneath a slightly phosphatic black shale nine feet thick. Peterson (1914), Williams (1939a), and Linch in Mansfield (1927), described a phosphatic shale at the base of the Brazer limestone in the northern Wasatch Mountains, and Baker, and others (1949), and Calkins and Butler (1943) described a black, locally phosphatic shale at the base of the Deseret in the Wasatch Mountains near Salt Lake City.

The black phosphatic shale, which apparently is of the same age at all of the above localities, is present as far south as the East Tintic Mountains (H. T. Morris and T. S. Lovering, in press). Its thickness is irregular and in places the shale is completely absent; except for the estimated thickness of 200 feet near Dry Lake, Utah (Williams, 1948, p. 1142), the greatest known thickness is in the East Tintic Mountains where Morris and Lovering (in press) report a



Locality	Thickness (feet)	Reference
1. Laketown, Utah	76	This report
2. Providence Canyon, Utah	15	" "
3. Blacksmith Fork, Utah	75	Williams, J. Stewart (1939a, p. 27)
4. Dry Lake, Utah	200(Est.)	Williams, J. Stewart (1948, p. 1142)
5. Ogden Canyon, Utah	19	This report
6. Beck's Spur, Utah	35	Willicken in Williams, J. Stewart (1939, p. 30)
7. Cottonwood-Amer. Fk. Area	25 or less	Calkins and Butler. (1943)
8. Northwest of Heber, Utah	17	Baker, et al (1949, p. 1174)
9. American Fork area, Utah	5-10	Crittenden, oral Communication (1954)
10. Oquirrh Range, Utah	9	Gilluly, (1932)
11. East Tintic Mountains, Utah	90-160	Morris, H.T., written Communication (1954)
12. Mount Nebo, Utah	10(Est.)	Smith, Elton V. (1956)

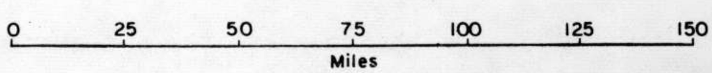


Fig. 3. Index map showing general location and thickness of known occurrences of phosphatic shale of Mississippian age.

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maximum of 160 feet (loc. 11, fig. 3). All localities from which the member has been described are west of the Uinta Mountains; however, it has not been reported from outcrops of the Brazer limestone in some of the areas intervening between the northern localities on figure 3 (Eardley, 1944; Williams, 1943). The phosphatic shale is non-resistant and usually weathers to form a covered slope or saddle between the more resistant overlying and underlying units. The component rocks resemble those of the phosphatic members of the Phosphoria formation and generally consist of dark brown to black, fissile, thin-bedded mudstone interbedded with dark gray to black, fissile, thin- to thick-bedded argillaceous carbonate rocks and thin, probably discontinuous layers of grayish-brown and black pelletal phosphorites. Williams (1943) described interbeds of sandstone from outcrops in Blacksmith Fork near Logan, Utah.

STRATIGRAPHY OF THE PARK CITY AND PHOSPHORIA FORMATIONS

History of nomenclature

The cherty carbonate rock, sandstone, chert, and phosphatic black shale that overlie the Wells formation, the Weber quartzite, and the Diamond Creek sandstone in this area, were first described in the eastern part of the Uinta Mountains by Powell (1876), who included them in the upper part of the Aubrey group as part of the Bellerophon limestone. Farther west along the Uinta Mountains and in the Wasatch Mountains, King (1878) described these rocks as part of the Permo-Carboniferous as did Berkey (1905, p. 522) and

Weeks (1907, p. 439). In the Central Wasatch Mountains, Boutwell (1907) described the beds overlying the Weber quartzite and underlying the red shales of the Triassic Woodside formation from outcrops on the north side of Big Cottonwood Canyon, assigned them a Pennsylvanian age, and named them the Park City formation. In 1909 Gale (Gale and Richards, 1910) found a phosphatic shale unit within the Park City formation and discussed the stratigraphic relationships of the phosphate deposits of the western field. On the basis of their findings, the Park City formation was later separated into three members: a lower sandy limestone and limestone member containing abundant chert nodules; a middle black, phosphatic shale member; and an upper cherty limestone, chert, and sandy limestone member.

During geologic mapping and stratigraphic studies in southeastern Idaho, Richards and Mansfield (1912, p. 684-689) designated the upper two members of the Park City formation as the Phosphoria formation of Permian age from exposures in Phosphoria Gulch near Georgetown, Idaho. They classed the lower member of the Park City formation in southeastern Idaho as part of the Wells formation of Pennsylvanian age because (1) no lithologic or faunal correlation of the rocks immediately underlying the phosphatic shale could be readily established due to lack of information in the area intervening between type localities (Richards and Mansfield, 1912, p. 687-690) (Girty, in Mansfield, 1927, p. 79); and (2) the lithology of the lower member of the Park City formation in southeastern Idaho was more similar to that of the underlying rather than to the overlying rocks. Richardson (1941, p. 24-25) extended the use of the Phosphoria-Wells terminology to rocks in the Randolph quadrangle, Utah.

Schultz (1918) described the phosphate-bearing beds and associated rocks in the Uinta Mountains as the Park City formation because of their similarity to and proximity to the type section of that formation. In his description, Schultz divided the formation into four units: a lower limestone member, a phosphatic shale unit, the upper or cherty limestone beds, and an uppermost thin-bedded, shaly gray limestone unit. The uppermost member is, where present, now classed as part of the Moenkopi formation (Kinney and Rominger, 1947) or the Woodside formation (Thomas and Kreuger, 1946, p. 1268); however, it resembles more the beds of the Dinwoody formation in the Wind River Mountains (Schultz, 1918, p. 47; Thomas and Kreuger, 1946, p. 1268; Hansen and Bonilla, 1954, p. 7).

In a paper on the "Park City" beds in the Uinta Mountains, Williams (1939a, p. 91) described a red beds unit within the upper cherty limestone member of the Park City formation. He named this unit the "Mackentire 'red beds' tongue of the Phosphoria formation" and stated that the upper two members of the Park City formation should be renamed the Phosphoria formation. Thomas later classed the Mackentire as a tongue of the Woodside formation (Thomas, 1939, p. 1249). In a later paper Williams (1943) chose to retain the name Park City formation throughout the area.

A thick sequence of Permian rocks was described from the southern Wasatch Mountains by Baker and Williams (1940). They differentiated the Park City formation and on the basis of faunal and lithologic evidence correlated it with the Park City formation at the type locality. Underlying it, they denoted successively the Diamond Creek sandstone and the Kirkman limestone of Permian age. Underlying the Kirkman limestone are the quartzites and limestones of the Oquirrh formation, the upper 8,000± feet of which has been designated as of Wolfcamp (early Permian) age (Bissell, 1950, p. 89). Because of the similarity in faunas, Baker and Williams (1940, p. 624) correlated the lower member of the Park City formation with at least part of the Kaibab limestone in the Colorado Plateau; consequently, they concluded that the upper two members of the Park City formation and equivalent parts of the Phosphoria formation are post-Kaibab in age.

The nomenclature used in this report follows that of McKelvey and others (1956) for the rocks of Park City age in the western phosphate field. The main elements of this nomenclature are described in the following pages.

Regional relationships

The rocks of Park City age in the area of this report are assigned to the Park City, Phosphoria, and Woodside formations, each of which has a distinctive lithic character. In southeastern Idaho and adjacent parts of Utah and Wyoming the rocks of Park City age consist mainly of chert, phosphorite, and carbonaceous mudstone and are designated the Phosphoria formation. These rocks intertongue southward and eastward with the carbonate rocks assigned to the Park City formation. The carbonate rocks of the Park City formation in turn intertongue southeastward and eastward with red beds, greenish-gray shales, and evaporites assigned to the Chugwater formation in central Wyoming and to the Woodside formation of Thomas (1939) in northern Utah (McKelvey, and others, 1956). A map showing dominant lithology of rocks of Park City age in Utah, Wyoming, Colorado and Idaho (fig. 4) illustrates the arcuate distribution of the areas where the rocks characterizing these formations are dominant. The intertonguing relationships of the three formations are illustrated by figures 5 and 6 and are discussed here to make clear their lateral and vertical relationships over the area.

The Park City formation at its type locality in Big Cottonwood Canyon near Salt Lake City, Utah, consists of a lower and upper or Franson member separated by the Meade Peak phosphatic shale tongue of the Phosphoria formation (fig. 5). The Park City formation is overlain by the Woodside formation of Triassic age and underlain by the Weber quartzite. The Phosphoria formation at its type locality consists, from oldest to youngest, of the Meade Peak phosphatic shale member, the Rex chert member, and the cherty shale member. It is underlain by the lower tongue of the Park City formation and overlain by the Dinwoody formation of Triassic age. The Franson member of the Park City is not present in southeastern Idaho, nor is the cherty shale member of the Phosphoria present in the area of this report.

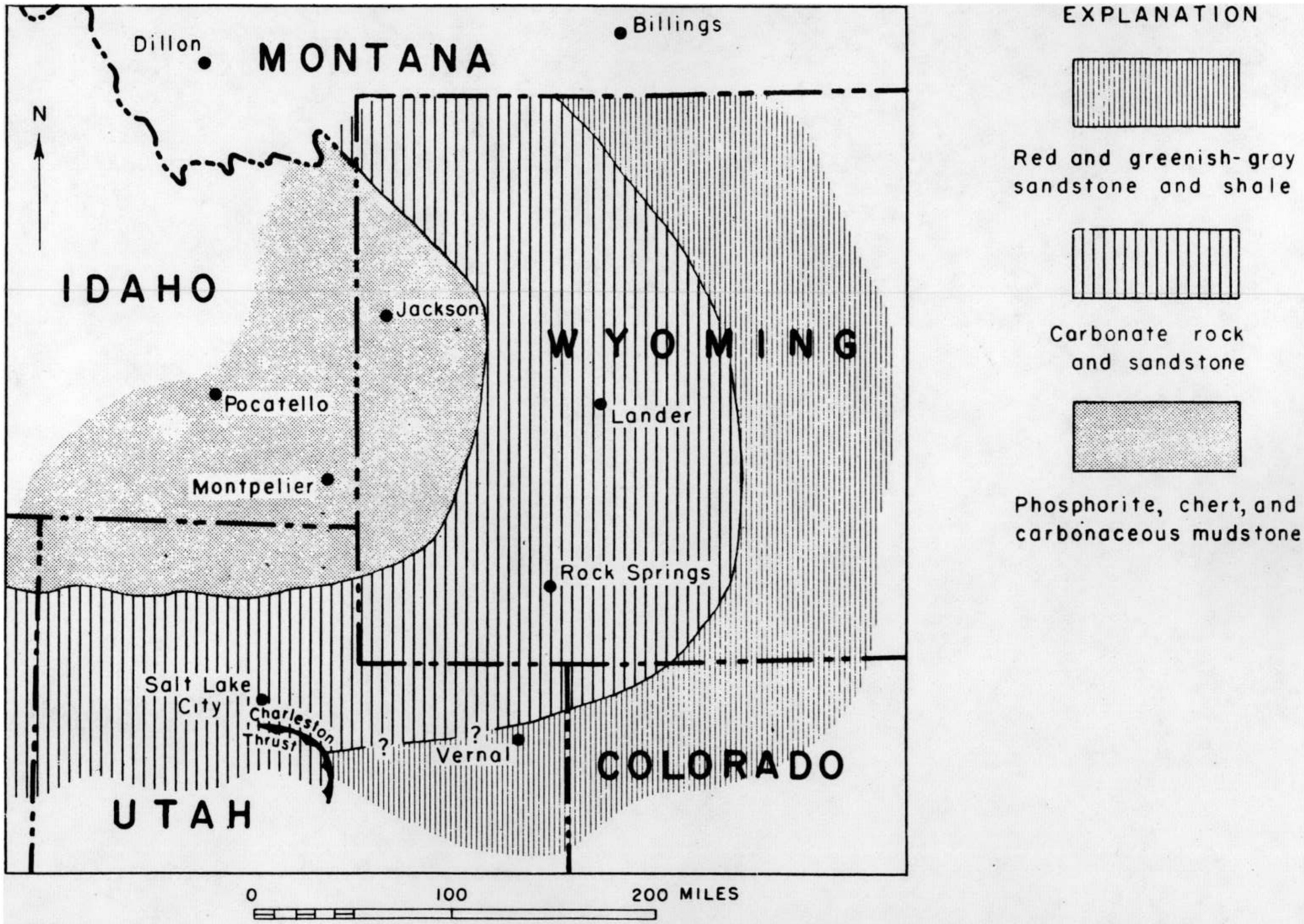

FIGURE 4. Map showing dominant lithology of rocks of Park City age in parts of Idaho, Wyoming, Utah, and Colorado. Modified after Sheldon (in preparation).

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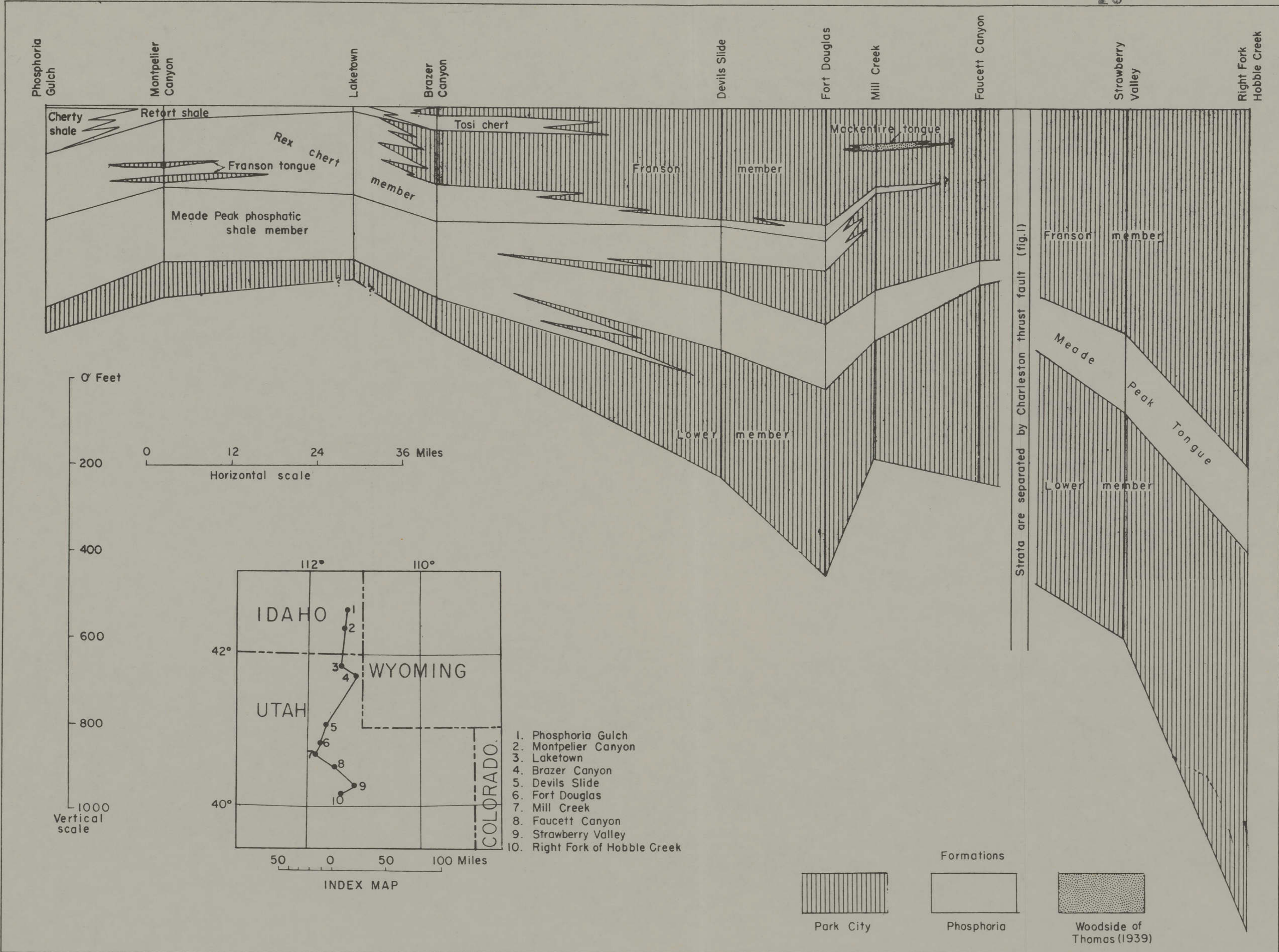

FIGURE 5. Diagram showing nomenclature and intertonguing relationships of the Permian Phosphoria and Park City formations, and the lower part of the Woodside formation between Phosphoria Gulch, Idaho, and the Right Fork of Hobble Creek, Utah. Sections at Faucett Canyon and Right Fork of Hobble Creek from Baker and others (1949, p.1188 and 1190).

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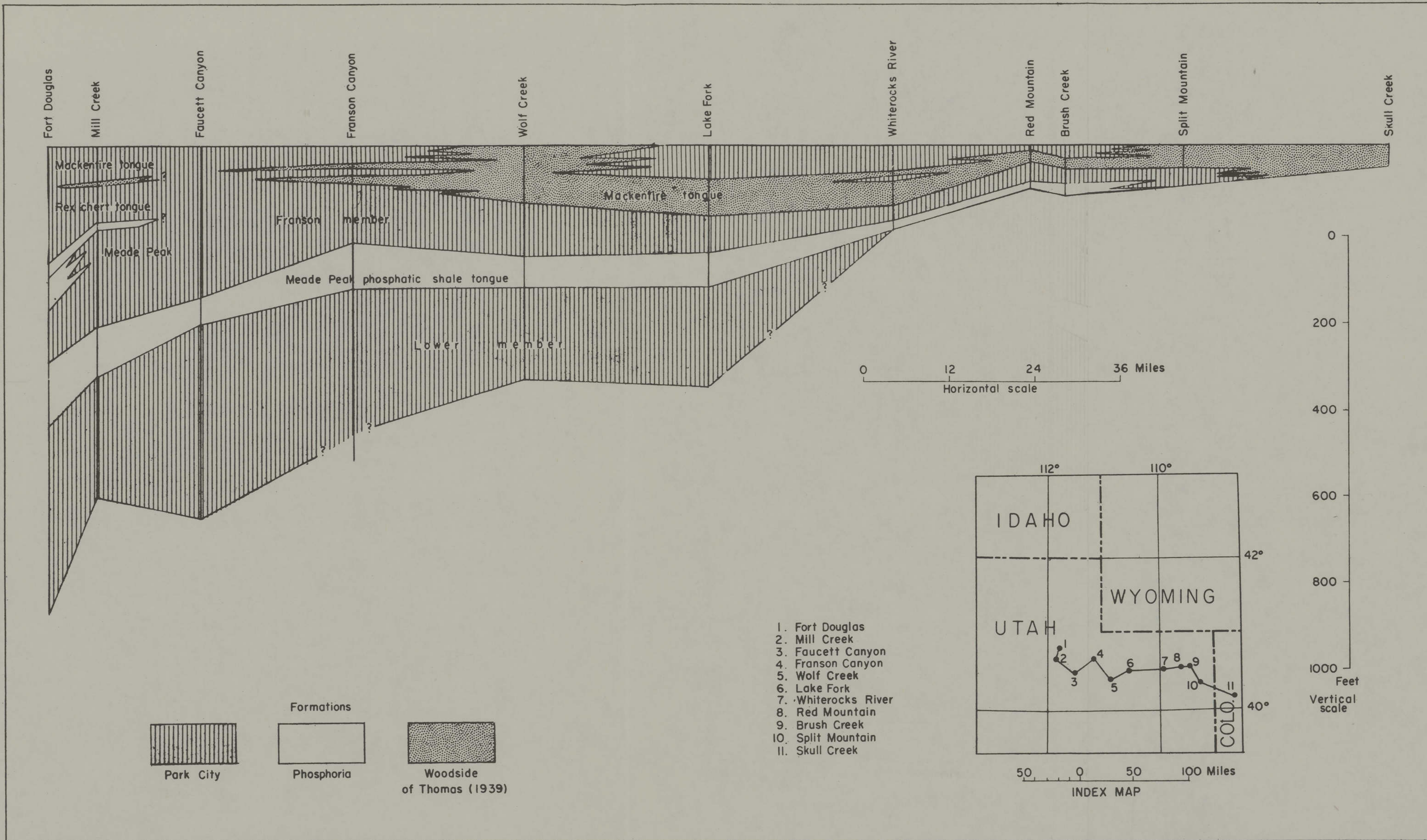

FIGURE 6. Diagram showing nomenclature and intertonguing relationships of the Permian Park City and Phosphoria formations, and the lower part of the Woodside formation between Fort Douglas, Utah, and Skull Creek, Colorado. Sections at Faucett Canyon (Baker and others, 1949, p. 1190); Whiterocks River and Red Mountain (Kinney, 1955, p. 50); Skull Creek, Colorado, (Thomas and Krueger, 1946, p. 1292).

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However, the Tosi chert member and Retort phosphatic shale member of the Phosphoria, equivalents of the cherty shale member, are present in northernmost Utah.

The lower member of the Park City formation persists over the area of this report with the exception of the southeastern part of the Uinta Mountains. It is underlain by the Weber quartzite in the central Wasatch and Uinta Mountains, the Diamond Creek sandstone in the southern Wasatch Mountains, and the Wells formation in the northern Wasatch area. The lower member is everywhere overlain by the Meade Peak phosphatic shale member of the Phosphoria formation.

The Franson member of the Park City formation intertongues northward from the type locality of the Park City formation with the upper part of the Meade Peak phosphatic shale tongue and the overlying Rex chert tongue of the Phosphoria in part of the central Wasatch area, as at Mill Creek, Fort Douglas, and Devils Slide (figs. 5 and 6, pl. 1). Further north, as in the Crawford Mountains, the Franson also intertongues with the Tosi chert tongue of the Phosphoria formation. The Franson member wedges out between the Crawford Mountains and Laketown, Utah (fig. 5). At Laketown the Phosphoria consists of the Meade Peak member, the Rex member, and a thin phosphatic shale unit tentatively assigned to the Retort phosphatic shale member of the Phosphoria; the Retort is overlain by the Dinwoody formation of Triassic age. Elsewhere in the northern Wasatch area the Franson is overlain by the Dinwoody formation. In the other areas in northern and eastern Utah, the Franson is overlain by the Woodside formation.

The Franson carbonate rock intertongues southward and eastward from the type area of the Park City formation/ with red beds and

/ Boutwell described a thin "red shale" in the upper part of the Park City formation at the type locality. This "red shale" is probably laterally continuous with the Mackentire tongue of the Woodside (figs. 5 and 6).

greenish-gray beds of the Woodside formation (fig. 6 and pl. 2).

The areal distribution of the four major lithologic groups--carbonaceous mudstone, phosphorite, and chert; carbonate rock; sandstone; and red beds and greenish-gray beds in the rocks of Phosphoria age, that is the rocks of Permian age overlying the lower member of the Park City formation and Weber sandstone--is shown by means of a map based on a ternary diagram (fig. 7) for which the end members are (1) phosphorite, chert, and carbonaceous mudstone, (2) carbonate rock, and (3) sandstone. The relationship of the red beds and greenish-gray beds to the other components is shown by isopachs of the total thickness of red beds and greenish-gray beds within the Park City formation.

The proportion of phosphorite, chert, and carbonaceous mudstone to carbonate rock and sandstone decreases from north to south in the western part of the area. In the north and northwest, the proportion of phosphorite decreases to the east so that the lines separating the various lithologies form an arcuate pattern around a central area in northernmost Utah and adjacent parts of Idaho and Wyoming where the rocks of Phosphoria age consist of phosphorite, chert and

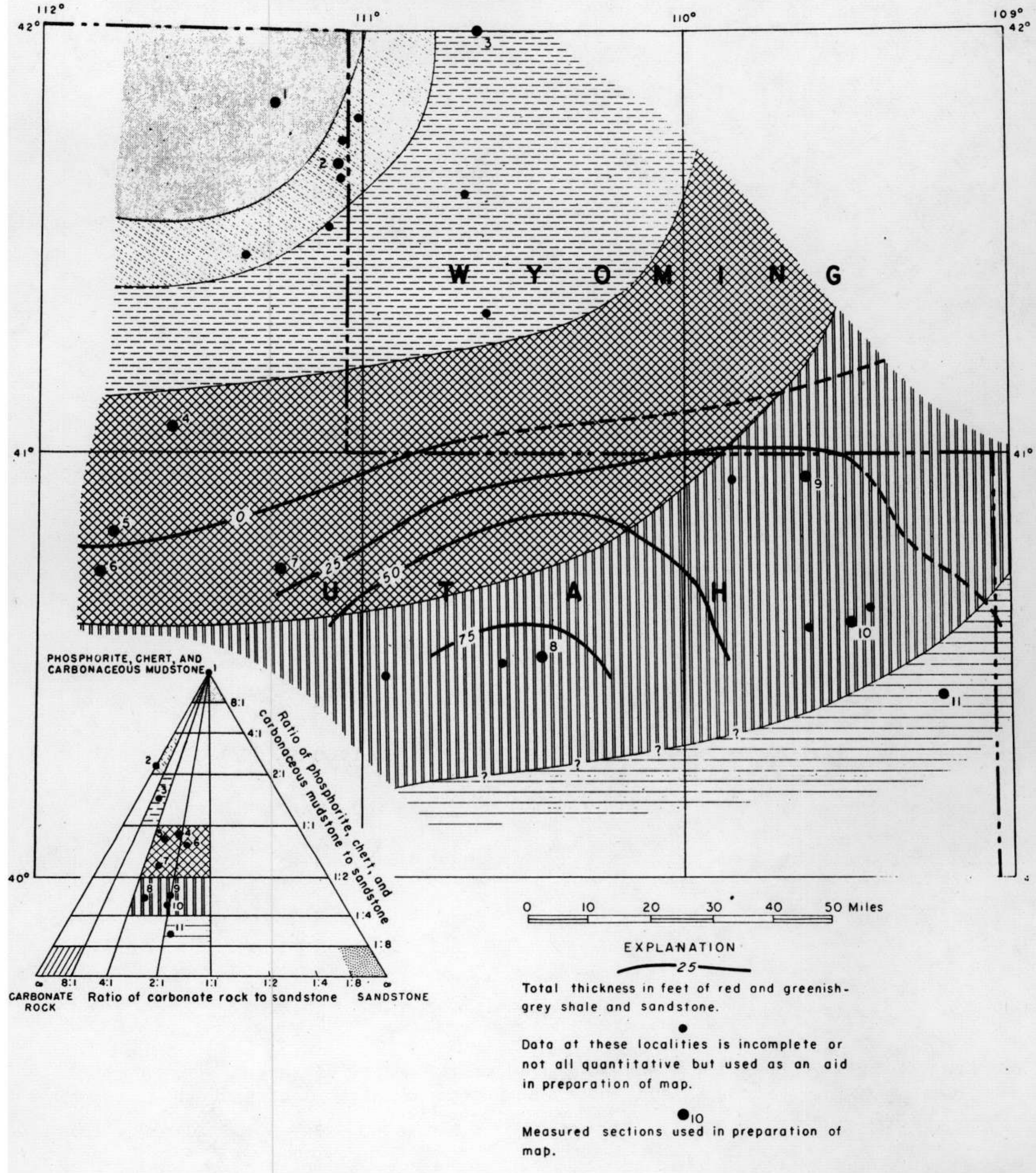

FIGURE 7. Map showing the areal variation in lithology of the combined Phosphoria formation, Franson member of the Park City formation, and Mackentire tongue of the Woodside formation of Thomas (1939) in eastern Utah and southwestern Wyoming.

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carbonaceous mudstone. The ratio of carbonate rock to sandstone decreases in the same directions as the ratio of combined carbonaceous mudstone, chert, and phosphorite to carbonate rock and sandstone. Sandstone is most abundant in the southwestern and northeastern sections. The red beds and greenish-gray beds are thickest in the south-central part of the area and thin to the north, east, and west.

According to Kummel (1954, p. 168), the direction of the change in lithology of the overlying rocks of Early Triassic age is nearly parallel to that outlined above.

Park City formation

The Park City formation at its type locality in Big Cottonwood Canyon near Salt Lake City, Utah, consists mostly of carbonate rock, some of which is cherty and calcareous sandstone. At the type locality the Park City formation is made up of a lower member and an upper member, designated as the Franson member by Cheney (in McKelvey, and others, 1956), separated by the Meade Peak phosphatic shale tongue of the Phosphoria formation. These two members are described below:

Lower member of the Park City formation

A typical section of the lower member of the Park City formation was described by Cheney (in McKelvey, and others, 1956) from exposures near the mouth of Mill Creek Canyon near Salt Lake City, Utah. At this locality the lower member is dominantly carbonate rock and carbonatic sandstone. Chert is relatively abundant as nodules and stringers, especially in the carbonate rock, although some beds of sandstone near the top of the unit contain abundant layers of chert nodules. Phosphate is present as thin beds of pelletal phosphorite and as internal casts of small gastropods in a distinctive shaly, carbonaceous, argillaceous carbonate rock unit 35 feet thick, 50 to 75 feet above the base of the member. Phosphatic brachiopod or fish scale fragments are found in several beds, each about 0.1 feet thick in the upper third of the member. (See the Fort Douglas and Devils Slide sections, pl. 1.)

The lower contact of the lower member is at the horizon above which carbonate rock and cherty carbonate rock are dominant and below which the sandstones or quartzites characteristic of the Weber quartzite, Diamond Creek sandstone, or Wells formation are the dominant lithologies. At the type locality a thick layer of limestone, 20 to 50 percent of which is composed of calcareous fossils and fossil fragments, constitutes the basal bed of the lower member. The upper contact is at the horizon above which the soft, dark brown to black carbonaceous mudstone and phosphate rock of the Meade Peak phosphatic shale member are dominant. The beds immediately underlying the Meade Peak member are cherty, calcareous sandstone or coarse siltstone or cherty carbonate rock.

The lower member of the Park City formation attains a maximum thickness of about 880 feet in the southern Wasatch Mountains (Baker, and others, 1949, p. 1188) where it consists mostly of carbonate rock, some beds of which are cherty or sandy, and calcareous sandstone.

In the central Wasatch Mountains at Fort Douglas (pl. 1), a few miles north of the type locality, the member is 290 feet thick and is composed of carbonate rock and carbonatic mudstone, much of which contains coarse silt and cherty carbonate rock. Sandstone beds at the type locality are generally coarse silt beds at Fort Douglas. At Devils Slide (pl. 1) the member is about 330 feet thick. The upper part of the member is similar to that at Fort Douglas; it consists of cherty carbonate rock and carbonatic mudstone containing a few thin phosphatic beds. The lower part of the member at Devils Slide is mostly thick to massive bedded gray carbonate rock. The distinctive shaly black carbonaceous, argillaceous carbonate rock unit which contains thin phosphate beds at Fort Douglas and at the type locality in Mill Creek Canyon is not present at Devils Slide. In the northern Wasatch area the lower member is 60 to 75 feet thick and is dominantly cherty carbonate rock.

The lower member thins and becomes more sandy eastward from the central Wasatch Mountains. It is not present on the south flank of the Uinta Mountains east of Lakefork (fig. 1). In this area the Meade Peak phosphatic shale tongue of the Phosphoria rests directly on sandstone of the Weber quartzite.

Franson member of the Park City formation

The Franson member of the Park City formation was named (Cheney in McKelvey and others, 1956) from exposures in Franson Canyon, Utah (fig. 1) where the member is 245 feet thick and is composed, in decreasing order of abundance, of carbonate rock, sandy carbonate rock, and calcareous sandstone (pl. 2). It overlies the Meade Peak phosphatic shale tongue of the Phosphoria formation and is overlain conformably by the Woodside formation of Triassic age. The Franson intertongues northward and westward with the Meade Peak, Rex, and Tosi members of the Phosphoria formation. Eastward and southward it intertongues with the Woodside formation.

Northern Wasatch Mountains.--In the northern Wasatch Mountains, which includes the Crawford Mountains for the purposes of this report (fig. 1), the Franson member of the Park City formation intertongues with the Rex and Tosi chert members of the Phosphoria formation (pl. 1). It wedges out between Brazer Canyon and Laketown (fig. 5) where the Rex chert and Retort phosphatic shale members make up the equivalent interval. In the Crawford Mountains, the Franson is split into two parts by the Tosi chert tongue.

The lower part of the Franson member at Brazer Canyon (pl. 1) is 130 feet thick and consists mainly of light gray and medium gray dolomite and minor amounts of cherty limestone. The chert occurs as nodules and stringers that both parallel and cut the bedding planes. The lower contact of the member at Brazer Canyon is at the top of a thin nodular phosphate bed that lies between the massive chert beds of the Rex chert member of the Phosphoria formation and the overlying carbonate rock. The upper part of the Franson member is approximately 15 feet thick at Brazer Canyon, where it is a thick-bedded to massive, slightly argillaceous, abundantly fossiliferous limestone. The majority of the fossils are bryozoans, brachiopods, and fragments of crinoid stems. Many of the brachiopods probably belong to the *Punctospirifer pulcher* fauna described by Girty (Mansfield, 1927, p. 79; J. E. Smedley, written communication, 1953).

The Dinwoody formation of Triassic age overlies this upper fossiliferous limestone unit of the Franson with apparent conformity.

Central Wasatch Mountains.--The Franson member intertongues with the Meade Peak phosphatic shale and Rex chert tongues of the Phosphoria formation in the central Wasatch Mountains (pl. 1 and figs. 1 and 5).

The lower tongue of the Franson, 60 to 100 feet thick, splits the Meade Peak into two parts. At Devils Slide the lower part of the Franson is composed of soft light brownish-gray fine-grained quartz sandstone. Further south, as at Mill Creek and Fort Douglas, the lower 15 to 35 feet of the tongue is quartz sandstone; overlying this is a bed, 5 to 15 feet thick, composed of angular fragments, as much as 3 feet in diameter, of carbonate rock, sandstone, and chert. The upper 40 to 50 feet of the tongue is light gray, thin- and thick-bedded carbonate rock; stringers of phosphorite are present near the top of this unit.

The main body of the Franson member overlies the Rex. This part of the Franson is 220 to 240 feet thick and is composed of carbonate rock, cherty carbonate rock, and calcareous sandstone. (See Fort Douglas and Devils Slide, pl. 1 and fig. 5.) As in the northern Wasatch Mountains, the uppermost 20 to 30 feet of the member is abundantly fossiliferous.

The Woodside formation, which overlies the Franson member of the Park City formation in this area, is generally described as consisting largely of red beds; nevertheless, at Fort Douglas and at the type locality of the Park City formation (Boutwell, 1907) a thin possibly discontinuous unit of light greenish-gray shale lies beneath the typical Woodside and rests with apparent conformity on the Franson member of the Park City formation. A similar unit, approximately 190 feet thick and composed of greenish-gray shaly argillaceous limestone interbedded with massive light gray and light grayish-brown, fossiliferous carbonate rock, overlies the Franson member at Devils Slide. There are thin layers of nodular chert in the lower 50 feet of this unit. Some of this shaly unit, which was included in the Park City formation by Eardley (1944, p. 834), may be equivalent to parts of the Franson member elsewhere in the area. However, this unit differs in lithology from the Park City formation and is more similar to the lower part of the Dinwoody formation described to the north by Kummel (1954, p. 169), so it is not included in the Park City formation.

The columnar section of the Franson at Devils Slide (pl. 1) is a composite section measured on both sides of the Weber River Canyon; hence, it may not be entirely correct in detail. The section of the Franson member at Fort Douglas (pl. 1) was measured from poor exposures. Except for the uppermost bioclastic limestone unit, no correlation is shown within the Franson between these two sections or between Devils Slide and Brazer Canyon.

Southern Wasatch Mountains.--The Franson member is mainly carbonate rock and calcareous sandstone in the southern Wasatch Mountains (fig. 1). It ranges in thickness from 600 feet at Strawberry Valley (pl. 1) to 830 feet at Hobble Creek (Baker, and others, 1949, p. 1189). The increase in thickness of the Franson from the central Wasatch area to the southern Wasatch area is abrupt and coincides with the Charleston fault (fig. 1).

At both the Strawberry Valley and the Right Fork of Hobble Creek localities the uppermost beds of the member, similar lithologically, contain abundant bryozoans, brachiopods, and other fossil fragments which at the Right Fork of Hobble Creek are typical of the *Punctospirifer pulcher* fauna (Williams, J. Steele, oral communication, 1954).

The Woodside formation unconformably overlies the Franson member of the Park City formation in part of the southern Wasatch Mountains (Baker and Williams, 1940, p. 624). At Strawberry Valley, however, the contact between the Woodside formation and Franson member is gradational.

Uinta Mountains.--The westernmost exposures of the Franson member in the Uinta Mountains (fig. 1) are at Franson Canyon (pl. 2), the type locality, where the member may be divided into three lithologic units. The lowest of these units is 75 feet thick and consists mostly of light gray and grayish-brown carbonate rock and minor amounts of sandy carbonate rock and calcareous sandstone. Chert as nodules, stringers, and beds is most abundant in the upper third of the unit. The lowermost bed of the unit contains abundant fragments of phosphatic inarticulate brachiopod shells. The middle unit is 70 feet thick and consists of light-gray and brownish-gray carbonate sandstone, some chert, and two thin beds of phosphate rock. The upper unit is 80 feet thick and is dominantly white and light-gray carbonate rocks; however, the most argillaceous beds in the lower 40 feet are reddish-brown, and many of the carbonate beds in the upper 40 feet contain abundant fossils and fossil fragments, some of which are phosphatic casts of bryozoans and possibly echinoid fragments. The reddish-brown beds are probably laterally continuous with parts of the Mack-entire tongue of the Woodside formation (fig. 6 and pl. 2). The contact with the Woodside formation is conformable.

A few beds of the uppermost fossiliferous unit contain Punctospirifer, Productids, and other types of brachiopods (J. E. Smedley, oral communication). This upper unit is lithologically similar to and is considered to be an extention of the fossiliferous limestone unit that is found at the top of the Park City formation at the localities to the west and north. Because of its unique lithologic characteristics and because it occurs at only this one stratigraphic position, immediately underlying the Triassic Woodside and Dinwoody formations, the limestone may represent nearly synchronous deposition over the entire area.

At Wolf Creek, southeast of the type area, the Franson member is only 125 feet thick. However, the lower part of the overlying red beds, mapped as Woodside shale by McCann (*in* Huddle and McCann, 1947), contain several carbonate rock beds that are similar lithologically to the carbonate rocks of the Franson member. Fossils from some of these beds were identified by James Steele Williams as of probable Permian age (Huddle, written communication, 1954). Therefore, the lower part of the Woodside formation in the vicinity of Wolf Creek (pl. 2) probably is laterally continuous with and equivalent to beds of the Franson member at Franson Canyon. The lithology of the lower part of the Woodside formation and the tongues of the Franson member are not shown on plate 2 because this part of the section has not been described in detail. At the sections measured east of Wolf Creek, on both flanks of the Uinta Mountains, the Franson member is divisible into a lower and upper carbonate rock unit separated by the Mackentire tongue of the Woodside formation (pl. 2).

At most localities in the Uintas the contact between the Meade Peak phosphatic shale member of the Phosphoria formation and the lower unit of the Franson member of the Park City formation is gradational. The lower unit attains a maximum thickness of 150 feet at Lakefork and decreases to a minimum thickness of about 40 feet at Split Mountain. Carbonate rock is dominant lithologically, although chert as nodules forms a characteristic part of the unit, as does calcareous sandstone, which generally occurs only in the upper 5 to 15 feet of the unit. At some localities this sandstone is conglomeratic.

The upper carbonate rock unit of the Franson member is 60 feet thick at Lakefork and 35 feet thick at Little Brush Creek, the easternmost section at which this upper unit can be identified. It is not present at Split Mountain (fig. 6). East and south of Little Brush Creek it presumably grades laterally into the light greenish-gray shales and brownish-gray mudstone and red beds of the lower part of the Woodside formation of Thomas (1939). Lithologically the upper unit of the Franson member is similar to the lower unit as it is composed chiefly of light colored carbonate rock, but it characteristically contains thin beds of cherty carbonate rock and some calcareous sandstone (pl. 2). The thinning of the unit and consequently much of the thinning of the Franson as a whole is thought to be due to lateral gradation to the south and east of the upper part of the member into the lower part of the Woodside formation.

At Split Mountain, the southeasternmost locality observed, the Franson member is only 39 feet thick. The Franson there corresponds to the lower unit of the member to the northwest. At this locality the greenish-gray sandstones and yellowish-orange calcareous mudstones that overlie the Park City formation are included with the Woodside formation.

Phosphoria formation

The Phosphoria formation at its type locality in Phosphoria Gulch near Georgetown, Idaho, consists of phosphatic and cherty shales and chert. The tongues and members of the Phosphoria formation that extend into the area of this report (fig. 1) are the Meade Peak phosphatic shale, Rex chert, Tosi chert and Retort phosphatic shale (McKelvey and others, 1956) (figs. 5 and 6) and are described in the following pages.

Meade Peak phosphatic shale member of the Phosphoria formation

The phosphatic shale member of the Phosphoria formation was recently named the Meade Peak phosphatic shale member of the Phosphoria formation by McKelvey (McKelvey and others, 1956) from exposures near Meade Peak, Idaho, where the member is about 200 feet thick and is composed dominantly of phosphate rock, carbonaceous mudstone, and mixtures of these two types. In Utah, the Meade Peak phosphatic shale member is composed mainly of dark colored phosphate rock, mudstone, carbonate rock, and intermixtures of these types, although mixtures of phosphate and carbonate are not common (pl. 1 and 2). Minor quantities of chert, generally as nodules, and quartz sandstone are present at some localities. The member characteristically is soft, thin-bedded, and brown to black. The dark color probably is due to the high content of carbonaceous material, because as much as 16 percent is present in some beds at Brazer Canyon. Generally, the Meade Peak is unexposed and characteristically forms a covered slope or saddle.

The upper and lower contacts (pl. 1 and 2) are generally placed at the break between the soft, brown or black, phosphatic carbonaceous mudstones and the more resistant, light-colored chert, carbonate rock and sandstone of the overlying and underlying units.

The member attains a maximum thickness of 220 feet at Fort Douglas. It thins to the east and south and is absent at Split Mountain (figs. 5, 6, and 8 and pl. 2). The regional and local variations in thickness and lithology are discussed in more detail in the following pages.

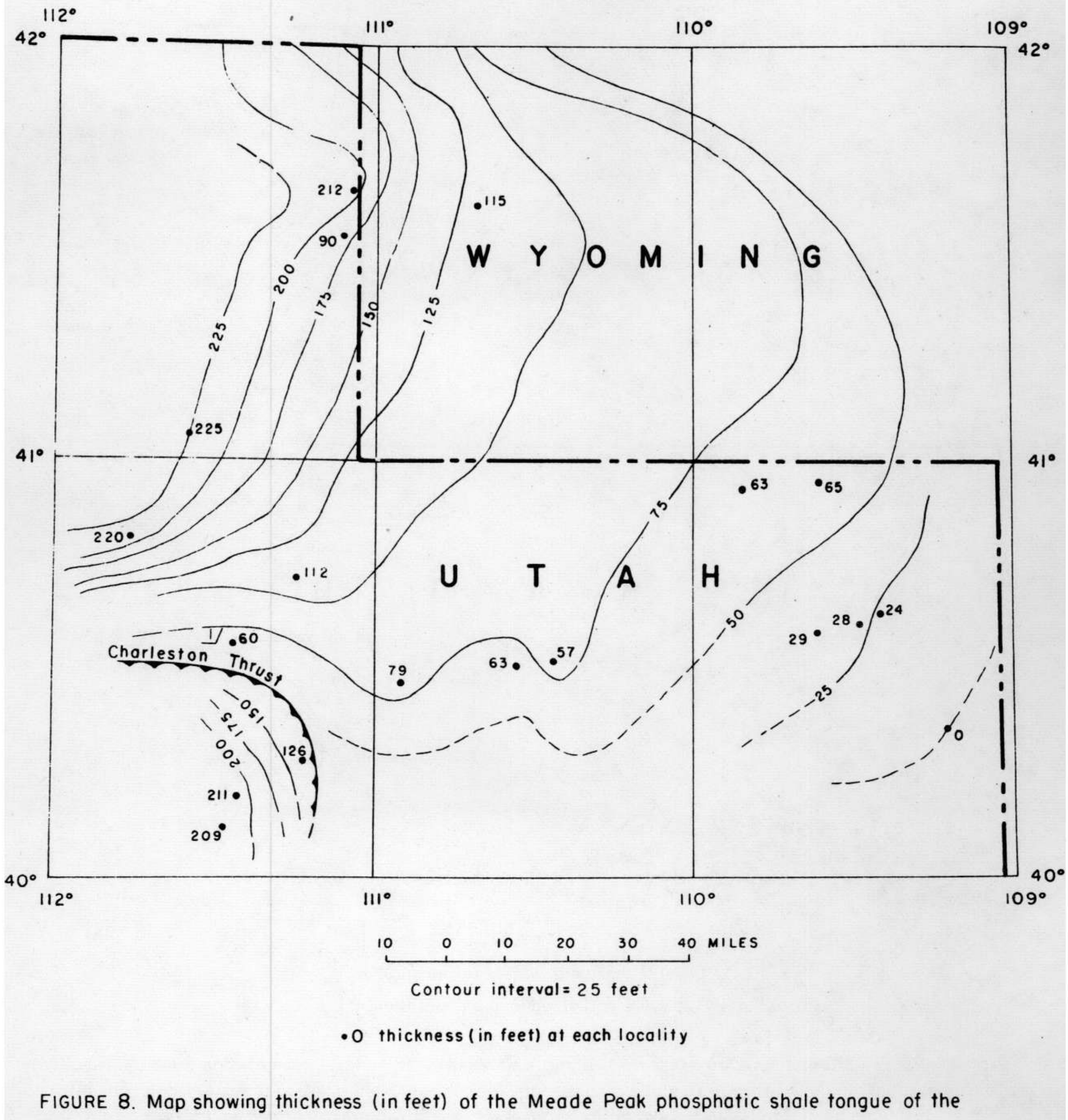

FIGURE 8. Map showing thickness (in feet) of the Meade Peak phosphatic shale tongue of the Phosphoria formation. 1/ Faucett Canyon, (Baker et al., 1949, p. 1190).

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Northern Wasatch Mountains.--In the northern Wasatch Mountains (fig. 1), the Meade Peak phosphatic shale member is 180 to 225 feet thick (fig. 5 and pl. 1). It is divisible into many relatively thin units that have been correlated northward into western Wyoming (McKelvey, 1946). In ascending order, the major zones in the Meade Peak are: 1) 40 feet of medium gray to black thin- to thick-bedded hard carbonate rock interbedded with a few thin beds of dark gray to black carbonatic phosphate rock; the basal 5 feet of this unit is mudstone, at the base of which is the "fish scale" bed that marks the base of the Meade Peak in this area and in southeastern Idaho; 2) 20 to 25 feet of argillaceous phosphate rock and mudstone; 3) 25 feet of brownish-gray thick-bedded carbonate rock and mudstone; 4) 30 feet of brownish-black and brownish-gray, thin- to thick-bedded, interbedded argillaceous phosphate rock and carbonate rock; 5) 4 to 5 feet of black carbonaceous vanadiferous mudstone which is separated from the overlying and underlying zones by beds of fossiliferous carbonate rock 1 to 2 feet thick; 6) 15 to 20 feet of brownish-black and black thin- to thick-bedded, interbedded dolomitic mudstone and argillaceous phosphate rock; 7) 2 to 15 feet of dark brownish-gray thin-bedded, laminated, slightly silty chert composed dominantly of siliceous sponge spicules; 8) 31 feet of dominantly dark gray to black, thin-bedded pelletal phosphate rock; 9) in some places a shaly thin-bedded mudstone up to 34 feet thick overlies the uppermost phosphate zone.

All of the above mentioned zones may be traced through the Crawford Mountains, with the exception of the southernmost area of outcrops. In the latter area, the Meade Peak is approximately 90 feet thick; although the upper phosphate unit is similar to the upper unit further north (pl. 2), the lower part of the member is dominantly dark colored carbonate rock and is much thinner (McKelvey, 1946, pl. 3)_/. Possibly part of the strata has been faulted out, but better

_/ McKelvey, V. E., 1946, Preliminary report on stratigraphy of phosphatic shale member of the Phosphoria formation in western Wyoming, southeastern Idaho, and northern Utah: U. S. Geol. Survey Open File report.

exposures than are now available are needed to evaluate this.

Central Wasatch Mountains.--The Meade Peak is 60 (Baker, and others, 1949, p. 1188) to 225 feet thick in the central Wasatch Mountains. It consists of an upper and a lower phosphatic shale split by a carbonate rock and sandstone tongue, 60 to 100 feet thick, of the Franson member of the Park City formation.

The lower phosphatic shale unit is 60 to 150 feet thick and is composed mainly of dark brown and black thin-bedded soft argillaceous phosphate rock, dark brownish-gray thin-bedded carbonatic mudstone, and light brownish-gray and dark gray massive argillaceous carbonate rock. The lower contact of the lower phosphatic shale unit is placed at the base of an argillaceous, slightly sandy, phosphate rock 1 to 3 feet thick. The lower 30 to 50 feet of this unit is black and brownish-gray argillaceous phosphate rock interbedded with brownish-gray argillaceous, phosphatic carbonate rock, and phosphatic carbonaceous mudstone. Most of the strata above are dark colored carbonate rocks or carbonatic mudstones. The uppermost beds contain abundant chert-coated calcite geodes and a few thin discontinuous nodular layers of phosphate rock.

The upper phosphatic shale unit, 60 to 80 feet thick, is thin-bedded, dark gray and black, phosphatic mudstone, argillaceous carbonate rock and argillaceous phosphate rock. The contact with the underlying tongue of the Franson is marked by a thin bed of nodular and pelletal phosphate rock. The upper contact is placed at the base of the chert of the Rex member. This upper phosphatic shale thins and feathers out rapidly to the south for at Mill Creek it is represented by only a few thin nodular phosphorite beds (pl. 1).

The upper phosphatic unit in the central Wasatch Mountains is probably laterally continuous with the upper phosphate at Brazer Canyon in the northern Wasatch Mountains. The underlying sandstone and carbonate rock tongue of the Franson probably is laterally continuous with the chert bed at Brazer Canyon; a similar facies change from spicular chert to sandstone has been demonstrated in a number of areas in Montana (Cressman, 1955) and Wyoming (R. P. Sheldon, 1954, oral communication). The lower part of the Meade Peak at Devils Slide and Fort Douglas probably is laterally continuous with most of the unit underlying the chert at Brazer Canyon; however, at Devils Slide the upper part of the lower member of the Park City, in which thin phosphate beds are present, probably is equivalent to the lowermost 40 feet of the Meade Peak phosphatic shale member at Brazer Canyon (fig. 5 and pl. 1).

Southern Wasatch Mountains.--The Meade Peak phosphatic shale tongue in the southern Wasatch Mountains (fig. 1) is 160 to 215 feet thick and is composed mostly of grayish-brown to black, thin- to thick-bedded calcareous mudstone, cherty mudstones, and phosphatic mudstone. Chert forms thick beds at Strawberry Valley (pl. 1), but to the west at the Right Fork of Hobble Creek and Wanrhodes Canyon only a few thin beds of chert are present. At the head of Little Diamond Creek the base of the tongue is marked by a bed of argillaceous, slightly sandy phosphate rock about 5 feet thick, which, with the exception of a few beds less than 1 foot thick at other localities, is the most phosphatic bed in the southern Wasatch area.

The correlation presented on plate 1 from Fort Douglas to Strawberry Valley is that established by Baker and Williams (1940, p. 543).

Uinta Mountains.--The Meade Peak thins from 225 feet at Fort Douglas to 122 feet at Franson Canyon in the western Uinta Mountains, a distance of only 20 miles. From Franson Canyon the tongue thins gradually to the east and south and is absent at Split Mountain near Vernal (fig. 8).

In the western part of the Uinta Mountains between Lakefork and Franson Canyon, and on the northeast flank of the Uinta Mountains, the tongue is divisible into three easily recognizable but gradational units (pl. 2). In ascending order these are: black carbonaceous soft phosphatic mudstone 10 to 20 feet thick, the base of which is generally phosphatic sandstone or sandy phosphate rock; dark-gray to black medium-hard thin- to thick-bedded argillaceous carbonate rock and carbonatic mudstone (much thinner at Horseshoe Canyon than further west); and light greenish-gray and gray, thin-bedded hard cherty carbonate rock and cherty mudstone that contain numerous lenses and beds of phosphatic mudstone. Much of the phosphate in this upper unit is as internal casts of small gastropods, pelecypods, and ostracods; although this type of phosphate is known elsewhere in the western phosphate field, it occurs in greatest known quantities in this zone in the Uinta Mountains.

The Meade Peak is 23 to 29 feet thick in the southeastern Uinta Mountains as at Brush Creek, Dry Canyon, and Little Brush Creek and is absent at Split Mountain (figs. 6 and 8, and pl. 2). The lower part of the member is composed mostly of thin-bedded light gray to grayish-brown, pelletal phosphate rock and subordinate amounts of mudstone. The upper part of the member is thin-bedded soft to medium-hard argillaceous phosphate rock and hard, thin- and nodularly bedded, cherty limestone; most of the phosphate is in internal casts of small pelecypods and gastropods. On the basis of lithologic resemblances, the upper and lower units are tentatively correlated with the upper and lower units of the Meade Peak in the western Uintas. The middle unit (argillaceous carbonate rock) of the Meade Peak in the western Uintas thus is thought to have no counterpart, or at most a very thin one, in the southeastern Uintas (pl. 2).

The Meade Peak in the Uinta Mountains probably represents only the lower shale unit described in the central Wasatch Mountains (fig. 6). The thin phosphorite beds in about the middle of the Franson member at Franson Canyon (pl. 2) are probably feather edges of the upper part of the Meade Peak.

Rex chert member of the Phosphoria formation

The Rex chert member as redefined by McKelvey (McKelvey and others, 1956) is present in most of the northern Wasatch Mountains area, where it overlies the Meade Peak. At Brazer Canyon (pl. 1) the Rex is 55 feet thick and consists of light grayish-brown, thin- to thick-bedded, hard chert and a few thin discontinuous beds of carbonate rock. The Rex is overlain by the Franson member, except at Laketown where the Rex is about 200 feet thick. There it is overlain by about 4 feet of phosphatic shale that may be a thin equivalent of the Retort phosphatic shale member of the Phosphoria formation.[/] This phosphatic

[/] The Retort is the uppermost phosphatic shale unit of the Phosphoria formation in Montana and Wyoming. It is not laterally continuous with the Meade Peak phosphatic shale member (McKelvey and others, 1956).

shale is overlain by the Dinwoody formation of Triassic age.

In the central Wasatch Mountains a thin chert unit, 6 feet thick at Devils Slide and 30 feet thick at Fort Douglas (pl. 1), that overlies the Meade Peak phosphatic shale member has been tentatively called the Rex chert tongue. The Rex is not known to be present elsewhere in the area of this report.

Tosi chert member of the Phosphoria formation

The Tosi chert member of the Phosphoria formation was described by Sheldon (<u>in</u> McKelvey, and others, 1956) from exposures near Tosi Creek, Wyoming. A tongue of the Tosi extends south to the Crawford Mountains. At Brazer Canyon (pl. 1), it is 30 feet thick and is composed of thin-bedded hard dark gray to black chert typical of the Tosi at its type locality. The lower contact of this member is placed beneath a thin nodular phosphate bed which occurs between the chert and carbonate rock. The upper contact is placed at the base of the carbonate rock of the upper part of the Franson member. The Tosi is not present west or south of the South Crawford section (pl. 1).

Mackentire tongue of the Woodside formation

The Mackentire tongue of the Woodside formation was first named by J. Stewart Williams (1939, p. 91) as a tongue of the Phosphoria formation from exposures in Mackentire Draw near the Lakefork River. (See Lakefork locality, pl. 2.) Thomas (1939, p. 1249) later redefined the Mackentire as a tongue of the Woodside formation. The use of the term "Mackentire tongue" has not been adopted by the U. S. Geological Survey.

At the type locality the Mackentire is 105 feet thick and at Little Brush Creek, the easternmost locality at which it has been identified, it is 35 feet thick (fig. 4). It changes from dominantly soft, reddish-brown, calcareous sandstone and siltstone at the type locality and in the central part of the Uinta Mountains to dominantly greenish-gray and dark yellowish-orange calcareous sandstones and siltstones in the eastern part of the Uinta Mountains, as at Horseshoe Canyon (for location see fig. 1) and Little Brush Creek (pl. 2). A bed of anhydrite 3.0 feet thick is also present at Horseshoe Canyon (fig. 1). The Mackentire tongue is thought to be continuous over the area for the following reasons. No more than one major red beds unit was found at any of the localities visited, and it is everywhere present as a tongue near the middle of the Franson member. The thickness and lithology of the tongue changes east, west, and north of this central portion of the Uinta Mountains, but both the thickness and lithology are nearly the same at any longitude on both flanks of the mountains. In addition, it can be traced in outcrop eastward along the north flank of the Uinta Mountains from the western end of the outcrop (fig. 1)--a locality at which the Mackentire is similar in thickness and lithology to that at Lakefork. That is, it is about 60 feet thick and wholly red beds. These red beds become thinner or pinch out to the east so that in the vicinity of Horseshoe Canyon (fig. 1) the unit is dominantly greenish-gray beds though lenses of red beds (Anderman, G. A., oral communication, 1955) and some anhydrite beds are present. The Mackentire is nearly the same character in the Little Brush - Brush Creek area 15 miles south of Horseshoe Canyon.

PHOSPHATE DEPOSITS IN UTAH

The only phosphate deposits that are being mined in Utah are the sedimentary deposits in the Meade Peak phosphatic shale member of the Phosphoria formation. Minable deposits of acid-grade phosphate are known only in the northern Wasatch Mountains; within this area phosphate is being mined only in the Crawford Mountains. Large reserves of furnace-grade rock are present in the Meade Peak member on the south flank of the Uinta Mountains near Vernal, Utah. The known phosphate deposits in the black shale at the base of the Brazer limestone and its partial equivalent, the Deseret limestone, are too low grade to be minable now or in the near future.

The phosphate deposits in Utah have been the subject of several early investigations by the U. S. Geological Survey and various private geologists (Gale and Richards, 1910; Jones, 1907, 1913; Blackwelder, 1910). The data available previously have been summarized and analyzed by J. Stewart Williams (1939) and Williams and Hanson (1942).

Because the latter two reports cover the subject previous to our investigations, this report on the phosphate deposits in Utah is based in general only on the data contained herein, in Smith and others, (1952), Cheney and others (1953), and in Swanson and others (1956). The discussion will be restricted to the areal distribution, vertical distribution, and character of the phosphate deposits with emphasis on the regional relationships. The details of accessibility and structure are discussed briefly only in those areas where it appears likely that phosphate will be mined in the near future.

Besides phosphorus, at least 40 elements have been identified in the Meade Peak (McKelvey, 1949, p. 52). Some of these elements, such as vanadium and selenium, are in both phosphatic and nonphosphatic beds, though more highly concentrated in the nonphosphatic carbonaceous mudstone; however, fluorine and uranium are mainly in phosphorite beds; and others, such as nickel, molybdenum, silver, and chromium, are concentrated chiefly in nonphosphatic beds. The highest grade deposits of vanadium in the Meade Peak phosphatic shale member in Utah are in the northern Wasatch Mountains area, and a brief discussion of its occurrence is given by McKelvey (1946).

Mineralogy and petrography

The phosphorites are marine sedimentary deposits. The phosphate in the Meade Peak phosphatic shale member is in the mineral carbonate-fluorapatite (Altschuler, and others, 1953, p. 9; Silverman, and others, 1952). Commonly, the mineral is submicrocrystalline and isotropic, but it also occurs in a crystalline anisotropic form. The first variety is frequently termed collophane, the second francolite (Lowell, 1952, p. 13-14).

The carbonate-fluorapatite occurs, in decreasing order of abundance, as structureless pellets and nodules, fossils and fossil fragments, oolites and pisolites, and as a cementing material in rocks generally composed, at least partially, of other forms of carbonate-fluorapatite. Most of the phosphate is pelletal, and most of the pellets are from 1/8 to $1\frac{1}{2}$ mm in size. The color of the pellets ranges from light brownish-gray to black. The darker colors are probably due to a larger amount of contained organic matter. In the eastern part of the Uinta Mountains, where the organic content of the member is low, the phosphate grains are light brownish-gray; and in the northern Wasatch Mountains, where the organic content is relatively high, most of the phosphate grains are dark gray or black. Most of the nodules are structureless, but some are aggregates of pellets or oolites or both. Pelletal carbonate-fluorapatite forms the greater part of all the economically important phosphate deposits.

The phosphate in fossiliferous material is the second most abundant form of carbonate-fluorapatite in Utah. Fish scales, bone fragments, fish teeth, and fragments of inarticulate brachiopods--materials that were phosphatic during the life of the organism--make up some beds; but internal casts of small gastropods, pelecypods, and other fossil material that was originally nonphosphatic, are also a common form of phosphate, especially in the Uinta Mountains area. In general the originally phosphatic fossil material is translucent light brownish-gray or light gray, and it commonly has a resinous appearance in hand specimen. The originally nonphosphatic fossil material is generally pale brown in color, and most of it ranges from 1-10 mm in size. Rarely does the phosphatic fossil material form beds thick enough to be of economic importance except when combined with other types.

Oolitic and pisolitic phosphates are common only in the northern Wasatch Mountains in Utah. The oolites are generally subelliptical and generally range in size from 1/8 to 1 mm, though pisolites as large as 5 mm in diameter have been found. No commercial deposits of oolitic phosphorite are known in Utah, although as mixtures with the other two major types it forms an abundant characteristic part of the acid-grade deposits in the northern Wasatch area.

Phosphate rock, which as used herein means any rock in which carbonate-fluorapatite is the dominant mineral, is generally dark gray to black, or dark brownish-gray to brownish-black, thick bedded, soft to moderately hard. In the eastern part of the Uinta Mountains, however, the phosphate rocks are generally light brownish gray to brownish gray and some have a greenish cast. A bluish-white bloom characteristically develops on the weathered surface of acid-grade phosphate rocks.

Phosphate rocks are mixtures of carbonate-fluorapatite, quartz as silt and sand, carbonate as calcite or dolomite, clay, mica, minor amounts of feldspar, and carbonaceous matter. The most common of these mixtures is carbonate-fluorapatite with clay and silt. Phosphatic sandstone or sandy phosphate rock is common only in the basal beds of the Meade Peak in the Uinta Mountains and central Wasatch Mountains. Phosphatic carbonate rock is uncommon except in the upper part of the Meade Peak in the Uinta Mountains where phosphate (mainly as internal casts of small fossils), chert, and carbonate are the chief rock-forming materials. The pelletal, oolitic, and nodular phosphate rocks are interbedded chiefly with dark colored carbonaceous mudstone, or calcareous mudstones. The bioclastic phosphorite is mainly interbedded with light colored cherty and argillaceous carbonate rocks. The beds range from laminae less than 1 mm to several feet in thickness but are generally between 0.5 and 1.5 feet thick.

An economically important characteristic of the phosphorite deposits is the lateral continuity of the phosphate and associated beds over large areas. For example, individual beds in the Meade Peak phosphatic shale member have been traced for more than 100 miles (McKelvey, 1949, p. 275). Beds can generally be traced many miles farther parallel to facies strike than they can be traced normal to facies strike. The grade and thickness of the phosphate beds, that can be traced over large areas, change; but within a mine or an area the size of the Crawford Mountains (fig. 1) the grade and thickness generally remain relatively constant except where the strata are markedly affected by post-depositional changes. Therefore, fairly safe predictions as to the grade and thickness of beds may be made in a mining district, but the errors in prediction will increase with size of the area and the distance between control points. Partly because of the large distance between measured sections and partly because one must trace units across facies strike (fig. 7), no individual beds can be traced from the northern to the southeasternmost part of the area of this report; however, some beds can be traced long distances (pls. 1, 2, and 3).

To facilitate the following discussion of the phosphate deposits, the phosphate rocks have been categorized as follows: 1) Acid-grade phosphate rock, which contains over 31 percent P_2O_5 (about 80 percent carbonate-fluorapatite)--generally is used in the manufacture of super and triple super phosphate fertilizers by acidulation; 2) furnace-grade phosphate rock, which contains between 24 and 31 percent

P_2O_5--generally is used in the manufacture of elemental phosphorus by the electric furnace method; and, 3) low-grade rock, which contains less than 24 percent P_2O_5 and cannot be used in current processes without beneficiation. A general discussion of the current methods of processing phosphate rock is given by Waggaman and Bell (1950).

A thickness of about 3 feet of acid-grade rock is now being mined in one part of the western phosphate field, and this is generally accepted as the minimum thickness of acid-grade rock that can be mined profitably if the beds are steeply inclined. Probably 4 feet of acid-grade rock is a more acceptable minimum especially for flat or gently dipping beds. About 12 feet of furnace-grade rock is the minimum thickness of this type rock now being mined, but under optimum conditions 5 feet of furnace-grade rock might support a competitive operation.

Enrichment of phosphorites by weathering

The effect of weathering on the P_2O_5 content of a given bed is an important factor, often overlooked, affecting the value of any phosphate deposit. Peterson pointed out in 1914 (p. 756) that "the amount of phosphate may decrease with depth owing to the leaching of the less[/] soluble constituents and the concentration of phosphoric

[/] It seems the word "less" is a misprint and should read "more."

acid in the leached zone." This weathering and consequent enrichment of phosphate is discussed briefly by Mansfield (1927, p. 217) and McKelvey, and others (1953, p. 4). According to L. D. Carswell of the U. S. Geological Survey, data gathered by some of the western phosphate mining companies indicate that the P_2O_5 content of a high-grade phosphate bed may decrease by as much as 5 percent 500 feet below the outcrop. For example, a unit that contains 34 percent P_2O_5 at the surface may contain only 29 percent P_2O_5 at depth. This enrichment at the outcrop by weathering probably affects the concentration of some of the other elements, particularly those commonly associated with the phosphorite. A deposit minable at the surface may not be minable, according to current mining grade cutoffs, a few tens or hundreds of feet below the surface; hence, an evaluation of the degree of weathering of a given deposit is necessary before the economic value of that deposit can be determined.

To evaluate the effect of weathering on a phosphate deposit the following factors should be taken into consideration. 1) The presence or absence of carbonate; 2) the presence or absence of organic matter; and 3) the geologic and geographic setting.

The presence or absence of carbonate in acid-grade phosphate rock--an indication of the degree of weathering--can be determined by a simple field test in which concentrated hydrochloric acid is dropped on a fresh rock surface. If the rock is highly weathered, there will be no reaction, presumably because most of the carbonate has been removed from the carbonate-fluorapatite; but, if the phosphate rock is unweathered, carbonate has not been removed so a slight effervescence will generally take place (McKelvey, oral communication).

The presence or absence of carbonate rock beds in their normal position in the strata is also an indication of the degree of weathering. Many of the carbonate rock beds in the phosphatic shale are continuous over rather large areas. For example, the "cap lime" (Mansfield, 1927, p. 76) is present nearly everywhere in southeastern Idaho; but, where the associated strata are highly weathered, the "cap lime" generally is represented by a thin residium of pale or dark yellowish-orange mudstone. Other carbonate beds, though perhaps not as extensive as the "cap lime," can at least be traced throughout nearly every mining district. Therefore, if it is known that carbonate rock beds should be present in the phosphatic shale in the general area of a given deposit, their absence or the presence of thin beds of yellowish mudstone in the normal position of the carbonate rock beds may indicate a high degree of weathering and consequent higher grade of the phosphorite beds.

Light-colored phosphate rock and mudstone are indications that the rocks have been highly weathered. An example is the strata at the Laketown locality where practically no carbonate rock is present and none of the mudstones are calcareous. The rocks are probably only a few feet to tens of feet beneath an old erosion surface at the base of the Tertiary Wasatch(?) formation. Both the value and chroma[/]

[/] Value and chroma are components of color as defined by the Munsell color system, which is briefly outlined by Goddard, and others, (1951). Value, which is the degree of lightness or darkness of a color, is expressed numerically--low values are dark colors and high values are light colors. Chroma, also expressed numerically, is the degree of saturation; i.e., the lower the chroma the less vivid the color, the higher the chroma the more vivid the color.

of the rocks in this section are higher than in other sections where the rocks are comparatively unweathered. The average value at Laketown is 6.0 and the chroma 2.9. Averages of approximately equivalent strata in a mine near Hot Springs a few miles to the north yield a value of 3.6 and chroma of 0.9. In a trench in the Crawford Mountains thought to be weathered to a lesser degree than the Laketown section, the value averages 3.7 and the chroma 1.4 for approximately equivalent strata.

The geologic and geographic setting of a particular locality may furnish some clues as to the degree of weathering. One would expect a higher degree of weathering in proximity to old erosion surfaces as described at the Laketown locality. The presence of numerous faults may facilitate circulation of ground water; hence, in a highly faulted area or, at least, in proximity to faults, a higher degree of weathering might be expected. In the open pit phosphate mine at Fort Hall, Idaho, the strata are cut by many small faults; the traces of these faults are commonly marked at the ground surface by topographic lows. The carbonate rocks have been highly weathered, and the grade of the phosphate rock is higher near the faults than in the topographically high areas between the faults where the carbonate rock beds are commonly unweathered (C. Sweetwood, oral communication). According to L. D. Carswell (oral communication) the lowest phosphate rock bed in southeastern Idaho is of slightly lower grade where samples were taken from trenches located in V-shaped canyons, in areas of young topography, as compared to those samples of the same stratigraphic interval taken from trenches on slopes of low gradient or on the sides of broad valleys, areas of mature topography, or in other areas where the mantle is thick. Furthermore, data suggest that rocks in a given interval from trenches on northward facing slopes contain more phosphate than rocks from trenches on southward facing slopes, probably because the degree of weathering, as indicated by a thicker mantle and denser vegetation, is greater on northward facing slopes. Weathering on such slopes is more intense because snow remains longer and surface material dries more slowly.

The relationship of the present or old water tables to the strata in any area may also prove useful in the evaluation of weathering and enrichment of the phosphate rocks.

Distribution, grade, and thickness of phosphate deposits

Phosphate deposits of Mississippian age

The phosphate deposits at the base of the Brazer limestone and its partial equivalent, the Deseret limestone, are not of high enough quality to be mined at any locality from which samples have been analyzed, and only those in the Tintic mining district, Utah (fig. 3) seem worthy of more explanation now. It should be emphasized, however, that not much analytical data are available concerning the phosphate content of this phosphatic shale. J. Stewart Williams (1939) has presented a few analyses and some are presented here.

One complete section of this member at Laketown and two partial sections, one near Ogden, Utah, and one near Logan, Utah have been measured and sampled. Abstracts and analytical data for these sections are presented in tables 1, 2, and 3. At the base of the shale member at Laketown, a bed of phosphate rock 3 feet thick contains 27.6 percent P_2O_5; however, at outcrops in Ogden Canyon the beds are so lean in phosphate that they were not sampled, and at Providence Canyon, 13.9 percent P_2O_5 is the maximum amount contained in any bed, and that bed is only 1.8 feet thick.

The phosphatic shale at the base of the Deseret limestone in the Tintic district (fig. 3) contains one bed about 2 feet above the base of the member that is 4 feet thick and contains 23.62 percent P_2O_5 and 0.14 percent V_2O_5. In addition the overlying 12.8 feet of beds contains 15.25 percent P_2O_5 and 0.32 percent V_2O_5. Lower grade phosphate beds occur in the overlying beds of the member. A unit 4 feet thick about 24 feet above the base of the member contains 1.12 percent V_2O_5 and 5.8 percent P_2O_5. Many of the overlying shale beds contain up to 0.54 percent V_2O_5, but the highest P_2O_5 content is only 11 percent (Morris, H. T., and Lovering, T. S., in press).

The distribution of minor elements in this phosphatic shale is not known except in the Tintic district where Morris reports that their concentration is similar to that in the Meade Peak phosphatic shale.

Table 1.--Part of the phosphatic shale member of the Brazer limestone measured and sampled in Providence Canyon near Logan, Utah. Measurements made in old pit on the south side of Providence Canyon two miles east of the canyon mouth in sec. 18, R. 2 E., T. 11 N., Cache County, Utah by R. W. Swanson and R. G. Waring in September 1951.

Providence Canyon, Utah. Lot number 1374

Bed no.	Sample number	Thickness (feet)	P_2O_5 1/	A.I. 1/	Description
PHOSPHATIC SHALE MEMBER OF THE BRAZER LIMESTONE:					
10	6776 RWS	2.2	5.3	63.5	Mudstone
9	6777 RWS	1.6	10.7	54.2	Mudstone, phosphatic
8	-	2.0	-	-	Limestone
7	6778 RWS	2.1	11.4	55.8	Mudstone, phosphatic
6	-	2.7	-	-	Limestone
5	6779 RWS	1.8	13.9	40.3	Mudstone, phosphatic
4	-	1.7	-	-	Mudstone, calcareous
3	-	0.6	-	-	Limestone
2	-	0.4	-	-	Mudstone
1	-	0.2	-	-	Chert
					Covered below
		15.3			Total thickness measured

1/ Samples analyzed for P_2O_5 and acid insoluble material (A.I.) by the U. S. Bureau of Mines Laboratory, Albany, Oregon.

Table 2.--Phosphatic shale member of the Brazer limestone measured and described in Ogden Canyon, Utah. Section measured in an old road cut on the north side of Ogden Canyon in $NW\frac{1}{4}$ $SW\frac{1}{4}$ sec. 16, T. 6 N., R. 1 E. Beds strike N. 10° E. and dip 25° W. This area is structurally complicated by many small faults and folds; however, the following section is thought to be representative of the shale member in the area. Section measured by R. G. Waring and R. A. Smart.

Ogden Canyon, Utah. Lot number 1373

Bed. no.	Thickness (feet)	Description
LOWER PART OF THE BRAZER LIMESTONE:		
	1.0	Limestone
PHOSPHATIC SHALE MEMBER OF THE BRAZER LIMESTONE:		
B-26	0.3	Mudstone, calcareous
B-25	0.7	Limestone
B-24	0.2	Mudstone, calcareous
B-23	1.3	Mudstone, phosphatic(?)
B-22	2.5	Mudstone, calcareous
B-21	0.3	Mudstone
B-20	1.5	Limestone
B-19	0.8	Mudstone, calcareous
B-18	0.3	Phosphate rock, calcareous
B-17	0.8	Limestone
B-16	0.2	Phosphate rock, calcareous
B-15	1.1	Limestone, argillaceous
B-14	0.1	Phosphate rock, calcareous

Table 2.--Continued

Bed. no.	Thickness (feet)	Description
PHOSPHATIC SHALE MEMBER OF THE BRAZER LIMESTONE--Continued:		
B-13	0.4	Mudstone
B-12	0.2	Mudstone, phosphatic(?)
B-11	0.3	Mudstone, calcareous
B-10	0.1	Phosphate rock, calcareous
B-9	0.2	Mudstone
B-8	0.1	Phosphate rock, calcareous
B-7	0.2	Mudstone
B-6	0.2	Phosphate rock, calcareous
B-5	0.2	Mudstone
B-4	1.0	Mudstone
B-3	1.9	Mudstone
B-2	0.7	Mudstone
B-1	3.1	Mudstone, calcareous
	18.7	Total thickness

Table 3.--Phosphatic shale at the base of the Brazer limestone measured and sampled 1 mile NE of Laketown, Utah. Measured and sampled on east limb of an overturned anticline in sec. 32, T. 13 N., R. 6 E., Rich County, Utah. Beds strike N. 10° W. and dip 80° E. Section measured by F. J. Anderson, R. G. Waring, and R. A. Smart and sampled by Waring and Smart in July, 1949. Laketown B Trench, Utah. Lot number 1291

Abstract of section

Bed No.	Sample No.	Thickness (Feet)	P_2O_5 1/	A.I. 1/	eU	Description
BRAZER LIMESTONE:						
B-40	3782-FJA	2.8	0.5	39.0	a 2/	Limestone, argillaceous
B-39	3781-FJA	3.6	0.4	43.5	a	Mudstone, calcareous
B-38	3780-FJA	4.2	0.5	45.7	a	Limestone
B-37	3779-FJA	3.2	0.6	27.8	a	Limestone, argillaceous
B-36	3778-FJA	1.6	0.6	90.5	a	Mudstone
B-35	3777-FJA	4.7	0.6	25.7	a	Phosphate rock, calcareous and limestone, argillaceous
B-34	3776-FJA	2.8	0.7	21.5	a	Limestone and mudstone, calcareous
B-33	3775-FJA	6.4	0.8	23.0	a	Mudstone, calcareous and limestone
B-32	3762-RGW	1.5	0.3	10.3	a	Limestone
B-31	3761-RGW	2.0	7.5	18.7	.002	Mudstone, calcareous and phosphate rock, calcareous

Table 3--Continued

Bed No.	Sample No.	Thick-ness	P_2O_5	A.I.	eU	Description
BRAZER LIMESTONE--Continued						
B-30	3760-RGW	1.0	11.1	22.5	0.003	Mudstone, calcareous and phosphate rock
B-29	3759-RGW	0.8	6.5	46.3	0.002	Mudstone, calcareous and chert
B-28	3758-RGW	0.8	0.6	23.7	a	Limestone, argillaceous
B-27	3757-RGW	1.7	3.3	27.8	0.001	Limestone, argillaceous and phosphate rock, calcareous
B-26	3756-RGW	1.2	12.5	26.1	0.003	Mudstone, calcareous and phosphate rock, calcareous
B-25	3755-RGW	1.2	7.4	42.8	0.003	Mudstone, calcareous chert and phosphate rock, calcareous
B-24	3754-RGW	0.8	11.0	43.7	0.003	Chert and phosphate rock, calcareous
B-23	3753-RGW	0.8	0.5	40.2	a	Chert
B-22	3752-RGW	1.5	2.7	36.7	0.002	Mudstone, calcareous
B-21	3820-RGW	0.7	0.5	40.5	0.002	Mudstone, calcareous
B-20	3819-RGW	1.2	0.2	31.1	a	Limestone, argillaceous
B-19	3818-RGW	0.9	3.0	43.0	0.002	Mudstone, calcareous
B-18	3817-RGW	0.8	9.4	62.7	0.002	Phosphate rock, calcareous, argillaceous and mudstone

Table 3.--Continued

Bed No.	Sample No.	Thick-ness	P_2O_5	A.I.	eU	Description
BRAZER LIMESTONE--Continued						
B-17	3816-RAS	1.1	0.3	6.9	a	Limestone
B-16	3815-RAS	3.0	10.1	43.7	0.003	Mudstone, phosphatic(?)
B-15	3814-RAS	3.7	0.2	9.7	a	Limestone
B-14	3813-RAS	1.6	0.1	19.1	0.001	Limestone
B-13	3812-RAS	2.3	0.1	20.1	a	Limestone, argillaceous
B-12	3811-RAS	1.9	0.2	35.5	0.002	Limestone, argillaceous
B-11	3810-RAS	2.3	5.7	57.5	0.004	Mudstone, phosphatic
B-10	3809-RAS	2.6	0.1	6.2	a	Limestone, cherty
B-9	3808-RAS	4.2	0.1	26.3	a	Limestone, argillaceous
B-8	3807-RAS	1.2	5.4	48.0	0.003	Mudstone, calcareous, phosphatic
B-7	3806-RAS	0.6	3.8	50.5	0.003	Mudstone, calcareous
B-6	3805-RAS	2.2	0.1	27.7	0.001	Limestone, argillaceous
B-5	3804-RAS	0.8	1.4	44.3	0.002	Mudstone
B-4	3803-RAS	1.5	5.9	47.0	0.004	Mudstone, phosphatic calcareous
B-3	3802-RAS	1.1	0.6	28.0	0.002	Limestone, argillaceous

Table 3.--Continued

Bed No.	Sample No.	Thickness	P_2O_5	A.I.	eU	Chem U	Description
BRAZER LIMESTONE--Continued							
B-2	3801-RAS	3.1	27.6	12.7	0.005	0.004	Phosphate rock, argillaceous, calcareous and mudstone, phosphatic, calcareous
B-1	3800-RAS	0.1	33.1	1.7	0.006	0.006	Phosphate rock, calcareous

79.5 Total thickness of phosphatic shale member

1/ Samples analyzed for P_2O_5 and acid insoluble material (A.I.) by the U. S. Bureau of Mines Laboratory, Albany, Oregon.

2/ Absent.

The phosphate deposits in the Tintic mining district are low grade, compared to those in the Phosphoria formation in northern Utah, and would have to be beneficiated before use in making a commercial phosphorus product. Nevertheless, because of several unique economic factors, further investigation of these deposits and methods of beneficiating the phosphate rock is recommended. Large reserves of this rock are available in the Tintic district where the phosphatic shale unit is cut one or more times by underground workings at several levels in recently operating base-metal mines. Railroads and power facilities are available at the mines and thus save many of the initial costs involved in developing phosphate rock elsewhere. (Morris, personal communication, 1957.)

Phosphate deposits of Permian age

General relationships.--The most important and largest phosphate deposits in the western field are the phosphorites in the Meade Peak phosphatic shale member of the Phosphoria formation in southeastern Idaho, northern Utah, western Wyoming, and southwestern Montana; however, large reserves of phosphate are also present in the younger Retort phosphatic shale member of the Phosphoria in Montana. In the Phosphoria formation as a whole, the total phosphate content and the thickness of beds of phosphate containing more than 24 percent P_2O_5 are greatest in southeastern Idaho and decrease to the north, south, east, and probably to the west (Swanson and others, 1953). As would be expected then, the total phosphate content and thickness of beds of acid-grade and furnace-grade rock in Utah are highest in the northernmost part (figs. 9, 10, and 11).

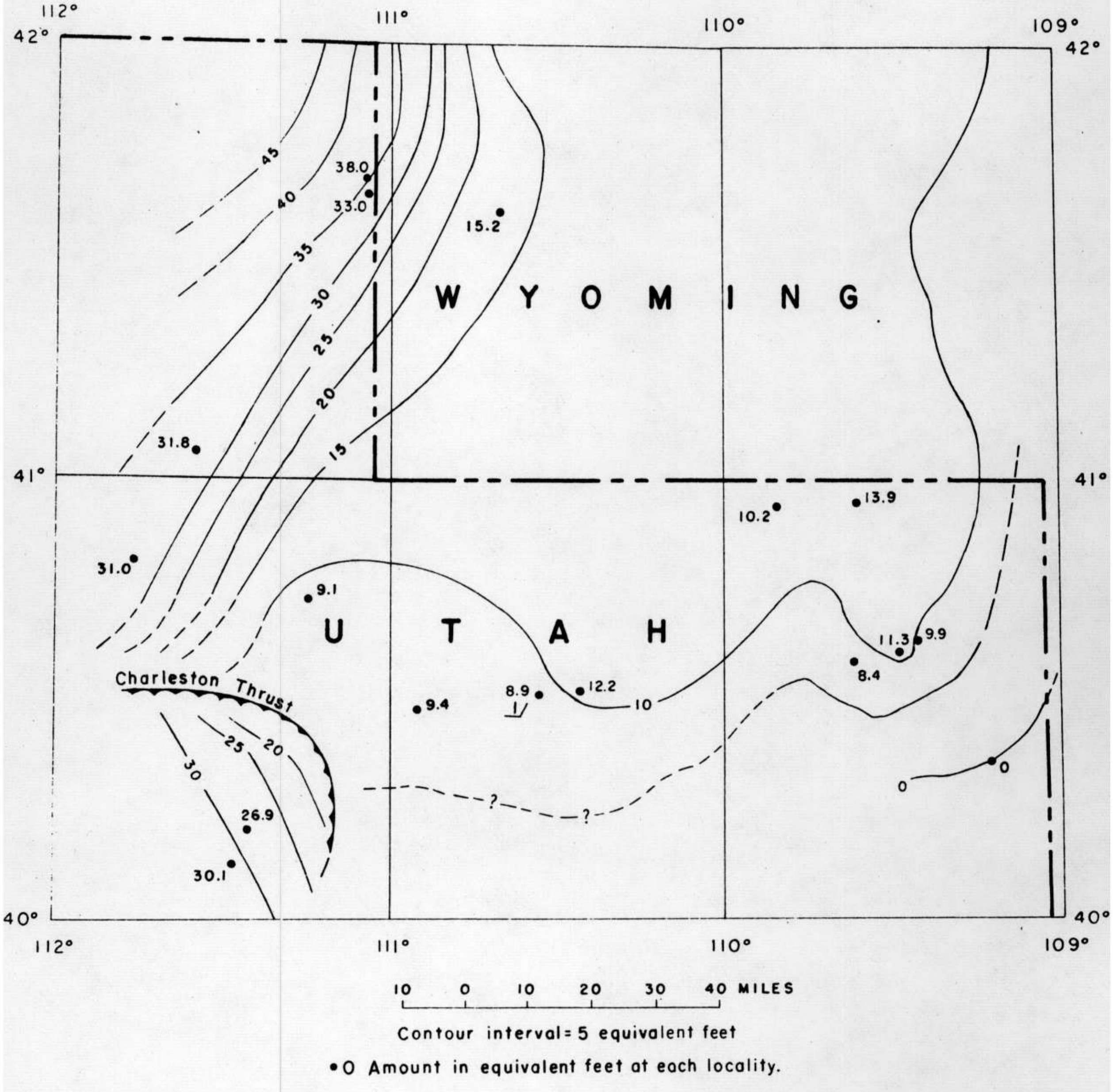

FIGURE 9. Map showing equivalent thickness and amount (in feet) at each sample locality of the total carbonate-fluorapatite in the Meade Peak phosphatic shale tongue of the Phosphoria formation. 1/ A few feet of phosphatic sandstone at base of member was not sampled so this figure is slightly low.

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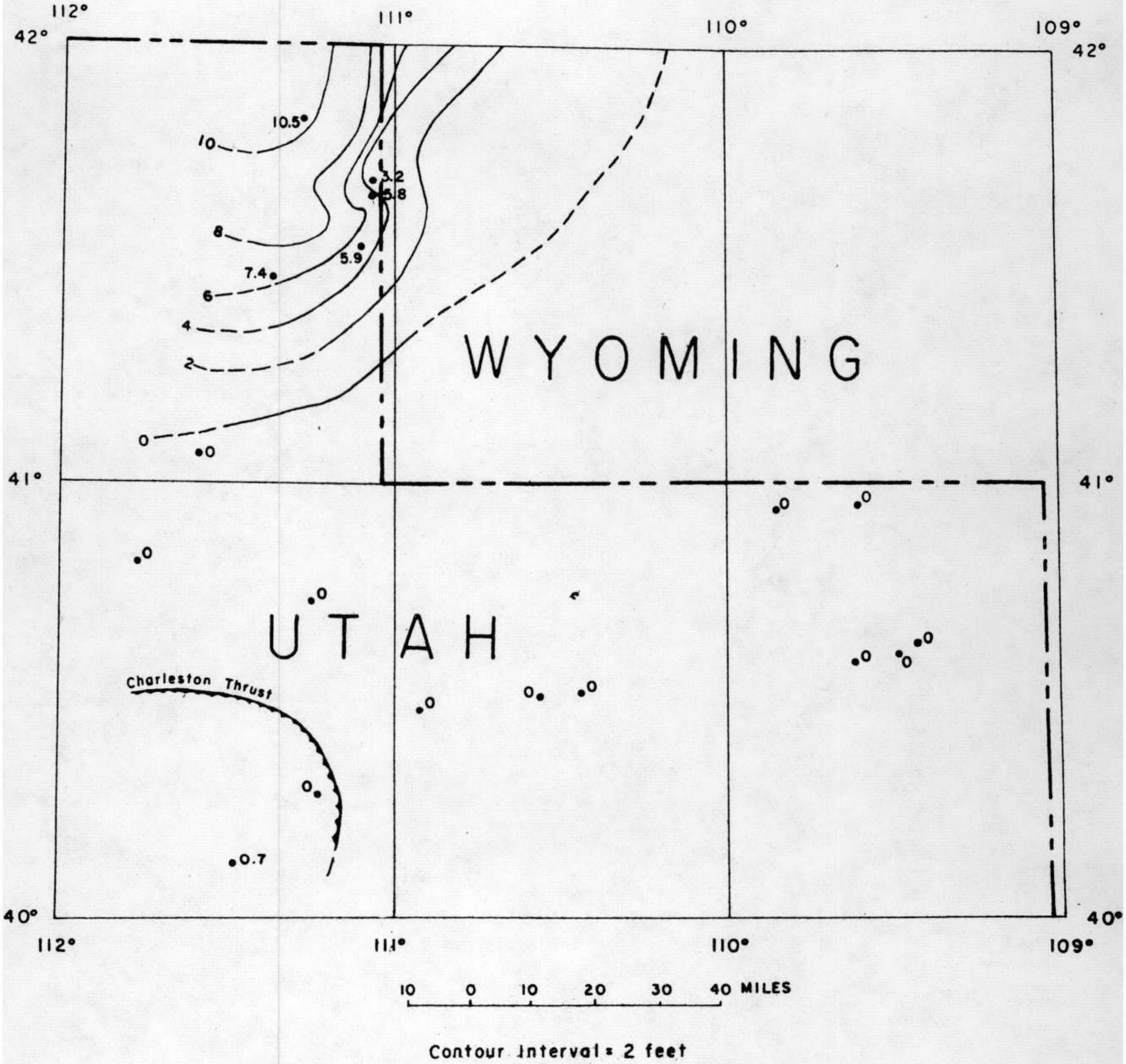

FIGURE 10 Map showing total thickness and amount (in feet) of beds in the Meade Peak phosphatic shale tongue of the Phosphoria formation that contain more than 31 percent P_2O_5.

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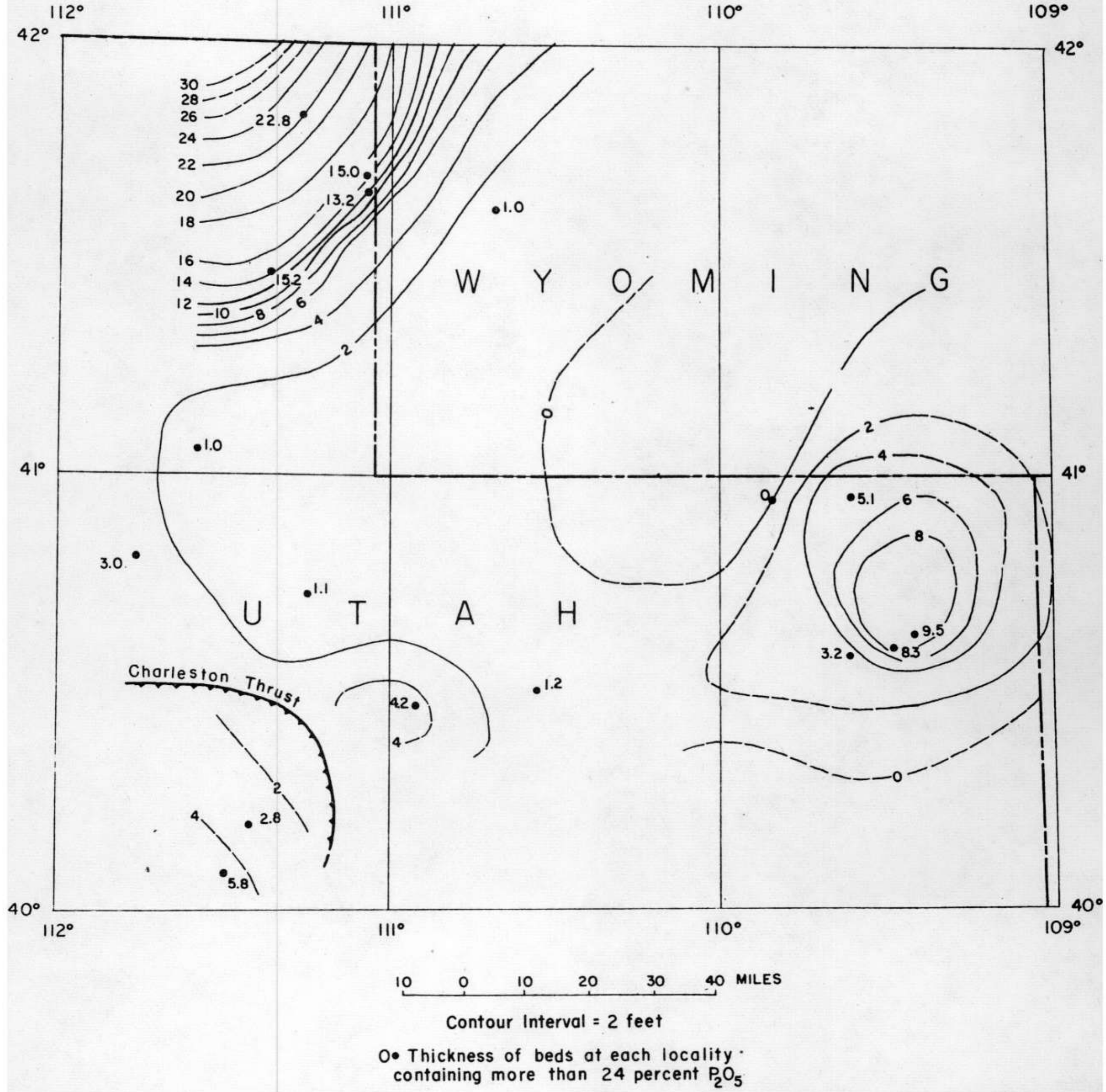

FIGURE 11. Map showing the total thickness (in feet) of beds in the Meade Peak phosphatic shale tongue of the Phosphoria formation that contain more than 24 percent P_2O_5 in the Uinta mountains.

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The slight decrease to the south (about 16 percent) in total phosphate content (fig. 9) in the western part of the area is accompanied by an increase of about 37 percent in the thickness of the Meade Peak phosphatic shale member (fig. 8). The greater thickness of the member is, therefore, mostly due to the greater amount of nonphosphatic sediments. As a result of this and the slight decrease in the amount of total phosphate present, the grade and thickness of phosphatic rocks decrease markedly southward (figs. 9, 10, and 11). South of the northern Wasatch area, no known beds of phosphate more than 1 foot thick contain as much as 30 percent P_2O_5; and, except in the Little Diamond Creek area in the southern Wasatch Mountains where 5.8 feet of beds contain 28 percent P_2O_5, no beds of minable thickness contain as much as 24 percent P_2O_5. In the northern Wasatch area, as at the Laketown locality, a sequence of beds 22.8 feet thick in the Meade Peak member contains more than 24 percent P_2O_5 whereas south of Sugar Pine Creek in the central and southern Wasatch Mountains (the Little Diamond Creek area excepted), only 1 to 3 feet of beds contains more than 24 percent P_2O_5.

The total phosphate content decreases southeastward from about 45 equivalent feet thickness of carbonate-fluorapatite in northern Utah to about 15 equivalent feet thickness of carbonate-fluorapatite in the area between Franson Canyon and Cumberland (figs. 1 and 9). This decrease in phosphate content nearly parallels, in both direction and rate, the decrease in thickness of the Meade Peak member (fig. 8).

Southward and eastward from this area, throughout the Uinta Mountains, the total phosphate content in the member remains essentially the same except in the easternmost part of the Uinta Mountains where the total phosphate content is slightly greater. The thickness of the Meade Peak, however, gradually decreases to the southeast and east in the Uinta Mountains. The anomalous high phosphate content of the Meade Peak in the eastern part of the Uinta Mountains occurs where the Meade Peak is thinner and the total phosphate content is slightly higher than in the rest of the Uintas. In this area, the thickness of beds of phosphate rock containing more than 24 percent P_2O_5 ranges from 3.2 feet at Rock Canyon to 9.5 feet at Little Brush Creek (fig. 11). In this area the phosphatic shale member is made up of about one-third carbonate-fluorapatite which is proportionately more than in southeastern Idaho where the total phosphate content of the member is greatest. This combination of thinness of the phosphatic shale member and relatively high total phosphate content is characteristic of the phosphatic members of the Phosphoria formation on the shoreward fringes of the field in Montana (Swanson and others, 1956, p. 8-11) as well as Utah.

Southward and eastward from the eastern part of the Uinta Mountains the thickness of beds containing more than 1 or 2 percent P_2O_5 decreases to zero in about 15 miles. Essentially no phosphorite is present at Split Mountain, Utah, nor at Vermillion Creek in the northwestern part of Colorado (Sears, 1924).

Thus, in only two major areas in Utah, the eastern part of the Uinta Mountains and northern part of the Wasatch Mountains, and one minor area, the Little Diamond Creek area in the southern Wasatch

Mountains, are beds of acid-grade and/or furnace-grade phosphate rock in the Meade Peak thick enough to be mined profitably at the present time. Of these two areas, only in the northern Wasatch Mountain area are the phosphate content and continuous thickness of phosphate beds great enough and costs of mining and transportation of the phosphate rock to the consumers cheap enough to make the deposits minable profitably at the present price of phosphate rock.

The phosphate in the Meade Peak phosphatic shale member generally is concentrated near the base and near the top, even though the base and top of the member are not at the same time horizons everywhere. For example, the uppermost phosphate zone in the northern Wasatch Mountains probably is not laterally continuous with the upper phosphatic beds in the Uinta Mountains (figs. 5 and 6). In the northern Wasatch Mountains, the upper beds in the phosphatic shale are the most phosphatic, and in the Uinta and central Wasatch Mountains the most phosphatic beds are near the base of the member. The distribution of phosphate in the Meade Peak in the various areas of Utah described in this report is discussed below.

Northern Wasatch Mountains.--The northern Wasatch area is the only area in Utah in which phosphate is acid-grade and is being mined. Furthermore, only in this part of Utah are beds of furnace-grade rock thick enough to warrant their exploitation for use now in the electric furnace process of producing elemental phosphorus. The highest grade phosphate beds are in the upper part of the Meade Peak member; the lateral continuity, thickness, lithology, P_2O_5 content, and stratigraphic position of these beds are shown on plate 3.

The sequence of beds in the upper phosphatic unit is as follows. Generally, the top is marked by a nodular and pelletal phosphate bed. (See Brazer Canyon section, pl. 3.) Underlying this are 3 to 4 feet of phosphate rock, generally pelletal and nodular, interbedded with carbonatic mudstone or carbonate rock. This unit, together with the uppermost nodular phosphate bed, averages 10 to 15 percent P_2O_5 at most localities. The underlying unit, locally referred to as the A bed (King, 1949, p. 286), is composed dominantly of pelletal phosphate, although oolites are present in some beds and the uppermost 0.1 to 0.5 foot of this unit is commonly nodular and oolitic phosphates. In the Crawford Mountains, which are represented by the easternmost line of sections on plate 3, the A bed attains a thickness of about 7.0 feet and contains as much as 31.5 percent P_2O_5, as in the Upper Brazer section (pl. 3). The bed has a minimum thickness of 5.3 feet and contains 30.5 percent P_2O_5 at Brazer Canyon. To the west of the Crawford Mountains as at Laketown and Sugar Pine Creek the equivalents of this A bed are difficult to define, but apparently they are 7.2 feet thick and contain 31.9 percent P_2O_5 at Laketown, and are about 7.5 feet thick and contain about 34 percent P_2O_5 at Sugar Pine Creek. Underlying the A bed in the Crawford Mountains is 2 to 4 feet of argillaceous phosphate rock, locally called the B bed, (King, 1949, p. 286), which averages 24 to 26 percent P_2O_5. Beneath this bed is 2 to 3 feet of carbonate rock or calcareous mudstone that contains only about 2 percent P_2O_5. Underlying the carbonate rock is 3 to 5 feet of argillaceous phosphate rock, called the C bed (King, 1949, p. 286), averaging 24 to 26 percent P_2O_5. Underlying this bed is chert or cherty mudstone, the top of which marks the base of the upper phosphate unit shown on plate 3. In the western part of the area at Laketown and Sugar Pine Creek, no thick mudstone or carbonate rock separates the B and C beds as in the Crawford Mountains. The B and C beds at Laketown have a combined thickness of 10.1 feet and consist of argillaceous phosphate rock that contains 23.8 percent P_2O_5. At Sugar Pine Creek the combined B and C beds are 8.2 feet thick and contain 26.5 percent P_2O_5. At the latter locality if the B and C beds are combined with the A bed, the whole unit is 15.4 feet thick and contains 30.8 percent P_2O_5.

At both Sugar Pine Creek and Laketown, overlying and underlying beds, separated from the A bed by thin phosphatic mudstones, contain more than 31 percent P_2O_5 and would no doubt be mined with the A bed. For example, as much as 13.8 feet of continuous beds averages 31.0 percent P_2O_5 at Sugar Pine Creek, and at Laketown 8.9 feet of continuous beds averages 31.4 percent P_2O_5. The phosphate content of the beds below the A bed increases to the west, as does the phosphate content of the Meade Peak as a whole, thereby accounting for the increased thickness of rock containing more than 31 percent P_2O_5 (pl. 3).

The thickest acid-grade deposits in the northern Wasatch area are in the Laketown and Sugar Pine Creek districts. These deposits have not been exploited because they are not as accessible as other deposits, they must be mined by underground methods, the reserves above entry level are not large, they are on the west overturned limb of a syncline complicated by many small faults and folds, and, until recently, not much has been known concerning the grade of the deposits. If the transportation difficulties can be overcome, the phosphate deposits in these two areas might be mined profitably.

At Laketown about 2 miles of outcrop of the Meade Peak exists (Richardson, 1941), and the phosphate reserves above entry level in this area are not large. South of the outcrop, the Meade Peak is concealed by Tertiary sediments, but it is possible that the Meade Peak continues, unbroken by major structures, for some distance beneath this cover. Thus, large reserves may be discovered south of the area of outcrop, beneath the Tertiary cover. The cost of transportation of the phosphate rock to the nearest railroad at Montpelier might be lowered by barging the rock on Bear Lake most of the distance to the railroad--further enhancing the value of these deposits. Bear Lake is only a little more than a mile from the north end of the outcrop.

The deposits at Sugar Pine Creek lie just south of the Randolph quadrangle, 26 miles south of the deposits at Laketown. They were briefly described by Gale (<u>in</u> Gale and Richards, 1910, p. 527-529) and were investigated in the early 1900's by geologists for the San Francisco Mining Company which owned many of the claims in the area. According to Gale, beds reported to contain 30 to 32 percent P_2O_5 were about 5 feet thick, but recently the author found the acid-grade zone to be 15.4 feet thick (Swanson, and others, 1956, p. 30). This is the greatest continuous thickness of beds averaging more than 30 percent P_2O_5 yet found in the western phosphate field. In view of the thickness of this acid-grade deposit, it seems worthwhile to investigate its lateral extent and structure to see if mining costs might be low enough to offset cost of transportation to the nearest railroad, about 30 miles down grade to Sage, Wyo.

It should be remembered, however, that the strata measured and sampled at both these places by the U. S. Geological Survey are only a few feet or tens of feet below an unconformity and erosion surface at the base of the Tertiary Wasatch(?) formation and that they probably have been enriched by weathering. This supposition is strengthened by the color of the rock, which is light greenish gray and gray, indicating that the carbonaceous material has been leached or altered; but, because the depth of weathering below the pre-Wasatch surface is great elsewhere, the enriched zone may be scores or hundreds of feet thick. The exploration costs of determining the location and extent of the Meade Peak under the Tertiary Wasatch formation at both these localities would be great; nevertheless, the stakes are high for the upper phosphate unit is probably as thick and as high a grade for some distance down dip beneath the Wasatch formation as it is now at the surface.

The A bed is being mined at two underground mines of the San Francisco Chemical Company, and it was recently mined in an open pit mine of the Simplot Company in the northern part of the Crawford Mountains. Large reserves of acid-grade phosphate rock remain in this bed, and large reserves of furnace-grade rock remain in the B bed in the Crawford Mountains. During the course of recent mapping, W. C. Gere (oral communication, 1954) of the U. S. Geological Survey found several small outcrops of the Meade Peak not shown on Richardson's map (1941). He is also finding that mapping on a smaller scale shows the structure to be much more complicated than that shown by Richardson. Proper further evaluation of the deposits will have to await the outcome of Mr. Gere's and others' detailed mapping.

The outcrops of Meade Peak described by Blackwelder (1910, p. 547-549) 25 to 30 miles east of Huntsville in the vicinity of Dry Bread Hollow were not sampled during this investigation. It is not known whether these deposits are acid-grade, like those at Sugar Pine Creek, or low-grade, like those a few miles to the south at Devils Slide in the Central Wasatch Mountains.

Central Wasatch Mountains.--Within the central Wasatch area, the highest grade phosphate beds are in two zones in different parts of the area, one near the top and one near the base of the member. None of the beds are thick or rich enough, however, to warrant their consideration as potential near-future sources of phosphate at the localities which have been sampled.

In the northern part of the central Wasatch area, in the vicinity of Devils Slide, the highest grade beds are in the upper part of the Meade Peak (Cheney, and others, 1953) and are probably laterally continuous with the upper phosphate zone at Brazer Canyon (pls. 1 and 3). Only 1 foot of the zone contains as much as 24 percent P_2O_5, however, and the thickest bed containing more than 20 percent P_2O_5 is only 1.8 feet thick. Consequently this area does not warrant further exploration in the near future.

In the rest of the central Wasatch Mountain area, that is south of the outcrop near Devils Slide, the highest grade phosphate bed is at the base of the Meade Peak member. Its thickness ranges from 2.5 to 4 feet and its P_2O_5 content from 24 to 27 percent at all of the localities sampled. It consists of fine- to medium-grained sandy phosphate rock interbedded with slightly argillaceous phosphate rock. The lens-like character of these sandy phosphate rocks has been demonstrated at several other places. For example, at Basin Creek, Wyoming (for location and description see Sheldon and others, 1954), a bed of sandy phosphate rock 12 feet thick thins to less than 3 feet within a strike length of 2 miles; the sandy phosphate rock being mined at Little Diamond Creek, Utah (Cheney and others, 1953, p. 40), is also from a lenticular bed. Perhaps, therefore, thicker deposits exist in local areas in the central Wasatch Mountains, but the grade of known deposits does not presently warrant the costly exploration required to find them.

Southern Wasatch Mountains.--In the southern Wasatch Mountains the most phosphatic beds in the Meade Peak are at the base of the member. Only in the vicinity of Little Diamond Creek, where beds 5.8 feet thick average 28.8 percent P_2O_5 (Cheney and others, 1953, p. 40), are the thickness and phosphate content great enough to be of interest as a potential source of phosphorus.

The phosphate content of the basal 4 to 6 feet of the member ranges from nearly 29 percent at Little Diamond Creek to 20 percent at Wanrhodes Canyon about 5 miles to the north, to 10 percent about 9 miles further north at Right Fork of Hobble Creek. At Strawberry Valley, about 15 miles to the northeast of Hobble Creek the only notably phosphatic bed in the lower part of the Meade Peak is one 0.7 foot thick about 7 feet above the base that contains 7.3 percent P_2O_5 (Smith and others, 1952; Cheney and others, 1953). These data suggest that the basal part of the Meade Peak becomes more phosphatic to the southwest in this southern Wasatch area. If so, the black shaly sequence of beds, believed to be equivalent to the Meade Peak by A. A. Baker (oral communication) that crops out a few miles east of Nephi, Utah, 20 to 30 miles south of Little Diamond Creek might contain minable deposits.

Uinta Mountains.--The only notably phosphatic beds in the Uinta Mountains west of Lakefork are argillaceous, sandy phosphate rocks at or near the base of the member (pl. 2), and these are not of minable grade and thickness. They are 2.3 feet thick and contain 21 percent P_2O_5 at Franson Canyon and are 3.7 feet thick and contain 19.5 percent P_2O_5 at Dry Canyon. These values are representative of the beds in the whole western Uinta Mountain area. Thus, no beds containing a minable quantity and quality of phosphate are present in this area.

In the eastern part of the Uinta Mountains, near Vernal (fig. 1), the Meade Peak contains thick low-grade deposits. The vertical distribution of phosphate in the member in the eastern Uinta Mountains is shown on figure 12. (Also see Kinney, 1955, pl. 5.) The highest grade beds (X, fig. 12), which range from layers 1.3 feet thick containing 25.4 percent P_2O_5 at Rock Canyon to layers 4.6 feet thick containing 26.3 percent P_2O_5 at Little Brush Creek, are about 2 feet above the base of the member. Beds nearly as thick and containing nearly the same amount of phosphate (Y, fig. 12) are present 2 to 6

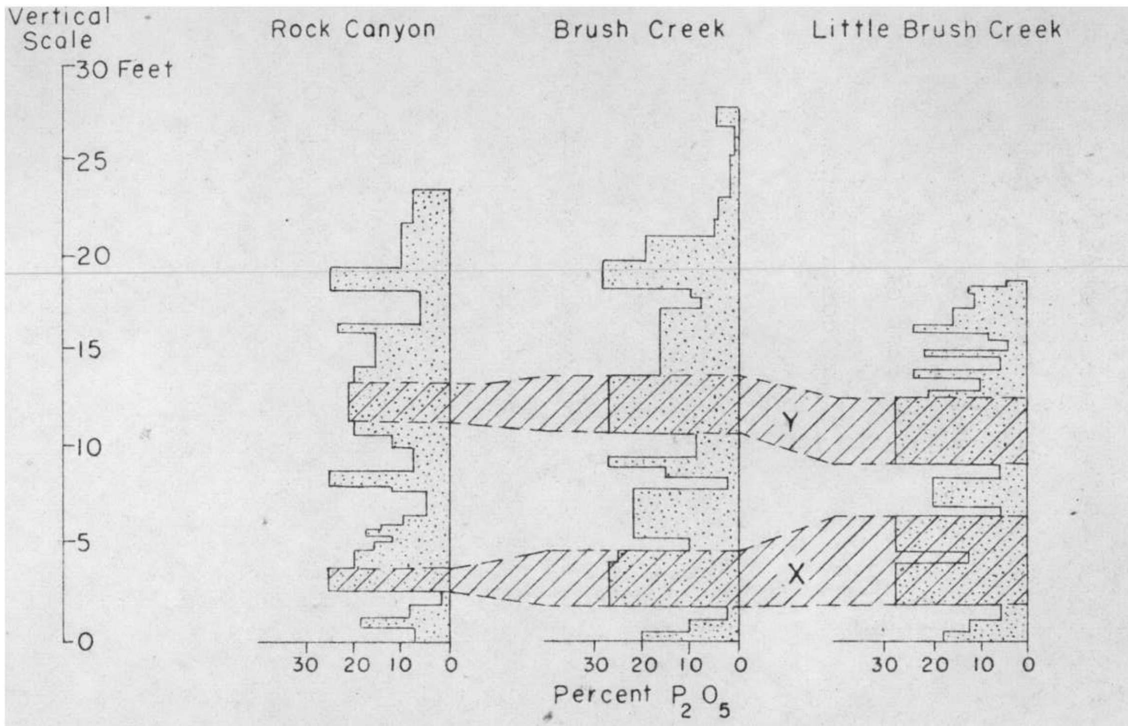

FIGURE 12. Graph showing thickness and P_2O_5 content of sampled units in the Meade Peak phosphatic shale tongue of the Phosphoria formation at three localities near Vernal, Utah. Units X and Y are shown by pattern. Data from Smith and others (1952).

feet above the top of the highest grade bed. Thus, there are two beds that average about 3.0 feet in thickness and contain 25-27 percent P_2O_5 separated by 2.5 to 7.0 feet of lower grade beds. If these two acid-grade beds could be mined selectively in the vicinity of Little Brush Creek, rock having a maximum thickness of about 8 feet and containing 25.5 percent P_2O_5 could be obtained. If the intervening beds were included, the total thickness would be about 11 feet and the P_2O_5 content about 23.5 percent. If a continuous unit including all the higher grade beds in the Meade Peak were mined, the total thickness would be 15.4 feet and the P_2O_5 content 21.7 percent. Any greater thickness would drop the grade below 20 percent. The thickness and phosphate content of the two acid-grade beds (X and Y, fig. 12) decrease slightly to the west at Brush Creek, where the maximum thickness is only about 6 feet and the P_2O_5 content is 27 percent. By including the intervening low-grade interval, the unit is about 15.7 feet thick and contains about 20.8 percent P_2O_5. However, the beds above the upper acid-grade bed (Y) are more phosphatic so that in the Brush Creek area a total of 20 feet which averages about 20 percent P_2O_5 could be mined.

The total phosphate content of the member, thickness and phosphate content of the furnace-grade beds, and the phosphate content of the low-grade interval decrease greatly to the west at Rock Canyon. The maximum thickness of the highest grade phosphate is 2.3 feet, and the P_2O_5 content is 22.9 percent. A zone 15.4 feet thick contains only 16.1 percent P_2O_5.

The outcrops of the Meade Peak extend, with minor breaks, 16 miles west of Dry Canyon to the Whiterocks River. The Meade Peak is 20 feet thick at the Whiterocks River outcrops (Kinney, 1955, p. 50); however, its phosphate content there is unknown. Because of the westward thickening of the Meade Peak and accompanying decrease in phosphate content of individual beds it appears that the Meade Peak between Whiterocks River and Rock Canyon would not contain deposits of high enough grade to make further investigations worthwhile.

Thus, from the data available, it appears that the best phosphate deposits in the southeastern Uinta Mountains are in the eastern part of the area of outcrop. In evaluating these data, it has not been possible to take into account the effect of weathering on the phosphate content. As discussed previously, the P_2O_5 content may decrease as much as 5 percent with depth in areas of advanced weathering; hence, due to differential weathering within the Little Brush Creek-Rock Canyon area changes from east to west might not be primary differences. Even if the change in grade is due mostly to secondary processes, the increase in grade from west to east might be important in consideration of mining. A study of the effect of weathering on these deposits would be worthwhile before more work is done on the deposits.

Because the Meade Peak forms dip slopes on the low-dipping south flank of the Uinta Mountain anticline (Kinney, 1955, pl. 1), much of the phosphate rock is amenable to strip mining. Probably, the biggest single factor inhibiting development of the Vernal deposits is their distance from railhead at Craig, Colorado--125 miles by highway. This factor may be overcome if Echo Dam on the Green River is built, for it would provide a nearby cheap power source that might make it possible to build a small electric furnace plant and process the rock at Vernal.

The Meade Peak crops out on the steep north flank of the eastern part of the Uinta Mountains, and at these outcrops the phosphate deposits are also low-grade. A unit 3.6 feet thick about 2 feet above the base averages 26.7 percent P_2O_5 at Horseshoe Canyon (fig. 1). About 6 feet of beds that include the acid-grade bed contains about 24 percent P_2O_5 and by including the 6-foot unit a zone 12.9 feet thick averages about 20 percent P_2O_5. The lateral extent of these units is not known. The only other locality sampled on this outcrop is Sols Canyon (fig. 1), where the total phosphate content is low and the most phosphatic unit is 1.6 feet thick and contains 16 percent P_2O_5.

The phosphatic beds are richer in phosphate at Horseshoe Canyon than at Sols Canyon. Carbonatic material forms only a small part of the beds at Horseshoe Canyon whereas at Sols Canyon carbonate rocks are numerous and carbonate forms a prominent part of the phosphatic beds (Cheney, and others, 1953, p. 23, 33). This difference in phosphate and carbonate content may be partly due to differences in the degree of weathering at the two localities. Nevertheless, much of the difference must be primary, and the total amount of phosphate and the phosphate content of individual beds in the Meade Peak decreases from Horseshoe Canyon to Sols Canyon.

Regardless of the origin of the differences in the phosphate content along the strike of the outcrops of the Meade Peak, the phosphate in the vicinity of Horseshoe Canyon is not minable at present. Because the beds dip steeply only small reserves of phosphate rock amenable to strip mining exist; therefore, they would have to be mined by underground methods; moreover, they are about 70 miles from the nearest railroad.

CONCLUSIONS

The major phosphate deposits in Utah are the acid-grade and furnace-grade deposits in the northern Wasatch Mountain area; these occur in the upper part of the Meade Peak member of the Phosphoria formation of Permian age. The deposits are now being mined and large reserves of phosphate rock remain. The thickness of the Meade Peak, the total phosphate content, and the thickness of beds of phosphate rock decrease to the southeast of the northern Wasatch area. No beds of minable phosphate rock are present in the western Uinta Mountains or in the central and southern Wasatch Mountains except for a small deposit near Little Diamond Creek in the southern Wasatch Mountains, but large reserves of phosphate rock, amenable to open-cut mining, exist on the south flank of the Uinta Mountains. These deposits, however, cannot be mined at the current prices of phosphate rock because of their low grade and the high cost of transportation to the nearest processing plants.

The phosphatic shale of Mississippian age apparently is continuous over a rather large area in northern and central Utah, but the phosphatic beds are low-grade and apparently of rather local extent.

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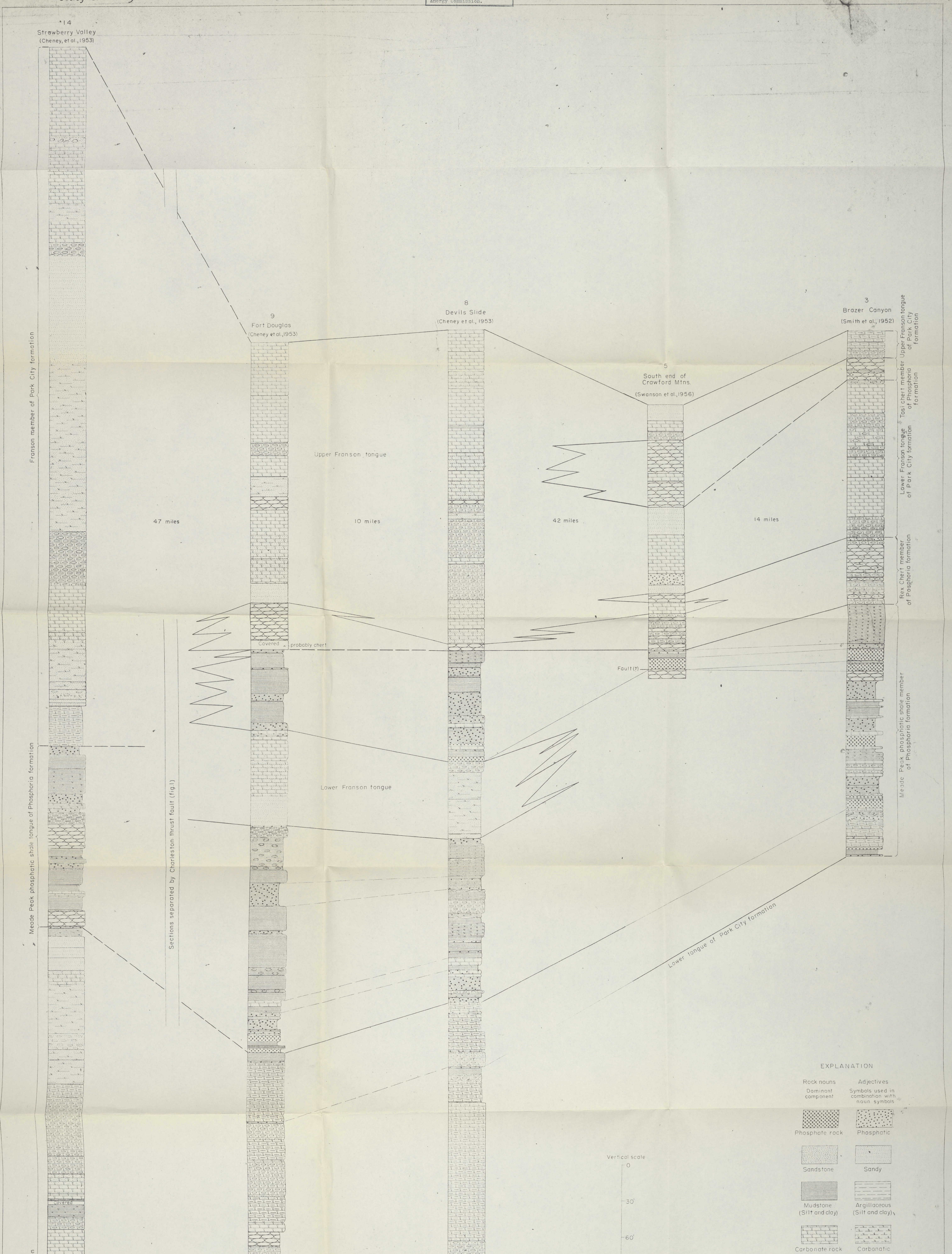

Plate 1 - Correlation chart of the Phosphoria and Park City formations from Strawberry Valley, Utah to Brazer Canyon, Utah.

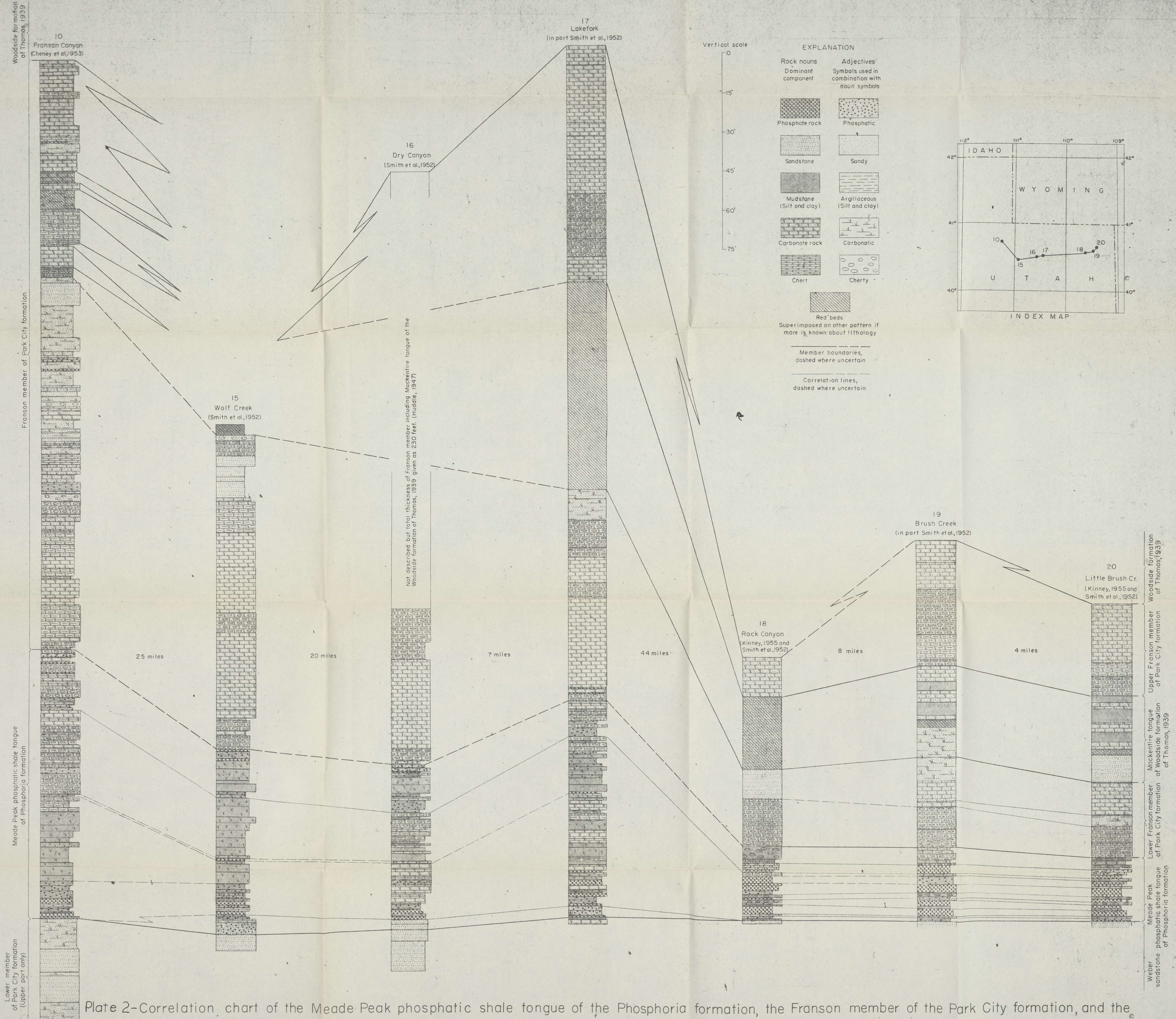

Plate 2-Correlation chart of the Meade Peak phosphatic shale tongue of the Phosphoria formation, the Franson member of the Park City formation, and the Mackentire tongue of the Woodside formation of Thomas, 1939 from Franson Canyon, Utah to Little Brush Creek, Utah.

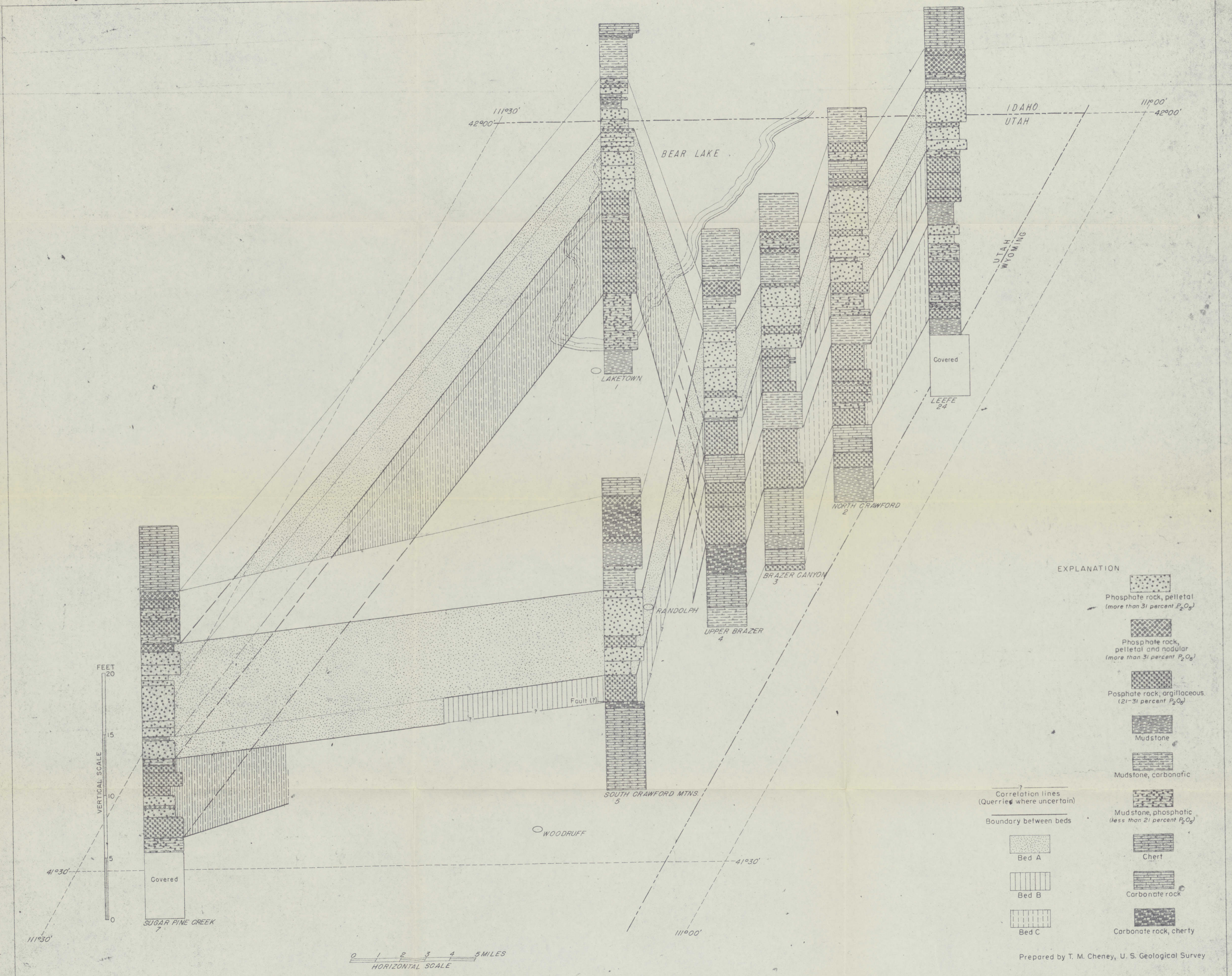

PLATE 3 - CORRELATION DIAGRAM OF THE UPPER PART OF THE MEADE PEAK PHOSPHATIC SHALE MEMBER OF THE PHOSPHORIA FORMATION

RANDOLPH QUADRANGLE, UTAH

This report or illu[illegible]
is based on work done on
behalf of the U. S. Atomic
Energy Commission.