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GEOHYDROLOGIC-ENGINEERING GEOLOGY EVALUATION OF THE SELMA GROUP IN WESTERN ALABAMA AND NORTHEAST MISSISSIPPI FOR POSSIBLE RADIOACTIVE WASTE DISPOSAL

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June, 1975

This report was prepared by Serge Gonzales under Consultant Subcontract 4310 with Union Carbide Corporation, Nuclear Division. The subcontract was administered by Oak Ridge National Laboratory

UNION CARBIDE

OFFICE OF WASTE ISOLATION
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FINAL REPORT

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Submitted to

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Prepared by

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INTRODUCTION--PROJECT OBJECTIVE AND LOCATION

The objective of this project is to determine and analyze the pertinent geologic and hydrologic features and structural-geomorphic setting of the Upper Cretaceous Selma Group as the latter is exposed from west-central Alabama into northeast Mississippi and south~~east~~westernmost Tennessee. All gathered data are being assessed in order to establish some level of feasibility with reference to the possible use of the thick chalk sequences in the Selma Group as a subsurface repository for high-level radioactive wastes.

Data for the project report have been synthesized from the published literature, unpublished sources, federal and state geologic-survey maps and records, personal field examinations, and discussions with other geoscientists. Information regarding the underground LPG storage facility located near Demopolis, Alabama was obtained in part from a summary prepared by another consultant. Well data for the area of greatest interest, namely the west-central and southwest Alabama region centered near Demopolis were largely furnished by the Alabama Oil and Gas Board. Examination of those chalk intervals being presently quarried was afforded by site investigations at the several active surface mines in the outcrop belt of the Selma Group.

Additional information and insight about the stratigraphy of the Selma Group, project objectives, "chalk" lithotypes, regional geology, and subsurface well data were garnered through discussions with Dr. Robert Frey of the Department of Geology, University of Georgia; Mr. Kenneth Reed of the United Cement Company at Artesia, Mississippi; Mr. Thomas Lomenick of the Union Carbide Corporation; Mr. Donald Moore of the Alabama Oil and Gas Board; and Mr. John Newton of the U. S. Geological Survey Water Resources Division in Tuscaloosa, Alabama. Their collective cooperation and assistance is kindly acknowledged. They, however, share none of the responsibility for the views and evaluations presented in this report.

The area of interest covered here (Figure 1) is located in a region of the Southeast known as the Eastern Gulf Coastal Plain. Here, sedimentary units of Upper Cretaceous and Tertiary age form outcrop belts adjacent to the Appalachian Mountain trend which extends southwestward from northeast Alabama. Reflecting the adjacent Mississippi River Embayment, these bands of outcropping strata change from their generally east-west orientation in south-central Alabama to initially a northwest and subsequently a north-south alignment by the northern part of Mississippi. This variable strike has been combined with gentle regional dips to the south and southwest to yield several physiographic sub-provinces whose topography and geomorphology largely reflect the lithologic character of the underlying bedrock.

Within that context, this study has focused upon the laterally persistent Selma Group which contains several fairly

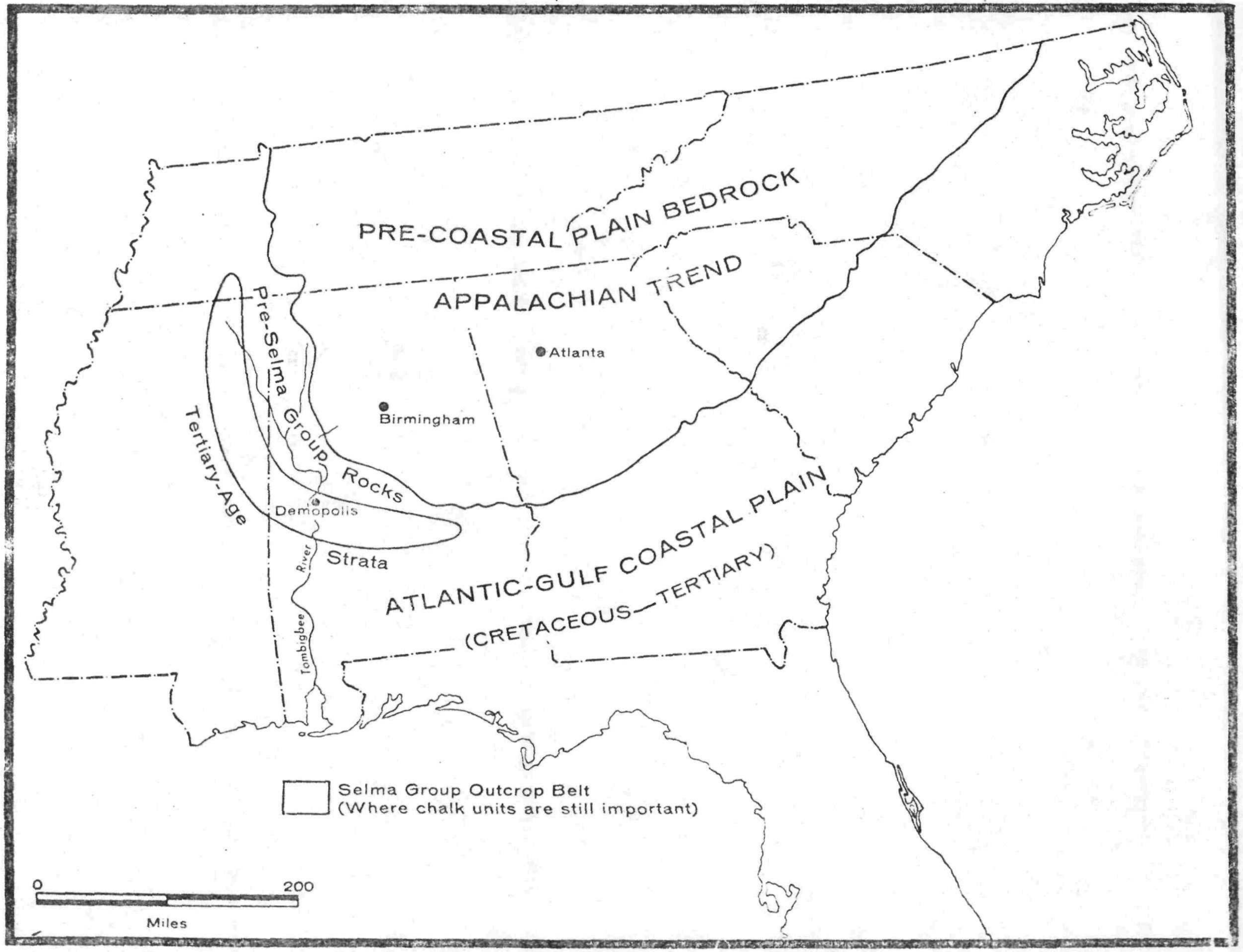

Figure 1. Index map of Eastern Gulf Coastal Plain showing continuity with Atlantic Coastal Plain, and the outcrop belt of the Selma Group where chalk units persist.

thick sequences composed of chalk and related chalky carbonates. This Upper Cretaceous stratigraphic unit rests unconformably upon the Eutaw Formation which in turn lies disconformably upon the upper units of the Tuscaloosa Group. Both the Eutaw and Tuscaloosa intervals are also Upper Cretaceous in age. Various Tertiary-age intervals overlie the youngest or Prairie Bluff Formation in the Selma Group, whose chalk-rich sequences experience lateral facies changes into sand-rich equivalents to the east in Alabama and to the north in Mississippi.

Particular attention has been paid to the well-developed chalk intervals in the Marengo and Sumter County region of western Alabama. Near Demopolis, Alabama, the Selma Group chalk interval reaches several hundred feet in thickness, and already serves as the site for an underground LPG storage facility. Considering also the proximity near there of a significant, laterally traceable faulted zone, an active surface quarry, several oil-exploration wells and available ground-water data, the specific focus of this study is by design the Demopolis, Alabama region.

DEFINITION--SELMA GROUP

The Selma Group is assigned to the Upper Cretaceous, specifically ranging in age from the Santonian to Maestrichtian Stages. Furthermore, the Selma Group has been correlated to be equivalent in large measure to the Gulfian Series consisting of the Austin, Taylor and Navarro Groups (Figure 2) of the Texas Gulf Coast. Within the subsurface geology of the State of Mississippi, namely well to the west and south of the outcrop belt of the Selma Group, usage of the term Selma is intended to collectively include all chalky and non-chalky units assignable to the Austinian, Tayloran, and Navarroan intervals mentioned above (Dinkins, 1966).

Massive chalk and related carbonates of Upper Cretaceous age in Alabama were originally designated the "Rotten Limestone" in 1857 by Winchell. Later, that designation was replaced with the term "Selma Chalk" as proposed by Smith, Johnson and Langdon (1894). In 1948, Murray more formally restricted the Selma as a group to include those stratigraphic units lying above the Eutaw Formation (Upper Cretaceous) and below the Ripley Formation (Upper Cretaceous). Based upon additional investigations on associated pre-Tertiary strata which contain chalk and facies equivalents of other chalky sequences in the Selma, the Selma Group as more recently envisioned includes all Upper Cretaceous strata above the Eutaw Formation and below the Tertiary System (Jones, 1967). The type locality for the Selma

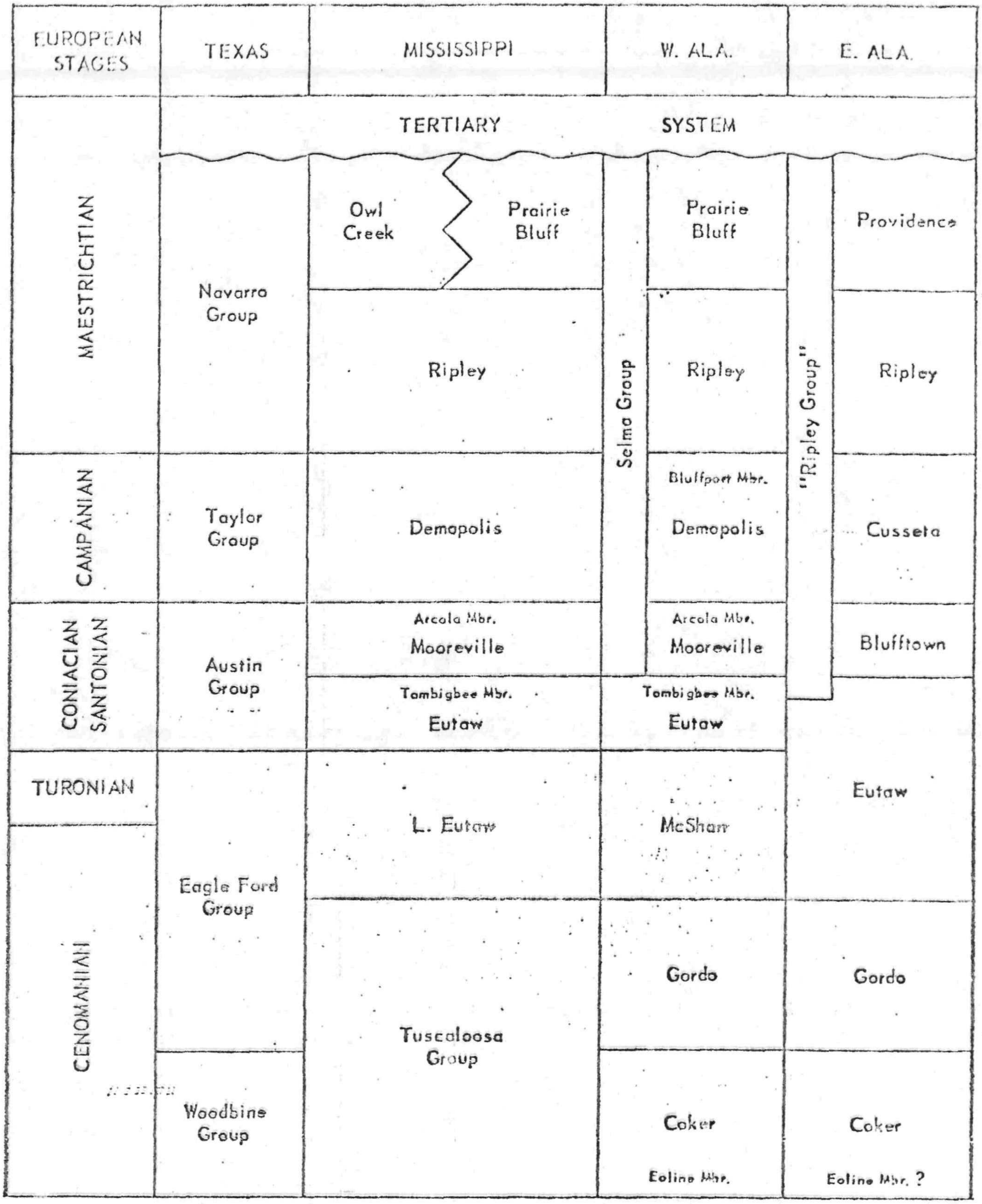

Figure 2. Upper Cretaceous correlation chart showing relative position of the Selma Group of the Eastern Gulf Coastal Plain and equivalent units to the west in Texas (modified after Jones, 1967).

Group is the high bluff along the Alabama River, at Selma in Dallas County, Alabama.

As thus recognized (Figure 3), the Selma Group consists of several identifiable chalk units; the Mooreville and Demopolis Chalks being the more prominent intervals. Calcareous clastics of the Ripley Formation are also assigned to the Upper Cretaceous interval. To understand the assignment of specific stratigraphic units to the Selma Group, additional comment is necessary.

Although originally designated as a stratigraphic tongue by Stephenson (1917) for beds exposed at Mooreville, Mississippi several miles east of the City of Tupelo, the term Mooreville was elevated to the status of formation in 1945 by the Mississippi Geological Society. Monroe (1946) extended a similar usage into Alabama. In both cases, the Mooreville includes a distinctive upper member, called the Arcola Limestone. The latter term, first proposed by Stephenson and Monroe (1938), is named for exposures at old Arcola Landing along the Warrior River, Hale County, Alabama.

Similarly, the term Demopolis was first used in 1903 by Smith as a division of the more massive chalk units in Alabama. This stratigraphic unit is named for a type locality along the bluffs of the Tombigbee River adjacent to the old warehouses at Demopolis, Alabama.

In dividing the earlier designation, "Selma Chalk", Monroe (1941) recognized three members: an unnamed lower chalk, the Arcola Limestone, and the uppermost Demopolis member. When the Mooreville Chalk with the Arcola Limestone at the top and the Demopolis Chalk were both assigned formational rank on the State Geologic Map of Mississippi in 1945, Monroe was moved one year later to extend that usage to Alabama. Thus, the Selma, because of distinctly separate formations being identified within it, rose to the status of group. In 1956, Monroe assigned an additional stratigraphic unit to the Demopolis Chalk by recognizing an upper member which he called the Bluffport Marl. The latter is named for exposures near an abandoned community along the Tombigbee River, near Livingston in Sumter County, Alabama. To a large degree, stratigraphic position within the Demopolis Formation (Chalk) is established from paleontologic evidence. For example, Monroe and Hunt (1958) used a zone of the small pelecypod Diploschiza cretacea and the very small brachiopod Terebratulina filosa in league with the regional zone of Exogyra cancellata to successfully determine position in their mapping of the Epes Quadrangle in western Alabama. Here, faulting has complicated the normal stratigraphic succession.

Because of their stratigraphic proximity and lithologic similarity, the Mooreville and Demopolis Chalks are not always separable in the subsurface. Where the Arcola Limestone Member is distinct and identifiable, such division is possible. In outcrop, the Demopolis is invariably more brittle and resistant than the Mooreville with the exception of the Arcola

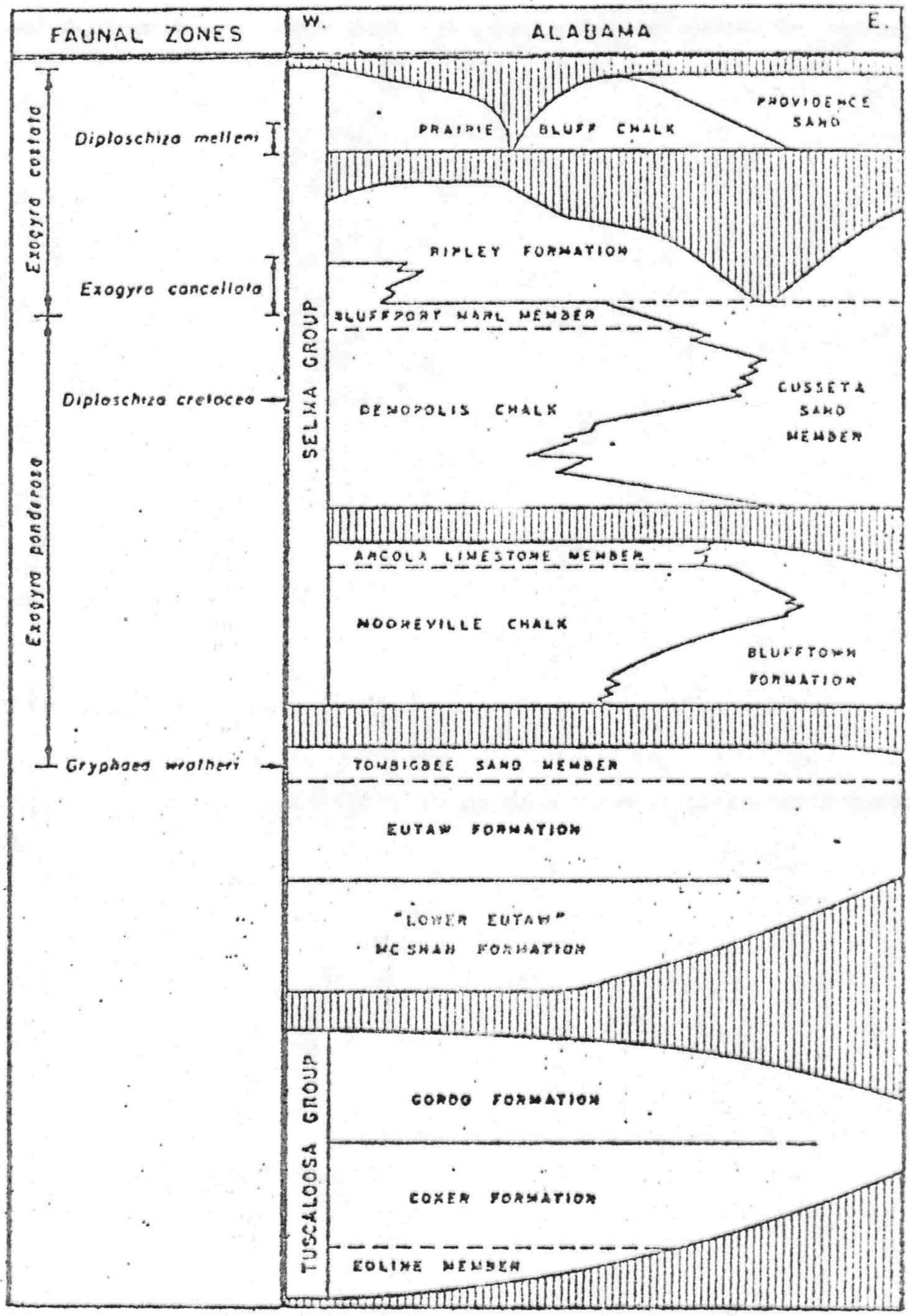

Figure 3. Upper Cretaceous stratigraphic succession in central to western Alabama showing principal faunal zones and disconformities (modified after Copeland, 1973).

Limestone, and therefore generally is more commonly exposed and occupies slightly more pronounced topography.

Overlying the Demopolis Chalk in certain localities and interfingering with that same unit toward eastern Alabama is the Ripley Formation. This non-chalk bearing stratigraphic unit was first used in the sense of a group in the mid 1800's, and has since undergone a reasonable measure of confusion and subsequent revision. The Ripley Formation, now known to be Upper Cretaceous on sound paleontologic evidence, at one time contained units now assigned a Tertiary age. As well, the Ripley Formation once included a chalk unit, the Prairie Bluff Chalk, which is currently considered a separate Upper Cretaceous formation.

As presently accepted, the Ripley Formation includes those dominantly sandy strata and lesser amounts of sandy-clay units which lie stratigraphically above the Bluffport Marl Member of the Demopolis Chalk in western Alabama and eastern Mississippi. To the east, the Ripley Formation, especially a lower member called the Cusseta Sand, interfingers laterally with the Demopolis Chalk. Thus, the Ripley Formation is both equivalent to and younger in age than the Demopolis interval.

The Prairie Bluff Chalk, originally designated a separate unit and later an interval equivalent to the Mooreville and Demopolis Chalks in the late 1800's, was raised to the status of formation by Stephenson and Monroe (1937). They defined this unit as a separate chalk unconformably overlying the

"Selma Chalk" or the Ripley Formation depending on geographic location. As first proposed by Winchell (1857), the Prairie Bluff limestone was named for strata exposed along the Alabama River in section 32, T. 14 N., R. 7 E. in Wilcox County, Alabama.

The Prairie Bluff Chalk therefore represents the uppermost unit assigned to the Selma Group in the general region of western Alabama and eastern Mississippi. Less thick and less continuous in outcrop than the Mooreville and Demopolis Formations, the Prairie Bluff Chalk laterally grades into sandy units in both an eastward and northwestern direction.

In summary, the Selma Group as now constituted consists of in ascending order: the Mooreville Chalk, with the Arcola Limestone as its upper, often readily identifiable member; the Demopolis Chalk, with the Bluffport Marl member at its top; the non-chalk bearing Ripley Formation; and, finally, the Prairie Bluff Chalk. In the case of the Mooreville, Demopolis, and Prairie Bluff Chalks, each grades laterally into lithologically different units to the east, particularly into clastic-dominated sequences. Toward the north and northwest, these same chalk intervals grade into mainly sand-rich units. The Demopolis Chalk represents the furthest outcrop extent of a chalk-carbonate unit of the Selma Group by extending into southern Tennessee as a prominent tongue.

Stratigraphically, the lower Mooreville Chalk and its equivalent Blufftown Formation of the Selma Group unconformably rests upon the Eutaw Formation. Similarly, the uppermost

Prairie Bluff Chalk of the Selma Group is disconformably overlain by the Tertiary (Paleocene) Clayton Formation. As shown schematically in Figure 3, stratigraphic hiatuses exist within the Selma Group between the Mooreville and Demopolis Chalks and between the Ripley Formation and the Prairie Bluff Chalk. In terms of correlation, the generally accepted view is that the lowest chalk of the Selma Group, or the Mooreville, is roughly equivalent to the upper portion of the Austin Chalk in Texas.

In terms of geological age, the assignment of an Upper Cretaceous designation to the Selma Group has clearly been established on the basis of both local and regional stratigraphic relationships and contained paleontologic remains. Fossils found within the Selma Group include several species of the diagnostic Cretaceous index fossil _Exogyra_. The Mooreville and Demopolis Chalk interval largely is embraced by the _Exogyra ponderosa_ zone, while the sandier sequence of the Ripley Formation and Prairie Bluff Chalk is contained within the _Exogyra costata_ zone. In addition, the Selma Group also contains several species of the genera _Ostrea_ and _Gryphaea_. As previously observed, the useful marker forms _Diploschiza cretacea_ and _Terebratulina filosa_ also are present. Also present is abundant micro-paleontological material, especially foraminiferal assemblages.

REGIONAL STRATIGRAPHY

In order to better understand the relationship between the various stratigraphic units by which the Selma Group is presently delineated, a discussion of regional stratigraphy provides an instructive complement to the preceding section. Particular attention is paid here to the major chalk intervals of the Selma Group, and their facies equivalents as understood from work in eastern Alabama and northeastern Mississippi. Generalized data on regional variations in thickness and lithic units represented are also included. Figures 4 and 5 diagrammatically show the lateral facies changes along the eastern and northwestern outcrop belts of the chalk phases respectively.

Mooreville Formation (Chalk)

Although typically reported in the literature as a chalk, the Mooreville Formation is primarily represented by lithologies that are closer to marls, calcareous clays and chalky shales. There is, however, considerable clay-rich, gray-weathering chalk in this stratigraphic unit. Unfortunately, the relatively low topography that reflects geomorphic expression on top of the Mooreville Formation precludes the development of large, well-defined outcrops from which the full sequence could be better studied. The typical soils and topography of the Black Prairie Physiographic Province are thus best developed upon the less resistant Mooreville

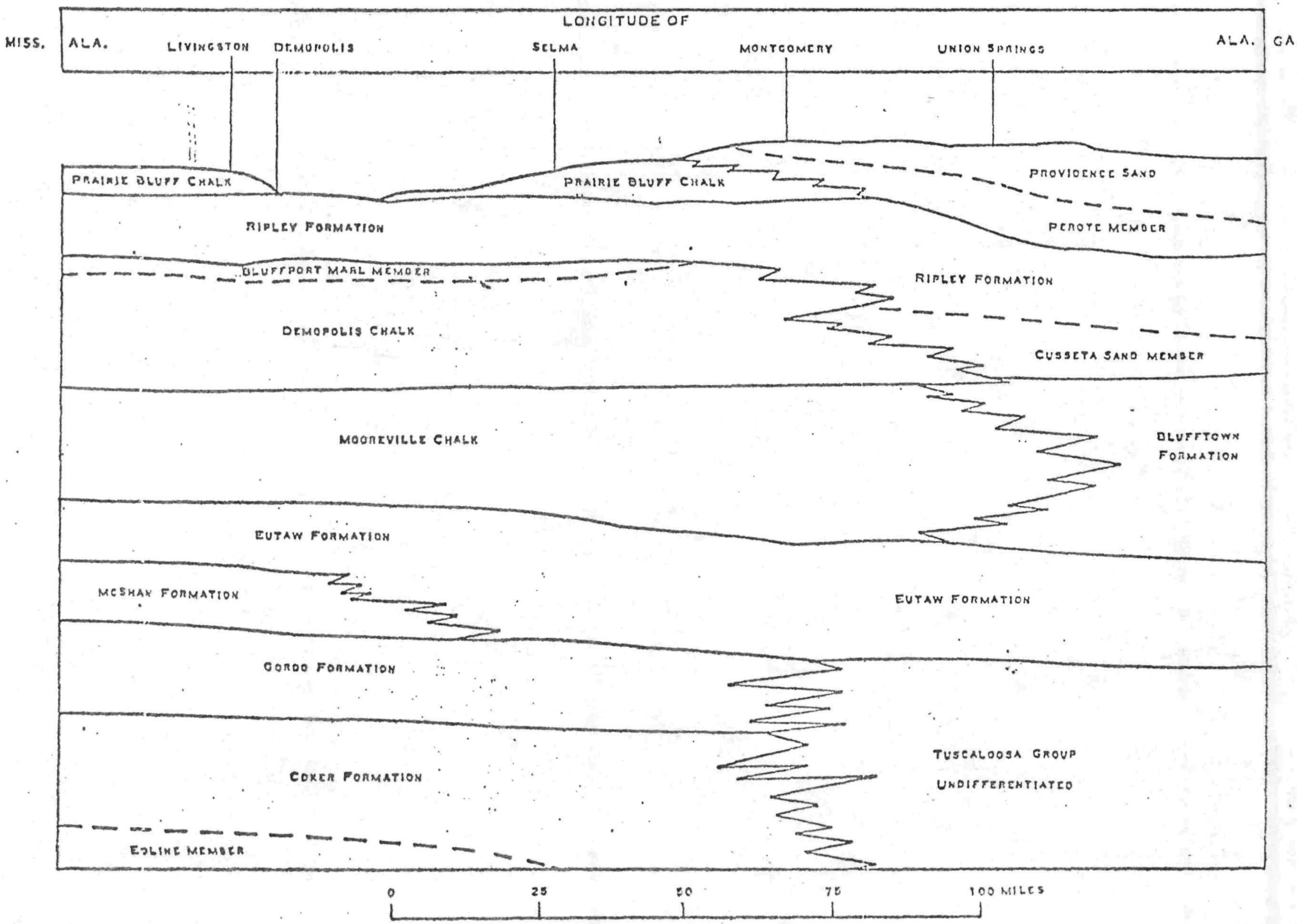

Figure 4. Generalized stratigraphic relations within Upper Cretaceous units, especially the Selma Group, from western to eastern Alabama (modified after Copeland, 1973).

Formation.

Studies have shown that the lower portion of the Mooreville Formation, or the non-Arcola Limestone section, thickens from approximately 265 feet in Sumter County of western Alabama, eastward to 400 or 600 feet in Montgomery County where the sequence has begun to change laterally into the clastic units of the equivalent Blufftown Formation. Much of the original chalky phase is replaced by glauconitic marl and no chalk extends eastward of Russell County, 15 miles west of the Georgia-Alabama state line. An interval of typical Mooreville Chalk up to 100 feet in thickness does extend as a tongue into the Blufftown Clastics from central Alabama to this eastward point. Thus, the thick Mooreville Chalk of western Alabama begins to diminish in continuity eastward of mid-central Alabama.

The Blufftown Formation consists mainly of sands, calcareous clays, thin limestones, and locally contains gravelly-conglomeratic zones near its base. Many of its units are glauconitic, micaceous, and slightly fossiliferous.

The relatively resistant Arcola Limestone member, which typically supports low hills and caps small roadside outcrops, maintains this persistent character in an eastward extent. The Arcola Limestone is dense, fossiliferous and commonly bored or otherwise perforated. It is brittle, rarely exceeds ten (10) feet in thickness, and contains a few feet of interbedded marl which closely resembles the Mooreville lithology.

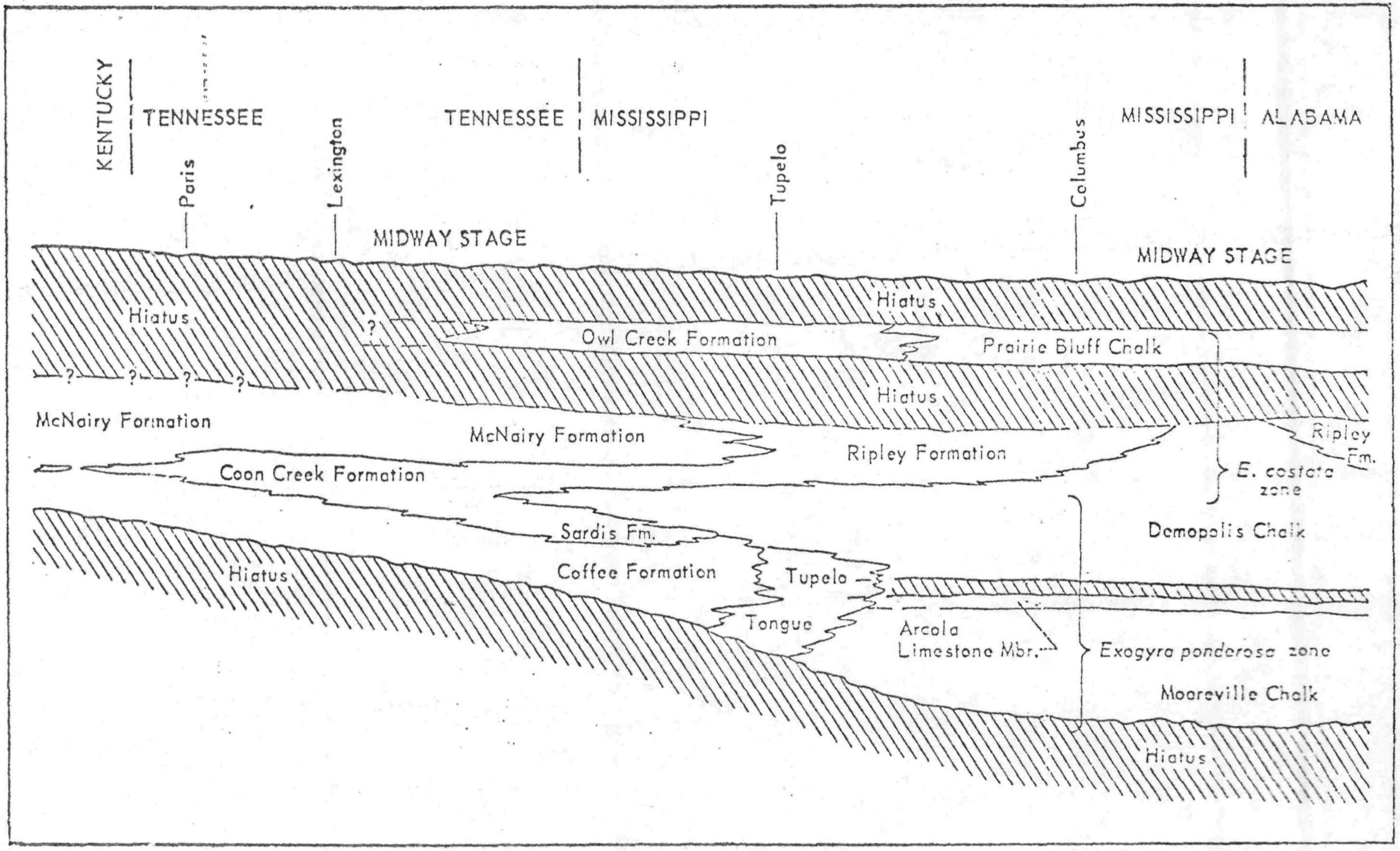

Figure 5. Generalized stratigraphic relations within post-Eutaw, Upper Cretaceous units, especially the Selma Group, from western Alabama to northern Mississippi and southern Tennessee (modified after Russell, 1967).

Along the southern outcrop belt in western Alabama, the resistant Arcola supports a prominent topographic cuesta.

The Mooreville Formation with the Arcola Limestone at its top also extends westward across the Alabama-Mississippi state line and follows the general outcrop pattern of the Selma Group into northeasternmost Mississippi. Throughout much of that outcrop, typical Mooreville lithologies are present and a thickness ranging from 200 to 300 feet is commonly developed. Approximately two-thirds of the way northward in this belt, however, the Mooreville Formation, including the Arcola Member, is gradually replaced by the sands of the Coffee Formation. The latter unit consists of cross-bedded sands and sandy clays, calcareous sandstone and gray clays, and in part is equivalent to the lower Demopolis Chalk which also begins to change laterally in this region. Several lithic units tend to be glauconitic in various outcrops while fossils are represented more typically by plant remains.

The Coffee Formation, named for strata exposed along the Tennessee River in Hardin County, Tennessee, is better developed from the Mississippi-Tennessee state line northward. Of variable thickness, the Coffee Formation also intergrades into other marine clastic equivalents of the Selma Group throughout western Tennessee. In some outcrops, the Coffee directly rests unconformably upon the Eutaw Formation. Thus, the typical Mooreville Chalk does not extend north of the City of Tupelo, Mississippi. Nearby toward the southwest of the

Mooreville outcrop belt, the persistent Arcola Limestone becomes no longer recognizable in the subsurface.

Demopolis Formation (Chalk)

Unconformably overlying the Mooreville Formation and equivalent strata, the Demopolis Formation is a more typical chalk sequence. Although enriched in clay in certain intervals and progressively more marl-rich toward the top, the Demopolis Formation represents a massive, white to light gray chalk interval (Figure 6). The formation ranges in thickness from approximately 500 feet in Sumter County, western Alabama, to 400 feet by Montgomery County in east-central Alabama. By this eastward extension, the Demopolis Formation has decidedly changed its lithologic character, and contains much more clay and sand. In fact, the classic chalk sequence of the general Demopolis, Alabama, region has split by this point into two chalky tongues which become more sandy as they thin eastward. Intervening between these more clastic-rich chalks is the Cusseta Sand. Gradually, the Demopolis Chalk interval is replaced by clastics of the Cusseta-Ripley sequence, as discussed shortly.

The outcrop belt of the Demopolis Chalk, typically ten miles wide, trends in a generally southeastward direction from the Mississippi state line through the Alabama counties of Sumter, Greene, Marengo, Hale, Perry and Dallas (Figure 7). To the east in Montgomery and Bullock counties, the change in

Figure 6. View of Jones Bluff, developed in Demopolis Chalk, Selma Group, along the Tombigbee River, near Epes, Sumter County, Alabama. Water level is higher than normal (crest at 55 feet), thus concealing lower portion of this classic locality.

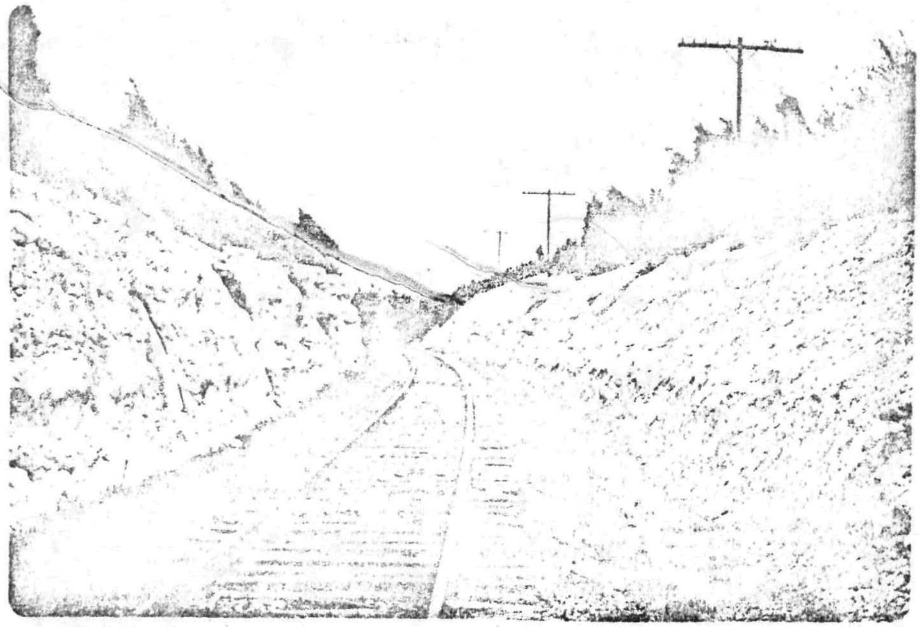

Figure 7. Outcrop of Demopolis Chalk, Selma Group, along Southern Railroad track, 3 miles east of Demopolis, Marengo County, Alabama. Distinctive weathered surface and non-stratified nature are evident. Location is immediately adjacent to LPG storage facility installed in underlying Mooreville Chalk.

lithologic character, the scarcity of thick outcrops and a lack of clear-cut stratigraphic relationships between increasingly similar lithologies, make concise differentiation of the Demopolis Formation, the Cusseta Sand, and the overlying Ripley Formation rather difficult. The existing view is that the Demopolis, as a true chalk, is replaced generally eastward of Selma, Alabama by increasingly sand-rich strata. In turn, the sand-rich Ripley Formation extends as a stratigraphically younger sequence over the Bluffport Marl Member of the Demopolis Chalk in a westward direction. The Ripley interval thus lies above the Demopolis Chalk and separates it from the less well-developed Prairie Bluff Chalk.

Because of these stratigraphic changes and the uniform character of the Demopolis Formation where it is a typical chalk, position within this stratigraphic unit is largely dependent upon paleontologic evidence. Monroe and Hunt (1958), working in western Alabama, were able to establish their relative stratigraphic position on the basis of Exogyra cancellata, Diploschiza cretacea and Terebratulina filosa. Based upon earlier work by Monroe (1956), these authors also identified the upper Bluffport Marl Member as a legitimate stratigraphic division within this general region. Although described as marl, the 65-foot unit contains marl, calcareous clay, chalky shale and shaly chalk. The upper extent of this "marl" member coincides with the top of the Exogyra cancellata faunal zone.

Within Mississippi, the Demopolis Formation consists of thick sequences of typical chalk lithology and more locally developed interbeds of calcareous (chalky) shale and clay (marl). In a northward direction, the Demopolis experiences both lateral facies change and a regional thinning. At the general latitude of Lee County, or slightly south of Tupelo, Mississippi, the chalk-marl sequence of the Demopolis is replaced by more arenaceous units of the Ripley Formation from above, and by similar lithologies of the Coffee Formation from below (Figure 5). A tongue of Demopolis Chalk lithology extends into Tennessee approximately ten miles north of Beech River, where the fossiliferous and calcareous units of the Coon Creek interval totally surplant the chalk phase.

At the Alabama state line, the Demopolis Chalk is nearly 500 feet thick. Based on drilling data, this stratigraphic unit thins to 330 feet in the subsurface of Oktibbeha County, Mississippi. Where the Demopolis lithology crosses the Tennessee state line, its thickness has decreased to less than 50 feet.

The Cusseta Sand consists of a variety of yellow-colored silty and clayey sand units interspersed with very calcareous sands. Some chalk and thin limestone also are present. This unit is now considered as a member (lower) of the Ripley Formation. The latter interval in turn tends to be extremely variable in thickness and has apparently experienced considerable post-depositional erosion (Monroe and Hunt, 1958).

This variability in thickness can be quite pronounced. For example, the Ripley Formation, in a relatively short eight-mile distance, ranges from 70 feet as exposed at Livingston, Alabama to 220 feet in outcrop along the Tombigbee River. The upper portion of the Ripley in this western Alabama area consists primarily of sandy clays, gray to yellow sands and thin fossil-bearing sandstones. Many sand zones are highly calcareous. Despite the calcareous cementation in many of the sandstone units, the Ripley stratigraphic interval is dominated by coarser clastic material. In some areas, the Ripley is deeply weathered to a saprolite-looking material largely reminiscent of Tertiary units with which it has been confused. Glauconite is typical of this interval as well as prominent zones of cross-bedding.

In western Alabama and across into eastern Mississippi, the outcrop belt of the Ripley Formation is extremely narrow, rarely exceeding one or two miles in width unless structurally disturbed as in the Livingston fault zone of Sumter County, Alabama. The Ripley maintains its sandy, glauconitic, cross-bedded characteristics as it extends into northeastern Mississippi.

In the northern extension of its outcrop belt, the Ripley grades into and combines with an additional stratigraphic unit, the McNairy Formation. The McNairy here is mainly an extremely cross-bedded sand with bright, dark-red colors, interbedded with zones of contrasting white sand.

South of the Tennessee state line, this interval overlies the highly fossiliferous Coon Creek sequence, exposed better further to the north in Tennessee. Thus, in northeast Mississippi, the Ripley interval is represented successively by the dark gray, fossiliferous and calcareous Coon Creek clay-marl interval and the overlying red-white McNairy sands.

Fortunately, the presence of abundant, useful index fossils within the Ripley and its facies equivalents enable a reasonably decent understanding of this stratigraphic interval despite a long history of confused use of the term in the literature.

Prairie Bluff Formation (Chalk)

This uppermost chalky unit within the Selma Group is not extensively represented by outcrops throughout the general Alabama-Mississippi area. Where present, it is furthermore extremely difficult to differentiate from the underlying calcareous Ripley Formation which it disconformably overlies. The Prairie Bluff in turn is deeply weathered, and overlain unconformably in turn by the Tertiary-age Clayton Formation.

Like other chalk units within the Selma Group, the relatively thin Prairie Bluff Formation extends eastward approximately two-thirds of the way across the State of Alabama, and is replaced increasingly by clastic units dominated by sand and clay. However, the resemblance between the calcareous, upper Ripley and the sand-rich "chalk" of the lower Prairie Bluff make differentiation this far to the east dubious at best. Jones (1967) even feels that such differentiation is not really possible east of Marengo County, Alabama. Even in western Alabama, the Prairie Bluff Chalk contains appreciable coarse sandy material.

Furthermore, post-Prairie Bluff erosion has removed large sections, or the entire interval in places, thus allowing Tertiary units to rest directly upon the Ripley Formation. The Prairie Bluff is also structurally deformed to the southwest of Demopolis, Alabama, by the Livingston fault zone, a feature which adds also to the difficulty in differentiating this unit from the similar Ripley Formation.

Further to the east, this youngest Selma Chalk interval is represented by a phase called the Providence Sand. To the west into Mississippi, the Prairie Bluff is a more brittle, white to gray-weathering chalk that locally is sandy and clay-rich. Throughout much of its outcrop belt, the Prairie Bluff is also locally phosphatic, with the latter material generally replacing fossils.

East of Linden in Marengo County, Alabama, the Prairie Bluff Chalk is mapped as being nearly 50 feet thick (Newton and others, 1961). The unit thins to as little as 15 feet, and may no longer be mappable eastward into Dallas County. Monroe and Hunt (1958) indicate that the thickest sequence in Sumter County, Alabama is 70 feet. The unit may reach as much as 90 feet in thickness in eastern Mississippi.

Along the northwest-trending strike of Upper Cretaceous strata, the Prairie Bluff Chalk is eventually replaced by the Owl Creek Formation. The latter is a resistant, glauconitic clay zone which, like the McNairy Formation, extends southward from thicker, better-developed exposures in Tennessee. Even though there are difficulties with the exact stratigraphy and lateral equivalent of the Prairie Bluff Chalk, clearly the unit is extensively eroded and weathered, being overlain by the Paleocene Clayton Formation throughout its entire outcrop belt.

In terms of thickness, the interval above the Eutaw Formation and below the Tertiary System has been shown on isopachs to range from 800 to 950 feet from Sumter County, Alabama across into Noxubee, Kemper and Winston counties, Mississippi (Morgan, 1970). Reflecting some non-chalk units within the Ripley interval, the actual total chalk approximates 650 to 800 feet. That thickness largely is due to the Mooreville and Demopolis Chalks. Near Demopolis, Alabama, these two units jointly attain an aggregate thickness of 750 to 800 feet (Newton and others, 1961).

In summary, the chalky-marl sequences of the Selma Group are best developed in western Alabama and eastern Mississippi. The Mooreville and Demopolis intervals constitute the thickest, most persistent and most characteristic chalks. By east-central Alabama and northeast Mississippi, all the Selma "chalks" have fully or partially experienced facies changes, generally into sand-dominated clastics. Erosion, depositional contrasts, similarities in lithic types and local structural features have each contributed to a certain degree of uncertainty about exact stratigraphic relationships and correlation. Paleontologic evidence has been useful in overcoming some of these difficulties.

LITHOLOGIC CHARACTERISTIC-CHALK SEQUENCES

In order to more fully understand the physical character and stratigraphy of the Selma Group, especially that of the Mooreville and Demopolis Formations, a comparative description of the various lithotypes that are commonly lumped into the term "chalk" is useful. In describing the Fort Hays Chalk of Kansas, Frey (1969) recognized the following four reasonably distinctive chalk lithotypes: (1) chalk, defined as a soft, friable, low-density, coccolithophorid micrite; (2) chalky limestone, differing from true chalk above in being harder and less friable, but with a typical conchoidal fracture and abundant micritic material; (3) chalky shale, primarily laminated to fissile rock unit that is enriched in argillaceous material, with subordinate quantities of chalky ingredients; and (4) shaley chalk, intermediate between chalk and chalky shale, with chalk components being more abundant than argillaceous debris, and whose bedding characteristics are not typically as thin and fissile.

True chalk thus contains mixtures of micro- to crypto-grained particles of calcium carbonate, dominately due to the abundant coccolithophorid micritic material. Fragmentary and whole foraminiferal tests similarly dominate any micropaleontologic content. Micro-fossil material is typically more common in chalk and chalky limestones than units in which argillaceous material becomes more abundant. In addition to these distinctive, extremely fine-grained constituents of true chalk units, the latter may also contain macro-fossils, organic material which is typically wood or in some cases lignitic matter, non-carbonate mineral material, such as clay minerals and quartz, and various authigenic materials. In many chalks, the latter include pyrite-marcasite nodules, which based on samples observed in the Demopolis Chalk, may represent replacement of organic material, possibly fecal debris. In addition to these features, Cretaceous-age chalks typically contain numerous prismatic plates from disarticulated and broken shells of the large pelecypod genus Inoceramus. These platelets may be concentrated in individual layers or as residual lag deposits in narrow discontinuous zones (Figure 8).

Bioturbation, referring to the burrowing or other organic disturbance of the soft chalk-rich sediments (pre-lithification) by various bottom-dwelling organisms, is another characteristic of most chalk units. Typically, more resistant burrows and other habitat dwellings may be preserved by organic-limonite residues which represent diagenetic alteration to the original physical passageway linings made in the fine-grained sediments by the original dweller organisms. A more detailed discussion of bioturbation and related phenomena appears in a recently released treatise edited by Frey (1975).

Also present in many chalks, especially where there are depositional interruptions or erosion intervals, are concentrations of phosphatic nodules and related material at the base

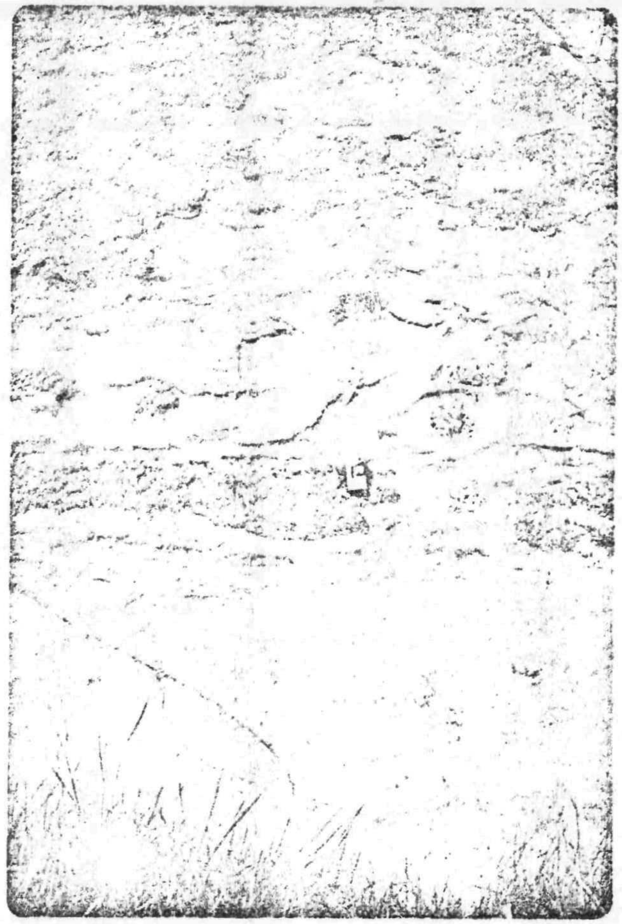

Figure 8. Exposure of Demopolis Chalk along Alabama County Road, west of Epes, Sumter County, Alabama. At this site, the Demopolis contains more clay than many outcrops but retains massive appearance. White flecks are disarticulated prisms from Inoceramus shells. Beer can as scale.

of units which overlie such stratigraphic breaks. Commonly, the phosphatic nodules are dark brown to black; where nodular material is absent or not well-developed, the phosphate is found replacing fossil material such as shells and similar debris.

The range of colors experienced from weathered outcrops of chalk and related chalky units is quite variable. Colors vary through several hues and tones of gray, light gray and white but also may include admixtures of yellow, yellow-gray, orange, olive-gray and a variety of light tans. As a general rule of thumb, the more gray or gray-yellow weathered surfaces are indicative of chalk units enriched in non-carbonate materials, such as clay minerals, quartz and micas. Olive-gray color may indicate the presence of some glauconite in addition to clays. Whiter to light gray-weathering chalk units, whether they are true chalks or chalky limestones, appear to indicate a somewhat greater carbonate fraction in the lithotype.

Representative samples collected from the Demopolis and Mooreville Chalks in the general western Alabama-eastern Mississippi area appear enriched in chalk-micritic material, and display colors ranging from very light gray (N8) to yellowish-gray (5Y7/2)--bluish-white (5Y9/1). Some weathered units may even range upward toward pale yellowish-orange or very pale orange (10YR8/6 to 10YR8/2). This preceding range of colors is by no means inclusive, and many other individual color designations (from categories in the Munsell Rock-Color

Chart) are likely to be present. For example, chalky shales in some localities tend to be olive-gray (5Y4/1) to light olive-gray (5Y5/2).

The term marl, or marlstone, has associated with it a considerable degree of ambiguity and confusion in terms of exactly what rock type is being identified. In the restricted sense, the term marl supposedly refers to relatively soft, friable clay shale in which there is a relatively high percentage of calcareous material. Marl has commonly been described in the literature as being interbedded with a variety of chalky lithotypes. Undoubtedly, there are some marl strata within the Selma Group chalk formations, although many might be better termed chalky shales. The differentiation in this case would be based upon the type of carbonate material present; true marls would contain non-chalky carbonate matter while chalky shales would reflect enrichment in coccolithophorid and related micro-fossil, chalky material. Proper identification on the basis of hand-sample examination alone may not always be possible.

Characteristically, the lithotypes represented in much of the Mooreville and Demopolis Formations fall within the range of chalky limestones, chalks, and shaley chalks. Also present, although less abundantly, are chalky-shale interbeds and some legitimate marls. The Arcola Limestone Member, at the top of the Mooreville Formation, represents a very good example of a fairly dense chalky limestone. Typically nodular and very resistant, this unit, although only a few feet thick, is a very persistent marker bed throughout the region of interest, and commonly is a ridge-cuesta former as a result.

The chalk and chalky limestone units of the Mooreville and Demopolis sequences share many characteristics in terms of their lithologic expression. Variations, however, include coloration, content of non-carbonate material, amount of chalk-micritic matrix, position of specific faunal zones and marker fossils. Predominant among the lithologic characteristics of those intervals dominated by chalks and chalky limestones are: (1) smooth weathering surfaces that commonly develop a conchoidal fracture or "exfoliated" surface; (2) intricate patterns of surface joints, many of which curve together and intersect in unusual orientations; (3) massive appearance, with true stratification essentially absent, except where interbeds of chalky shales and marls occur; (4) strong evidence in many intervals of organic bioturbation; (5) abundant, but localized disarticulated prisms of Inoceramus; (6) commonly abundant marcasite-pyrite nodules, carbonized wood and other organic fragments and mega-fossil material.

Where exposed along major streams, true-chalk units display resistant bluffs in which the typical massive bedding and range of surface-weathering colors can be readily noted. Another characteristic of the Demopolis Chalk throughout much of its outcrop belt is the formation of the feature called "balds". In these cases, rounded, exfoliated-like surfaces of chalk units are exposed at the land surface as thinly-developed, overlying black soil is removed by erosion. The more dense and resistant Demopolis Chalk does not lend itself as readily as the Mooreville Chalk to soil formation. The thinness of soil overlying the curved, rounded weathering surfaces works in combination to provide these exposed geomorphic features more commonly in the outcrop belt of the Demopolis Formation.

Both the "exfoliated" weathered outcrops and intersecting curved joints appear related to each other and are mainly surficial features (Figure 9). The extremely fine-grained micritic material in the chalk intervals appears to be self-sealing at depth. Although evidence at outcrops shows minor seepage of water along some of these joints and weathering surfaces, the impermeability of these chalks at depth suggests that such near-surface openings do not extend appreciably into the subsurface.

As already described, the youngest chalk of the Selma, the Prairie Bluff, is a thinner, more irregularly distributed unit. In fact, throughout much of its irregular outcrop pattern, the Prairie Bluff is more likely an arenaceous chalky limestone. Where present, it is more resistant and dense than the underlying Mooreville-Demopolis chalks and chalky limestones. As a result and where not fully eroded away, the Prairie Bluff is a fairly persistent ridge-cuesta former. Where the Prairie Bluff is somewhat thicker, as in the general Sumter and Lowndes County area, there also are legitimate

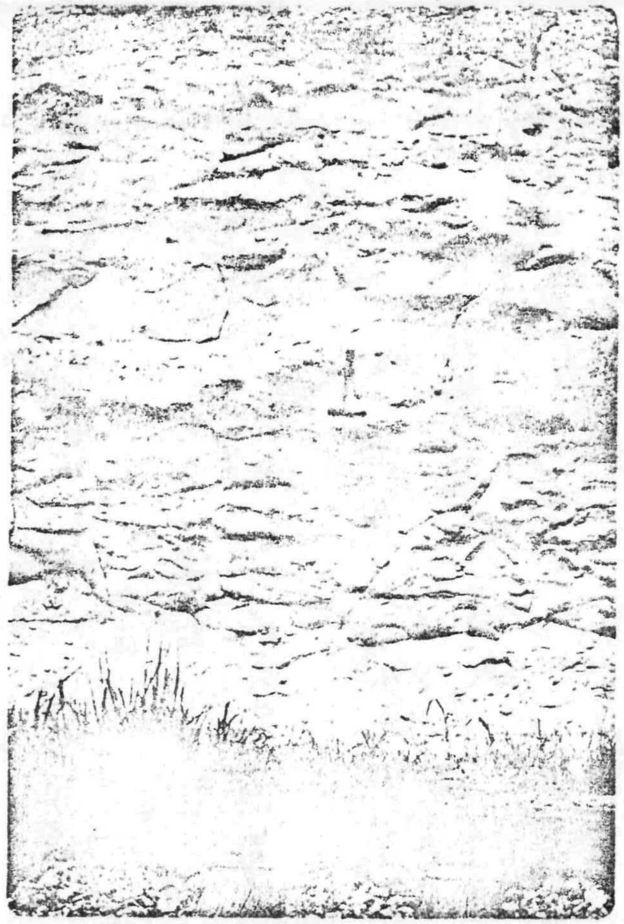

Figure 9. Closeup view of Demopolis Chalk, Selma Group, along Southern Railroad track, adjacent to LPG storage facility. Illustrated is the chalk's typical massive, non-stratified expression and "exfoliation-like" weathered surface. Several arcuate joints related to this weathering also visible. Geologic hammer as scale.

chalk units present. These are not quite as resistant as the more arenaceous intervals of this youngest "chalk".

One relatively minor, but distinctive lithotype is deserving of brief comment. Several thin zones of bentonite (altered volcanic ash) were originally reported within the Mooreville Formation from several localities in Hale and Dallas Counties, Alabama by Munyan (1940). Similarly, Dinkins (1960) identified three discrete marker beds of bentonite within the Mooreville Chalk sequence that is well exposed along Cedar Creek in southern Lowndes County, Mississippi. Their more resistant nature gives rise in such exposures to a sense of stratification to the otherwise massive chalk. Dinkins reported no carbonate fraction from these units in his analyses. It is not known with certainty, however, what is the full lateral extent of the various bentonite horizons, or exactly how many such units exist in the Mooreville Chalk.

STRUCTURAL-GEOLOGY SETTING

Regional Features

As part of the sedimentary sequence comprising the Gulf Coastal Plain, the Selma Group of Alabama-Mississippi and Tennessee belongs to that thickening wedge deposited upon a south to southwest sloping surface of eroded-weathered Paleozoic and crystalline basement rocks. Within west-central and western Alabama, the strike of the sedimentary units is predominantly east-west, but gradually changes to reflect the pronounced Mississippi Embayment to the west, and becomes due north-south by the time one reaches the latitudes of northern Mississippi. Such strike orientations embrace both the Selma Group and units stratigraphically above and below it.

The regional dip for the majority of sedimentary sequences in the Eastern Gulf Coastal Plain is to the south and southwest at an average value of some 40 to 50 feet per mile. This regional structural configuration together with variably resistant lithologies has given rise to the development of the several alternating cuestas and lowlands typical of this belted coastal plain.

As part of the extremely thick sedimentary material deposited in the Gulf Coast Geosyncline, there is a general tendency for the stratigraphic sequence to increase in total thickness in a generally seaward (present-day) direction. Based on available oil-exploration well data from the northern tier where the Selma Group is exposed, the total stratigraphic section overlying the eroded Paleozoic-crystalline basement approximates 4000 feet. Some 35 to 40 miles south of this point, information indicates the stratigraphic sequence exceeds 10,000 feet. Recent oil exploration in extreme southwest Alabama has been directed at Jurassic-age drilling objectives in excess of 20,000 feet in depth.

In addition to this generally southward thickening, the stratigraphy and thickness of the sedimentary sequence together with shallower structures are influenced by the presence of deeper Jurassic-age salt and related salt tectonics. Recent drilling activity for hydrocarbons within the Smackover and Norphlet intervals of Jurassic age has indicated deep structural realignments in response to depositional centers and movements due to salt flowage. In fact, several oil fields have been discovered within these deep Jurassic intervals in southernmost Choctaw County, immediately to the south of Sumter and Marengo Counties.

In addition to this geological situation, salt tectonics have been involved in the formation of the piercement salt domes and related anticlines and faults found in southwesternmost Alabama and southeastern and south-central Mississippi. This area, known as the Central Interior Salt Dome Province, contains a number of identified salt domes and their corresponding associated structures. Although smaller and less numerous than their counterparts further to the south and west in onshore and offshore Louisiana and Texas, the salt domes within the Interior Basin are related to the same basic depositional and salt-tectonic history as the larger Gulf of Mexico salt dome province.

In south-central, southwest and south Alabama and extending into southeastern Mississippi, salt tectonics responsible for these Interior Basin salt domes have also been the cause of several major fault zones and folds within overlying strata. Such related structures have commonly been involved as the trapping mechanism for several significant oil and gas fields discovered in Alabama and Mississippi. On a regional basis, the faults just described can be traced in a general west-northwest direction across the State of Mississippi and may be found to extend throughout northern Louisiana and northeastern Texas as part of a major regional network of faults which surround the general Gulf of Mexico depositional-structural basin.

Major structural units within southwestern Alabama include the Gilbertown, Bethel, and Pollard fault zones in addition to the Mobile graben system. The Hatchetigbee Anticline and Citronelle Dome are two prominent anticlinal features known to occur in southwesternmost Alabama.

Also found on a regional basis, especially in the more competent strata of the Coastal Plain, are many vertical joints and fractures. There appears to be one regional set with a definite northeast-aligned orientation, while a second regional set displays a predominately northwest strike orientation.

Although major regional structural elements such as fault systems and salt domes plus other structures related to salt tectonics have been extremely important in the general Alabama-Mississippi area, little evidence is available to suggest that certain local structural features in the general Selma Group outcrop are related to these larger regional features. An exception in part are the many joints found in Selma Group chalks, and these appear related to the same tensional forces responsible for the joint sets previously mentioned.

Local Features

The general Demopolis and adjacent western Alabama region presents a relatively uncomplicated set of local structural-geology elements. The regional strike of the Selma Group is at this point in a northwestern direction, and regional dips are from 35 to 40 feet per mile to the southwest. Based on well data from northern Marengo County, the stratigraphic sequence, including the Selma Group, approximates 4000 feet in thickness. An exploration well drilled in section 3, T. 16 N., R. 2 E. in northern Marengo County penetrated 3375 feet of Coastal Plain sedimentary sequence prior to bottoming in Ordovician-age basement (McWilliams, 1970).

Several small-scale faults and related structural anomalies have been mapped in both the Tertiary and Cretaceous sediments of western Alabama. The most significant, local structural feature is the unusual zone of relatively intense deformation that has been named the Livingston Fault Zone (Figures 10, 11, and 15). As mapped by Newton and others (1961), in the general vicinity south and southwest of Demopolis, the Livingston Fault Zone includes a number of narrow, high-angle reverse faults, and some associated normal faults (Figure 10) which cut the Selma Group, including the Prairie Bluff Chalk and the Ripley Formation. This faulting is displayed at the surface five miles south and southwest of the city, and extends eastward to the small community of Old Spring Hill, within northern Marengo County. McWilliams (1970) in his gravity survey of this area also interpreted several small, independent faults in the southern tier of the county, and one fault immediately southeast of Demopolis. Correlation between oil-test wells using electric logs has also revealed faulting in western Wilcox County that has affected the Selma Group chalk units. While these faults are not within the Livingston trend, they do indicate additional structural activity.

Monroe and Hunt (1958) also mapped the Livingston Fault Zone in detail throughout Sumter County and western Marengo County, and found it to consist of numerous, high-angle reverse faults which have badly sliced the Selma Group, thus making geologic mapping difficult due to similar lithotypes being involved (Figure 11). Faults in the eastern edge of the Livingston trend have been interpreted as being partially responsible for mineralized water in the normally fresh-water Eutaw Formation (Newton and others, 1961). Jones (1967) has

Figure 10. High angle normal fault cutting upper Demopolis chalk interval adjacent to main portion of Livingston fault zone in Sumter County, Alabama. Height of outcrop is approximately 30 feet.

also shown the Livingston fault zone to be responsible for the normal faulting and section-repetition in the exposures along the Tombigbee River adjacent to the U. S. Highway 80 Bridge (Rooster Bridge).

The writer also observed identifiable evidence of faulting activity within the Demopolis Formation in the quarry floor and walls of the Mississippi Department of Agriculture lime quarry just north of Macon, Mississippi. At this site, there is considerable evidence of stratigraphic offset as well as observable fault traces. Prominent slickensides are present and are much more developed than those often seen along joints in these chalk units. Because this zone of disturbance is on strike with the western Alabama Livingston zone, there is a good possibility that some of the faulting extends that far west.

Detailed geological investigations of the subsurface implications of the Livingston Fault Zone have not been conducted. As Jones (1967) has observed, this fault zone is unusual in that it represents the only significant reverse faults known to occur in the Eastern Gulf Coastal Plain. Monroe and Hunt (1958) suggested analogy with "ribbon faulting" first described in Utah, and felt that salt migration, as there, may have caused the Livingston faulting. Moore (1971) has shown that the northernmost extent of Jurassic-age salt is in the southeast corner of Marengo County. If salt did not exist beneath Sumter County and westward, salt migration and associated ribbon faulting may not explain this unusual fault zone.

Figure 11. Several fault segments within the Prairie Bluff Chalk (?) along small creek adjacent to Interstate Highway 59, north of Livingston. Exposure is within Livingston fault zone where reverse faults predominate. Man (6 feet) as scale.

Schneeflock (1972), relying on his interpretation of seismic data, has proposed in his master's thesis that the more brittle Selma Chalk collapsed in response to alignment over a zone or flexure of faulting in the underlying Paleozoic basement. Whether these seismic data can be so precisely delineated to reveal this structural correspondence is open to some question. At least, Schneeflock's concept represents an alternate view.

However, it must be stated that despite the fairly abundant faulting and the unusual character of the Livingston Fault Zone, little adverse effect has been perpetrated upon the Selma Group in the general Demopolis area. Or, stated another way, the nearly 20 years of successful operation at the subsurface LPG terminal excavated in the Mooreville Chalk indicates that this relatively nearby faulting has exerted no adverse effects. Salinity changes in the Eutaw Formation within the Livingston fault zone proper occur well to the southwest of Demopolis. The suggestion is strong that upward migration of saline waters from depth has taken place along these faults. Elsewhere, however, it would appear reasonable that the faults within the chalk are sealed at depth and do not act as open avenues of communication. This phenomenon may well be due to the very fine-grained nature of the chalky units which tends to seal ruptures such as small faults and joints. There may even be a component of flowage to the fine micritic material. Many surface joints show little evidence of water movement due to being so sealed.

The age of this faulting may be as late as Eocene because Paleocene age units appear involved. Some would dispute that the overlying Paleocene, at an erosional surface especially, shows conclusive evidence of faulting, and thus a late Cretaceous or early Tertiary (pre-Eocene) age may be the case. Any resolution regarding more recent movement along any of these faults is not possible at this time.

As noted in a preceding section on lithology, the chalk units of the Selma Group typically reveal prominent joints. The latter are generally vertical, typically have curved joint surfaces and intersect in irregular orientations. Commonly, some joints show minor movement as evidenced by poorly developed slickensides. Haddox (1963), based on over 2000 measurements, found that 92 percent of the joints observed in the Demopolis Chalk in eastern Mississippi were vertical. These joints could be aligned in two sets, one with a northeast strike (N 60-70° E) and the other with a northwest orientation (N 70-80° W). He also believes that certain stream courses are influenced by these joints.

There is essentially no evidence of solution along any of these joints. They further appear closely related to the spalling type of weathering in the chalks, and probably result from tensional forces acting in unison with the unusually fine-grained chalk lithotypes. Compaction of the fine-grained micritic ooze toward lithification may have also played a role. The joints largely do not appear as effective avenues of water movement.

EARTHQUAKES AND HISTORICAL SEISMICITY

The outcrop belt and shallow (less than 1500 feet in depth) subsurface extension of the Selma Group collectively occur within zones of relatively low seismic risk (Figure 12). In fact, the southernmost portion of the outcrop belt within Alabama actually lies within a zone of zero seismic risk, indicating that the probability (as based on historical records) of damage from earthquakes is essentially nil.

Although the States of Alabama and Mississippi, where the Selma Group is developed and exposed, have themselves experienced little historical seismic activity, areas within these states have recorded earthquake intensities from seismic events occurring in adjacent areas. Of particular interest in this regard is the high-risk zone assigned to the Southeast as the result of the very destructive Charleston, South Carolina earthquake of 1886, and the seismic activity concentrated in the New Madrid Belt centered in northwestern Arkansas, southeastern Missouri, and southern Illinois. The largest seismic events recorded from that high-risk zone occurred during 1811-1812, and are estimated to have exceeded magnitude 8 on the Richter Scale.

The New Madrid Belt is therefore of greater interest. Earthquakes in this particular trend are historically more frequent and typically register large magnitudes and intensities. By comparison in terms of seismic frequency, the

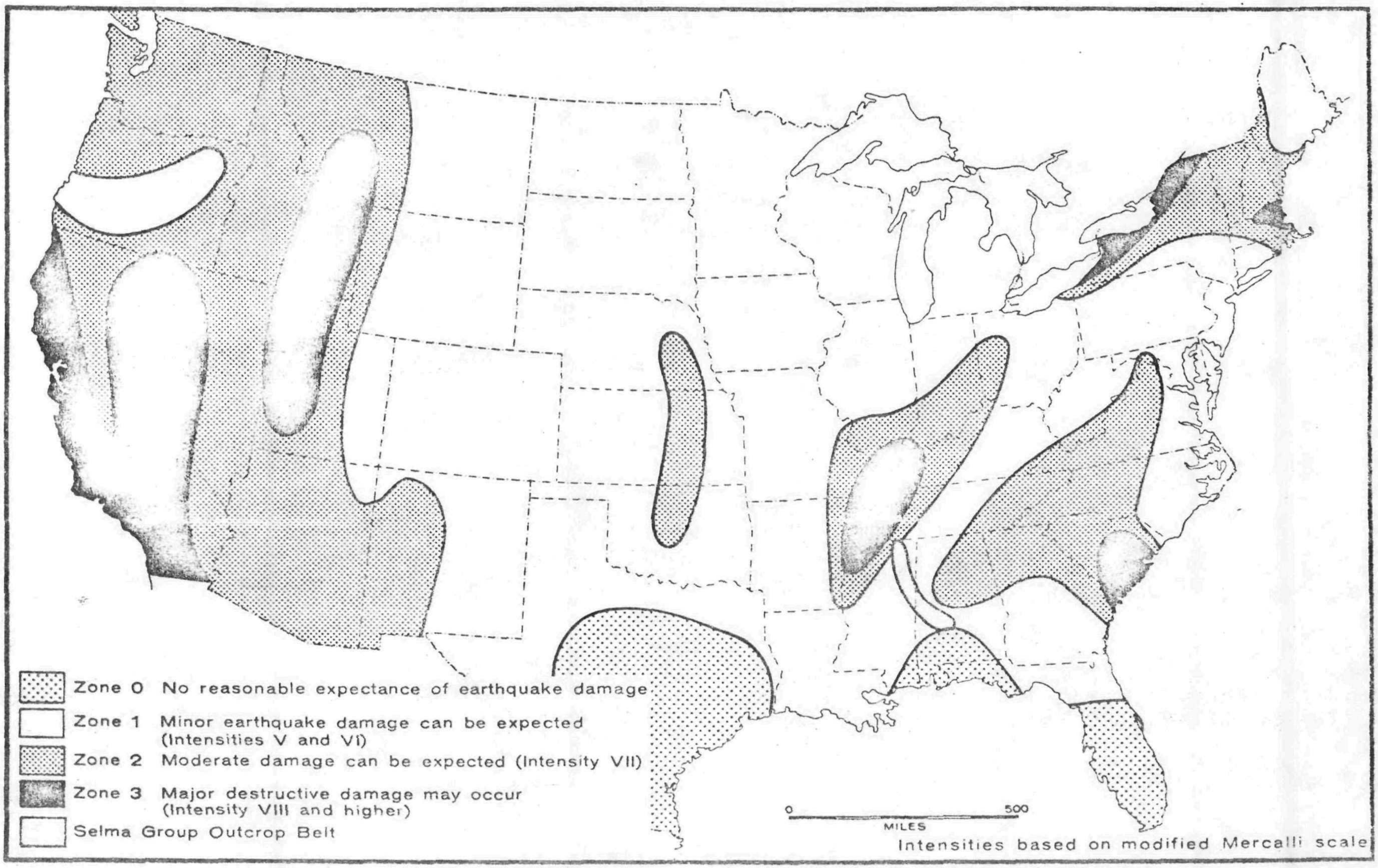

Figure 12. Seismic-risk map for the conterminous United States showing relative location of the main outcrop belt of the Selma Group (modified from the U. S. Coast and Geodetic Survey).

zone delineated by the one major Charleston earthquake is of lesser consequence. Despite greater seismic activity in the New Madrid Belt, effects on areas underlain by the Selma Group are relatively negligible in terms of measurable damage. Intensities (based upon the Modified Mercalli Scale) ranging upward to values of VII have been experienced in northernmost Alabama from the more significant seismic events of the New Madrid Belt. Damage from even these events has however been relatively small to surface structures. Consequently, although the New Madrid Belt is relatively proximal to the area under consideration in this report, significant seismic hazard would not appear to exist for the Selma Group, particularly within the area surrounding Demopolis, Alabama as a result. The center of that high-risk zone lies some 275 miles to the northwest of the general Demopolis area.

With regard to specific seismic events within the States of Alabama and Mississippi, the historical record indicates little activity. One relatively minor, recorded event did, however, occur in 1886 within the general Sumter and Marengo County area through which the Selma Group outcrops. This seismic activity preceded the large-magnitude Charleston earthquake by some six months. Although no magnitude value was assigned to this southwest-Alabama earthquake, records indicate that it was of comparatively low intensity, being felt primarily by small communities located along the Tombigbee River. Of interest here is the possibility that this seismic event may have in some way been related to the relatively intensely deformed Livingston fault zone which crosses the Tombigbee River near U. S. Highway 80 in Sumter County, Alabama and trends in a general northwest direction across the Alabama-Mississippi state line.

Based on data tabulated in the U. S. Geological Survey Earthquake Information Bulletin, the majority of significant seismic events, of which there have been less than ten (10) within Alabama, have been concentrated in the northeastern portion of the State (Figure 13). This relationship thus aligns the majority of the State's seismicity with the southwesternmost extension of the Appalachian Mountain trend. None of these earthquakes, all but one of which are located more than 100 miles northeast of the Selma Group's outcrop belt, have recorded intensities greater than VII on the Modified Mercalli Scale.

There occurred, however, in 1971 a seismic event which registered a magnitude of 3.9 on the Richter Scale, and whose epicenter, located at 33.1° North Latitude and 87.9° West Longitude, placed it some 43 miles north-northwest of the City of Demopolis, Alabama. Occurring in early March, the event was monitored by the Jesuit Seismological Association in St. Louis, Missouri, and represents the most recent seismic activity in the section of Alabama nearest the Selma Group (Coffman and Von Hake, 1973). Significantly, no structural damage was experienced from this relatively low-intensity

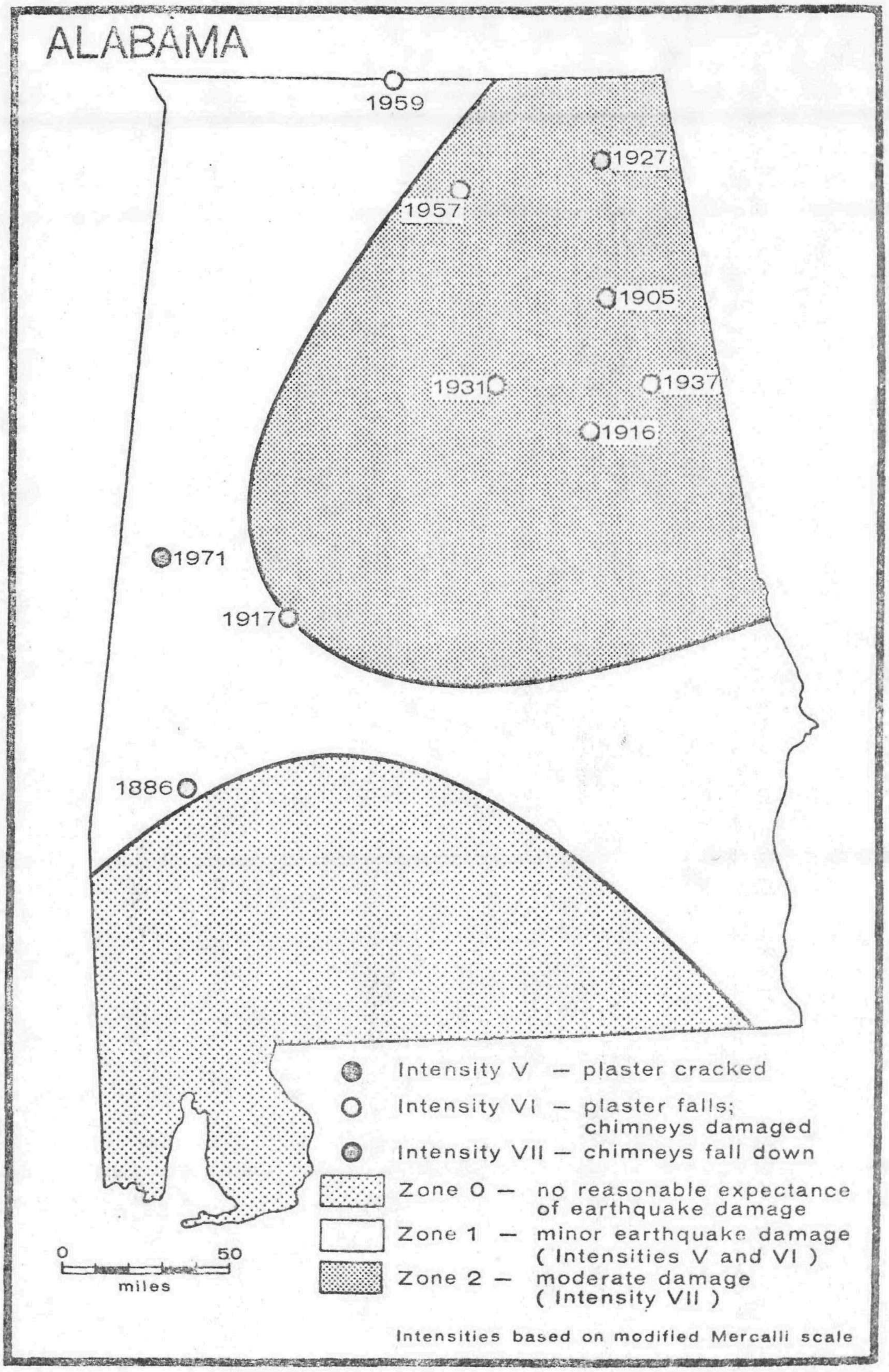

Figure 13. Historically recorded earthquakes within the State of Alabama showing epicentral locations, intensities and date of event (modified from the U. S. Geological Survey Earthquake Information Bulletin).

event. Since 1971, data indicate that no additional seismic activity has occurred within the State of Alabama.

According to records maintained by the National Oceanographic and Atmospheric Administration Environmental Data Service, no seismic events of potentially damaging intensity have occurred within the State of Mississippi. In 1967, however, two events of relatively low magnitude did take place some eighteen (18) miles northeast of the City of Greenville, located in extreme western Mississippi. Although the larger of these events registered an intensity of value VI over an area of 25,000 square miles, no effect from this event was felt in Alabama, or in the outcrop belt of the Selma Group in easternmost Mississippi. Based on data acquired to date, no additional seismic activity has been experienced in the State of Mississippi directly. Furthermore there is no evidence that seismic events of sufficient magnitude have occurred in adjacent areas outside the State to exert an influence on the eastern and norhteastern corner where the Selma Group is either exposed or close to the surface.

Bollinger (1973), in analyzing seismic activity within the southeastern United States, has identified the following three regional trends: (1) South Appalachian seismic zone, which coincides with the general Appalachian Mountain belt and any subsurface extensions toward the southwest; (2) South Carolina-Georgia seismic zone, which runs transverse to the South Appalachian zone, and includes within it the historically significant Charleston, South Carolina area; (3) Central Virginia seismic zone, which is also transverse to the Appalachian zone, but has a slight offset. All of the seismic events propagated in Alabama would fall within Bollinger's South Appalachian zone. Furthermore, the only significant seismicity known from the Southeast's coastal plain regions is that associated with the Charleston, South Carolina area. Bollinger also observed that the felt areas or the areal extent of surface phenomena from which intensity information can be derived, were surprisingly large, being more extensive than West Coast felt areas for similar size events. Most Southeast felt areas appear to be elliptical in plan view and parallel more or less any regional strike. This would thus give essentially elliptical felt areas elongated northeast-southwest for most of the Alabama seismic events.

The following statements can be made with regard to the overall earthquake hazard and historical seismicity of the region geologically related to the Selma Group. First, no large-magnitude seismic event has ever taken place in the States of Alabama and Mississippi. Secondly, those events which have been recorded in the two-state region have been generally distant from the Selma Group, and have yielded relatively low intensities (less than value VIII in all cases). The general effect of such earthquake activity has been negligible in the general Demopolis, Alabama area despite extensive felt areas. Thirdly, the only significant, seismically active zone, the New Madrid Belt, lies considerably to the northwest of the Selma Group's outcrop area. It is further felt that, even as seismic events continue to take place in the New Madrid Belt, their intensity effects within the Selma Group, particularly in the subsurface, will likewise be negligible. Fourthly, the relatively few, low-intensity events that have occurred within the outcrop belt of the Selma Group are believed not to pose any significant earthquake hazard for a subsurface, radioactive waste-repository located in the Selma Group. As indicated already in this section, the most recent seismic event, recorded in 1971, appears to bear no genetic relationship to any observable structural-geology element in the vicinity of the Selma Group. In summary, there seems to be little reason for concern with regard to the overall integrity of the Selma Group in response to local or near-regional seismicity.

REGIONAL GEOMORPHOLOGY

The outcrop belt of the Selma Group, especially the Mooreville and Demopolis Chalks, is intimately related to the physiographic development of much of the Eastern Gulf Coastal Plains. This region consists of a series of alternating lowlands and cuestas. As discussed by Thornbury (1965), these geomorphic features are the result of greater thicknesses and numbers of Cretaceous and Tertiary formations as compared to the region east of here in Georgia, differences in weathering resistance and the general structural attitude of the units involved. For this region, the designation "belted coastal plain" has been applied in response to the greater width of the province and its contrasting topographic zones. In this particular geomorphic setting, the escarpments are infacing and oriented generally parallel to the strike of the onlapped Cretaceous-Tertiary sedimentary wedge which butts against the buried Paleozoic and older rocks of the Appalachian Mountain trend.

As shown in Figure 14, the line of juncture between the Coastal Plain and the Appalachian Trend in Alabama does not display the somewhat classic "fall-line" characteristics developed further to the east in the coastal plain of Georgia and the Carolinas. Nevertheless, the first physiographic division lying to the south and southwest of the contact between coastal-plain sediments and Paleozoic rocks of the Appalachians is called the Fall-Line Hills. This sub-province

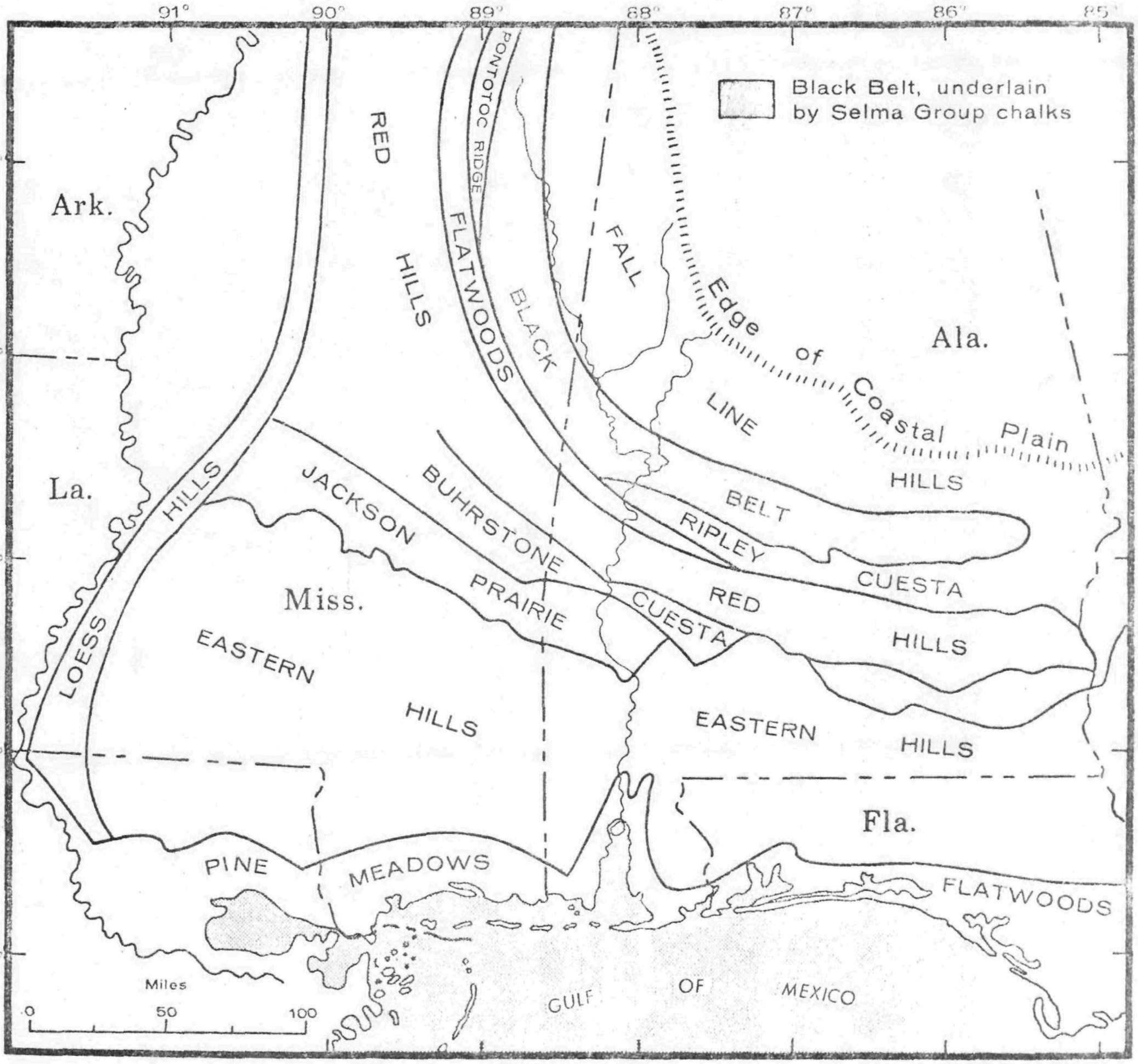

Figure 14. Eastern Gulf Coastal Plain and its principal physiographic sub-provinces and its belted character of alternating lowlands and infacing cuestas. Black Belt (= Black Prairie Belt) coincides with the outcrop trend of Selma Group chalk units (modified after Thornbury, 1965).

is developed on the Upper Cretaceous-age Tuscaloosa and Eutaw Formations, and attains moderate relief. The latter varies from 200 to 250 feet while the average width approximates 40 miles. Because of the topography and sandy nature of the underlying parent-material, the soils are generally poor, and more commonly left in forest than cultivated for crops.

Immediately adjacent to the Fall-Line Hills on the south and southwest is the region known as the Black Belt or Black Prairie Belt. The latter draws its name from the prominent black soils which are developed on the chalks and related chalky carbonate units of the Selma Group. The Black Prairie Belt extends from northeasternmost Mississippi into western and west-central Alabama, and continues as a recognizable geomorphic feature to the approximate latitude of Montgomery County, Alabama. Because of the lithologic changes which occur within the Selma by that point, the weathering products change and the province has lost its distinctive expression.

The most typical features of the Black Prairie Belt are its well-developed, dark-brown to dark gray and black soils, a gently undulating surface and very low relief with elevations generally between 100 and 200 feet. The belt ranges in width from 20 to 25 miles. Its low-lying topography and characteristic soils are a direct result of weathering upon the chalk and chalky-limestone bedrock of the Selma Group. As previously observed under the discussion of stratigraphy, the characteristic features of this sub-province are better developed above the less resistant, more clay-rich Mooreville Formation than where the harder, more pure chalks of the Demopolis are involved.

Because of the high degree of impermeability to the chalks and related chalky limestones underlying this belt, streams in the area are predominately small. Many are intermittent. Those streams which flow through the area usually have developed their headwaters elsewhere, thus establishing sufficient bank storage to enable their passage through this particular sub-province. The two major streams which cross this belt are the Tombigbee and Black Warrior Rivers. They in fact merge in western Alabama due northwest of the town of Demopolis or approximately in the middle of the Black Prairie Belt.

Dissection by these major streams into the bedrock of this sub-province has been as much as 60 feet in some places. This feature has been interpreted by some to indicate dissection downward from a Pliocene-age gravel surface deposited on top of the Selma Group. There is some evidence that the present-day Black Prairie Belt may have been once covered by gravels largely equivalent to the "Lafayette gravels" of the Midwest and Mississippi Valley. If this interpretation is correct, the majority of such gravels and river-terrace sands have been removed since the late Pliocene by stream dissection and erosion. This would make the exhumed Selma Group expressed as the Black Prairie Belt a Pleistocene-age strath. The characteristic black soils would thus have formed since the

Pleistocene on the exposed chalky bedrock. Furthermore, the deep dissection by the larger streams represents a form of superposed stream development on top of the exhumed Black Prairie strath. This pronounced stream downcutting explains the existence of several prominent bluffs formed in Selma Group chalks. Despite this dissection, both major rivers have developed observable floodplains.

The predominately black and dark gray soils developed within the Black Prairie Belt are classed as calcimorphic soils. The latter include those which typically form on parent materials of high lime content, and whose surface horizons are typically neutral to slightly alkaline in chemical character. Commonly, the soils formed in humid climates develop upon a grass vegetation. Originally given the soil name Rendzina, these black soils are now called Rendolls under the U. S. Soil Conservation Service's new soil classification. Where the Mooreville Formation serves as bedrock, the black Rendolls exhibit high fertility and reasonably well-developed profiles. Here, the black soils support the original grasses and good cultivations of soybeans and cotton. Soils developed on the Mooreville Chalk generally lack appreciable forest cover. Because subsoils in even well-developed Rendolls are typically thin and the entire soil tends to be friable, erosion, especially where intensified by agricultural practices, can pose problems.

In that portion of the Black Prairie Belt underlain by the Demopolis Formation, soils tend to be less fertile, more thinly developed, and more readily eroded. One contributing factor to the less fertile characteristics in this area is the fact that the chalk and chalky limestones of the Demopolis are of greater purity and more resistant to weathering than the adjacent Mooreville interval. Therefore, soil-forming processes are not able to weather material to yield as great a thickness of soil, and the non-carbonate, clay fraction is reduced because of the greater carbonate purity.

As a result of thinner profiles, soil erosion in that part of the Black Prairie Belt underlain by the Demopolis is more pronounced. This is the case even though the general nature of the gentle topography persists. Bald areas, representing places where erosion has completely stripped the soil away to expose rounded, exfoliated-like chalk bedrock, are principally developed in this particular area. A corresponding characteristic of the Black Prairie Belt where supported by the Demopolis Chalk is that vegetation is much sparser and less dominated by grassy types. The Demopolis outcrop belt supports abundant cedar trees, which commonly surround or grow nearby to the "balds" developed by erosion into the Demopolis chalky sequence.

Physiographically, the Ripley Formation, containing greater amounts of sand and other non-carbonate lithotypes, is generally more resistant across the State of Alabama and forms another geomorphic sub-province called the Ripley Cuesta.

This feature lies immediately to the south and west of and overlooks the Black Prairie Belt of the more typical Selma Group carbonates. Where the Prairie Bluff Chalk is involved in the stratigraphic succession, it too occupies a topographically higher position than the undulating prairie lands developed on more chalk-rich carbonates. In part, this is due to the more resistant nature of the associated Ripley Formation which is commonly indistinguishable from the Prairie Bluff in this area. Also contributory is the fact that the Prairie Bluff is more silty and arenaceous, especially in Mississippi, and thus becomes more resistant in a manner similar to the Ripley Formation. The Ripley Cuesta, and in turn the portion associated with the thinner Prairie Bluff sequence, is much better developed within Alabama. As a significant topographic feature, the Ripley Cuesta begins to diminish by the Mississippi-Alabama state line. However, with additional stratigraphic units, it reappears in northern Mississippi and there is called Pontotoc Ridge, which rises 200 to 300 feet above the Black Prairie Belt.

To the south of the Ripley Cuesta and in response to the more resistant sands of the overlying Paleocene Clayton Formation there develops a geomorphic sub-province entitled The Red Hills. In part, this physiographical area exhibits appreciable dissection and more pronounced topography than the sub-provinces described to this point. Sediments of the Wilcox Formation also play a geological role. Westward in Mississippi, an additional province called The Flatwoods is developed on the intervening Eocene-age Midway Formation and displays a characteristic lowland somewhat similar to, but not as pronounced as, the Black Prairie Belt. In east-central Mississippi where the Ripley Cuesta-Pontotoc Ridge diminishes, this sub-province is contiguous to the Black Prairie Belt. In southwest Alabama, there is some minor development of a Flatwoods-type topography between the Ripley Cuesta and The Red Hills. Where present, this feature occurs on the Paleocene Porters Creek Clay.

The Black Prairie, especially as developed on the Demopolis and Mooreville, persists to the Mississippi-Tennessee state line. However, as a result of the lateral facies changes involving the Mooreville and the Coffee Formation, and the Demopolis and the Coon Creek-McNairy interval, the Black Prairie Belt decreases in width and is in part replaced along the west by the more resistant east-facing cuesta called Pontotoc Ridge. As one progresses into southern Tennessee, the gradual thinning of any recognizable chalk phase corresponds with the dimunition of the Black Prairie Belt.

Thus, the topographic expression of a persistent geomorphic sub-province, the formation of a large area of characteristic calcimorphic soils, the partial control over development of surface drainage and the absence of any significant solution features typical of many carbonate terrains are all directly related to the abundant chalks and chalky limestones of the Selma Group. Clearly then the stratigraphic position and physical-chemical nature of the Selma Group lithotypes have played an important role in the regional geomorphology of west-central to western Alabama and northeastern Mississippi.

MAN-MADE EXCAVATION-PENETRATION

In addition to the three surface-mining sites to be discussed more fully in the next section, an important construction project related to the Selma Group is the underground facility for the cavern storage of liquified petroleum (gas) products (LPG). The Demopolis LPG facility is presently operated jointly by the American Petroleum Company (AMOCO) and Atlantic Richfield Petroleum Company (ARCO), and has a total storage capacity of 15 million gallons, or the equivalent of 365,000 barrels. The facility, installed by Fennix and Scisson Company of Tulsa, Oklahoma, commensed operation in 1957 and is located within section 22, R. 3 E., T. 18 N., east of Demopolis, Alabama (Figure 15).

Comprising the storage facility are two separate caverns excavated by means of two independent, large-diameter vertical shafts drilled to a depth of 300 feet into the lowest chalk, or the Mooreville Chalk, of the Selma Group. The Mooreville Chalk is approximately 300 feet thick at this particular site; total thickness of all chalk units within the Selma Group in this general locality is slightly more than 900 feet. The vertical shafts, located 800 feet apart, were each cased with 42-inch casing after drilling. Excavation in the subsurface was by lateral drifts, in turn followed by room and pillar excavation. Pillars are approximately 45 feet in diameter while rooms vary from 14 to 16 feet in width, and 25 feet in

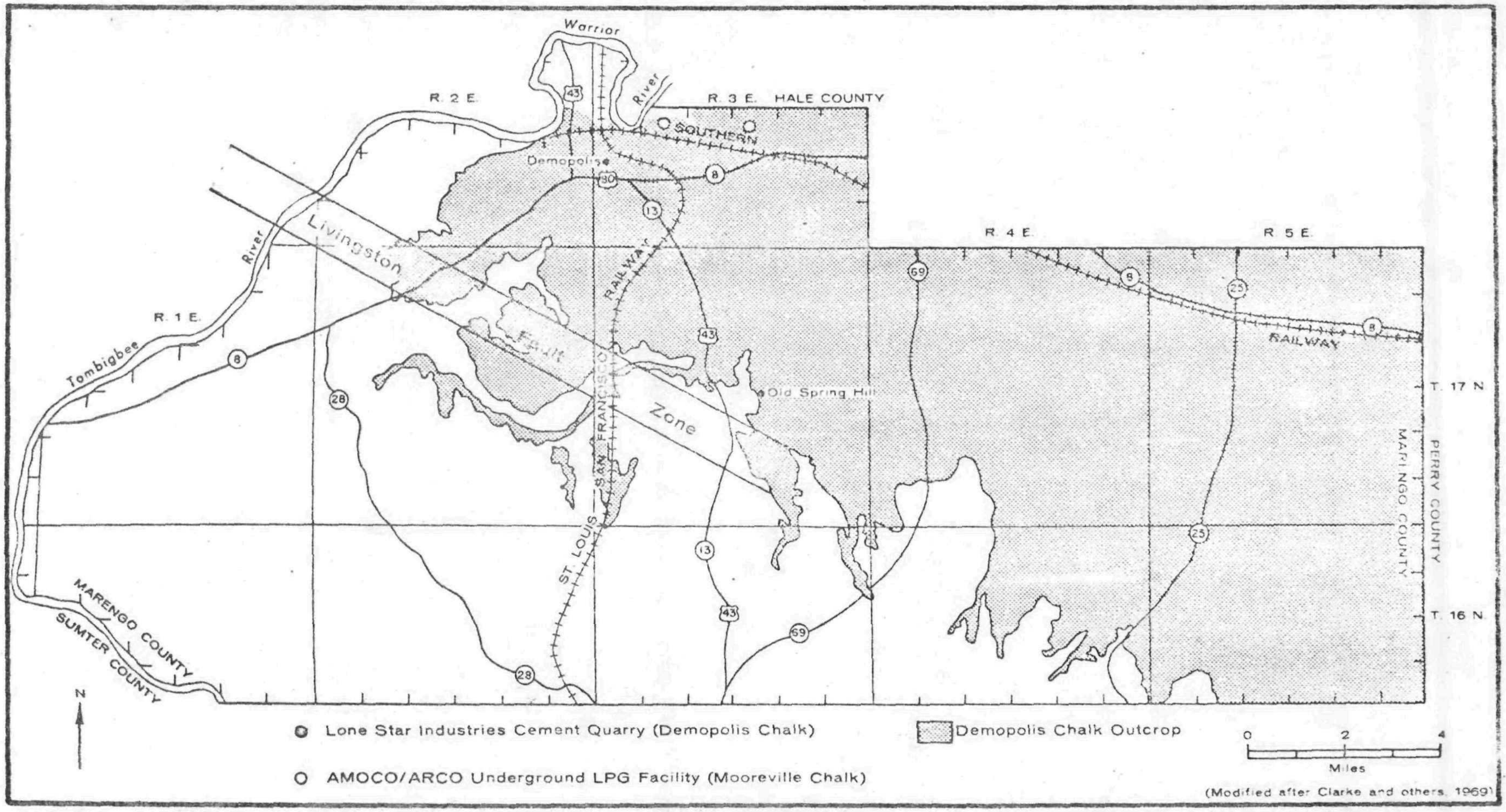

Figure 15. Generalized map of northern Marengo County, Alabama showing geologic extent of Demopolis Chalk, and the locations of an underground LPG facility, a surface quarry and the Livingston fault zone.

height.

The original joint owners of the facility, Tuloma Gas Products Company and Sinclair Oil Company, originally ascertained that excavation within the Mooreville Chalk would require additional supporting measures. Efforts to utilize rock bolts on four-foot centers as a supplement to the pillars in supporting the "back" within the rooms proved unsuccessful due to dehydration of the exposed chalk bedrock. This in turn allowed the installed rock bolts to slip from their anchorage points.

Thereafter, equilibrium conditions were allowed to become established as portions of the back fell and a natural arch developed following initial excavation. Once spalling was largely terminated, injection of petroleum products was begun.

Compatibility of the site with regard to the storage of liquid petroleum has been clearly established through nearly 20 years of successful operation. No contamination of the stored petroleum products has resulted from rock-liquid interaction. No inflow of water has been experienced due to the extremely low permeability of the chalk in which the storage caverns are excavated. Fractures, joints and microfaults observed at the surface adjacent to the storage facility by this report's writer undoubtedly have been successfully sealed considerably above the subsurface level of the storage facility. This is a characteristic directly related to the extremely fine-grained nature and allied physical properties of these chalk units.

In the course of exploratory drilling for petroleum, which is generally felt to occur in stratigraphic horizons deeper than the Selma Group, a sizeable number of test wells have been drilled through the chalk sequence. For those counties most closely associated with the general Demopolis area, oil-well data have been tabulated in Appendix A from records of the Alabama Oil and Gas Board.

A large number of wells have also been drilled into the ground-water aquifers within the deeper Eutaw and Gordo Formations which underlie the Selma Group. Unfortunately, the U. S. Geological Survey's records reflect location and depth information on probably not more than 60 percent of all the water wells drilled in these several western Alabama counties (Newton, personal communication, 1975).

Although those wellbores located near the immediate Demopolis area have not created any known hazard for the existing LPG storage facility, they must be viewed with some caution for any future radioactive-waste repository. This is because they represent potential breach points with regard to the penetrated chalk horizons. Even though the risk is much less than with salt beds where solution due to water inflow can be hazardous, penetration points through even a very fine-grained carbonate horizon cannot be taken lightly. Some of the older wells undoubtedly have collapsed and have become sealed, but others are no doubt open to the surface. Any potential local site would need as part of its feasibility a detailed check from interviews with property owners, courthouse records and State-agency files.

RECOVERY OF GEOLOGICAL RESOURCES

The Selma Group, although not a major producer of economically important raw materials, is a source of certain geologic resources. Included in the latter are: (1) limestone as one non-metallic resource; (2) petroleum hydrocarbons; and (3) ground water. In addition, deposits of low-grade phosphate and foundry sand have been delineated in west-central Alabama. Commercial production of these two potential resources appears doubtful at this time.

The most important economic-geology resource recovered from the Selma Group is chalk (limestone). This fine-grained, impure carbonate is in turn utilized in the manufacture of Portland cement and agricultural lime. Active quarries within the outcrop area of interest covered by this report include the: (1) Mississippi Department of Agriculture and Commerce site, located near Macon, Mississippi, along the west side of U. S. Route 45, approximately two miles north of that route's intersection with Mississippi State Route 14; (2) United Cement Company (Division, Texas Industries, Incorporated) facility, located near Artesia, Mississippi in sections 29 and 32, R. 16 E. and T. 18 N.; and, (3) Lone Star Industries quarry, located immediately east of Demopolis, Alabama in section 20, R. 3 E., T. 18 N. In all these locations, the rock unit quarried is impure chalk belonging to the Demopolis Formation (Chalk).

Although data on the chemical quality of the chalk at the United Cement Company site have been requested, to date they are not available. Chemical analyses of the Demopolis chalk mined from the Lone Star Cement Company property is included with several other analyses in Table 1 . The information tabulated includes analyses of samples taken adjacent to the quarry property, elsewhere in Marengo County and from adjacent counties. Although there is observable variability in the calcium-carbonate content of the Demopolis Chalk, data presented by Clark and others (1973) indicate that specific intervals within this stratigraphic unit can show a wide range in their content of insoluble residues. More specifically, there are within the Demopolis Chalk intervals which contain in excess of fifty percent residues, or a non-carbonate fraction dominated by clay minerals and sand-sized impurities. To aid in calcining, and fluxing the alumina, a mixture of iron ore and sand is added to the raw feedstock. The Lone Star Cement Company quarry, originally opened in 1898, is located two sections west of the underground LPG storage facility; but, the latter is excavated in the older Mooreville Chalk beneath the Demopolis Chalk.

With regard to the general relationship of the other two quarries, namely those at Macon and Artesia, Mississippi, they are located some 60 and 75 miles, respectively, to the northwest of Demopolis. Neither of these sites would thus appear to jeopardize the integrity of the immediate Demopolis

Table 1. Selected Chemical Analyses of the Demopolis Chalk in Marengo and Adjacent Counties, Alabama.

Sample Information	Chemical Constituent-Percent by Weight			
	Calcium Carbonate ($CaCO_3$)	Magnesium Carbonate ($MgCO_3$)	Silica (SiO_2)	Iron-Aluminum Oxides
Average - 81 samples from near original cement plant, Demopolis, Alabama (after Burchard, 1940)	78.67	1.40	9.48	7.58
Average - 75 feet of drill core, Lone Star Cement Company Quarry, east of Demopolis (after Clarke and others, 1973)	82.52	1.08	8.42	7.06
Average - 10 samples distributed through Demopolis, Perry County (after Szabo, 1972)	78.42	1.15	12.82	5.98

region, and none of the three facilities would appear to pose any hazard of the underlying Mooreville Chalk. The continued acceptable performance of the underground petroleum storage facility proximal to the long-active Demopolis quarry site serves to support that statement.

The Selma Group has also had significance with regard to the production of petroleum hydrocarbons, especially within the State of Alabama. In 1944, the discovery of the Gilbertown field in Choctaw County led to the first commercial production of crude oil even though some natural gas had earlier been produced from two then-abandoned gas fields. The Gilbertown oil field has subsequently produced more than ten (10) million barrels of oil from sands within the Eutaw Formation (deeper producing horizon) and fractured chalk zones within the Selma Group (shallower producing horizon). Entrapment is along an east-west trending fault whose northern block is downthrown to the north. All productive wells are situated within the up-thrown southern block, and production is less than 3,500 feet. This landmark oil field is located some fifty (50) miles south-southwest of Demopolis, Alabama.

To the west in Mississippi where individual chalk units may not be differentiated in the subsurface, the Selma Group is also an oil-productive stratigraphic horizon. As mentioned in the preceding section on stratigraphy, the Selma Group generally refers to the undifferentiated chalky-carbonate section that includes the Austinian, Tayloran and Navarroan time-rock equivalents. This distinction is actually maintained in a transition from Mississippi westward to where the classic Gulfian sequence can be subdivided in Texas.

For example, the Pickens oil field in eastern Yazoo County, Mississippi produces from the Selma Group at an average depth of slightly more than 4,500 feet, although deeper horizons are productive there as well.

Generally speaking, the Selma Group or specific chalk intervals within it are not target horizons within northeast to eastern Mississippi or west-central Alabama. Although the Selma Group as the focus of this report is typically not a productive horizon in existing petroleum fields within Alabama and Mississippi or an exploration objective in new wells, the sequence has been penetrated in both states by numerous exploratory drill holes seeking other stratigraphic targets (see Appendix A).

Because of their physical-lithologic characteristics, the chalk units within the Selma Group exhibit extremely low permeability and porosity. Thus, stratigraphic intervals such as the Mooreville, Demopolis, and Prairie Bluff "chalks" do not represent productive ground-water aquifers.

In their study of water resources for Marengo County, Alabama, however, Newton and others (1971) found that isolated sand units within the Ripley Formation were a secondary ground-water source. This was particularly the case in the east-central portion of the county near the communities of Magnolia and Linden. Water-producing sand bodies within the Ripley Formation generally lie between 125 and 650 feet in depth, although some wells exceed 850 feet. The Ripley Formation, although stratigraphically both equivalent and younger in part to the Demopolis Chalk, is the only productive ground-water aquifer within the Selma Group. Nevertheless, this interval in the Selma Group is only locally productive and is much less relied upon as a water source than the deeper Eutaw Formation.

In a similar fashion, the Ripley Formation, principally from several different lenticular sand bodies, yields fresh ground water in eastern and northeastern Mississippi (Shows, 1970). In central Mississippi, the Ripley Formation is a principal ground-water aquifer; in extreme northeastern Mississippi, especially in areas near the Tennessee border, the Ripley increases in thickness through the addition of facies-change sands from the McNairy Formation. Here, the Ripley has become the most important ground-water aquifer in the area.

As was the case in Alabama, the Demopolis and other chalk units of the Selma Group are essentially impermeable and do not therefore yield ground water. Within northeast Mississippi, such limitations also pertain to the younger Prairie Bluff-Owl Creek interval except locally where sandy units begin to predominate.

Several of the chalk units within the Selma Group are also reported to be enriched in phosphate. In one such case, the resulting deposit has been evaluated as a potential phosphate resource. Of particular significance are deposits located in Perry County, where the phosphate occurs within the basal Mooreville Chalk of the Selma Group. Szabo (1972) has mapped a continuous zone of phosphatic material consisting of nodules, grains and fossil molds along the lower contact of the Mooreville Chalk with the underlying Eutaw Formation. Undoubtedly, this association at a stratigraphic boundary indicates a form of discontinuous deposition, erosional break or some type of unconformable relationship. In most stratigraphic compilations, these units are shown separated by an observable unconformity.

The P_2O_5 content of the phosphatic zone in the basal Mooreville ranges upward to nearly 2.8 percent although values as low as 0.07 percent were obtained from certain test samples. The average percentage-grade therefore is less than the above maximum. Total reserves of potential phosphate have been calculated to be only 2.5 million tons (Szabo, 1973). When the current and forecast markets for domestic phosphate production are considered, the possibility that this type of deposit will find any near-term economic utilization becomes rather remote.

Phosphatic concentrations elsewhere within the Selma Group have also been re-described in recent years by Clark and others (1969). These phosphatic materials appear concentrated within two separate stratigraphic horizons, namely the uppermost Prairie Bluff Chalk and the Bluffport Marl member of the Demopolis Chalk, within Marengo County, Alabama. Because of inconclusive data due to poor outcrop conditions, exact assessment of the quality and quantity of these phosphate materials within the Selma Group has not yet been possible. However, one test boring near Linden reportedly penetrated the Prairie Bluff chalk unit where a ten-foot zone of phosphatic debris was concentrated. This same phosphate-rich interval has been traced eastward into Wilcox County by Clarke and others (1970). As is the case in Marengo County, the phosphate is concentrated within a zone lying beneath the stratigraphic contact with the overlying Tertiary (Paleocene) Clayton Formation. Random samples collected within Wilcox County have yielded phosphate values as high as 21.4 percent BPL (Bone Phosphate of Lime).

Despite the relatively persistent lateral extent of the phosphate concentrations within the Prairie Bluff Chalk, this study believes that, similar to the occurrences in Perry County, the phosphate within the Selma Group will not be commercially recovered in the foreseeable future.

Another geologic resource potentially available from units in the Selma Group is foundry-quality sand, found in the Ripley Formation. Clarke and others (1969) estimated that under fairly thin overburden the Ripley Formation northeast of Linden (15 miles south of Demopolis) contained 15 million tons of sand. Additional reserves are available under thicker overburden in this largely non-chalk sequence of the Selma Group. No commercial development has yet been undertaken; and, even in the event of future extraction, such activity would not pose any hazard to the chalk sequences to the north and northwest.

GROUND-WATER HYDROLOGY

Based on the prevailing outcrop patterns, the moniclinal, south to southwest dips, and the existence of the thick, largely impermeable Selma Group stratigraphically above, artesian-water conditions have been created within the deeper Eutaw Formation and Tuscaloosa Group in western Alabama and eastern Mississippi. Both the Eutaw and Tuscaloosa intervals are dominated by sands and sandstones, and thus display excellent porosity and permeability to act as ground-water aquifers. These deeper units receive their aquiclude sealing from the very impermeable chalks and chalky limestones of the overlying Selma Group. Although the piezometric pressures of these deeper aquifers are not sufficient to sustain flowing wells but in a few lowlying areas, large industrial and municipal well fields using centrifugal pumps extract several millions of gallons of water daily from these Upper Cretaceous aquifers.

Of some concern with reference to those aquifers beneath the Selma Group is water quality. Downdip or in the vicinity of faulted zones which can act as loci for upward migration, these units show an increase in dissolved solids, especially the chloride ion. Within the general Demopolis-northern Marengo County, Alabama area, the highly mineralized nature of the water in the Tuscaloosa Group precludes its use currently (Newton and others, 1971). Water from the Eutaw Formation, generally the best regional source, shows a decrease in water quality downdip to the southwest, and proximal to the Livingston fault zone. The latter may allow more saline water from the Tuscaloosa interval to communicate upward (Newton and others, 1961). Pumping over the years has also caused a slight local decrease in water quality in the Eutaw Formation because of deeper saline water moving upward toward points of depression. The 400-feet Eutaw interval is generally reachable by wells drilled from 800 to 1300 feet in depth.

As noted in the preceding section, the Selma Group is for all practical purposes impermeable, and as such, does not constitute a ground-water source. An exception to that is of course afforded by the minor production of fresh water from the Ripley Formation, where sand units are local aquifers. This relationship was also covered in the preceding section. The thick, massive chalk intervals of the Selma Group simply do not possess ground water due to their high degree of impermeability. As already discussed, the Selma Group chalks serve as the sealing device for the deep Upper Cretaceous artesian systems of the Eutaw and Tuscaloosa intervals.

Additional evidence of the impermeable nature of the Selma Group is illustrated by the fact that surface-water retention time is very slight in the Black Prairie physiographic province. Streams there are floored in the chalk sequence and thus runoff and transit through these stream basins are rapid. Streams crest and recede quickly during precipitation, supplying no bank storage for later replenishment, or recharge to the ground-water regime. Many smaller streams are thus intermittent, going dry during low or deficient rainfall.

Furthermore, very few of the joints or fractures found developed in the Selma Group chalks show evidence of solution-widening, or appreciable water flow. Some can be seen to be emitting minor near-surface water, and others are iron-stained or bleached, indicative of some water movement along these ruptures. But, for the most part, joints, even in fairly deep outcrops, are dry in appearance or show no evidence of appreciable water movement.

Even where the region's major trunk streams, i.e. the Black Warrior and Tombigbee Rivers, have dissected into the Selma Group some 60-70 feet, there is no evidence of lateral flow outward from the streams into the chalk intervals. Add to this evidence the fact that water influx to the Demopolis LPG storage facility has never been a problem, and it is evident that regionally the thick chalk sequences of the Selma Group exhibit a pronounced measure of impermeability. The extremely fine-grained nature of the micritic carbonate material and the high degree of compaction and cohesion to the resulting chalky units constitute the major cause for this impermeable character. Joints and fractures appear to be near-surface phenomena, probably self-sealing at depth, and solutioning is not evident. Thus, secondary porosity has not been developed to any appreciable degree either. Only in the close vicinity of faulting, such as the Livingston Fault Zone, might there be some secondary porosity. Where chalk units are replaced lithologically, or micritic material in the chalky intervals becomes less abundant, the very impermeable character of the lithotypes remains because chalky clay-shales and marls are developed with their corresponding clay-mineral content.

There is thus little to no evidence to suggest that water infiltration would pose a problem to subsurface caverns excavated in the massive Demopolis or Mooreville Formations of the Selma Group. Breaching of these units by geologic stream erosion during the next several thousand years also appears unlikely to pose a hydrologic hazard to any subsurface repository. The only hydrologic concern would appear to be in regard to the integrity of water wells drilled to these deeper aquifers through the Selma Group chalks.

CULTURAL DEVELOPMENT

The western Alabama-eastern Mississippi region (focus is on the Demopolis area) embraced by the outcrop belt of the Selma Group retains largely a rural, agricultural orientation in terms of cultural development. This is in part due to the richness of the fertile Black Prairie Belt soils which support a favorable agricultural economy. As the leading beef cattle and dairy area in the State of Alabama, the region raises extensive hay, pasture, and soybeans. The Black Belt as a result contains the largest-per-size farms in the State.

All counties within the region surrounding Marengo County have less than 60 percent urban populations, and several have less than 40 percent. The largest municipality is Selma in Dallas County, and is the only community having more than 25,000 inhabitants. Demopolis in Marengo County has more than 5000 residents; the population ranges from 2500 to 5000 for the communities of Linden (Marengo), Greensboro (Hale), Eutaw (Greene), York (Sumter) and Marion (Perry). There are of course numerous small hamlets and other small communities as well. Population density for all these counties is less than 50 people per square mile, except for Dallas County where the range is 50 to 100 per square mile.

In terms of major cultural features, the following summarized points can be made:

1. Two natural-gas pipelines cross the area; one trending

east-west through northern Marengo County and the other northeast-southwest through the southern part of the County.

2. Two power stations, one a 48.9 MW turbine and the other a 500 MW thermal plant, are located in the area. The former is run by Alabama Power in Demopolis, Alabama, and the latter is maintained by an EMC in southern Greene County. High tension transmission lines (110 + 220 KV) run from these plants and several substations.

3. There is the usual development of subsidiary electric lines, telephone cables and above-ground lines and radio-television transmitting facilities.

4. No commercial airfields are located in close proximity. The closest is situated at Tuscaloosa, several miles to the northeast. There are however non-commercial strips in Demopolis, and Hale, Greene, Perry, and Sumter Counties.

5. The region is served well by several railroads, namely two branch lines of the St. Louis/San Francisco, a branch and main line of the Southern Railroad and a branch line of the Louisville and Nashville railroad.

6. Similarly, the road network is quite adequate as Interstate 59 passes through the heart of the area in a northeast-southwest direction, and portions of U. S. Routes 11 and 43 run through the region. There are several State highways, which in turn are supplemented by numerous paved and dirt roads maintained by individual counties.

7. The nearest military base is Craig Air Force Base, 5 miles east of Selma in Dallas County.

8. Several outdoor recreation areas exist along dammed drainages, as those associated with Demopolis and Warrior Lakes, west and north of Demopolis respectively. Located in western Sumter County, Gainesville Lake represents another outdoor recreational facility. Chickasaw State Park is in southwest Marengo County, while a portion of Talladega National Forest lies several tens of miles northeast of Demopolis.

9. The area lacks any major tourist attraction or facility, and has only one state historic site, located near Demopolis.

There would not therefore appear to be any concentration of cultural features that might jeopardize consideration of the region for a radioactive-waste repository. Transportation via railways and major highways is good, thus lending itself to the safe movement of containerized solid wastes. No historical or ecologically sensitive sites would appear endangered by surface construction supportive of an underground repository. The relatively widespread population and lack of any major centers of urbanization are additional positive points. Although some very beneficial agricultural land would have to be withdrawn, the infusion of industrial support of a repository might be an offsetting economic factor.

If the site of any future radioactive-waste repository must be distantly removed from population or well-travelled transportation routes, the general Demopolis area would not qualify from a cultural development standpoint. If, on the other hand, a predominately rural, slightly developed region is amenable, this western Alabama-eastern Mississippi region may be worthy of further consideration.

ASSESSMENT AND RECOMMENDATIONS

Many different schemes have been proposed in the last three decades with regard to the safe and proper disposal of radioactive wastes produced in the production of weapons and nuclear-electric energy. Excellent summaries and discussions of the many geologic and non-geologic methods suggested may be found in articles by Blomeke and others (1973), Kubo and Rose (1973) and Winograd (1974). Although no effort will be made here to evaluate these many proposals, some comparison to the most feasible geologic approach, i.e. disposal in bedded salt, may be at least outlined.

As Lomenick (1973) has observed, the six main advantages for using salt for radioactive waste disposal (solids) are the following: (1) essentially impermeable; (2) widespread and abundant; (3) high structural strength; (4) low cost of developing space; (5) good thermal conductivity; (6) location in areas of low seismicity. Salt's natural ability to be self-sealing through plastic flow with regard to joints and other openings represents an additional positive feature.

Although much work on and success with bedded salt came about from the Lyons, Kansas area, and progress is being made in the general Carlsbad, New Mexico region, interest in other potentially feasible geologic environments remains active. The three leading possibilities according to Blomeke and others (1973) are shale-clays and related argillaceous lithotypes, crystalline bedrock such as granite or basalt and certain carbonate rock types such as dolostone and limestone, including chalk.

It is of course the latter rock type, and in specific those within the Selma Group, with which this report is concerned. Having reviewed a considerable array of geologic-hydrologic information, this brief section will attempt to establish a general feasibility for the Selma Group chalk sequence, judge the major areas of concern and outline some possible future topics for additional investigation.

The thick (600-850 feet) Mooreville-Demopolis sequence clearly shows evidence of well-delineated impermeability. These units can be traced along strike and/or downdip for several tens of miles before lateral facies changes modify the stratigraphic succession. So, the thick impermeable chalky units are reasonably widespread. No data were available to compare the structural strength of chalk with salt, but it is felt that there would not be an appreciable difference. Excavations, both at the surface and in an underground LPG facility, illustrate the economic amenability of mining chalk. Likewise, no data were available to compare thermal conductivity, and because of possible dessication-spalling effects, acquisition and evaluation of such data are deemed highly advisable. The latter could nicely be integrated into comparison between uniaxial and triaxial-shear compression studies to yield comparative rock strengths. The location of the Selma

Group clearly coincides with a region of very low seismic activity. Evidence presented elsewhere in this report strongly suggests that chalk units may also be partially self-sealing due to a combination of factors related to minute grain size and compaction.

Thus, on a preliminary basis, the Selma Group chalks near to the general Demopolis area would appear to share to some degree several of the desirable attributes of bedded salt.

A major concern to both evaporites and many carbonate units is dissolution by circulating ground water. Rates of such dissolving migration have been calculated over geologic time for the Castile Formation in southeast New Mexico. Despite obvious solution action in many carbonates, there is little evidence that this phenomenon adversely affects chalk units. Certainly such is the case for the Selma Group chalks. Although soft and friable and reducable to a lowland topography, there is no direct evidence of noticeable solutioning activity in the 70+ million years since their deposition. The total exclusion of water, the very fine-grained texture, high degree of compaction and resulting impermeability appear to preclude solutioning, at least in the study area.

The Mooreville-Demopolis sequence, despite an ability to seal some joints, is affected by some faulting, i.e. the Livingston, Alabama fault zone, and by other independent faults. The suggestion is strong that in an extensively faulted area, migration of fluids up the faults does occur. Evidence is not at hand to ascertain what effect in a lateral sense these faults have on the chalks.

These chalks commonly are clay-rich and little is known on the exact clay mineralogy. Less is known on what the responses of these clays would be in regard to moisture release, shrinkage or other effects upon thermal alteration. Bentonites, known to be sensitive to differences in water content, have been identified in the Mooreville Formation. Whether bentonitic clays occur elsewhere in the chalks is not known. Clearly, an area in need of several different investigative approaches is the study of the clay minerals of these (and other) chalks. Another area of study would be to determine the relative response of different chalk lithotypes to thermal and other stresses.

A primary concern, as it was in the Lyons, Kansas area, is the effect of wellbore penetrations on the integrity of the potential disposal horizon. Data from oil-exploration operations seem to indicate a reasonable degree of certainty that all wells are identified and positioned; however, not the same can be said about water wells drilled to deep horizons below the Selma Group. As mentioned in an earlier section, a detailed investigation would need to be conducted on a more localized potential site in order to establish an acceptable level of certainty.

In summary, there are many favorable elements about the thick Mooreville-Demopolis chalk sequence in western Alabama-eastern Mississippi with regard to additional consideration for radioactive waste storage. This report recommends further studies, as in part outlined here, to more precisely delineate the advantages and disadvantages of storage in chalk units. As an ongoing phase, it also recommends that this Alabama-Mississippi chalk sequence be compared with others, such as those in Texas and Kansas, and other uniquely "dry" carbonate intervals to see how geologic-hydrologic features are similar or different. The initial feasibility of these Selma Group chalks is deserving of various additional investigations.

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APPENDIX A

County	Oil/Gas Board Permit Number	Well Location	TD/Well or Data-	Chalk Interval
Dallas	B12W	sec 19, T17N, R7E	1000'	-
	B61W	sec 2, T15N, R8E	1088'	-
	849	sec 35, T13N, R9E	-	base-1079ss
	1314	sec 24, T13N, R9E	-	base-887ss
	1318	sec 13, T13N, R9E	-	base-863ss
	1329	sec 7, T13N, R10E	-	base-804ss?
Greene	B312	sec 6, T21N, R2E	1208'	-
	B324	sec 11, T20N, R1E	2616'	base-240 log
	26	sec 6, T20N, R2E	880'	-
	78	same as B312	no data	
	770	sec 17, T23N, R1W	5510'	base-270 log
	802	sec 18, T23N, R1W	no data	
	803	sec 17, T23N, R1W	no data	
	809	sec 9, T23N, R1W	-	base-60 log
	810	sec 6, T23N, R1W	-	base-100 log
	811	sec 5, T23N, R1W	1880'	base-130 log

County	Oil/Gas Board Permit Number	Well Location	TD/Well or Data-	Chalk Interval
	1673	sec 1, T20N, R2E	no data	
	1810	sec 17, T23N, R1E	no data	
Hale	B24W	sec 27, T18N, R4E	1500'	-
	B94W	same as B24W	1200'	-
	B246	sec 11, T21N, R3E	no data	
Marengo	B33W	sec 1, T17N, R2E	1175'	-
	B55W	sec 12, T17N, R2E	1040'	-
	B59W	sec 24, T18N, R2E	900'	-
	B89W	sec 18, T17N, R3E	1400'	-
	B92W	sec 10, T15N, R2E	1140'	-
	B95W	sec 5, T15N, R3E	1193'	-
	B98W	same as B95W	1100'	-
	B243W	sec 29, T15N, R2E	1920'	-
	19	sec 23, T14N, R1E	-	453 ss iso - 1020
	44	sec 3, T16N, R2E	-	base-728ss
	85	sec 18, T12N, R1E		1035 ss iso-1035
	124	sec 31, T14N, R1E	-	590 ss iso - 1020

County	Oil/Gas Board Permit Number	Well Location	TD/Well or Data-	Chalk Interval
	141	sec 18, T13N, R1E	-	772 ss iso - 1040
	144	sec 20, T13N, R1E	-	997 ss iso - 1040
	501	sec 17, T17N, R5E	-	base-325 ss
	548	sec 35, T16N, R2E	-	base-890 ss
	1541	sec 1, T14N, R4E	-	base-965 ss
	1550	sec 35, T14N, R2E	-	370 ss iso - 1005
	1557	sec 9, T12N, R3E	-	655 ss iso - 1110
	1559	sec 29, T17N, R5E	-	base-409 ss
	1570	sec 32, T14N, R1E	-	base-1617 ss
	1702	sec 11, T12N, R3E	-	base-1595 ss
Perry	B37W	sec 7, T17N, R6E	1195'	-
	B40W	same as B37W	895'	-
	B65W	sec 30, T18N, R6E	590'	-
	B77	sec 30, T16N, R6E	875'	-
Sumter	B1W	sec 20, T20N, R1W	930'	-
	B2W	sec 33, T19N, R2W	1062'	-

County	Oil/Gas Board Permit Number	Well Location	TD/Well or Data-	Chalk Interval
	B42W	same as B1W	737'	-
	B46W	sec 9, T20N, R2W	735'	-
	B53W	sec 11, T20N, R2W	700'	-
	B67W	sec 13, T17N, R2W	1010'	-
	B90W	sec 36, T17N, R2W	1240'	-
	B110W	same as B12	1000'	-
	B105W	sec 4, T18N, R2W	1260'	-
	B238W	sec 33, T18N, R1W	1140'	-
	B276W	sec 3, T18N, R1E	655'	-
	B279W	same as B276W	867'	base-550 log
	B282W	same as B238W	1200'	-
	100	sec 36, T19N, R4W	-	160 ss
	177	sec 29, T18N, R1E	-	base-645 ss
	378	sec 7, T20N, R3W	no data	
	445	sec 26, T17N, R2W	-	120 ss iso - 860
	537	sec 34, T20N, R2W	-	base-506 ss
	1006	same as 445	-	125 ss iso - 860
	1040	sec 4, T23N, R3W	-	base-142 ss

County	Oil/Gas Board Permit Number	Well Location	TD/Well or Data-Chalk Interval	
	1056	same as B90W	-	187 ss iso - 875
	1160	sec 5, T21N, R2W	-	base-287 ss
	1363	sec 15, T19N, R2W	-	base-618 ss
	1478	sec 27, T16N, R1E	-	base-885 ss
Wilcox (west of R9E)	B106W	sec 29, T12N, R8E	1235'	-
	B249	sec 30, T11N, R5E	2500'	-
	B268	sec 21, T11N, R5E	2562'	-
	31	sec 7, T11N, R5E	-	720 ss iso - 1120
	67	sec 31, T12N, R5E	-	942 ss
	93	sec 6, T11N, R5E	-	574 ss iso - 1110
	328	sec 13, T11N, R7E	-	base-1516 ss
	547	sec 17, T13N, R8E	-	base-963 (?)
	581	sec 34, T11N, R6E	-	855 ss iso - 970 + 150' faulted
	614	sec 29, T11N, R6E	-	833 ss iso - 1075
	670	sec 4, T11N, R5E	-	555 ss iso - 1120
	746	sec 17, T12N, R9E	-	base-930 ss (?)

County	Oil/Gas Board Permit Number	Well Location	TD/Well or Data-Chalk Interval	
	974	sec 29, T11N, R7E	-	613 ss iso - 1120
	1113	sec 4, T14N, R6E	-	base-852 ss
	1304	sec 14, T14N, R6E	-	base-862 ss
	1429	sec 29, T11N, R6E	-	base-2066 ss
	1432	sec 10, T12N, R6E	-	base-1905 ss
	1435	sec 9, T13N, R7E	-	base-780 ss
	1446	sec 34, T12N, R5E	-	904 iso - 1210
	1474 + 1475	same as 1446	-	base-2104 ss
	1539	sec 4, T13N, R7E	-	base-659 ss
	1699	sec 24, T11N, R5E	-	iso - 1100
	ST1	sec 17, T11N, R6E	-	830 ss iso - 990 + 200' faulted
	ST2	sec 20, T11N, R6E	-	1042 ss iso - 755 + 350' faulted

ss = subsea elevations

log = log depth only

iso = isopach thickness of Selma Group (E - log)