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Wolfe City Sand

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Na Montmorillonite-Kaolinite Facies

SPRING 1964
Bulletin No. 6



*Stratigraphy of the Taylor Formation
(Upper Cretaceous), East-Central Texas*

ARTHUR O. BEALL, JR.

*"Creative thinking is more important
than elaborate equipment--"*

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

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BAYLOR GEOLOGICAL STUDIES

BULLETIN NO. 6

*Stratigraphy of the Taylor Formation
(Upper Cretaceous), East-Central Texas*

ARTHUR O. BEALL, JR.

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Spring, 1964

Baylor Geological Studies

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Stratigraphy of the Taylor Formation (Upper Cretaceous), East-Central Texas

ARTHUR O. BEALL, JR.

ABSTRACT

The purpose of this study was to interpret the stratigraphy of the Upper Cretaceous (Gulfian Series) Taylor Formation in East-central Texas. The investigation involved mapping, description, and correlation of stratigraphic units at the surface and in the subsurface.

Results of the study indicate that the term "Upper Taylor Marl Member" of the Taylor Formation should be suppressed and that the section should be combined with the overlying Neylandville Marl. Furthermore, it is suggested that the Neylandville Formation be reduced to the rank of member and classified as the upper member of the Taylor Formation, since the Neylandville Formation, as defined by Stephenson, does not possess a mappable lower contact. The contact of the Taylor Marl (redefined) and the Nacatoch Sand (Navarro Group) is, therefore, a mappable contact between valid lithostratigraphic units.

It is concluded that the Taylor Marl is a neritic marine unit deposited near the eastern edge of the stable Texas craton or platform; the Taylor Marl thickens rapidly eastward from the shelf edge into the East Texas basin. Taylor deposition began after erosional truncation of the upper Austin Chalk and development of a broad submarine channel across the southern part of the area. The influence of a deltaic environment north of the study area is apparent from the sedimentary features and stratigraphic relationships of the various members of the Taylor Marl. The deltaic influence in

the study area was most pronounced during deposition of the Wolfe City Sand Member.

Slow regression, which began in this area near the end of Austin Chalk deposition, continued during deposition of the Taylor Marl and Navarro Group. The Pecan Gap Chalk Member of the Taylor Formation represents a period of relative structural stability and quiescence.

Although a Tertiary age is normally assigned to the Luling-Mexia fault zone, faulting contemporaneous with Taylor deposition is indicated by rapid thickening of the formation across faults.

The dominant clay mineral in the Taylor Marl, as determined by x-ray diffraction, is montmorillonite; the montmorillonite exchangeable cation population ranges from sodium to calcium-magnesium rich. Sodium montmorillonite is associated with a high kaolinite, high quartz, low calcite marl, whereas calcium-magnesium montmorillonite is associated with a low kaolinite, low quartz, high calcite marl. When these data are integrated with the other stratigraphic variables, a subtle facies relationship can be postulated. The calcium-magnesium montmorillonite facies probably represents a deeper or more basinward sediment, whereas the sodium montmorillonite facies evidently reflects nearness to source. The mechanism responsible for this clay mineral differentiation may result from base exchange in the depositional environment.

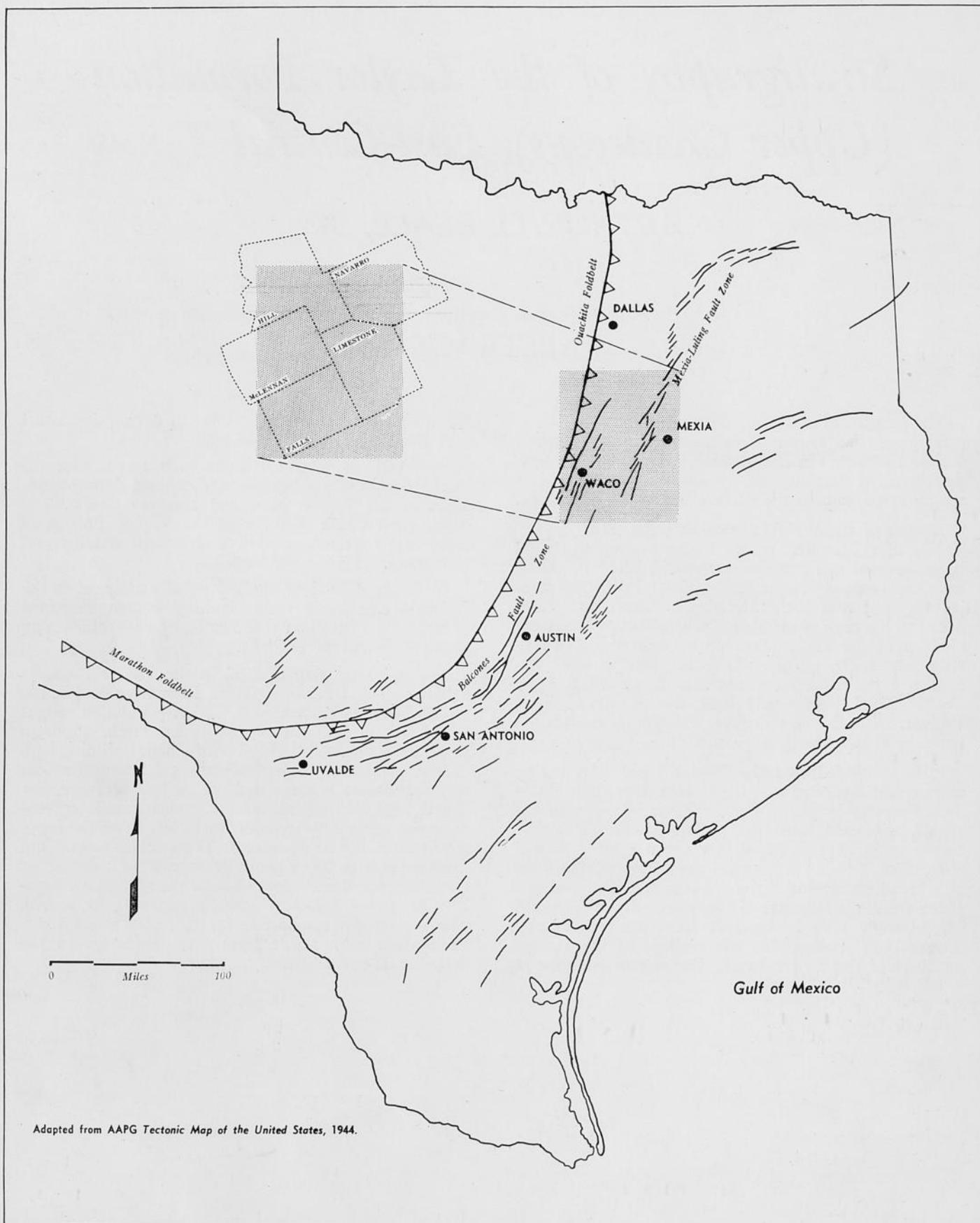


Fig. 1. Index map.

INTRODUCTION¹

PURPOSE

The purpose of this study was to interpret the stratigraphy of the Upper Cretaceous (Gulfian Series) Taylor Marl of East-central Texas. The investigation involved mapping, description, correlation and depositional-environmental interpretations of stratigraphic units at the surface and in the subsurface of the study area.

LOCATION

The area of investigation (fig. 1) extends from 31°15'N to 32°00'N latitude and from 96°35'W to 97°15'W longitude. It includes parts of Hill, McLennan, Falls, Limestone, and Navarro counties with the following cities situated along or near the boundaries: Hillsboro on the north, Waco on the west, Mexia on the east, and Marlin on the south.

PREVIOUS WORK

R. T. Hill (1890, pp. 115-116), in one of the earliest descriptions of the strata now called the Taylor Marl, described the "*Exogyra ponderosa* marls" at Blue Bluffs, 6 miles east of Austin, Texas. These exposures consist of blue, unconsolidated and unlaminated clays, which upon weathering become dull yellow "owing to the oxidation of the contained pyrites of iron. Their chief accessory constituent is calcite in a chalky texture and they are more calcareous at their base than at the top" (*idem*, p. 115). These sections were placed in the "Blue Bluffs Division" (Hill and Penrose, 1889, p. 471; Hill, 1889, p. xiii), a name later suppressed.

In 1892 Hill applied the name "Taylor Marl" to exposures of the *Exogyra ponderosa* marls at the type locality near Taylor, Williamson County, Texas (fig. 2). Hill (1901, p. 337) noted that the middle portion of the Taylor Formation apparently contains few well-preserved fossils, yet fossil impressions occur. Hill (*idem*) also observed that the Taylor Marl becomes slightly arenaceous, concretionary, and fossiliferous upward, indicating gradation into the overlying Navarro Formation [Group].

In 1918, Stephenson (p. 155) studied the Taylor Marl in northeastern Texas, divided the formation into members, and described the fauna (fig. 2). Stephenson applied the name "Wolfe City Sand" to a section composed of 75 to 100 feet of fine calcareous sandstone in a railroad cut of the Gulf, Colorado and Santa Fe Railway, 1.5 miles northeast of Wolfe City, Texas. Stephenson (*idem*) traced the Wolfe City Sand Member from a point east of Pecan Gap in Delta County, Texas, to a point southwest of Farmersville in Collin County, Texas.

Stephenson also proposed (*idem*, p. 156) the name "Pecan Gap Chalk Member" (fig. 2) for 50 feet of bluish-gray, slightly bituminous, more or less argillaceous

and sandy chalk, which overlies the Wolfe City Sand near Pecan Gap, Texas. He noted that the chalk contains an abundant but poorly preserved fauna. Stephenson considered the Pecan Gap Chalk to be the uppermost member of the Taylor Marl in Northeast Texas.

Later, Stephenson (1927, pp. 9-10) defined the upper contact of the Taylor Marl in Central Texas as unconformable with the Navarro Group, because of the absence of *Exogyra cancellata* (which Stephenson considered to be "Navarro in age") from Hill County to the Rio Grande, a distance of over 300 miles.

Dane and Stephenson (1928) described the stratigraphic relationships of the Pecan Gap Chalk Member to the underlying Wolfe City Sand and Lower Marl members, and to the overlying Upper Taylor Marl Member (fig. 2). Thickness and lithologic descriptions were also noted. In addition, Dane and Stephenson assigned the name "Durango Sand Member" to a sand of "recognizable continuity and importance" which is "about 350 to 400 feet above the top of the Austin chalk" (*idem*, p. 51). The member was described as "hard sand and calcareous sandstone with plentiful comminuted shell fragments. . . . The basal contact is irregular and sharp and beneath it soft black marl crops out."

In 1928 Dane and Stephenson (pp. 52-53) also described two chalk beds in Falls County, one near Marlin (Marlin Chalk) and one near Lott (Lott Chalk). Other chalk beds such as the Rogers Chalk of Bell County, which was named by Adkins and Arick (1930, p. 65), and the Coolidge Chalk of Limestone County, which was named by Reiter (1930, pp. 322-323), are approximately equivalent to the Pecan Gap Chalk (Ellisor and Teagle, 1934, p. 1509).

Ammonoids from the Taylor Marl have been described by Adkins (1928, p. 30). Adkins (*after* Böse and Cavins, 1928, p. 13) considered the Taylor Marl as mainly of Santonian age based on studies of the ammonoids.

In 1933 Stephenson (p. 1358) presented a more complete discussion of the Taylor-Navarro contact, stating that it definitely is unconformable (fig. 2). His evidence was that the Navarro (*Exogyra cancellata* zone) of Central Texas is separated from the Taylor Formation below "by a thin zone of phosphatic nodules and phosphatic molds of mollusks" (*idem*, p. 1357). In Texas, "the large smooth forms of *Exogyra*, commonly referred to as *E. ponderosa* Roemer, are found in beds stratigraphically lower than the *Exogyra cancellata* zone, and no authentic occurrence of that species is known from the *E. cancellata* zone proper" (*idem*, p. 1358).

Ellisor and Teagle (1934, pp. 1508, 1513) divided the Pecan Gap Chalk Member (fig. 2) into three microfaunal zones—the *Flabellamina compressa* zone (basal), the *Diploschiza cretacea* zone (middle), and the *Bolivina incompressa* zone (upper). They traced these zones from White Cliffs, Arkansas, to Medina County, Texas. The *Flabellamina* and *Bolivina* zones are absent in Limestone and Falls counties but present in Navarro County, while the *Diploschiza* zone is present in Limestone and Falls counties but absent in Navarro County (*idem*).

¹Modified from a thesis submitted in partial fulfillment of the requirements for the M.S. degree in Geology, Baylor University, 1963.

Stephenson (1934, p. 273) noted that *Diploschiza*, in association with other fossils, was a basis for correlating the Pecan Gap Chalk with the Selma Chalk of Alabama. He stated that "*Diploschiza* has not yet been found in the typical Pecan Gap Chalk of northeastern Texas" (*idem*, p. 275).

In 1937 Stephenson suggested that the upper 250 feet of the Austin Chalk is absent in the Waco area [based on paleontological evidence], thus making the contact of the Austin Chalk and overlying Taylor Marl unconformable.

J. T. Rouse (1944) studied the Pecan Gap Chalk Member, Wolfe City Sand Member, and Annona Chalk of East Texas, and stated (*idem*, p. 524) that in "southern Lamar County and northern Delta County the upper part of the Wolfe City is chalky sand." He considered the Wolfe City Sand Member to be a continuous bed and described it as becoming more chalky eastward until represented by a slightly arenaceous chalk, equivalent to the Annona Chalk near Clarksville, Texas. The Pecan Gap Chalk unconformably overlies the Wolfe City Sand, but the chalk does not occur above the Annona Chalk (*idem*, p. 529).

Blank, Stoltenberg, and Emmerich (1952, pp. 5-15) described in detail the lithology of the Wolfe City Sand and Pecan Gap Chalk of northeastern Falls County. The contact between the Wolfe City Sand and the Pecan Gap Chalk was considered to be unconformable as indicated by the presence of glauconite, by an undulatory contact, and by signs of reworking. The Pecan Gap Chalk was described as consisting of a lower hard chalk bed from 8 to 25 feet thick, 90 to 100 feet of highly calcareous marl, and an upper chalk 13 feet thick, "which in turn passes transitionally upward into additional highly calcareous marl" (*idem*, p. 5).

The contact between the Pecan Gap Chalk and Wolfe City Sand is the "only easily identifiable stratigraphic marker in the experimental area" (Blank *et al.*, 1952, p. 5). This contact was traced from Mart in McLennan County to Marlin in Falls County. It was demonstrated that most of the chalk outcrops in the Marlin area are of the less resistant upper chalk rather than the basal resistant chalk. Also, "the Pecan Gap belt of outcrop as shown on the geologic map of Texas (Darton *et al.*, 1937) is too narrow and too far east to include both of these chalks. At some places it has been based on the lower zone, at others on the upper" (Blank *et al.*, 1952, p. 5). It was also noted that *Diploschiza cretacea* had been found at the stratigraphic horizon of the upper chalk (*idem*, p. 15).

The microfauna of the Taylor Marl was listed and described by Frizzell in 1954. He considered the basal Taylor Formation and the highest Austin strata to be time equivalent, based on distinctive foraminifers (*idem*, p. 39). He also noted that the Neylandville Marl of the Navarro Group should be included with the Taylor Marl (fig. 2). The Neylandville Marl faunal list (*idem*, p. 48) shows 41 species common to the Taylor Marl and Navarro Group, 38 species in common with the Taylor Formation, 9 species in common with the other formations of the Navarro Group, and 2 species restricted to the Neylandville Marl (Navarro Group),

making a total of 90 recognized species within the Neylandville Marl. Frizzell (*idem*, pp. 39-49) gave the following foraminiferal statistics: Taylor Formation—289 species belonging to 23 families; Lower Taylor Marl Member—182 species from 21 families; Wolfe City Sand Member—81 species belonging to 13 families; Pecan Gap Chalk Member—144 species from 18 families; and the Upper Taylor Marl Member—200 species belonging to 19 families.

PROCEDURES

A base map was prepared from an enlarged portion of the Waco Sheet, Army Map Service map NH 14-3 (1:250,000; contour interval, 50 feet). The field base map scale was 1:125,000 or approximately 1 inch to 2 miles. Wells and surface localities are located by numbers and described in Appendix I. The outcropping Taylor Formation was mapped on aerial photographs and topographic maps.

The formation is not well exposed in the area. Most exposures are steep to vertical outcrops in stream banks or shallow erosional gullies. Elsewhere the formation, which is commonly covered by a thick soil layer, crops out in flat cultivated prairie land.

Samples were normally obtained from shallow trenches dug vertically on the face of the steep outcrops. Several overlapping trenches were dug where exposures are of considerable areal extent. In relatively flat soil-covered areas, samples were collected with a portable power auger; it was possible to sample to a depth of 6 feet with the auger, thereby obtaining relatively unweathered material.

Fossils were collected and placed in the stratigraphic framework to determine relationships between fauna and lithology which might be useful in interpreting depositional environments.

All samples were examined microscopically to supplement the field lithologic and paleontologic description. Selected samples were subjected to detailed petrographic study, insoluble residue analyses, or x-ray diffraction analyses (Appendix II).

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Professors O. T. Hayward, L. F. Brown, Jr., and J. W. Dixon, Department of Geology, and Professor J. L. McAtee, Jr., Department of Chemistry, Baylor University, contributed suggestions and advice during the investigation and preparation of the report. Appreciation is extended to Messrs. Harold D. Holloway and Jack Phillips, formerly consulting geologists of Mexia, Texas, for use of equipment and data; to Dr. Donald Owen, Bureau of Economic Geology, The University of Texas, for critical reading of the manuscript; and to many individuals who contributed field assistance and advice throughout the study. My wife, Barbara Jean, assisted in preparing the original manuscript. Alice K. Praisnar, Baylor University, drafted the final illustrations.

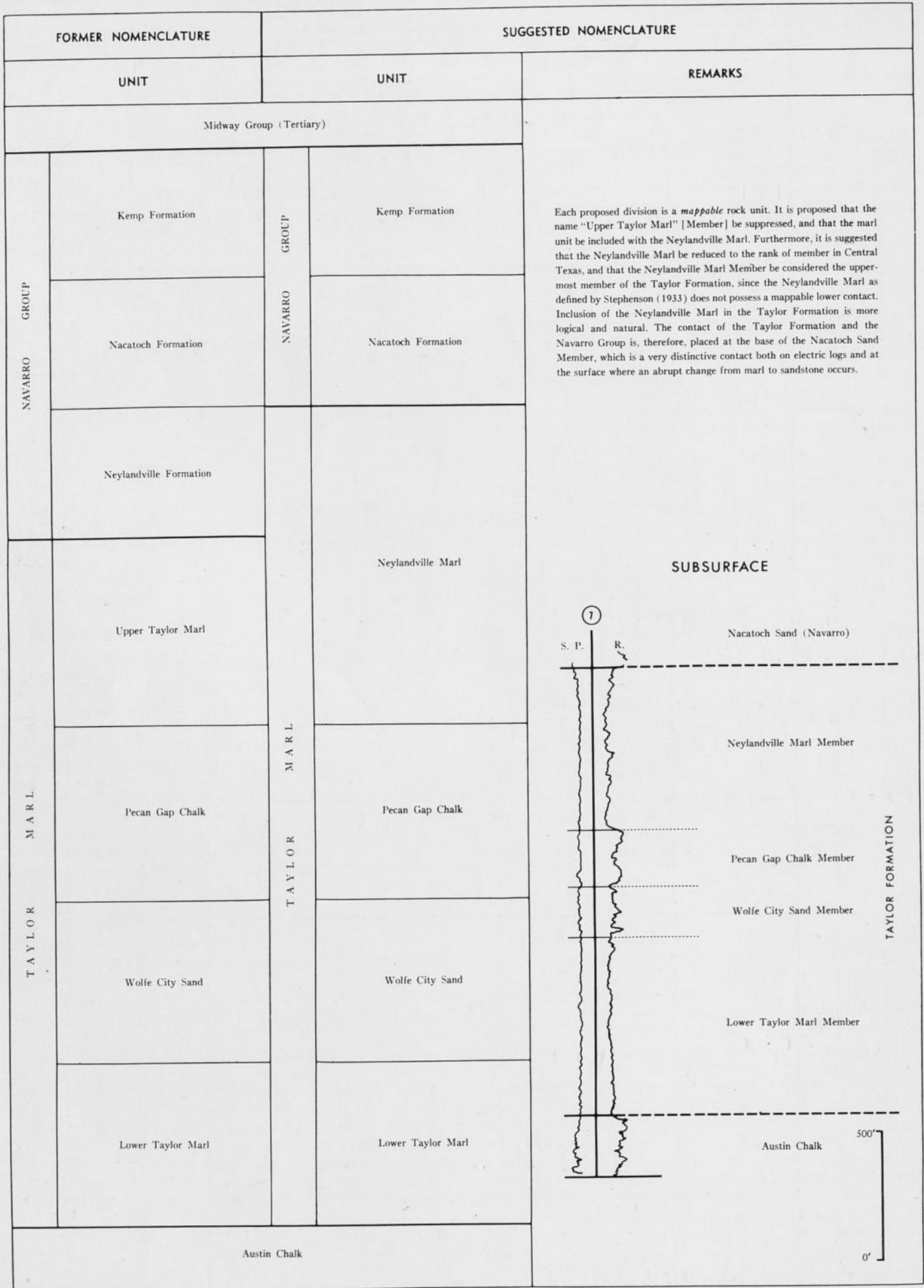


Fig. 3. Proposed reclassification, Taylor Formation, East-central Texas. The term "Lower Taylor Marl Member" does not satisfy requirements of the American Stratigraphic Commission, since the member bears the same name as the formation. However, application of a formal name for this lower member is purely nomenclatural and should await additional study of the regional aspects of the Taylor Formation in Texas.

STRATIGRAPHY

NOMENCLATURE—CLASSIFICATION

A formation has been defined by the American Commission on Stratigraphic Nomenclature (1956, p. 2006) as a “. . . laterally traceable lithologic genetic unit.” The Commission further noted (*idem*) that “The limits of formations should be horizons of change that will best express the geologic development and structure of the region and will give to the formations greatest practicable unity of constitution.” The writer believes that this objective concept of rock classification is the only logical approach to sound lithostratigraphic and, for that matter, biostratigraphic research.

The Taylor Marl, as defined by Stephenson (1918, p. 156), does not satisfy the aforementioned objective criteria for valid lithostratigraphic usage, at least in the area of study. For example, the upper contact of the Taylor Formation was defined by Stephenson (*idem*) as an unconformity based on the absence of the *Exogyra cancellata* zone, which is not mappable. In this area the Taylor Marl and the Neylandville Formation (Navarro Group) can not be separated by a reasonably continuous mappable contact at the surface or in the subsurface (fig. 5-A, B).

The Taylor Formation has been subdivided by most workers in the area into four gradational but supposedly lithologically distinct members—Lower Taylor Marl Member, Wolfe City Sand Member, Pecan Gap Chalk Member, and Upper Taylor Marl Member (figs. 2, 3). As the present study progressed, it became apparent that only the lower members of the Taylor Formation were mappable. The upper member of the formation (Upper Taylor Marl) can not, as previously mentioned, be differentiated lithologically or stratigraphically (fig. 4) from the overlying Neylandville Marl [formation] of the Navarro Group, since both so-called stratigraphic units were deposited in a continuous and relatively unchanged sedimentary environment within the study area. Therefore, the first distinctive mappable contact above the top of the Pecan Gap Chalk Member of the Taylor Formation is the base of the Nacatoch Formation of the Navarro Group (figs. 2, 3) and not a paleontologic (biostratigraphic) “boundary.”

In the present investigation, special emphasis has been given the sedimentary and structural histories of the Lower Taylor Marl, Wolfe City Sand, and Pecan Gap Chalk members of the Taylor Formation, since

they are mappable objective lithologic units. Although included in this report, the stratigraphy and sedimentary-structural significance of the Upper Taylor Marl Member receives limited consideration, because the proper interpretation of this upper “member” of the Taylor Formation must be based on future studies in conjunction with the overlying Neylandville Formation.

Use of the term “Upper Taylor Marl Member” in this report is, therefore, a matter of expediency, but the writer strongly urges further study of the post-Pecan Gap Chalk strata in East-central Texas, not only to understand better the late Cretaceous history of the region but to establish a workable and useful rock classification as a basis for needed additional specialized studies.

Any future modification of the nomenclature of this interval should avoid unnecessary additions or changes to the present classification scheme. The writer proposes a reclassification (fig. 3) in which the only change involves suppressing the “Upper Taylor Marl Member” and combining that section with the overlying Neylandville Marl. The redefined Neylandville Formation has been tentatively reduced in rank to member and placed in the Taylor Formation (fig. 3). However, further studies of the post-Pecan Gap Chalk rocks of the region may demonstrate that the Neylandville (redefined) genetically belongs more logically with the younger formations of the Navarro Group. In addition, further study of these uppermost Cretaceous rocks may indicate the need of a massive, sweeping revision in order to develop a truly useful lithostratigraphic classification on which to base much needed biostratigraphic and other research.

The classification proposed (fig. 3) may or may not be an answer to nomenclature-classification problems in the post-Austin Cretaceous rocks of this region, but it is intended, at least, to serve as a guide until additional studies indicate the need and direction for improvement. For example, the precise correlation of the members of the Taylor Formation with type localities outside the area has not been definitely demonstrated; however, in this region the classification or subdivision of the section is satisfactory, and any further changes involving the Taylor Formation should be purely nomenclatural.

CLAY MINERAL PROCEDURES

The Taylor Marl is a calcareous clay containing considerable local amounts of sandy marl, sand, and some chalk. The marl contains varying amounts of silt-sized quartz, glauconite, phosphate nodules, calcite fragments, pyrite, microfossils, and macrofossils. Since the marl is composed predominantly of clay minerals, x-ray diffraction analysis of the marl was undertaken to determine if the various clay minerals could be correlated with gross lithology, fauna, and general facies relation-

ships. The physico-chemical significance of such correlation was useful in interpreting the depositional environment of the Taylor Marl.

Outcrop samples and well cuttings were collected throughout the Taylor Marl (fig. 12; Appendix II). Untreated samples were pulverized, screened to <0.074 mm, and analyzed by x-ray diffraction after equilibrating at 50 percent relative humidity. Oriented slides were prepared from the mass sample, analyzed, and then

glycolated and analyzed again by x-ray diffraction. Following this procedure the amount of each clay mineral type, as well as non-clay minerals, was estimated.

The clay minerals in the marls, which are composed dominantly of dioctahedral montmorillonite, were estimated quantitatively by comparing intensities of the strongest peaks of montmorillonite, quartz, and calcite with the corresponding peaks of known mixtures (by weight) of pure minerals. This procedure is not precise, but it is probable that at least the relative proportions are constant and, therefore, useful. Illite and kaolinite were estimated by relative intensities and included in the clay mineral fraction (Appendix II).

Much work has been done in recent years on the genesis, distribution, and alteration of clay minerals. Environmental versus detrital hypotheses for clay mineral distribution have been proposed by various authors (e.g. Grim, 1953, 1958; and Weaver, 1956, 1958, 1959).

The term montmorillonite, as used herein, is defined as those clay minerals which consist of two silica tetrahedral sheets with a central alumina octahedral sheet (Si:Al approximately 2:1).

The tetrahedral and octahedral sheets are combined so that the tips of the tetrahedra of each silica sheet and

one of the hydroxyl layers of the octahedral sheet form a common layer. Montmorillonite is also characterized by the substitution within the lattice of aluminum for silicon in the tetrahedral sheet and/or magnesium or iron for aluminum in the octahedral sheet. Charge deficiency may also be due to vacancies or voids within the lattice. The lattice charge is, therefore, unbalanced. The net negative charge of the lattice is balanced by positively charged exchangeable cations, which occur between the silicate layers. The c-axis spacing depends somewhat on the size of the interlayer cations and the amount of water necessary for hydration of the cation (Grim, 1953, pp. 59-64).

Sodium, calcium and magnesium are commonly found to be the three most abundant exchangeable cations in montmorillonite under natural conditions. Ideally, at 50 percent relative humidity the sodium montmorillonite would possess a single water layer resulting in a basal (001) spacing of 12.6 Å, while calcium-magnesium montmorillonite would contain a double water layer and a corresponding value of 15.4 Å (Williams *et al.*, 1953, p. 134).

The distribution and depositional significance of clay minerals are considered for each individual member.

DESCRIPTION

GENERAL FEATURES

In East-central Texas the Taylor Formation is a marly clay locally containing considerable sandy marl, sand and some chalk. Typical marl of the Taylor Formation may contain varying amounts of silt-sized quartz, glauconite pellets, phosphate nodules, calcite fragments, macrofossils, and microfossils. The Taylor Marl unconformably overlies the Austin Chalk and cannot be properly separated from the overlying Neylandville Formation of the Navarro Group.

In the area of study, the Taylor Marl crops out (fig. 4) in a northeast trending belt in the highly faulted area between the Balcones and Luling-Mexia fault systems. The Taylor Marl strikes approximately N. 12° to 16° E. and increases in dip southeastward with an average dip of 90 feet per mile. Locally, faulting has distorted the strata.

Faults present in the area are normal tensional faults, which trend from approximately N. 35° E. to N. 10° W. Calcite veins, slickensides, and thin zones of sheared clay are common along the faults. Balcones faults are dominantly down-to-the-east; Luling-Mexia faults appear to compensate for the displacement of the Balcones faults by displaying down-to-the-west displacement, forming a vaguely defined graben system.

The Taylor Marl crops out in the Blackland Prairie, which is typified by black soils developed on the marl and chalk beds of the Upper Cretaceous formations. Faulting and differential resistance to erosion have primarily defined local drainage patterns and physiographic expression. The more resistant sandstone and limestone beds form poorly expressed northwest-facing cuestas; for example, the sandy beds in the Wolfe City Sand Member commonly support a moderate escarpment. Normal drainage flows southeastward, but faults

commonly divert or control stream patterns (fig. 4). Fault alignments, which are normally expressed by soil variations, topography and drainage patterns, were plotted from aerial photographs and checked with topographic maps in the field.

Native vegetation in the Blackland Prairie is at present predominantly a mixture of short grasses and weeds with a brushy overgrowth of small mesquite trees. Larger areas of chalk outcrop support cedar brakes. The remaining hardwood timber is largely elm and hackberry. Various types of deciduous oak trees commonly occur on sandy soils developed on the Wolfe City Sand Member (Templin *et al.*, 1958, pp. 8-9). Most of the Blackland area is now in cultivation.

Floods are frequent in the prairie area and drainage is slow. The climate is humid subtropical.

AUSTIN-TAYLOR CONTACT

Stephenson (1927, p. 7) stated that the upper 250 feet of the Austin Chalk is missing in the Waco area, relative to the Austin Chalk in Dallas County, Texas. He supported this interpretation with paleontological evidence which inferred that the contact of the Austin Chalk and the overlying Taylor Marl is unconformable.

Seewald (1959, p. 14) indicated that the Austin Chalk in the Bruceville-Waco area of central McLennan County is approximately 100 feet thinner than in the northern part of the county. Seewald verified his surface work with subsurface electric well log correlations.

The contact between the Austin Chalk and the Taylor Marl is rarely well exposed and/or it is a fault contact. The contact, normal or faulted, can be observed at the surface in the southwestern part of the map area, and it is locally exposed northeastward through Waco to a

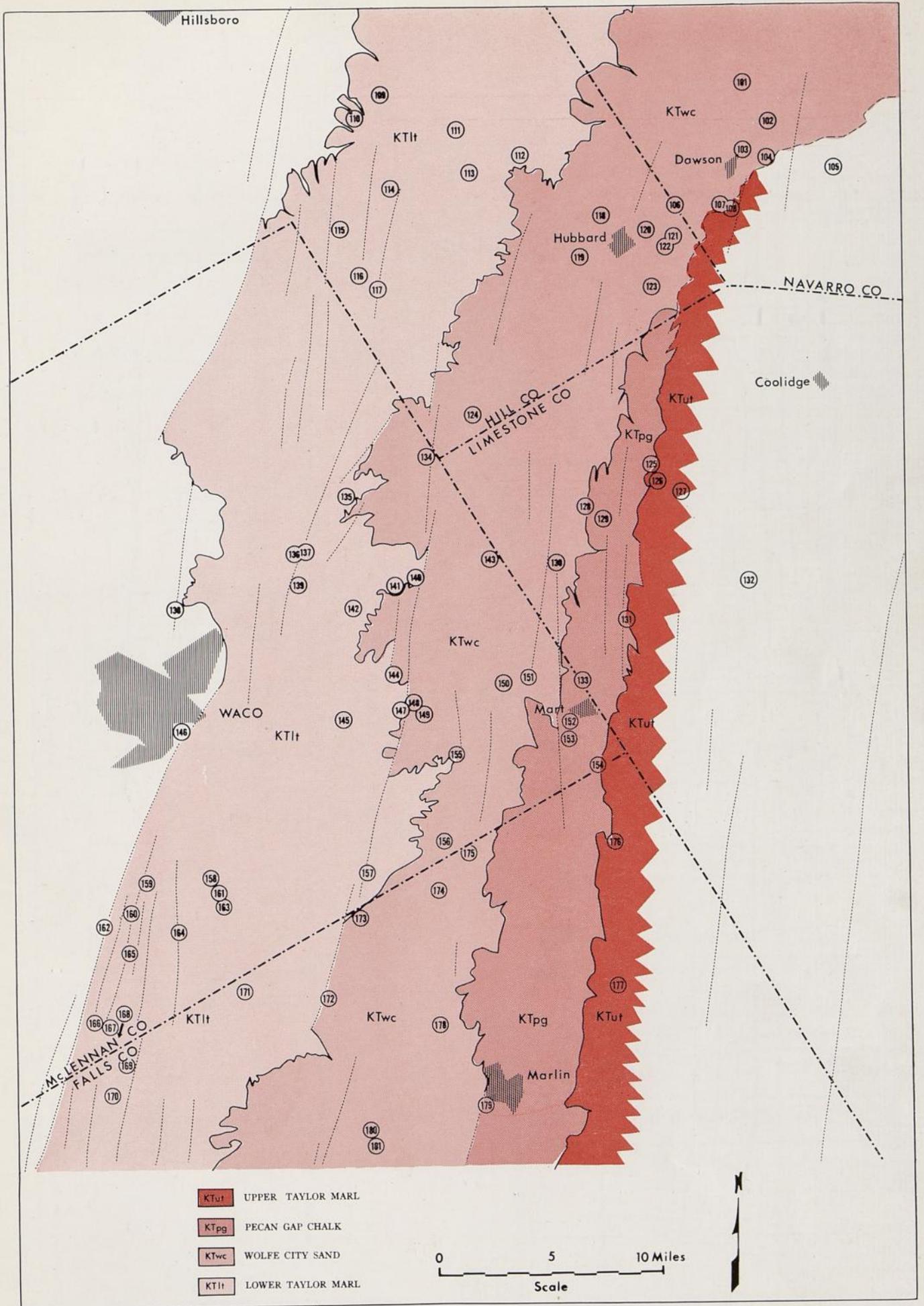


Fig. 4. Geologic map, Taylor Formation, East-central Texas. All numbered localities are surface locations (Appendix I).

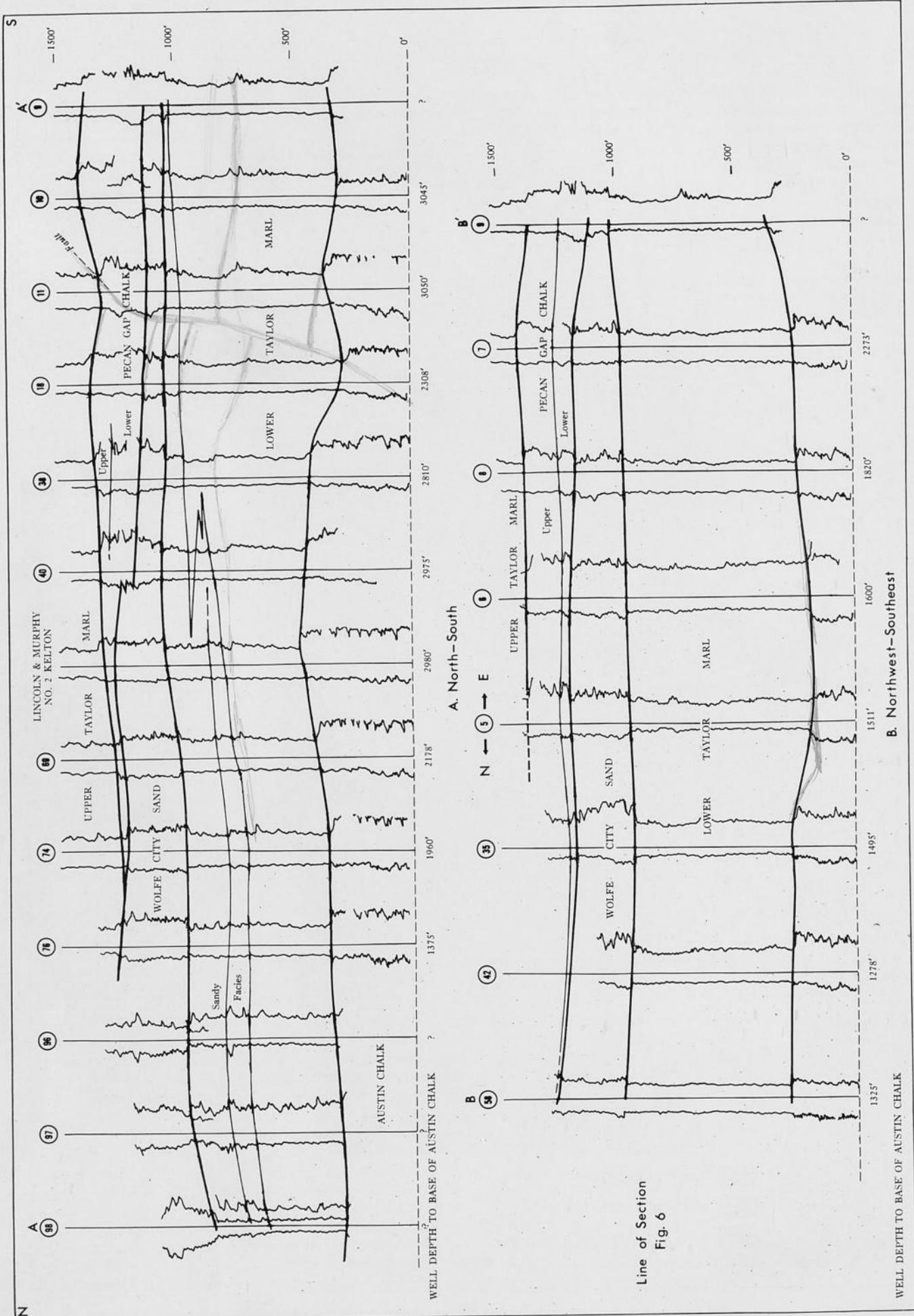


Fig. 5. Cross sections, Taylor Formation, East-central Texas.

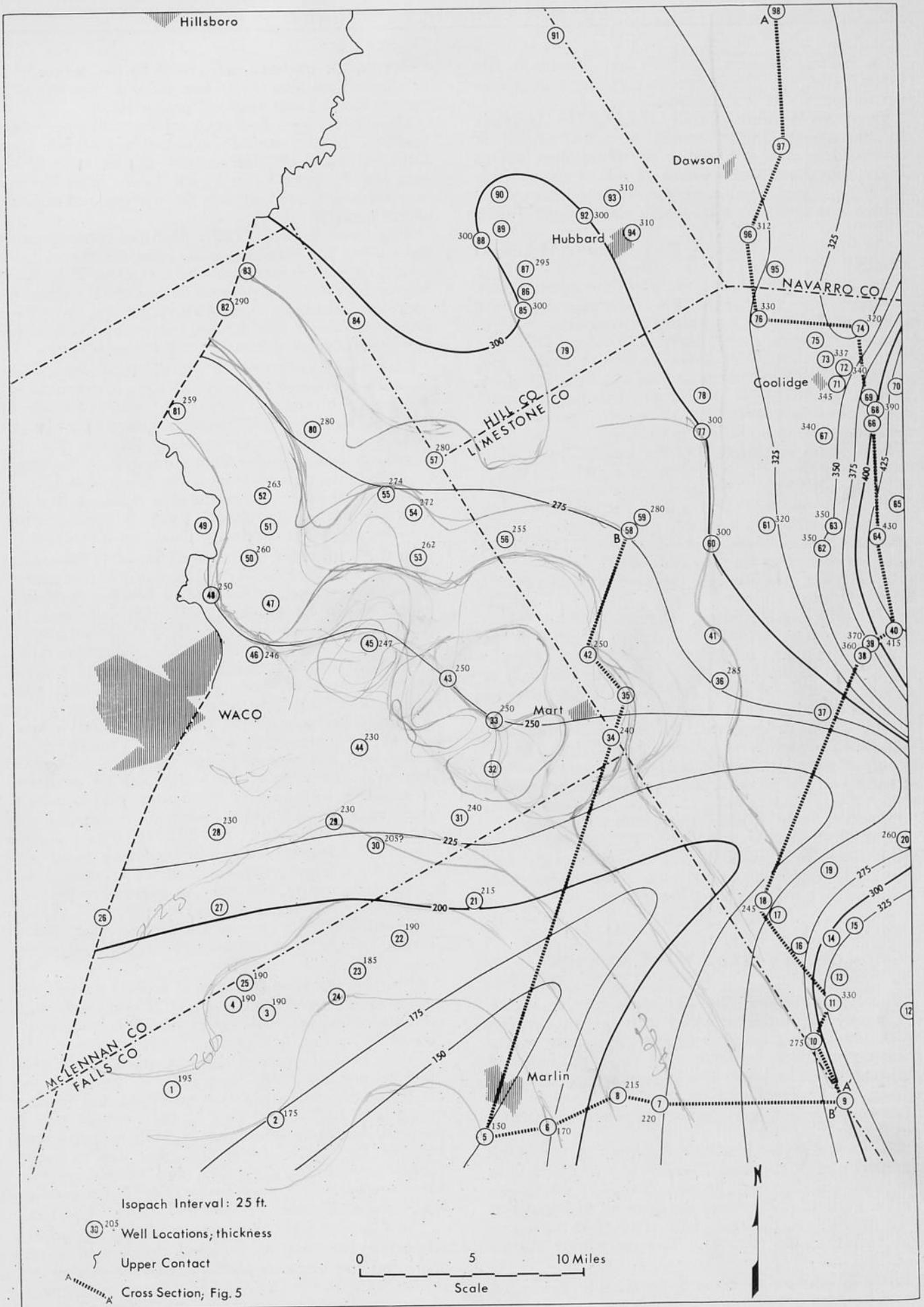


Fig. 6. Isopach map, Austin Chalk, East-central Texas.

point midway between Hillsboro and Malone in Hill County (fig. 4). The contact is normally a fault contact throughout most of the area.

In central McLennan County (locality 138, Appendix I)² the Austin-Taylor contact is unconformable as evidenced by dark soft marl or phosphate-filled borings in the uppermost Austin Chalk, as well as a very sharp lithologic change from hard, fossiliferous chalk of the Austin Formation to soft, blocky marl of the Taylor Formation.

On Waco Creek (locality 146) in central McLennan County, the Austin-Taylor contact is distorted by faulting and is poorly exposed. "Here the topmost chalk stratum is a massive chalky limestone containing *Inoceramus*, followed by a sharp lithological break into blue-black Taylor shale" (Adkins, 1932, p. 448).

In southwestern McLennan County at locality 166, the Austin-Taylor contact was placed immediately above borings at the top of the Austin, although the marl above the chalk contains less phosphatic material when compared to central McLennan County.

In the area of locality 166, the Lower Taylor Marl immediately above the basal contact resembles the underlying Austin Chalk. This section was considered basal Taylor Marl because of the absence of abundant clams or other fossils in the basal, slightly darker Taylor Marl and because of the greater hardness and weathered platy appearance of the marl beds of the Austin Formation. Faulting has obscured the precise contact at this locality.

The strongest supporting evidences for an unconformable contact between the Austin Chalk and the Taylor Marl are subsurface relationships. Electric log correlation demonstrates an irregular thickness of Austin strata in the area (fig. 5-A, B). An east-west trending broad channel in the upper surface of the Austin Chalk is suggested by isopach relationships (fig. 6). Correlation of individual beds of the Austin Chalk indicates that thickening and thinning of the formation in the channel area was caused by erosion rather than depositional variations, since individual beds of the Austin Chalk display little thickness variation along strike (fig. 5-B). The lowest points along the channel (figs. 5-A, B; 6) are structurally and stratigraphically lower than the top of the thicker chalk section in the northern part of the area.

LOWER TAYLOR MARL MEMBER

The Lower Taylor Marl is a dark gray to brown, dominantly montmorillonite clay with varying amounts of silt-sized quartz, calcite fragments, glauconite pellets, phosphate nodules, hematite, and finely disseminated pyrite or pyrite nodules. Fresh exposures of the marl display blocky conchoidal fracture, and develop poor fissility and a light gray to buff or white color upon weathering.

The Lower Taylor Marl thickens from 520 feet in the northern part of the area (locality 98) to 755 feet in the south (locality 6). An isopach map of the Lower Taylor Marl (fig. 7) shows the greatest thicknesses in wells which lie in the area of the channel in the top of the Austin Chalk (fig. 6). The underlying Austin

Chalk rapidly thickens eastward along the eastern edge of the subject area (430 feet thick at locality 64); each individual unit thickens proportionally.

Contemporaneous faulting is evidenced by a decreased thickness of the member eastward across the large Luling-Mexia fault zone on the eastern edge of the area (fig. 7). Locally, the Lower Taylor Marl Member is exceptionally thick against the western, downthrown side of the fault (*idem*).

Hager and Burnett (1960) described contemporaneous faulting in Cretaceous rocks along the Mexia-Talco fault system of Hopkins and Delta counties. They noted fault activity during deposition of the Glen Rose Formation, Fredericksburg and Washita groups, Woodbine Formation, Eagle Ford Group, Pecan Gap Chalk Member of the Taylor Formation and Midway Series.

Contemporaneous faulting was evidently active along the eastern edge of the area throughout deposition of the Taylor Formation, since the downthrown side of this fault system received more sediment than the upthrown side. Also, approximately 200 feet less displacement occurs on the fault at the top of the Pecan Gap Chalk than at the base of the Austin Chalk.

The southeastern part of the area is lowest structurally; the base of the Austin Chalk is approximately 2650 feet below sea level in wells at localities 9 and 10.

In the southern area the basal Lower Taylor Marl is relatively calcareous, but the thickness of this calcareous zone could not be determined because of faulting complications. At localities 159, 165, 167, and 168 (each locality approximately 250-300 feet above the Austin Chalk; projected interval from subsurface data), an exposed chalky, massively bedded marl contains several marly chalk beds a foot thick. Within these marly chalk beds are very large specimens of the ammonoid *Parapuzosia* and the pelecypod *Inoceramus*, as well as other small pelecypods. Underlying the chalky marl is a zone of pyritic and hematitic marl of undetermined thickness. At locality 167, a small lens of hematite and limonite (oxidized pyrite) occurs, which varies from 0.5 to 4 inches in thickness. Pyrite nodules are abundant at this locality; limonite "rosettes" (decomposed pyrite nodules) were also observed. A large vertebrate tooth (Plesiosaur?) and a large specimen of *Durania* (an aberrant pelecypod) were collected from this interval at locality 159. Calcite and fossil fragments are also common in small isolated "nodes," which appear to be internal molds of pelecypods.

Overlying the basal chalky marl zone in the southern area is a gray to brown, massively bedded marl, which contains echinoids, small clams (locality 164), and a "cancellate" variety of *Exogyra* (localities 169 and 185).

In the northern part of the area, the Lower Taylor Marl is predominantly light gray to grayish-brown marl; it is less calcareous, more quartzose, and approximately 200 feet thinner than in the southern part of the area. No highly calcareous or pyrite-hematite zones exist in the north; fossils are also less abundant. *Exogyra ponderosa*, *Gryphaea*, and *Ostrea* are rare. Good exposures of Lower Taylor Marl in the northern area occur at localities 109 and 110.

The Lower Taylor Marl Member rests unconformably on the truncated Austin Chalk throughout the map area, and the basal member grades conformably into the overlying Wolfe City Sand Member. The magnitude of the unconformity separating the Austin Chalk and

²Refer to localities on figure 4 (surface) or figures 6-9 (subsurface) and Appendix I.

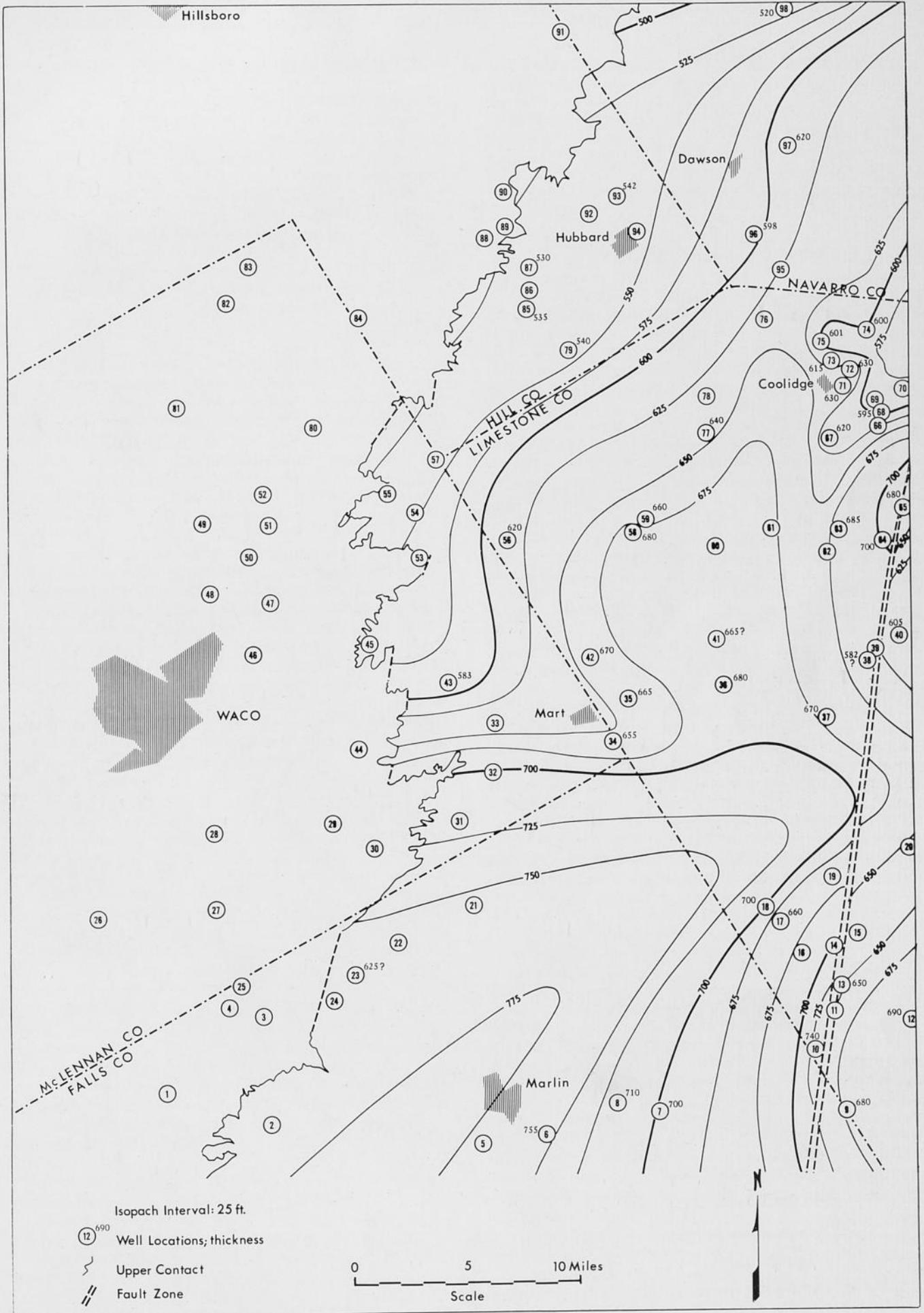


Fig. 7. Isopach map, Lower Taylor Marl Member, Taylor Formation, East-central Texas.

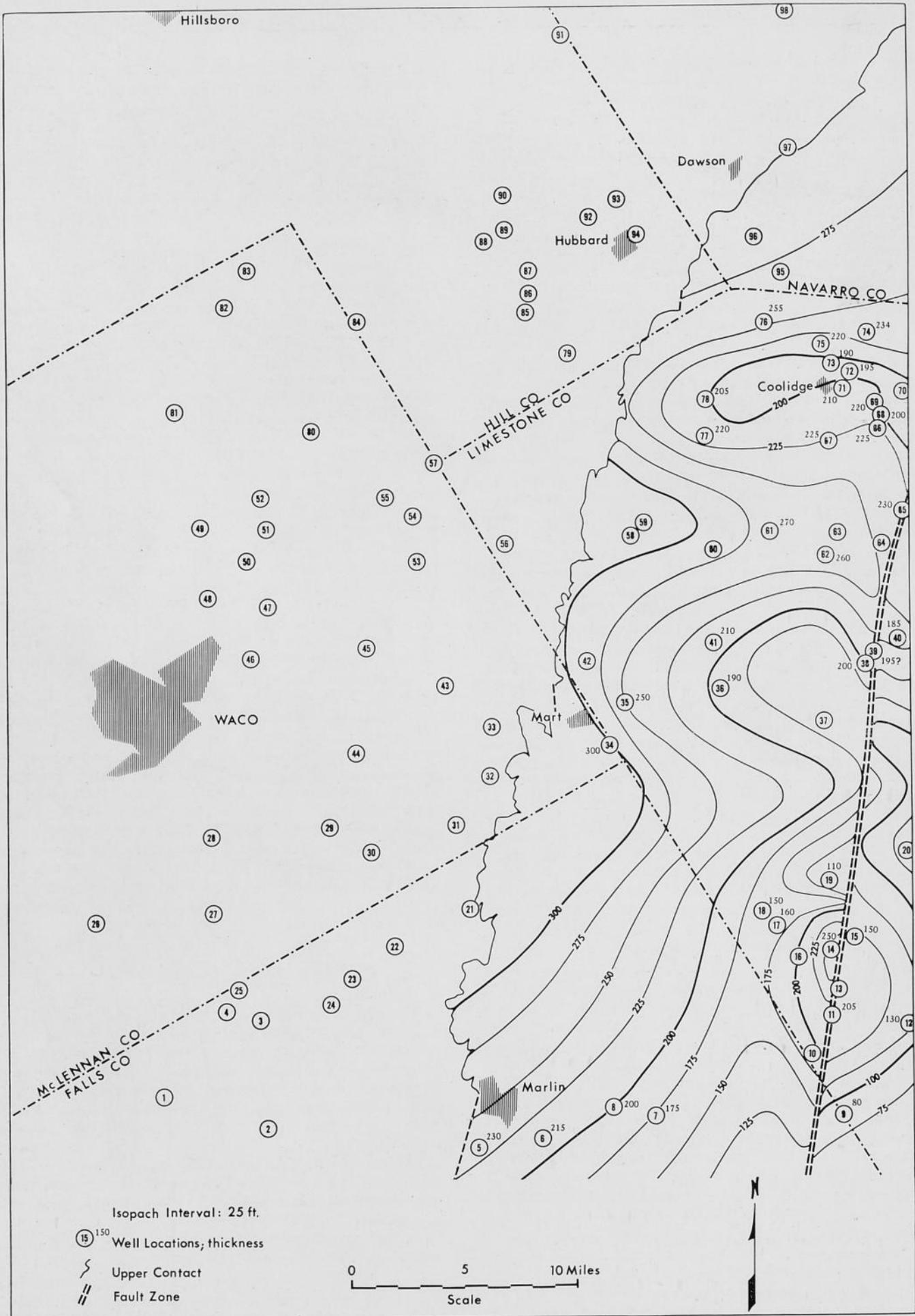


Fig. 8. Isopach map, Wolfe City Sand Member, Taylor Formation, East-central Texas.

Lower Taylor Marl Member decreases southeastward across the area.

The Lower Taylor Marl-Wolfe City Sand contact is exposed at localities 135, 141, and 157; the contact is marked by an upward gradational increase in sand and silt and by a corresponding decrease in the marl content. The Lower Taylor Marl Member immediately below the upper contact is marked by an increased quartz and kaolinite content. At locality 157 the upper part of the Lower Taylor Marl Member contains more than 20 percent quartz with the percentage increasing upward. Unique features in this interval are small siltstone nodules about 3 inches long, which resemble the lithology of the overlying Wolfe City Sand Member. Impressions of *Inoceramus* occur in this interval, as do abundant microfossils.

Marl samples (localities 157, 172), which were collected immediately below the Lower Taylor Marl-Wolfe City Sand contact, contain relatively abundant sodium montmorillonite, considerable quartz and kaolinite, and a small amount of calcite.

Microfossils are relatively abundant throughout the Lower Taylor Marl; 182 species have been described from 21 families (Frizzell, 1954, pp. 41-43). Megafossils present include *Durania*, *Parapuzosia*, *Exogyra ponderosa*, a "cancellate" variety of *Exogyra*, *Ostrea*, *Inoceramus* (several species), and *Anomia*, as well as various unidentified ammonoids, pelecypods, echinoids, shark teeth, and other vertebrate teeth and bones.

The dominant clay mineral in the Lower Taylor Marl Member as determined by x-ray diffraction is dioctahedral montmorillonite, which ranges from (1) a dominantly sodium montmorillonite associated with marl containing more than 5 percent kaolinite, a high percentage of silt-sized quartz, and a low percentage of calcite fragments and microfossils to (2) a dominantly calcium-magnesium montmorillonite with low kaolinite and quartz and a high calcite content.

In the southern part of the area, clay minerals of the Lower Taylor Marl vary from dominantly calcium-magnesium montmorillonite associated with a high amount of calcite fragments, microfossils, and little or no silt-sized quartz to a mixed-layer calcium-magnesium sodium montmorillonite associated with equal amounts of calcite and quartz. In the northern part of the area, the dominant clay mineral suite grades from a sodium montmorillonite containing a high amount of fine silt-sized quartz and little calcite or microfossils to a sodium calcium-magnesium montmorillonite with moderate amounts of quartz and calcite.

A distribution curve (fig. 10) was developed by comparing the calcite and quartz content with the sodium montmorillonite to calcium-magnesium montmorillonite ratios. These data (*idem*) and the mean curves indicate that sodium montmorillonite is commonly associated with a high quartz, low calcite marl, and that calcium-magnesium montmorillonite is normally associated with a low quartz, high calcite marl. This relationship is used later to interpret the possible environmental significance of clay mineral facies relationships in the Lower Taylor Marl Member.

Accessory clay minerals in the marl beds of the Lower Taylor Member include small amounts of kaolinite and illite; kaolinite is commonly more abundant. The basal (001) reflection of the montmorillonite is normally broad and indicates some interlayering with illite, although this was not estimated quantitatively.

A relationship exists between kaolinite and the type of montmorillonite or the calcite and quartz content of the marl. Lower Taylor Marl samples (fig. 12) having from 5 to 15 percent kaolinite appear to be restricted to the northeastern area and to the upper part of the member in the central and southwestern areas. Illite does not occur in sufficient quantities to evaluate thoroughly the significance of its distribution.

WOLFE CITY SAND MEMBER

The Wolfe City Sand Member is dark gray to light gray or brown, sandy or silty marl interbedded with thin sandstone lenses from 0.1 of an inch to 1.5 feet thick (commonly 1 to 2 inches thick). The member conformably overlies the Lower Taylor Marl Member and is unconformably (?) overlain by the Pecan Gap Chalk Member.

In the area the Wolfe City Sand displays the following regional relationships: (1) Average grain size increases northward; (2) thickness increases northward at the expense of the underlying Lower Taylor Marl Member from about 200 feet in the south to approximately 300 feet in the north; (3) non-marly, uncemented sand increases northward; and (4) massive, unlaminated, reworked, and less well-sorted sandstone increases northward.

Sandstone lenses are cemented with crystalline, fine to coarse-grained calcite. Blank *et al.* (1952, p. 12) stated that the Wolfe City Sand is composed predominantly of quartz grains with lesser amounts of feldspar, mica, and chert. Marcasite, ilmenite, zircon, and colorless garnet occur with traces of tourmaline and rutile. Calcium carbonate in the member ranges from 5 to 15 percent.

The average grain size and mineral assemblage of various sandstone lenses and sandy marl beds of the Wolfe City Member vary within the area. A resistant sandstone bed in the upper part of the Wolfe City Sand (locality 101), for example, contains angular to sub-angular quartz grains (0.07 to 0.1 mm), which display undulose extinction. Calcite and fossil fragments, as well as volcanic rock fragments, are common in the bed; various less abundant minerals (described above) are also present. Opaque minerals compose less than 5 or 10 percent of the sandstone. At locality 180 a thin siltstone lens with very thin marl laminae contains less magnetite, less glauconite, and fewer microfossils, as well as displaying smaller average grain size (0.04 mm) and better rounded grains than locality 101. All of the sandstone lenses at locality 180 are clearly cross-bedded.

The Wolfe City Sand crops out in the area (fig. 4) along a narrow band about 7 to 9 miles wide from a point west of Marlin in Falls County to the area west of Dawson in Navarro County. Weathered sand beds within the Wolfe City Member are commonly light to buff-brown; a slight greenish cast occurs in weathered marls. The sandstone lenses, more resistant to erosion than the marl beds, form small ledges. Cross-bedding and filled borings are more apparent on weathered surfaces.

The Wolfe City Sand Member, which conformably overlies the Lower Taylor Marl Member, is unconformably overlain by the Pecan Gap Chalk Member from the southern part of the area to a point about 5.5 miles northwest of Coolidge in Limestone County. Northward

from that point the Pecan Gap Chalk becomes marly and evidence of the Wolfe City-Pecan Gap unconformity could not be observed (figs. 5-A, 12). It is possible that this "Pecan Gap marly facies" is laterally gradational with uppermost sands of the Wolfe City Sand Member farther north; poor exposure in this area prohibited adequate study of facies relationships. No evidence of unconformity, however, has been observed along the contact of the Wolfe City Sand and the "marly facies" of the Pecan Gap Chalk.

Where typical Pecan Gap Chalk occurs, the base of the member is a hard, massive, relatively uniform, areally persistent chalk unit, which rests upon typical silty marl of the Wolfe City Sand Member. An unconformable Wolfe City-Pecan Gap contact is evidenced by glauconite, borings in the underlying marl filled with chalk, inclusions of marl in the overlying chalk, undulatory upper surface of the Wolfe City Member, and the abrupt lithologic change from silty marl below to massive chalk above. This contact is well exposed at localities 128, 129, and 175.

Fossils are not as well preserved nor as abundant in the Wolfe City Sand as in the Lower Taylor Marl and the Pecan Gap Chalk members. *Inoceramus* impressions and casts of *Baculites* occur, although preservation is poor. Microfossil content ranges from absent to abundant. Frizzell (1954, pp. 44-45) recognized 81 foraminiferal species belonging to 13 families in the Wolfe City Sand. Round to oval filled borings, which commonly weather out on top of sandstone ledges, are more abundant in the northern part of the area (locality 102).

An unusual sedimentary structural feature, which is composed of steeply dipping sandstone ledges, occurs in the northern portion of the area. At locality 102, dips of 2° were measured at a bearing of S 70°E; the ledges are probably large, massively bedded, foreset beds with no internal structure. The thick ledges commonly pinch out abruptly, but they may occur elsewhere in the vicinity at the same stratigraphic level (localities 102 and 103). Cementation exhibited by the sandstone lenses appears to be primary, since fresh exposures and well cuttings are commonly well cemented and possess characteristics similar to surface occurrences. Primary cementation is supported by Blank *et al.* (1952, p. 11).

In the subsurface the Wolfe City Sand displays thickness variations similar to variations observed at the surface. The Lower Taylor Marl thickens southward and the Wolfe City Sand thickens northwestward (figs. 7, 8). Maximum thicknesses of Wolfe City Sand overlie relatively thinner areas of the Lower Taylor Marl in the northern part of the area (fig. 8). Contemporaneous faulting during deposition of the Wolfe City Member is evidenced by a decrease in thickness eastward across a fault of the Mexia system (*idem*).

PECAN GAP CHALK MEMBER

The Pecan Gap Chalk Member has perhaps been studied in more detail by various workers than any other member of the Taylor Formation; however, the relationship of the Pecan Gap Chalk to other members of the formation is still not well understood.

In 1952 Blank *et al.* described the Wolfe City Sand and Pecan Gap Chalk in northeastern Falls County, at

which time they differentiated an "upper" and a "lower" chalk and concluded that most of the chalk outcrops in that region correspond to the less persistent "upper" chalk. Blank *et al.* further noted (*idem*, p. 12) that "the Pecan Gap chalk belt of outcrop is too narrow and too far east to include both of these chalks. At some places it has been based on the lower zone, at others on the upper." They also noted that *Diploschiza cretacea* occurred at the stratigraphic level of the "upper" chalk.

The Pecan Gap Chalk Member thins or becomes more clastic in the northern part of the area (figs. 5-A; 9, 12), and the outcrop (fig. 4) terminates northward between Hubbard and Coolidge. In the southern portion of the area, approximately 280 feet of Pecan Gap Chalk occur in the Jarman, No. 1 Garrett (locality 10). In the Killam, No. 1 Stone (locality 41) in the mideastern portion of the area, only 52 feet of Pecan Gap Chalk are present. Rapid northward thinning of the Pecan Gap Chalk Member and the apparent thinning of the lower unit can be observed on electric logs (fig. 5-A). Basinward (fig. 5-B) the Pecan Gap Chalk thickens and becomes lithologically more uniform, containing no marl between the basal and upper chalks. In the Cockburn & Zephyr, No. 1 Buie (locality 7), the Pecan Gap Member consists of 215 feet of uniform chalk.

At locality 175 the basal part of the Pecan Gap Chalk rests unconformably on silty marl beds of the Wolfe City Sand Member. The base of the Pecan Gap Member is a massive, poorly bedded, light gray chalk bed, which weathers white and contains glauconite. The bed contains abundant *Baculites*, other ammonoids, gastropods, *Inoceramus* internal molds, and *Exogyra ponderosa*; microfossils are also abundant. At localities 128 and 129, the exposed basal chalk bed of the Pecan Gap Member is very similar to the chalk bed at locality 175. The basal chalk bed is about 13 feet thick near Mart in Ferrell, No. 1 Gillam (locality 35).

The Pecan Gap Chalk is normally composed of microfossils, megafossil fragments, and microcrystalline calcite in a clay matrix. Well-rounded quartz grains also occur in the member, becoming more abundant and slightly less rounded in the middle or marly unit of the Pecan Gap Chalk. The dominant clay mineral in the member is montmorillonite.

Overlying the basal part of the Pecan Gap Chalk in the southern part of the area is a softer chalk, grading upward into a marl, which in turn grades into another thinner chalk unit and finally into the Upper Taylor Marl Member. The softer chalk which overlies the basal chalk is dark gray, impure, and locally contains *Diploschiza cretacea* (locality 153), as well as gastropods, worm tubes and fragments of *Durania*.

The *Diploschiza cretacea* zone described by Ellisor and Teagle (1934, p. 1508) was the middle zone (fig. 2) of their classification; Blank *et al.* (1952, p. 12) also reported the same species from the upper chalk. Apparently *Diploschiza cretacea* occurs throughout the Pecan Gap Chalk in the area of study, and it is not, therefore, a useful zone fossil within this part of the section.

The upper part of the Pecan Gap Chalk Member, which grades conformably into the overlying Upper Taylor Marl Member, is the lateral equivalent of the basal portion of the Upper Taylor Marl of the northwestern part of the area (fig. 5-B).

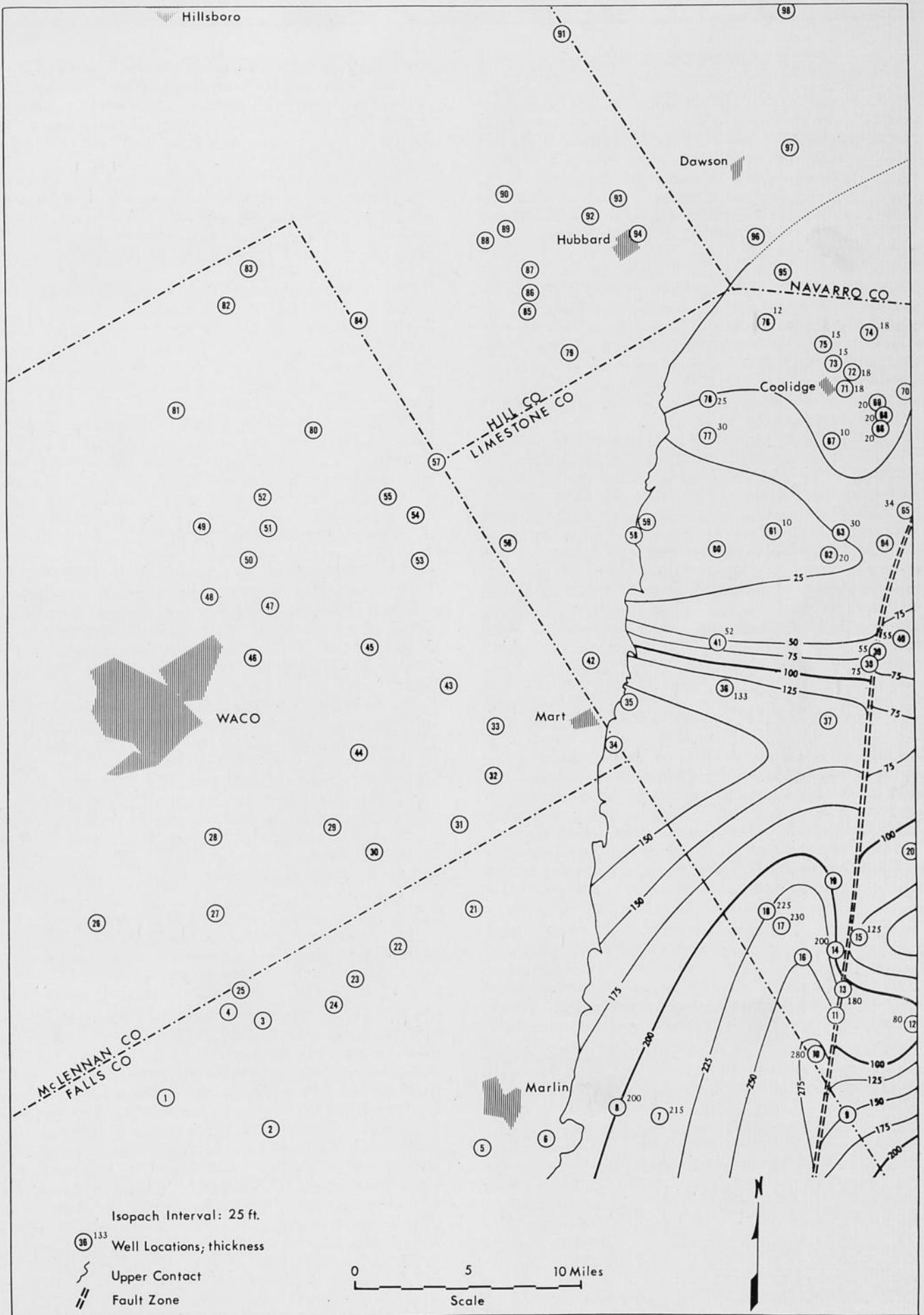


Fig. 9. Isopach map, Pecan Gap Chalk Member, Taylor Formation, East-central Texas.

UPPER TAYLOR MARL MEMBER

The Upper Taylor Marl Member is light gray, dominantly montmorillonitic clay with varying amounts of calcite fragments, silt-sized quartz, glauconite, disseminated pyrite, and locally high concentrations of phosphatic material. When unweathered, the marly clay is blocky with conchoidal fracture similar to that displayed by the Lower Taylor Marl Member. The Upper Taylor Marl becomes brown and slightly fissile when exposed to weathering.

The Upper Taylor Marl conformably overlies the Pecan Gap Chalk in the southern part of the area, but in the north the marl is partially equivalent to the upper chalk units of the Pecan Gap Member (fig. 12). The Upper Taylor Marl, which is the uppermost member of the Taylor Formation according to previous workers (Stephenson, 1933, p. 1358), grades conformably into the overlying Neylandville Formation (Marl) of the Navarro Group (p. 11).

Typical Upper Taylor Marl is exposed at localities 104, 108, 176, and 177. Bentonite seams composed of yellow, buff or white, iron oxide-stained calcium-magnesium montmorillonite occur at localities 104 and 108.

Underlying the bentonite seam at locality 108 (but not present at locality 104) is a zone of abundant phosphatized fossils and nodules. Although megafossils are not abundant in the Upper Taylor Marl of the area, this phosphatic zone contains abundant internal molds of *Baculites*, *Inoceramus*, small unidentified pelecypods, ammonoids, gastropods, and vertebrate teeth and vertebrae. At all other phosphate localities, rare small pelecypod shells were observed.

TAYLOR-NAVARRO CONTACT

Stephenson (1927, p. 10) considered the Taylor-Navarro contact in Central Texas to be unconformable, as evidenced by the absence of the zone of *Exogyra cancellata* from Hill County to the Rio Grande. In 1933 (p. 1358) Stephenson again stated that the Taylor-Navarro contact is definitely unconformable and noted that the Navarro Group (*Exogyra cancel-*

lata zone) is separated from the underlying Taylor Formation by a thin zone of phosphatic nodules and phosphatic molluscan molds. Stephenson's original Taylor-Navarro contact was drawn from southeast of Marlin in Falls County to a point southeast of Purdon in Navarro County.

The Upper Taylor Marl Member and the Neylandville Formation (Navarro Group) are lithologically similar in the area; for example, comparison can be made of typical Upper Taylor Marl at localities 104, 108, 127, 176, and 177 and typical Neylandville Marl at localities 105 and 132.

The Neylandville Marl was defined by Stephenson (1933, p. 1358) as the section between the top of the Taylor Marl and the base of the Nacatoch Sand (Navarro Group). At locality 105 the Neylandville Formation consists of slightly sandy to silty marl containing some sand lenses and large, calcareous, white-weathering, claystone concretions. The lithologic similarity of the Upper Taylor Marl Member and the Neylandville Marl, poor exposures, and absence of a mappable contact prevented their division into separate rock units for the purpose of this study (p. 11). No widespread characteristic fossils were observed nor were any phosphatic zones (such as the phosphatic zone at locality 108) found to mark Stephenson's Taylor-Navarro "contact." Frizzell (1954, p. 48) considered that the Neylandville Marl should be included in the Taylor Formation because of the diagnostic microfauna.

Pryor (1960, pp. 1480-81), in a study of Cretaceous sediments of the upper Mississippi embayment, noted the occurrence of *Exogyra ponderosa* (present in the Taylor Marl) and *E. costata* (a typical "Navarro Group fossil") at the same stratigraphic horizon.

No persistent lithologic break was recognized in the subsurface at the stratigraphic level of Stephenson's (1927, p. 10) Taylor-Navarro "contact." Correlation of the "contact interval" can be accomplished using several different local horizons. The transition of Upper Taylor Marl into Neylandville Marl suggests that they are genetically related and are the products of one continuous depositional episode. Nomenclature-classification problems involving the Taylor-Navarro contact are discussed elsewhere (p. 11).

DEPOSITIONAL ENVIRONMENTS

LOWER TAYLOR MARL MEMBER

Following deposition of the Austin Chalk, the uppermost portion of the formation was locally removed, possibly by submarine channeling. Isopach relationships of the Austin Chalk (fig. 6) reveal a broad "channel" or linear thin pattern in the southern part of the area. This channel is more pronounced along a northeastward to eastward trend (fig. 11) near the eastern edge of the study area where the Austin Chalk rapidly thickens downdip. This thickening trend in the Austin Chalk probably delineates a shelf edge during Austin and Taylor deposition. Southeast of the study area, the Taylor and Austin formations thicken rapidly into the East Texas basin.

Taylor Marl deposition in the area was initiated by sedimentation on the eroded surface of the Austin

Chalk. Deposition in the erosional, topographically low areas on the Austin Chalk surface resulted in thicker Taylor Marl sections in the channel area (fig. 7).

Two distinct depositional environments can be postulated for the Lower Taylor Marl Member—a northern and a southern environment (figs. 10, 12). The northern near-shore (possibly inner neritic to neritic) marine environment contains a sparse megafauna, less abundant microfauna relative to the southern environment, and an accumulation of sodium-rich montmorillonite (p. 19) associated in a marl with a high kaolinite, high quartz and low calcite content. The muddy, slightly turbulent water must have prevented an abundant benthonic fauna. The presence of thin sand stringers in the Lower Taylor Marl in this northern area, as well as the higher concentration of kaolinite, points to a relatively nearby source or shoreline. It is possible

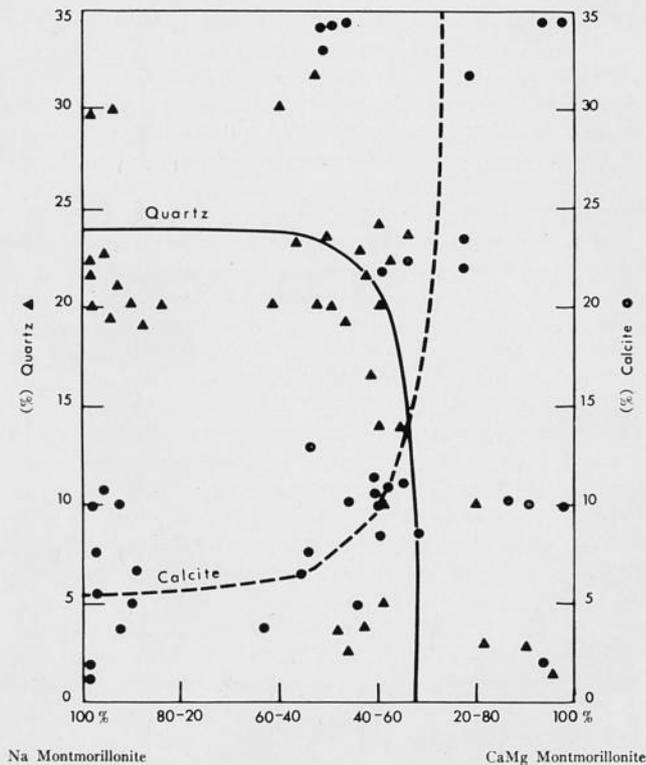


Fig. 10. Calcite-quartz to clay mineral ratios, Taylor Formation, East-central Texas.

that these northern Lower Taylor Marl sediments represent a subdeltaic or prodeltaic environment. The locus of deltaic sedimentation is an environment where there is little winnowing or mineral segregation of sediments, often called "a rapid dumping type of deposition."

The postulated *southern* Lower Taylor Marl environment contrasts with the northern environment because of the presence in the south of a more abundant fauna, a higher concentration of iron compounds (pyrite, hematite, and glauconite), phosphate nodules, and the presence of calcium-magnesium-rich montmorillonite with very little kaolinite (<5 percent) associated in a marl with a high calcite and low quartz content, which may indicate deeper water deposition (possibly neritic to outer neritic) or a lower energy marine environment farther from the source area. Small pelecypods, large ammonoids, echinoids, large rudistid and/or chomid pelecypods, and vertebrate fragments (Plesiosaur?) suggest a neritic environment in which deposition was slower than in the northern part of the area. Turbulence and amount of suspended sediment were probably less in the southern part of the area during deposition of the Lower Taylor Marl Member as evidenced by the more abundant fauna and less clastic (or more dominantly chemical) nature of the sediments. When the post-Austin and pre-Taylor submarine channel was filled, the differentiation between the northern and southern environments gradually became less distinct, until eventually the total Lower Taylor Marl depositional environment was relatively homogeneous during deposition of the upper part of the member.

Some vulcanism occurred during the latter part of Lower Taylor Marl deposition, as shown by the presence of bentonite seams. South-central Texas (Travis

County area) may have been the source of the volcanic ash; another possible source could have been the volcanic terrain of southwestern Arkansas (Ross *et al.*, 1929).

Several explanations [Beall, 1961; unpublished Baylor geology master's thesis defense field trip guidebook] can be offered to explain the observed montmorillonite distribution within the Lower Taylor Marl Member: (1) Alteration of a dominantly sodium montmorillonite to calcium-magnesium montmorillonite as the clay was transported farther from the source; (2) differences in source areas—one source furnished predominantly calcium-magnesium montmorillonite while another source furnished predominantly sodium montmorillonite, possibly with different influx rates; (3) differential settling rates for calcium-magnesium montmorillonite (representing a more basinward or deeper water deposit) relative to sodium montmorillonite (representing a near-source or near-shore, shallower water deposit); (4) alteration either during or after burial, possibly through reworking by organisms; or (5) alteration after burial by migrating calcium and/or magnesium-rich formation fluids in the southern part of the area.

Other evidence available on the depositional conditions of the Lower Taylor Marl Member, as well as the association of montmorillonite with other mineral constituents of the marl, suggests that the clay distribution is probably the result of either the first or the fourth explanation listed above. Grim (1953, p. 144) stated that calcium ions will more easily displace sodium ions than sodium ions will replace calcium ions in montmorillonite clays. Subsequent workers have also established the same order of replaceability in clay mineral base exchange in sea water (Carroll and Starkey, 1960, pp. 80-101). Carroll and Starkey (*idem*) also noted that magnesium was more effective than calcium in replacing sodium. Therefore, introduction of a dominantly sodium-rich montmorillonite into the depositional environment should result in a higher concentration of sodium montmorillonite nearer shore, with a gradual basinward (or reduced energy environment) decrease in sodium content because of a gradual conversion to calcium and/or magnesium-rich montmorillonite through base exchange. Quick burial and minimum reworking of the sodium-rich montmorillonite clay would contribute to its eventual stability.

In Upper Mississippian (Chesterian) rocks of the Anadarko basin, Weaver (1958, p. 281) noted that "shales on the north flank of the basin usually contain Ca^{++} montmorillonite whereas the presumed equivalent shales on the south flank are Na^{+} montmorillonites. This difference may reflect the relatively large amount of calcite associated with the Chesterian sediments on the north flank."

Settling rates of montmorillonites (or any clay mineral) are not affected (Whitehouse *et al.*, 1960, p. 54) by changes in $\text{Na}^{+}:\text{Mg}^{++}$, $\text{Na}^{+}:\text{Ca}^{++}$, or $\text{Mg}^{++}:\text{Ca}^{++}$ ratios in saline water. The presence of more abundant kaolinite in the northern portion of the study area substantiates the theory of Whitehouse *et al.* (*idem*).

A study of the overlying Wolfe City Sand Member, which is gradational with the Lower Taylor Marl Member, indicates that Wolfe City sediments were entering the study area from the northwest (figs. 8, 11, 12), which further substantiates a northwestern shallower or near-shore environment and a southeastern (basinward) deeper water environment.

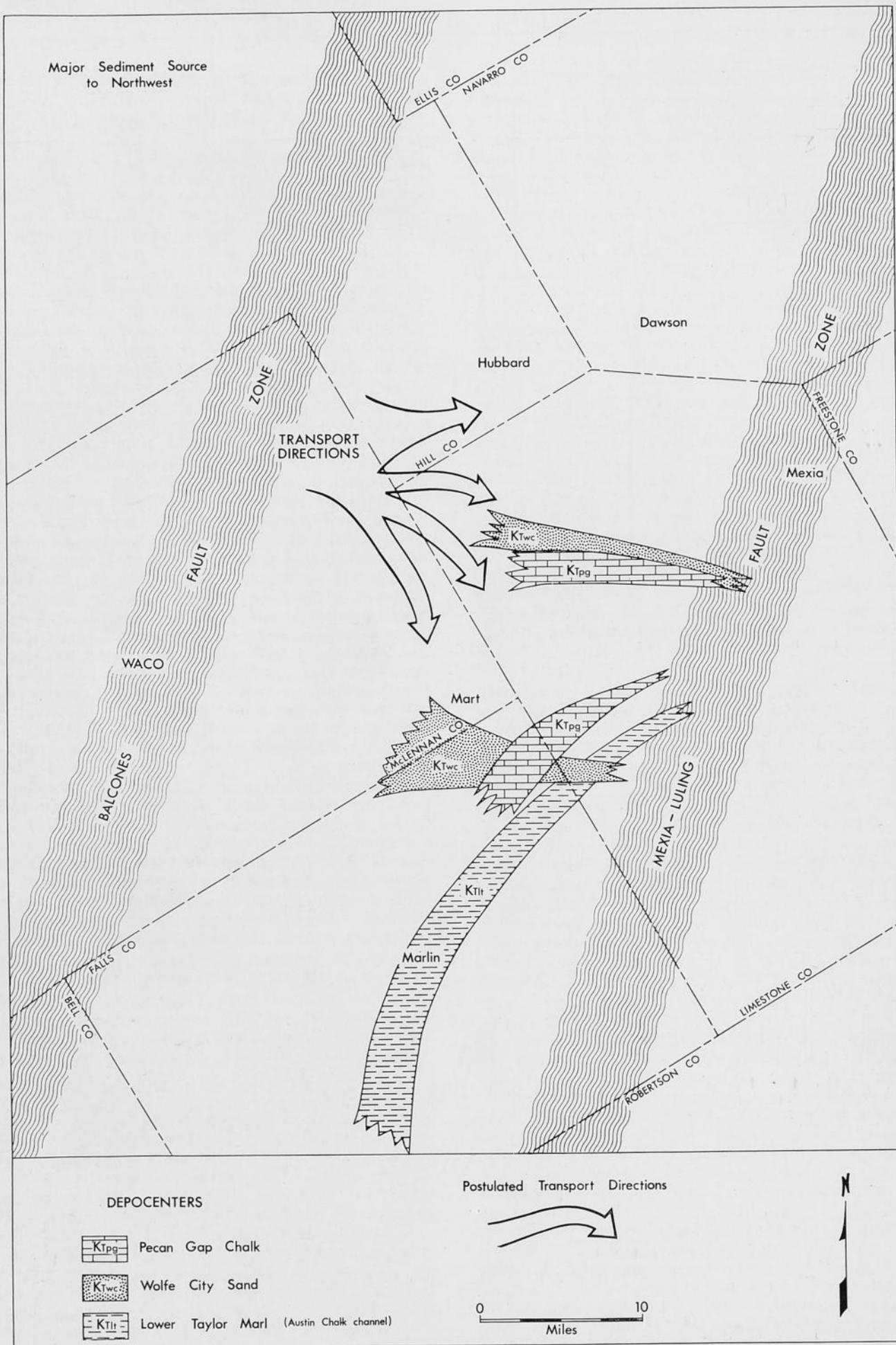


Fig. 11. Depositional and structural trends, Taylor Formation, East-central Texas. Diagrammatic representation of areas of maximum deposition (deponents) for certain members of the Taylor Formation.

The nature of the source rocks for the clay in the Lower Taylor Marl is difficult to postulate. The original sodium-rich montmorillonite possibly reflects freshly weathered sedimentary rocks composed dominantly of montmorillonite, or basic igneous extrusive terrain. Alteration of illite to montmorillonite is not considered a satisfactory explanation (Weaver, 1956).

Most Paleozoic clays which have been analyzed from North-central and West Texas are dominantly illitic, although montmorillonite is quite common (Weaver, 1958). Analyzed clays from the Lower Cretaceous Walnut Formation of Central Texas reveal the presence of montmorillonite and illite, whereas the subjacent Paluxy Formation contains abundant kaolinite and illite (Atlee, 1962, p. 12). Research now in progress by the writer shows that montmorillonite, illite, and kaolinite are common in the Central Texas Pepper-Woodbine Formation, the Del Rio Clay, and the Maness Shale. Silver (1963) noted the presence of illite, kaolinite, and montmorillonite in the lowermost part of the Eagle Ford Group (Upper Cretaceous) of Central Texas.

Upper Cretaceous clays in the Mississippi embayment area (Pryor and Glass, 1961, p. 38) are dominantly montmorillonitic and kaolinitic containing subsidiary illite and chlorite.

The termination of Lower Taylor Marl sedimentation was marked by the influx of fine-grained quartz sand and silt, which is assigned to the Wolfe City Sand Member.

WOLFE CITY SAND MEMBER

The Lower Taylor Marl Member grades conformably into the overlying Wolfe City Sand Member. The influx of sand (figs. 11, 12) represents either an uplift in the source area with an increased velocity of streams entering the depositional area and/or a slight south-eastward shoreline regression. Both factors were possibly responsible for the increased influx of sand and silt.

A general northward increase in grain size, increase in thickness (fig. 8), increase in uncemented and poorly sorted sand, and the northward appearance of more massive unlaminated sandstone point to a northwestern dispersal center during Wolfe City deposition.

Marine invertebrates were either relatively rare or shell material was subsequently destroyed. Small pelecypods, unidentified boring organisms, and internal molds of *Baculites* have been observed; the microfauna range from abundant in some sandy marls to sparse in sandstones. Deposition must have been sufficiently rapid to prevent development of an abundant benthonic fauna.

The vertical alternation of sand lenses and sandy marl beds may be explained by the action of storms, by periodic uplift in the source area, or by lateral migration of deltaic distributaries. Individual sandstone lenses are thicker and more massive in the northern part of the area indicating a northern environment of high energy, while sandstone lenses in the southern part are thinner, often laminated and finely cross-bedded, indicative of lower energy deposition.

The Wolfe City Sand (fig. 8) thins southeastward; the thickest part is located in areas where thin deposits of Lower Taylor Marl occur (figs. 7, 8, 11, 12). The

transitional nature of the Lower Taylor Marl and Wolfe City Sand, as well as the "deltaic appearance" of the Wolfe City sands, suggests that thicker parts of the Wolfe City Member may represent relatively higher energy deposition, which was responsible for these clastic sediments (such as occur in modern deltas).

The fault of the Mexia fault system in the southeastern part of the area was undoubtedly active during Wolfe City Sand deposition, since the member thins eastward across the fault (fig. 8).

A Wolfe City Sand deltaic environment is postulated for at least the northern part of the area where beds dip at twice regional dip (2° SE). In a marine delta, waves and currents work to remove the exposed part of the delta and to spread the eroded sediment, resulting in a shallow neritic, subaqueous, topset plain. The foreset slope of the marine delta is gentle, yet may extend down into the bathyal zone (Barrell, 1912, pp. 377-446). The Lower Taylor Marl and the Wolfe City Sand members reflect neritic and deltaic or prodeltaic deposition in the northern part of the area.

The presence in the Wolfe City Sand of quartz with undulatory extinction, feldspar (sodic plagioclase), zircon, garnet, staurolite, and rutile indicate a metamorphic provenance (Folk, 1959, p. 95). The presence of abundant volcanic rock fragments indicates contemporaneous vulcanism. The composition, grain angularity, grain size, and heavy mineral assemblage characterize the Wolfe City Sand as a submature to mature, very fine sandstone, which ranges from subgraywacke to volcanic arkose (*idem*, p. 119). Sands of the Wolfe City Member were derived in the north, probably from pre-existing sandstones which were subsequently mixed with volcanic debris during Wolfe City deposition. Locally, a period of non-deposition and/or erosion followed Wolfe City deposition and preceded Pecan Gap Chalk sedimentation.

PECAN GAP CHALK MEMBER

The uppermost part of the Wolfe City Sand (at least in the south) was removed or reworked prior to Pecan Gap Chalk deposition as evidenced by an unconformable contact. Correlation of well logs (figs. 5-A, B) reveals a sharp contact between the underlying sandy marl and the chalk; the contact gradually disappears downdip.

In the northern part of the area, the Pecan Gap Chalk grades northward laterally into sandy marl of the Wolfe City Member. The Pecan Gap Member is normally thickest where the Wolfe City Sand is thin (figs. 8, 9, 12). Therefore, the erosion (unconformable contact) between deposition of the Wolfe City and the Pecan Gap members on the outcrop in the southern part of the area is not extensive and had little effect on the subsequent depositional pattern of the chalk.

If deposition of the Pecan Gap Chalk was a function of lower energy but with a depositional pattern (fig. 11) similar to that of the Wolfe City Member, a lesser thickness of chalk should occur in the northern part of the area where the Wolfe City is thickest.

The Pecan Gap Chalk consists of microcrystalline calcite, megafossil fragments, and microfossils cemented in a clay matrix containing some well-rounded, fine-grained quartz. In the southern part of the area, where the

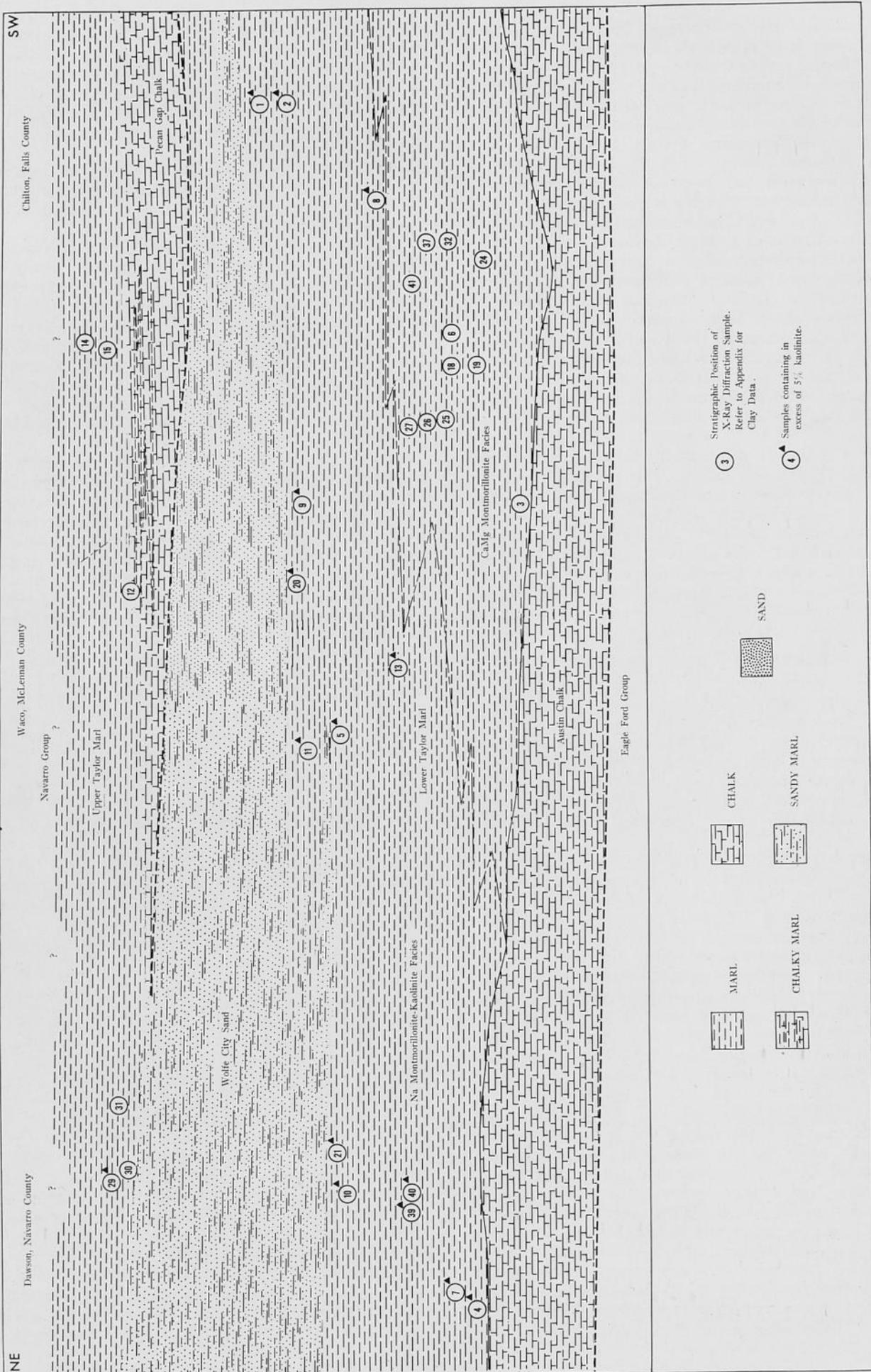


Fig. 12. Diagrammatic facies cross section, Taylor Formation, East-central Texas. For additional clay mineral data, as well as correlation of samples with locality numbers, refer to Appendix II.

Pecan Gap Chalk is well developed, the member consists of a basal chalk bed grading upward into marl and finally into a thin upper chalk unit. In the extreme southeastern part of the area, a fairly homogeneous thick chalk section is interpreted from electric logs (figs. 5-A, B).

The top of the Pecan Gap Chalk grades upward and laterally northward into the Upper Taylor Marl Member. This northward chalk to marl facies change is punctuated by the abrupt thinning of the chalk near the middle of the area (figs. 9, 12) as a result of the northward disappearance of the upper thin chalk bed present in the southern area.

Deposition of the chalk was evidently a function of depth and/or low energy, while the marl reflects an influx of clay into the basin. The presence of a thin sandstone lens in the upper chalk bed of the Pecan Gap Member in the south (locality 131) probably represents either an increase in sand supply or redistribution of sand from the northern part of the area to the south by submarine currents.

An abundant megafauna, abundant calcium carbonate, presence of calcium montmorillonite as the dominant clay mineral, sparsity of quartz, and rapid chalk to marl facies changes indicate that chalk accumulation occurred in a localized, low energy environment. The site of chalk deposition was probably shallow neritic near the shelf edge with little clastic sediment supply. Glauconite and phosphate in the member may be indicative of slow deposition (Grim, 1953, p. 353).

Contemporaneous faulting also occurred during Pecan Gap Chalk deposition, as evidenced by an abrupt

eastward thinning across the fault of the Mexia system (fig. 9).

Following Pecan Gap Chalk deposition in the north, and contemporaneous with deposition of the uppermost chalk bed of the member in the south (figs. 5-A, 12), environmental conditions shifted to more "clastic" deposition resulting in the Upper Taylor Marl.

UPPER TAYLOR MARL MEMBER

Following deposition of the Pecan Gap Chalk, clay was introduced into the basin as a result of either renewed uplift in the source area, regression of the shoreline, or lateral migration of deltaic distributaries. Bentonite seams in the Upper Taylor Marl Member indicate that vulcanism was again active.

The Upper Taylor Marl is composed of approximately equal amounts of sodium and calcium-magnesium montmorillonite associated with glauconite, phosphate, calcite, pyrite, and an abundant microfauna and megafauna. Conditions were evidently similar to those during deposition of the Lower Taylor Marl.

Thickness values are not available for the Upper Taylor Marl, since the unit grades imperceptibly upward into the overlying Neylandville Formation (p. 22).

The Upper Taylor Marl is a regressive deposit. The calcite content decreases upward; the presence of glauconite, phosphate nodules and phosphatized fossils (including vertebrate remains) indicate a near-shore marine environment with local areas of unusually slow deposition.

CONCLUSIONS

1. The Taylor Marl (consisting of four members—Lower Taylor Marl, Wolfe City Sand, Pecan Gap Chalk, and Upper Taylor Marl) as defined by Stephenson (1918) is not a valid lithostratigraphic unit, since the contact with the overlying Navarro Group within the area cannot be defined at the surface or in the subsurface.
2. It is recommended that the upper contact of the Taylor Formation be placed at the base of the Nacatoch Sand (Navarro Group). Therefore, the Neylandville Marl (originally of the Navarro Group) and the original Upper Taylor Marl Member should be combined as the redefined Neylandville Marl Member of the Taylor Formation.
3. The Austin Chalk-Taylor Formation contact is unconformable, based on stratigraphic evidence. Thickness variations displayed by the Austin Chalk and the Lower Taylor Marl Member of the Taylor Formation define a broad, probably submarine channel cut into the upper surface of the Austin Formation. At the surface, the two formations are commonly in fault contact.
4. The Lower Taylor Marl Member is the thickest member of the Taylor Formation. Although in general the member appears homogeneous, x-ray diffraction studies define two subtle clay facies representing distinctive depositional environments: (a) A northern near-shore marine environment characterized by sodium-rich montmorillonite, high kaolinite, high quartz and low calcite content, as well as a sparse fauna; and (b) a southern deeper-water and/or lower energy environment farther from the source area, characterized by calcium-magnesium-rich montmorillonite, rare kaolinite, high calcite, and low quartz content, as well as an abundant fauna, abundant iron compounds and phosphate nodules.
5. The gradational contact between the Lower Taylor Marl Member and the Wolfe City Sand Member is marked by an upward increase in sand content. Northwestward across the area the contact descends stratigraphically, as the Wolfe City Sand Member thickens.
6. The Wolfe City Sand Member is characterized by northward thickening, by a northward increase in grain size of the sandstones, and by the appearance of more massive sand units in the northern part of the area. The marine fauna ranges from absent to abundant. Stratigraphic relationships suggest that the member was deposited rapidly, possibly in a deltaic environment.

7. The Pecan Gap Chalk-Wolfe City Sand contact is sharp and unconformable in the south and gradational and conformable in the north. The Pecan Gap Chalk Member thins and pinches out in the northern part of the area. The Pecan Gap Member, which contains an abundant marine fauna, has been zoned by previous workers on the basis of foraminifers.
8. The Pecan Gap Chalk-Upper Taylor Marl contact is gradational and conformable. Northward, the contact descends stratigraphically; in the northern part of the area where the Pecan Gap Chalk is absent, the Upper Taylor Marl and the Wolfe City Sand members are conformable.
9. The Upper Taylor Marl cannot be differentiated in the study area from the overlying Neylandville Marl of the Navarro Group. The Upper Taylor Marl, which generally resembles the Lower Taylor Marl, should be studied carefully in conjunction with the Neylandville Marl.
10. Faulting in the Mexia-Luling fault system was active during most of Taylor deposition, as indicated by abrupt thickening of the various members on the western downthrown side of the major fault.
11. The Taylor Formation reflects the final marine regression of the Cretaceous Period in Central Texas, interrupted by minor strand-line fluctuations represented by the marl, chalk, and sand (members) relationships within the formation.
12. Problems recommended for further investigation include:
 - (a) Environmental and paleoecological studies;
 - (b) extension of the detailed clay mineral studies to include the upper three members of the formation;
 - (c) detailed investigation of sedimentation-faulting relationships, particularly along the Mexia zone;
 - (d) accurate delineation of the Navarro-Nacatoch contact as the upper limit of the redefined Taylor Formation;
 - (e) extension of the present studies eastward into the East Texas basin; and
 - (f) studies of the Upper Cretaceous-Lower Tertiary transition in Central Texas.

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APPENDIX I

SUBSURFACE LOCALITIES

Well No.	Driller and Owner
1	P. W. Curry, No. 1 Newman. Falls County.
2	Chilton Water Company, No. 1 water well. Falls County.
3	Abshier & Jones, No. 1 Avery. Falls County.
4	H. K. Hamilton & L. S. Torrance, No. 1 Guderian. Falls County.
5	Hays, No. 1 Bargainer. Falls County.
6	Bailey-Obermeyer, No. 1 W. Allen. Falls County.
7	Cockburn & Zephyr, No. 1 N. D. Buie. Falls County.
8	Miers & Greenawalt, No. 1 O. R. Gilliam. Falls County.
9	W. A. Reiter, No. 1 Ezell. Limestone County.
10	J. W. Jarman, No. 1 Lola Garrett. Limestone County.
11	Zephyr Oil Company, No. 1 Kay Kilpatrick. Limestone County.
12	Allen Barton Company, No. 1 R. L. Nance. Limestone County.
13	W. S. Guthrie, No. 1 Eva Suttle. Limestone County.
14	Zephyr Oil Company & W. H. Foster, No. 1 Myrtle Norris. Limestone County.
15	W. A. Reiter et al., No. 1 G. C. Lown. Limestone County.
16	W. A. Reiter, No. C-1 Gunter. Limestone County.
17	Lone Star Producing Company, No. 1 Billy Criswell. Limestone County.
18	W. B. Hinton, No. 1 R. W. Carter. Limestone County.
19	Newton & Reiter, No. 1 W. T. Lattner. Limestone County.
20	Cannon & Barron, No. 1 Fee. Limestone County.
21	A. R. Scheaf & W. T. Baresch, No. 1 Pavelka. Falls County.
22	Banks, No. 1 Kerr. Falls County.
23	Mid-States, No. 1 B. E. Mitchell. Falls County.
24	McKinsey Brothers, (fee unknown). Falls County.
25	Golinda Co-op, No. 1 water well. Falls County.
26	Gray Oil Company, No. 1 C. B. & H. C. Warren. McLennan County.
27	Rosenthal Water Company, No. 1 O'Dowd. McLennan County.
28	J. L. Myers & Sons, No. 1 Youngblood. McLennan County.
29	F. & H. Oil Production Company, No. 1 Wardlaw. McLennan County.
30	Layne Texas Company, No. 1 Texas Power & Light. McLennan County.
31	J. L. Myers & Sons, No. 1 Riesel school. McLennan County.
32	George F. Hurt, No. 1 Helm. McLennan County.
33	R. J. Caraway, No. 1 Slaughter. McLennan County.
34	Mae Belcher, No. 1 E. B. Smyth. McLennan County.
35	Ferrell Drilling Company, No. 1 J. R. Gillam. Limestone County.
36	M. M. Miller, No. 1 J. C. Rogers. Limestone County.
37	Gulf Oil Corporation & Frank Bryant, No. 1 Bevill Estate. Limestone County.
38	Gant, No. 1 J. Richardson. Limestone County.
39	W. E. Walker, No. 1 R. M. Heplin. Limestone County.
40	Burke Royalty Company, No. 2 Arnett. Limestone County.
41	O. W. Killam, No. 1 W. D. Stone. Limestone County.
42	Balcones Oil Company, No. 1 Jackson. Limestone County.
43	J. L. Myers & Sons, No. 1 Mart water well. McLennan County.
44	J. L. Myers & Sons, No. 1 H&H Water Supply Corporation. McLennan County.
45	Mt. Carmel Center, No. 1 water well. McLennan County.
46	J. L. Myers & Sons, No. 1 Pardo. McLennan County.
47	J. L. Myers & Sons, No. 1 Tiery. McLennan County.
48	J. L. Myers & Sons, No. 1 Lakeview school. McLennan County.
49	J. L. Myers & Sons, No. 1 Elm Mott school. McLennan County.
50	Layne Texas Company, No. 3 Connally Air Base water well. McLennan County.
51	C. R. Porter, No. 1 E. D. Mazanec. McLennan County.
52	C. R. Porter, No. 1 Kophal. McLennan County.
53	William H. Winn, No. 1 James L. Morrow. McLennan County.
54	R. L. Wheelock, Jr., No. 1 Willie Peal. McLennan County.
55	Simon Korshoj, No. 1 Ferguson. McLennan County.
56	H. H. Hodde et al., No. 1 Ernest Weiss. Limestone County.
57	S. H. Riggs, No. 1 Grindstaff. McLennan County.
58	J. S. Cosden, Jr., No. 1 Bower. Limestone County.
59	Richardson & Sprigiel, No. 1 McDaniel. Limestone County.
60	Hunt Oil Company, No. 1 Union Central Life Insurance Company. Limestone County.
61	Texas Company, No. 1 W. A. Keeling. Limestone County.
62	W. M. Coats, No. 1 Nussbaum. Limestone County.
63	Kelton & Lincoln, No. 1 J. W. Compton. Limestone County.
64	A. F. Tinney, No. 1 A. R. Reed. Limestone County.
65	L. W. Callender, No. 1 M. I. Burney. Limestone County.
66	Zephyr Oil Company, No. 1 C. R. Yelverton. Limestone County.
67	Stanolind Oil & Gas Company, No. 1 John Bell. Limestone County.
68	Zephyr Oil Company, No. B-2 Peeples. Limestone County.
69	Hayden Farmer Drilling Company, No. 1 National Bank of Wortham. Limestone County.
70	J. R. Bunn, No. 1 Windmill. Limestone County.
71	J. R. Bunn & Sumas Producing Company, No. 1 Wright. Limestone County.
72	Stanolind Oil & Gas Company, No. 1 Brooks. Limestone County.
73	J. R. Bunn, No. 1 Moore. Limestone County.
74	W. B. Hinton, No. 1 Brodnax. Limestone County.
75	Bunn, Willis & Sumas, No. 1 B. Gordon. Limestone County.
76	T. J. Johnson, No. 1 Ida Jackson. Limestone County.
77	St. Anthony Oil Corporation, No. 1 Allen. Limestone County.
78	Anco, No. 1 Wallace. Limestone County.
79	Davidson & Fitzpatrick, No. 1 Grant. Hill County.
80	Layne Texas Company, No. 1 Leroy Tours-Gerald water well. McLennan County.
81	Baylor University Geology Department & J. Phillips, No. 1 J. L. McCain. McLennan County.
82	J. L. Myers & Sons, No. 3 West water well. McLennan County.
83	Smith & Breyer, No. 1 C. A. Russell. McLennan County.
84	Camtex Oil Corporation, No. 1 Cartwright. Hill County.
85	Joe Thompson, No. 2 Easter Doherty. Hill County.
86	Flanagan, No. 1 Johnson. Hill County.
87	Stroube & Thompson, No. 1 Beard. Hill County.
88	Dalton J. Woods, No. 1 J. A. Estes. Hill County.
89	A. O. Phillips, No. 1 Vosburg. Hill County.
90	R. J. McMurrey, No. 1 J. P. Riley. Hill County.
91	George Rahal, No. 1 Lewis Martin. Hill County.
92	Joe Thompson, No. 1 Jack Carr. Hill County.
93	C. A. Lee, No. A-1 Hight. Hill County.
94	J. L. Myers & Sons, No. 1 City of Hubbard. Hill County.
95	Benz Oil Company, No. 1 Graham. Navarro County.
96	Benz Oil Company, No. 1 Nehring. Navarro County.
97	Benz Oil Company, No. 1 Turner. Navarro County.
98	Benz Oil Company, No. 1 Call. Navarro County.
99	Lytle, Holloway and Phillips, No. 1 Atlantic Refining Company. Limestone County. Not located in map area.

SURFACE LOCALITIES

101. Wolfe City Sand Member; exposed in spillway of Navarro Mills Dam, Richland Creek, approximately 0.9 mile west of Navarro Mills and 4.1 miles northeast of Dawson. Navarro County.
102. Wolfe City Sand Member; exposed in branches of Richland Creek over 0.25 of a square mile, south of roadside park on State Hwy. 31, 2.7 miles northeast of Dawson. Navarro County. Hard, crystalline, buff sandstone ledges interbedded with sandstone and some marly sandstone; top of beds have borings. Some bedding dips 2°.
103. Wolfe City Sand Member; exposed in low-water crossing of branch of Richland Creek and east along its south bank, 0.9 mile east-northeast of Dawson. Navarro County.
(b) Buff to brown, crystalline sandstone ledge; undulating top and bottom; borings, tracks, *Baculites* and *Inoceramus* casts
-----1.5 feet
(a) Uncemented sand underlying ledge-----3 feet
- 104.* Upper Taylor Marl Member; exposed in banks of small branch of Battle Creek intersecting with F.M. 709, 2.7 miles east of Dawson. Navarro County.
(c) Brown, massive marl.
(b) Yellow to buff bentonite seam; weathers orange, buff to white; iron oxide-stained-----10 inches
(a) Brown, massive, fossiliferous marl-----7 feet
105. Neylandville Marl, Navarro Group; exposed in road cut of F.M. 709, 6.8 miles east of Dawson. Navarro County. Buff to brown marl and sandy marl with some interbedded thin sandstone lenses. Large calcareous septaria up to 1.5 feet in diameter-----15 feet
106. Wolfe City Sand Member; exposed in road and in drainage ditches of county road 4 miles east of Hubbard and 3 miles southwest of Dawson. Navarro County.
107. Wolfe City Sand Member; exposed along drainage ditch of county road and in Massacre Creek, 1 mile southwest of Dawson. Navarro County. Hard, crystalline sandstone ledge interbedded with sandstone and sandy marl; buff to brown.
- 108.* Upper Taylor Marl Member; exposed in drainage ditch of county road 2 miles south of Dawson. Navarro County. Brownish-gray, massive marl; phosphatic with teeth and vertebrae near base; 3-inch thick bentonite near middle; high montmorillonite at top-----40 feet
- 109.* Lower Taylor Marl Member; exposed in meanders of branch of Ash Creek along F.M. 171, 5 miles northwest of Malone. Hill County.
110. Lower Taylor Marl Member; exposed in drainage ditch along F.M. 1242, 4.6 miles south of Bynum. Hill County.
- 111.* Lower Taylor Marl Member; exposed in banks of branch of Ash Creek at intersection with F.M. 171, 2 miles northwest of Malone. Hill County. Gray to buff marl; blocky and massive-----5 feet
- 112.* Lower Taylor Marl-Wolfe City Sand contact zone; exposed in road cut of F.M. 171, 2.25 miles southeast of Malone. Hill County. Dark gray, blocky marl; weathers buff; grades upward into sandy marl with some thin sandstone lenses at top-----12 feet
- 113.* Lower Taylor Marl Member; exposed in drainage ditch along F.M. 308, 2 miles southwest of Malone. Hill County. Brown to buff marl; massive and blocky.
- 114.* Lower Taylor Marl Member; exposed in meanders of branch of Ash Creek, along county road 3.9 miles west-southwest of Malone. Hill County. Interbedded light and dark marl; buff when weathered; small unidentified pelecypods, *Inoceramus*-----8 feet
115. Lower Taylor Marl Member; exposed in meanders of Brookeen Creek, along county road 5 miles north-northwest of Birome. Hill County. Gray to brown marl; massive and blocky-----3 feet
116. Lower Taylor Marl Member; exposed in banks of Brookeen Creek, along county road 1.9 miles north-northwest of Birome. Hill County. Gray to brown marl; massive and blocky-----5 feet
117. Lower Taylor Marl Member; exposed in branch of Brookeen Creek, along county road 1.2 miles north of Birome. Hill County. Light gray to brown marl; massive-----5 feet
118. Wolfe City Sand Member; exposed in meander of Postoak Creek near F.M. 171, 1.6 miles northwest of Hubbard. Hill County. Buff to gray, sandy marl; interbedded with sandy lenses (3 to 4 inches thick)-----8 feet
119. Wolfe City Sand Member; exposed in tributary of Lake Hubbard near a county road 0.5 mile north of the lake, 1.6 miles west of Hubbard. Hill County. Brown, buff to gray, sandy marl; interbedded with sandstone lenses-----7 feet
120. Wolfe City Sand Member; exposed in St. Louis-Southwestern Railroad cut 1.7 miles east of Hubbard. Hill County. Buff to brown, sandy marl and sandstone lenses-----8 feet
121. Wolfe City Sand Member; exposed in branch of Massacre Creek near a county road 2.4 miles east of Hubbard. Hill County. Buff to brown, sandy marl; interbedded with thin sandstone lenses-----4 feet
122. Wolfe City Sand Member; exposed in branch of Pinoak Creek near a county road 2.3 miles east of Hubbard. Hill County. Gray to buff sandstone and sandy marl, containing rare sandy lenses-----5 feet
123. Wolfe City Sand Member; exposed in branch of Pinoak Creek at intersection with F.M. 171, 2.3 miles south-southeast of Hubbard. Hill County. Gray to buff, sandy marl and sandstone lenses-----6 feet
124. Wolfe City Sand Member; exposed in banks of Packwood Creek 1.7 miles southwest of Mount Calm on State Highway 31. Hill County. Sandy marl; interbedded with sandstone lenses-----5 feet
- 125.* Pecan Gap Chalk Member; exposed in small branch of tributary of Navasota River near a county road 0.8 mile west of Delia. Limestone County. Middle Pecan Gap Chalk; chalky marl; weathers buff to brown; some large pelecypods.
126. Pecan Gap Chalk Member; exposed in small branch of tributary of Navasota River, 1.8 miles south of Delia. Limestone County. Upper Pecan Gap Chalk; chalky, buff marl.
127. Upper Taylor Marl Member; exposed in drainage ditch at intersection of county road and State Hwy. 341, 3 miles northeast of Prairie Hill. Limestone County. Brown, massive, blocky marl.
128. Wolfe City Sand-Pecan Gap Chalk contact; exposed in abandoned quarry 3.5 miles north-northwest of Prairie Hill along F.M. 737. Limestone County.
(b) White, massive to slightly bedded chalk containing high amount of glauconite near contact. Borings into the marl filled with chalk; inclusions of marl in basal chalk; *Baculites* and *Inoceramus*-----6 feet
(a) Brown, silty marl-----6 inches
129. Wolfe City Sand-Pecan Gap Chalk contact; exposed in quarry in farm pasture near F.M. 737, 2.8 miles northwest of Prairie Hill. Limestone County.
(b) White, massive to slightly bedded chalk; contains high glauconite content near contact. Borings into chalk filled with marl; *Inoceramus* present-----6 feet
(a) Brown, silty, marl; borings contain chalk-----2 feet
130. Pecan Gap Chalk Member; exposed in drainage ditch near top of hill south of U. S. Hwy. 84, 1.8 miles east of Watt. Limestone County. Basal Pecan Gap Chalk; weathers white, massive; some *Baculites* casts.
131. Pecan Gap Chalk Member; exposed along creek bed for 0.5 of a mile in tributary of Cottonwood Creek 3.5 miles south of Prairie Hill. Limestone County. Upper Pecan Gap Chalk; buff, brown to cream; abundant *Gryphaea*, *Exogyra*, small unidentified pelecypods; interbedded, fairly continuous, thin (2 inches thick) sandstone lens which shows magnitude of faulting-----15 feet
132. Neylandville Marl, Navarro Group; exposed in road cut of F.M. 1245, 0.9 mile northwest of Frosa. Limestone County. Brown to buff, glauconitic, slightly sandy marl with small lenses of sandstone; *Inoceramus* present-----8 feet
133. Pecan Gap Chalk Member; exposed in drainage ditch in county road along McLennan-Limestone County line 2 miles north of Mart. Limestone County. Lower Pecan Gap Chalk; weathered white to buff; contains unidentified pelecypods, *Inoceramus*, and *Baculites*.
134. Wolfe City Sand Member; exposed in road cut on State Hwy. 31, 4.2 miles west of Mount Calm. McLennan County. Sandy marl; weathers greenish-yellow; small lenses of sandstone.
135. Lower Taylor Marl-Wolfe City Sand contact zone; exposed in drainage ditch of county road in Roberts Creek valley 2 miles north of State Hwy. 31, 3.5 miles east of intersection of State Hwy. 31 and U. S. Hwy. 84. McLennan County. Gray marl; grades upward into sandy marl interbedded with very thin sandy lenses-----20 feet
- 136.* Lower Taylor Marl Member; exposed in banks and adjacent hills of Wildcat Creek along county road 1 mile north of State Hwy. 31, 1.5 miles northeast of junction of State Hwy. 31 and U. S. Hwy. 84. McLennan County. Light gray to buff when weathered; light gray when fresh; slightly laminated, massive, blocky, abundant organic debris.
- 137.* Lower Taylor Marl Member; exposed in banks of Wildcat Creek west of county road 1 mile north of State Hwy. 31, 1.5 miles northeast of junction of State Hwy. 31 and U. S. Hwy. 84. McLennan County. Light gray to buff; laminated to massive; some small pelecypods.

*X-ray analyses are indicated by *. Mileages are airline distances. Localities 182-188 (Falls County) are not within the map area (fig. 4).

138. Lower Taylor Marl-Austin Chalk contact; exposed near top of bluff of White Rock Creek at junction with Brazos River; near gravel pit on F.M. 933, 4 miles north of junction with U. S. Hwy. 84, McLennan County. White chalk with borings filled by Taylor Marl; phosphatic nodules; sharp lithologic break between hard chalk to soft marl. Described by Seewald (1959).
 (b) Taylor Marl-----5 feet
 (a) Austin Chalk-----89 feet
139. Lower Taylor Marl Member; exposed in banks of Tehuacana Creek, 400 yards north of U. S. Hwy. 84, 1 mile east of Bellmead, McLennan County. Buff to gray marl; blocky and massive-----6 feet
140. Wolfe City Sand Member and Lower Taylor Marl Member; exposed in bank of Williams Creek immediately south of U. S. Hwy. 84, 4.5 miles east of junction with State Hwy. 31. One of Stephenson's type sections for the Durango Sand, McLennan County. Wolfe City sand "terrace" of sand lens fragments loosely cemented in bank; variable in thickness. "Terrace" sharply overlies dark gray to black marl-----10 feet
141. Wolfe City Sand-Lower Taylor Marl contact zone; exposed on small hills along county road south of Williams Creek 2 miles northwest of Elk, McLennan County-----20 feet
- 142.* Lower Taylor Marl Member; exposed in banks of tributary of Williams Creek near a county road 4 miles west of Elk, McLennan County. Wolfe City Sand at top of hill. Gray to dark brown marl; massive and blocky-----12 feet
143. Wolfe City Sand Member; exposed in drainage ditches of U. S. Hwy. 84 at intersection with F.M. 939, McLennan County. Buff-brown, sandy marl and sandy ledges-----5 feet
144. Wolfe City Sand Member; exposed in bank of tributary to Tradinghouse Creek near a county road 2.8 miles north of Hallsburg, McLennan County. Sandy marl; some lenses of sandstone.
145. Lower Taylor Marl Member; exposed 1 mile north-northeast of Harrison Switch in banks of Tradinghouse Creek 0.1 mile west of county road, McLennan County. Buff to gray marl; massive, conchoidal fracture.
- 146.* Lower Taylor Marl-Austin Chalk contact; intersection of Waco Creek and South 4th Street, Baylor University, McLennan County.
 (b) Gray marl; weathers buff; indistinct contact with underlying chalk; complicated by faulting-----7 feet
 (a) Typical Austin Chalk; weathers white; contains *Inoceramus* impressions-----2 feet
147. Wolfe City Sand Member; exposed in bank of tributary to Tradinghouse Creek 1 mile north of Hallsburg, McLennan County. Sandy marl in fault contact with sandy marl, marl, and sandstone lenses-----4 feet
148. Wolfe City Sand Member; exposed in tank excavation and dam on tributary of Tradinghouse Creek 1.8 miles northeast of Hallsburg, McLennan County. Sandy marl; some sandstone lenses.
149. Wolfe City Sand Member; exposed in drainage ditch along county road 2 miles east of Hallsburg, McLennan County. Sandy marl; local lenses of sandstone-----5 feet
150. Wolfe City Sand Member; exposed in banks of Riggs Creek 3.4 miles northwest of Mart and 1 mile north of Battle Lake, McLennan County. Yellow to buff, sandy marl.
151. Wolfe City Sand; exposed in tributary of Big Creek approximately 3.5 miles northwest of Mart. Yellow to buff, sandy marl.
152. Pecan Gap Chalk Member; exposed in small streams on western city limits of Mart 0.1 mile north of State Hwy. 164, McLennan County. Upper Pecan Gap Chalk, massive, white.
153. Pecan Gap Chalk Member; exposed in banks of Big Creek 50 yards downstream from bridge on old Mart-Riesel road, 0.5 of a mile southwest of Mart, McLennan County. Basal to "intermediate" Pecan Gap Chalk; weathers white to buff; gray when fresh. Some chalk exhibits evidence of reworking; fossils abundant—*Diploschiza cretacea*, *Ostrea*, *Pecten*, several unidentified gastropods, a nautiloid, and annelid worms-----8 feet
154. Pecan Gap Chalk; exposed in tributary of Big Creek 2 miles south of Mart, McLennan County. Upper chalk; white, massive; *Inoceramus*-----4 feet
- 155.* Lower Taylor Marl Member; exposed in bank of Manos Creek at intersection of Manos Creek and State Hwy. 164, 6 miles west of Mart, McLennan County. Black to gray; weathers brownish-gray; slightly fissile to massive; very dark when fresh-----10 feet
156. Wolfe City Sand Member; exposed 1.2 miles southwest of Riesel in banks of Sandy Creek, McLennan County. Buff to yellow, sandy marl; *Inoceramus* impressions-----5 feet
- 157.* Lower Taylor Marl Member; exposed in bluff of the Brazos River 1 mile southwest of Lake Creek reservoir, McLennan County. Poorly laminated marl; becomes more calcareous upward; 1-inch thick bentonite seam near base-----30 feet
- 158.* Lower Taylor Marl Member; exposed in road cut of U. S. Hwy. 77, 0.9 mile north of Rosenthal, McLennan County. Buff, blocky marl; overlain by soil cover and terrace deposits-----3 feet
- 159.* Lower Taylor Marl Member; exposed in south bank of Castleman Creek near county road 2 miles southeast of U.S. Hwy. 81, McLennan County.
- 160.* Lower Taylor Marl Member; exposed in drainage ditch along county road 1.4 miles south and 0.3 of a mile east of U. S. Hwy. 81 between two branches of Castleman Creek, McLennan County. Buff, blocky marl; jointed and faulted; some fossil fragments and impressions of *Inoceramus*-----9 feet
- 161.* Lower Taylor Marl Member; exposed in small tributary of Castleman Creek beside U. S. Hwy. 77, 1.5 miles north of Rosenthal, McLennan County. Buff, blocky marl-----8 feet
162. Lower Taylor Marl Member; exposed in bank of Bull Hide Creek under bridge on county road 1.5 miles southeast of U. S. Hwy. 81, McLennan County. Gray marl; severely weathered; in fault contact with Austin Chalk; structurally distorted-----8 feet
- 163.* Lower Taylor Marl Member; exposed 0.1 mile north of Rosenthal along U. S. Hwy. 77, McLennan County. Buff, blocky marl-----3 feet
- 164.* Lower Taylor Marl Member; exposed in bank of Dry Creek near a county road 2 miles west of Rosenthal, McLennan County. Light gray marl; weathers buff-brown; massive to blocky or platy. Small pelecypods well preserved; some thin-shelled and poorly preserved echinoids; fault of small displacement-----15 feet
- 165.* Lower Taylor Marl Member; exposed in bank of Bull Hide Creek, along county road 3.2 miles east of Lorena, McLennan County. Buff, brown to gray marl; locally very calcareous; *Parapuzosia* and *Inoceramus*-----40 feet
166. Lower Taylor Marl-Austin Chalk contact; exposed in bank of North Cow Bayou 2.5 miles south-southeast of Lorena, McLennan County. Hard ledge of Austin Chalk with chalk and marl-filled borings overlain abruptly by Lower Taylor Marl; some phosphatic material-----11 feet
167. Lower Taylor Marl Member; exposed north of county road in eroded area near tributary of North Cow Bayou 3 miles south-southeast of Lorena. Chalky marl containing a hematite lens.
- 168.* Lower Taylor Marl Member; exposed in tributary of North Cow Bayou near a county road 4 miles south-southeast of Lorena, McLennan County.
169. Lower Taylor Marl Member; exposed in tributary of North Cow Bayou near county road 4.8 miles southeast of Lorena, Falls County. Buff, weathered marl; *Coraliochama*, *Exogyra cancellata*.
- 170.* Lower Taylor Marl Member; exposed in tributary of South Cow Bayou east of F.M. 107, 3.3 miles west of Mooresville, Falls County. Buff to brown marl; *Parapuzosia*, *Inoceramus*, and "cancellate" variety of *Exogyra*-----20 feet
- 171.* Lower Taylor Marl Member; exposed 1.5 miles south of Golinda in drainage ditch along U. S. Hwy. 77, Falls County. Severely weathered, buff marl; blocky when fresh-----5 feet
- 172.* Lower Taylor Marl Member; McKinsey oil well location in the Satin Field 2.2 miles northeast of Satin, Falls County.
173. Wolfe City Sand Member; exposed in ditch of road through pasture 0.4 mile west of county road along east bank of Brazos River, 0.8 mile south of McLennan-Falls County line and 4.3 miles west of State Hwy. 6, Falls County. Buff, sandy marl with hard lenses approximately 1.5 inches thick-----4 feet
174. Pecan Gap Chalk Member; exposed along banks of Sandy Creek south of bridge on F.M. 2307, Falls County. Blocky, white to gray chalk at base; grades upward into chalky, buff, blocky marl and highly calcareous marl. *Exogyra ponderosa* and *Gryphaea* abundant; rare *Ostrea*-----10 feet
175. Wolfe City Sand-Pecan Gap Chalk contact; exposed in bank of Sandy Creek 0.8 mile east of State Hwy. 6 and 0.6 mile north of F.M. 2307, Falls County.
- 176.* Upper Taylor Marl Member; exposed 1 mile north of Otto near county road in banks of tributary of Big Creek, Falls County. Brownish-buff to white, highly calcareous marl; blocky when fresh, slightly fissile when weathered-----8 feet
177. Upper Taylor Marl Member; 1 mile east of McClanahan near F.M. 147 in banks of Keechi Creek, Falls County. Brownish-buff, severely weathered, calcareous marl; blocky when fresh-----4 feet
178. Wolfe City Sand Member; exposed in ditch of county road and in adjacent creek 1 mile east of F.M. 2117, 3.5 miles north-northwest of Marlin, Falls County. Buff, sandy marl-----3 feet

179. Pecan Gap Chalk Member; exposed in tributary of Big Creek near gavel pit in city limits of Marlin, Falls County. White to buff chalk; severely weathered-----3 feet
180. Wolfe City Sand Member; 0.8 miles south of Triangle along F.M. 320 in tributary of Deer Creek, Falls County. Alternating tan to gray, slightly fissile sandstone and sandy tan to gray marl; sandstones are lenticular; locally contain teeth and borings-----40 feet
181. Wolfe City Sand Member; 0.4 of a mile south of Triangle along F.M. 320 in drainage area of Deer Creek; scattered exposures over small area, Falls County. Very sandy buff marl; small sandstone lenses-----4 feet
182. Lower Taylor Marl Member; 2 miles east of Cego on F.M. 1950 in tributary of Cottonwood Creek, Falls County. Blocky, tan-gray marl; weathers buff to light-buff; slightly fissile when weathered-----4 feet
183. Lower Taylor Marl Member; 0.5 of a mile south of Cego and 2.9 miles north of Durango in small creek on east side of county road, Falls County. Blocky, tan-gray marl; weathers buff; exhibits some fissility.-----5 feet
184. Wolfe City Sand Member; 1.8 miles northwest of Durango in bank of Deer Creek, Falls County. Severely weathered sandy marl, and hard crystalline sandstone ledges cemented with calcium carbonate; ledges range from 1 to 5 inches thick.
185. Lower Taylor Marl Member; exposed in small branch of Deer Creek 3.8 miles west of Durango, Falls County. Brown marl; abundant small clams, *Durania*, *Exogyra cancellata*, and *Ostrea*-----20 feet
186. Wolfe City Sand Member; exposed along county road 1.5 miles north of Durango, Falls County. Weathered, buff, sandy marl and hard, crystalline sandstone ledges; ledges range from 1 to 3 inches thick.
187. Pecan Gap Chalk Member; Falls of the Brazos on county road 3.6 miles south and 2.5 miles east of Triangle. Brazos River flows over exposure creating small rapids, Falls County. White to gray, massive chalk; abundant *Exogyra ponderosa*; faulted.
188. Wolfe City Sand Member; 1.6 miles northeast of F.M. 935 and 1.4 miles northwest of Durango in drainage ditches of county road, Falls County. Highly weathered, buff sandy marl and hard, crystalline sandstone ledges from 1 to 4 inches thick.

APPENDIX II

X-RAY DIFFRACTION DATA¹

2/Sample No.	Locality No.	Montmorillonite Na:CaMg	Montmorillonite %	Kaolinite %	Illite %	Quartz %	Calcite %	Diffraction Peak: Montmorillonite (001)
1	172	100:0	55	10	3—	20+	10—	broad
2	172	95:5	55	10	3—	20	10	broad
3	146	20:80	65	--	3—	10	20+	broad
4	109	30:70	60	5	5	20+	10	broad
5	137	50:50	50	10—	tr.	20	20+	broad
6	161	40:60	60	--	tr.	20	20+	broad
7	111	40:60	60	8	tr.	20+	10	
8	171	40:60	60	10	--	20+	10	
9	157	50:50	55	15	--	20+	10	sharp
10	112	50:50	55	15	--	20	10—	
11	136	50:50	50	8	8	20	10	broad
12	125	50:50	60	--	3—	30+	5	sharp
13	142	100:0	40	15	5	30	10—	broad
14	176	45:55	70	--	--	20+	10	sharp
15	176	45:55	70	--	tr.	20+	10	
18	158	60:40	65	3—	--	20	10	sharp
19	163	50:50	60	3—	3—	20	10+	
20	155	60:40	50	10	3—	30	5—	
21	113	50:50	60	5	5	20—	10—	

2/Sample No.	Locality No.	Montmorillonite Na:CaMg	Montmorillonite %	Kaolinite %	Illite %	Quartz %	Calcite %	Diffraction Peak: Montmorillonite (001)
22	3/99	100:0	60	5	5	20+	10	sharp
23	99	100:0	55	5—	3—	30	5+	sharp
24	165	50:50	60	3—	--	5—	30+	diffuse
25	159	10:90	60	3—	--	5	30+	broad
26	159	50:50	55	3—	?	5—	35+	broad
27	159	50:50	55	--	--	5—	35+	broad
29	108	35:65	60	5	5	20+	10—	sharp
30	108	40:60	90	--	--	3—	3—	very sharp
31	104	50:50	90	--	--	3—	3—	very sharp
32	168	20:80	45	3—	10	5—	35+	broad
37	168	10:90	55	--	--	--	45+	diffuse
39	114	40:60	65	10	tr.	15	10—	sharp
40	114	50:50	60	10	tr.	20	10—	sharp
41	170	5:95	60	--	--	?	40	diffuse
42	99	95:5	65	3—	3—	20	5—	broad
43	99	95:5	65	5	5	20+	5—	broad
44	99	50:50	60	10	5	20	5	
45	99	95:5	60	5	5	20+	10—	broad
46	99	95:5	60	5	10	20	5—	broad

¹These clay data are estimates based on comparison of diffraction intensities of Taylor Formation samples with mixtures of pure minerals (weight percentages). The ratio of sodium (Na) montmorillonite to calcium-magnesium (CaMg) montmorillonite is given in parts per hundred. All percentages are based on the total sample and are correct within approximately 5

percent. Note the following symbols: slightly less than (—); slightly greater than (+).

²Refer to Figure 12 for position of sample in facies of Taylor Formation.

³Lytel, Holloway and Phillips, No. 1 Atlantic Refining Company, located north and slightly east of area.

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