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CLAY MINERALOGY AND CLAY-MINERAL FACIES OF THE LOWER CRETACEOUS TRINITY GROUP, SOUTHERN OKLAHOMA

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

FREDERICK H. MANLEY, JR.

Norman, Oklahoma

1965

CLAY MINERALOGY AND CLAY-MINERAL FACIES OF THE LOWER CRETACEOUS TRINITY GROUP, SOUTHERN OKLAHOMA

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CLAY MINERALOGY AND CLAY-MINERAL FACIES OF THE LOWER CRETACEOUS TRINITY GROUP, SOUTHERN OKLAHOMA

INTRODUCTION

In the past, established principles of stratigraphy, paleontology, and other geologic disciplines have been applied to correlation and zonation of the Lower Cretaceous Trinity Group in southern Oklahoma with limited success. This study of the clay mineralogy of the section was undertaken to assess the potential of clay minerals in solving stratigraphic problems. The results have demonstrated that clay-mineral assemblages can provide effective and reliable zonations. In conjunction with other studies, the assemblages can be used reliably to help correlate and interpret the depositional history of a section even where sediments contain no persistent units and only poorly preserved or non-diagnostic fossils.

The sediments of the Trinity Group of southern Oklahoma are heterogeneous over a wide area. They represent shelf deposits laid down by a northwestward transgressing sea on the northwestern side of the Cretaceous Gulf of Mexico (Figure 1). The sediments strike northeastward and dip east-southeastward at less than 50 feet per mile. Field and laboratory examinations show that lithology and chemical

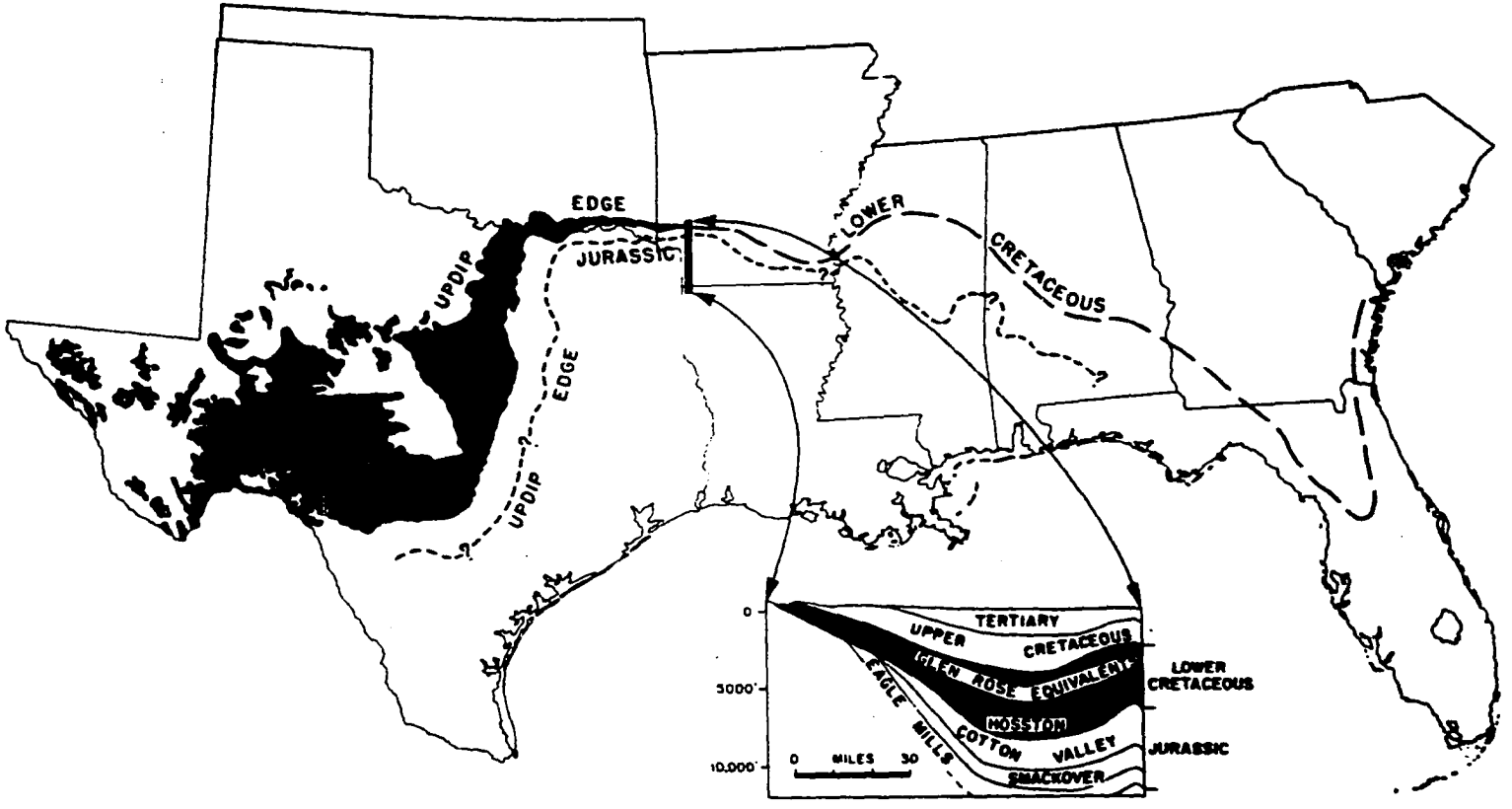


FIGURE 1
DISTRIBUTION OF LOWER CRETACEOUS,
GULF COAST PROVINCE

character of the sediments vary widely both laterally and vertically. The Trinity rock units consist of poorly indurated clays, fine to coarse sands, and conglomerates, and locally marl and limestone.

Location and Description of Area

Figure 2 shows the geographic location of the area studied and the generalized outcrop of the Trinity Group sediments in southern Oklahoma. The major outcrop is a broad sinuous band extending from the Red River south of Ardmore in Love County, Oklahoma, northward through Carter County, thence eastward through Johnston, Marshall, Atoka, Bryan, Pushmataha, Choctaw, and McCurtain Counties into Arkansas. The length of the outcrop in Oklahoma is slightly more than 210 miles. The width varies from about 8 to 20 miles (Plate 1).

The outcrop area has a surface relief of 150 to 200 feet forming a gently rolling topography covered by an exceptionally thick growth of deciduous and coniferous trees. The sediments are best exposed along banks of large rivers, in quarries, and in road cuts. Plates 3 to 9 show some of these typical exposures. Most areas are either intensely weathered (Plate 3), covered with alluvium, and/or masked by thick vegetation.

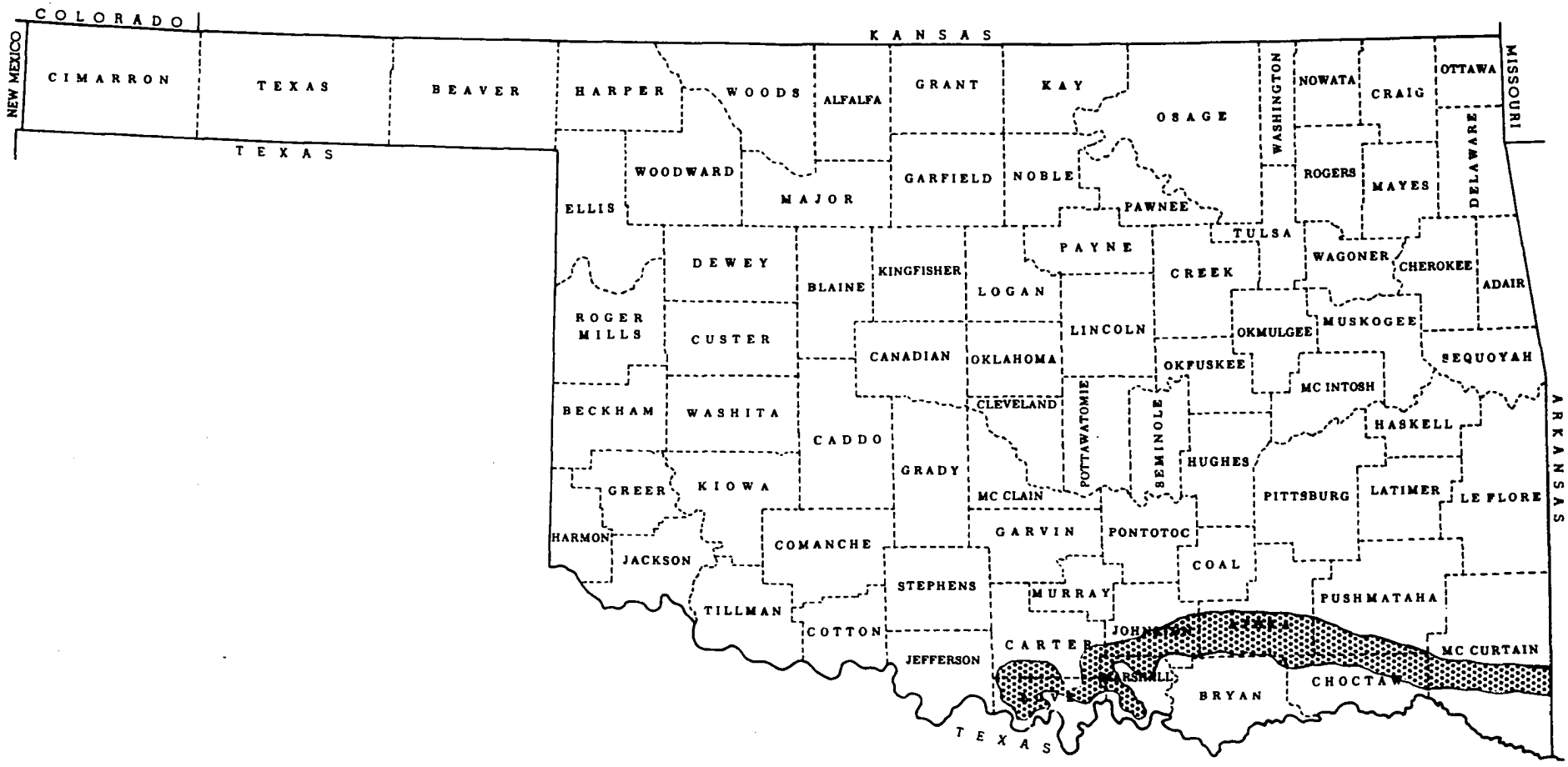


FIGURE 2
LOCATION MAP OF AREA STUDIED

LITHOSTRATIGRAPHY

The Lower Cretaceous sedimentary rocks of southern Oklahoma are divided into three rock units or groups. The principal subdivisions of the Lower Cretaceous, in ascending order, are the Trinity, Fredericksburg, and Washita Groups. All are considered to be Comanchean in age (Imlay, 1945).

The strata considered in this study include only those of the Trinity Group. The Trinity Group includes (ascending) the Holly Creek Formation, the DeQueen Limestone, the Antlers Sand, and the Baum Limestone Member.

The Holly Creek Formation is composed of gravels interbedded with fine sand, silt, and clay. The DeQueen Limestone consists of argillaceous and pelletiferous biomicrudites and biomicrites interbedded with varicolored silty clays, silt, and very fine sands. The Holly Creek and DeQueen Formations are exposed only in the eastern portion of the study area in southern McCurtain county.

The Antlers Sand, consisting of silty to sandy clays, fine- to coarse-grained, loosely consolidated orthoquartzites, with argillaceous cement, and local gravels and conglomerates, is exposed across the entire study area (Plate 1).

The Baum Limestone Member, composed of basal red clay, limestone conglomerate, algal limestone, and arkosic limestone, has its maximum development in an area about 15 miles long and 10 miles wide that borders the southern part of the Arbuckle Mountain region in eastern Carter and Western Johnston Counties. Only the clays that interfinger with the Baum member of the Antlers and the beds of Pre-Baum age that underlie it were studied. For complete details on the general geology, petrology, and economic geology of this limestone, the reader is referred to Wayland and Ham (1955). Other than this limestone facies, and the DeQueen and Holly Creek Formations of southern McCurtain County, the Antlers Sand comprises the entire Trinity Group of southern Oklahoma (Plate 1).

Prior to the present study, only three workers have studied one or more Lower Cretaceous rock units across the entire length of outcrop in southern Oklahoma. Forgotson (1957, 1963) published subsurface stratigraphic information on the entire Trinity Group; Prewitt (1961) studied the subsurface beds of the Cretaceous Coastal Plain of southern Oklahoma; and Blau (1961) completed the first petrologic study of the Goodland Limestone, overlying the Trinity Group, along its entire outcrop in southern Oklahoma.

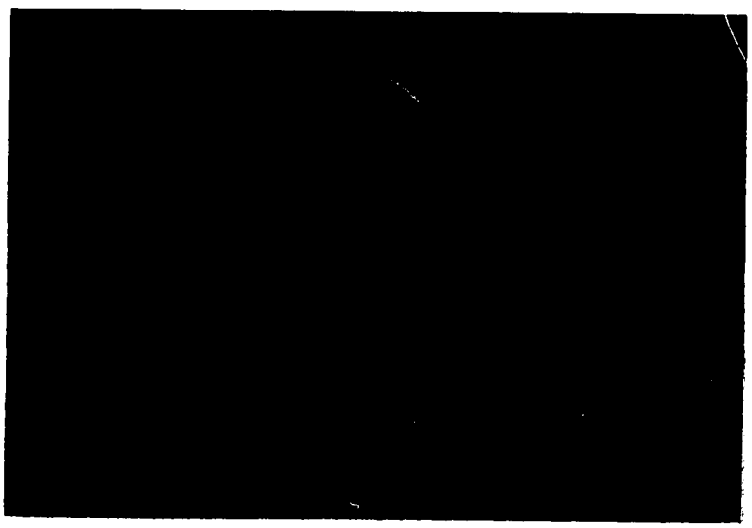
Only isolated segments of the Trinity Group, however, were examined petrographically or mineralogically prior to this investigation. No study of the clay minerals of any portion of the Lower Cretaceous sediments of southern Oklahoma has ever been published.

PLATE 3

Typical exposures of the Antlers Sand (A and B) showing extensive oxidized zone (A).

PLATE 3

A



B

PLATE 4

A. Outcrop of conglomerate and lenses of laminated sand at base of Trinity Group. NE1/4, SE1/4, SE1/4, Sec. 2, T5S, R3W.

B. Close-up view of carbonate- and argillaceous-cemented laminated sand lens.

PLATE 4

A

B

The top of the Trinity Group is here defined as the top of the Antlers Sand. The base of the Trinity Group, in the eastern portion of the area of investigation, is defined as the base of the Holly Creek Formation. In the western portion of the area, from western McCurtain County to the Red River, Love County, the base of the surface exposures of the Trinity Group is the base of the Antlers which onlaps the underlying Holly Creek Formation and DeQueen Limestone.

Formations of the Trinity Group

Holly Creek Formation: From exposures near Little Holly and Holly Creeks southeast of Dierks in Howard County, Arkansas, Vanderpool (1928) derived the name "Holly Creek clay".

In Oklahoma, the name "Holly Creek" is applied, according to Davis (1960), to the Cretaceous stratum below the DeQueen Formation.

The Holly Creek Formation in Oklahoma ranges from 30 to 100 feet in thickness in its outcrop area (Honess, 1923), but thickens to as much as 1,070 feet (Davis, 1960) in subsurface in the southern part of McCurtain County. The outcrop area in eastern McCurtain County at the Arkansas State line is about two and one-half miles wide. From this area westward, it occurs as an irregular band and narrows to about one-fourth mile in width in sec. 36, T. 5 S., R. 23 E., and to a few hundred feet in width in sec. 1, T. 6 S., R. 23 E., where it is conformably overlapped by the DeQueen and Antlers Formations.

At the few surface exposures where it can be observed, the Holly Creek Formation consists of discontinuous layers and irregular lenses of poorly indurated and/or poorly sorted gravels, sands, siltstones, and clays. The gravel particles (from granules to boulders) are surrounded by a matrix of all possible combinations of clay, silt, and sand. Locally, the gravels are asphaltic or may contain thin lenses of asphalt.

The majority of gravel-size particles are of two grades — pebbles and cobbles. Examination of both fresh and weathered surfaces of these pebbles and cobbles indicates that they were derived entirely from the Paleozoic rocks of the Ouachita Mountain System. The percentage composition of the gravel is approximately 25 sandstone and shale, 25 chert, and 50 vein quartz. Commonly the chert content is about 35 percent near the Arkansas State line and the sandstone and shale content is about 10 percent. Vein quartz is dominant throughout the formation, but increases from about 55 percent near the eastern edge of the outcrop area to 60-65 percent in the western area of the outcrop. The amount of chert decreases towards the western portion of the outcrop to about 15-25 percent.

Few, if any, of the layers and lenses within the Holly Creek Formation can be traced for distances much greater than a few miles. During the field season of 1960, the writer and Peter E. Blau traced a thin, 0.4 to 0.5 foot, asphaltic layer from north of Broken Bow for five miles to the east. This layer may persist farther eastward, but because of the scarcity of exposures, as a result of both the flatness

of the stream valleys and the extensive alluvial cover, farther tracing was not attempted.

In order to determine shore-line trends, gravel orientation studies of the Holly Creek Formation were conducted in the standard manner (Krumbein, 1939). Examination of 1,600 field-oriented cobbles from 16 stations, using the standard technique of reorientation in the laboratory (Krumbein, 1939) resulted in obtaining preferred orientation diagrams of the long axes of the cobbles (Plate 1). Numerous quarries and road cuts within the Holly Creek Formation were examined and combined into sixteen stations which in turn were plotted as composite orientation plots on Plate 1. This combining and compositing was necessary because of the unequal distribution of quarries, gravel pits, and road cuts along the base of both the Holly Creek and Antlers Formations.

Where exposed, the Holly Creek-DeQueen boundary is gradational. There is a pronounced westward thinning and, at each successive outcrop from east to west, the Holly Creek is in contact with a thin (less than one foot) basal limestone bed of the DeQueen. This lowest limestone layer appears to lap onto, grade into and/or interfinger with, the uppermost gravel of the Holly Creek. Thus, going west, each basal limestone layer is stratigraphically higher than the preceding one, resulting in a contact that does not rise, but remains at about the same elevation due to the concomitant thinning of the Holly Creek and overlying DeQueen.

No paleontologic study has been made of the Holly Creek Formation. According to Davis (1960) it is the oldest formation of the Trinity Group cropping out in Oklahoma and is of Early Cretaceous age. According to Imlay (1945) the Holly Creek is equivalent to the Holly Creek of Arkansas, which is equivalent to a part of the Rodessa Formation of Arkansas, Louisiana, and east Texas, and to the basal sand of the north-central Texas Trinity Group. No basal sands are present in the outcrops of the Holly Creek in McCurtain County where it lies with angular unconformity upon the rocks of Paleozoic age.

DeQueen Limestone: In 1918, Miser and Purdue applied the name "DeQueen" to fossiliferous limestone and an equal or greater amount of green clay with gypsum and celestite near the base, for exposures at and near the town of DeQueen, Sevier County, Arkansas.

The DeQueen Limestone was mapped in Oklahoma by May (1950) and by Davis and Fair (1957). It crops out in McCurtain County as a narrow sinuous band ranging in width from several hundred feet to more than one-half mile. The outcrop band is only exposed in road cuts or in a few streams, such as along the Mountain Fork River and Yanubbee, Yashau, and some branches of Lukfata and Boktukla Creeks. These sections are small and incomplete and it is difficult to locate stratigraphically these isolated segments within the DeQueen. Even the large exposed section along the banks of the Mountain Fork is not complete. The best exposure of the DeQueen in McCurtain County is along State Highway 21 from 1.5 to 2 miles north of its intersection with U. S. Highway 70 at Broken Bow. At this locality, and in the area about 500

feet east and west of the highway, the DeQueen Limestone is from 35 to 40 feet thick. The variation in thickness is due to both the irregular surface of the underlying Holly Creek Formation and to slumping of thin (0.3 to 0.5 feet) layers of limestone occurring between beds of clay.

The DeQueen Limestone ranges in thickness from 40 to 45 feet in the eastern part of McCurtain County to less than a foot at the western extremity of its outcrop. Downdip it attains a maximum thickness of 190 feet at the southeastern edge of the county (Davis, 1960).

The general lithology of the DeQueen varies (ascending) from a 0.5 to 1.5 foot limestone conglomerate at its base to overlying layers of varying thicknesses of sandy micrites, sandy argillaceous micrite, sandy argillaceous biomicrudites, and argillaceous and pellitiferous biomicrudites all separated by layers of silty to sandy, varicolored clay (Plate 5). No one layer, except for a 2.5 to 3.0 foot thick unit, 10 feet below the base of the Antlers, is physically and petrographically persistent across the outcrop area. The amount of clay, sand, pellets, and fossils varies both vertically and laterally. Even the exception mentioned above is not completely uniform in petrology. In general, the grain size of the terrigenous material present in each limestone layer tends to decrease upward (Plate 5). The terrigenous material is everywhere present laterally, but there is a slight increase in amount and in size, towards the west. This is perhaps a function of the nearness to shore at the time of deposition.

PLATE 5

Representative photomicrographs of the DeQueen Limestone from exposures along State Highway 21 from 1.5 to 2 miles north of its intersection with U. S. Highway 70 at Broken Bow. Plate 5 depicts the general decrease in size and amount of terrigenous material (ascending) and the increase in fossil and carbonate material in the middle of the exposure trend. The sequence of photomicrographs (ascending) is as follows: A-B-C-D-E (C_1 is an enlargement of C).

A. Coarse sandy micrudite; 12x.

B. Sandy argillaceous micrudite; 12x.

C. Argillaceous and pellitiferous biomicrite; 12x.

C_1. Enlargement of argillaceous and pellitiferous biomicrite showing recrystallization of mollusk shells, replacement by sparry calcite, and presence of scattered pellets; 29x.

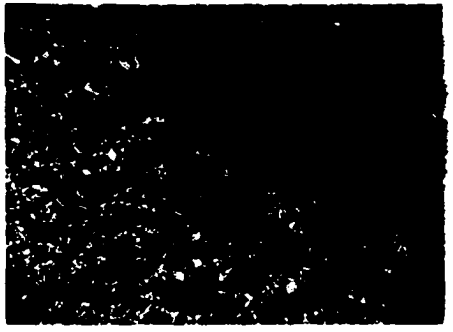
D. Sandy and pellitiferous biomicrudite; 12x.

E. Sparse biomicrudite. All fossil fragments are well-rounded; 12x.

PLATE 5

B

C_1



E

A

C

D

The DeQueen Limestone is of Early Cretaceous age and is the middle formation of the Trinity Group of the Comanche Series in McCurtain County (Davis, 1960). The limestone is fossiliferous, the most common Early Cretaceous fossils, according to May (1950, p. 39), being Cassiope branneri and Ostrea franklini. The DeQueen Limestone is regarded as being equivalent to a part of the Glen Rose Formation of Texas according to Vanderpool (1928), Stanton (1928), Imlay (1945), May (1950), and Davis (1960).

Antlers Sand: Hill (1901), used the term "Antlers sands" for the supposed clastic equivalent of all the Trinity formations north of Parker County, Texas. Adkins (in Sellards et al., 1932) used the name "Antlers sand" when he proposed that the Oklahoma sand was the marginal equivalent of the entire Trinity Group. In a summary of the Stratigraphy of Oklahoma, Gould (1925) stated that the name "Antlers sand" held priority as the name for the Trinity correlative in Oklahoma.

In southern McCurtain County, the Antlers Sand is conformable with the underlying DeQueen Limestone. Where the DeQueen is absent, the Antlers lies unconformably upon the underlying rocks of Paleozoic age. This unconformable relationship extends from R. 23 E. in McCurtain County nearly 200 miles to southern Love County near the Red River (Plate 1). Due to extremely poor exposures in the area where the Antlers conformably overlaps the older rocks of Cretaceous age, it may be that the Holly Creek gravels reappear west of sec. 1, T. 6 S., R. 23 E.; but in this study, all basal gravels or conglomerates west of this point are considered basal Antlers.

The Antlers is conformable to the overlying Goodland (Goodland-Walnut) Limestone. This Antlers-Goodland contact is placed at the base of the lowest bed of sparse biomicrite or biomicrudite (Comanche Peak facies of Blau, 1961) of the Goodland in the eastern portion of the dissertation area. Elsewhere, the contact is located at the base of the lowest "Exogyra shell agglomerate" (Blau, 1961), the sandy biomicrudite Walnut facies of the Goodland Limestone (Plate 6). Both types of the Antlers-Goodland contact are regular and sharp. Some of the best exposures of the Antlers-Exogyra shell agglomerate (Walnut facies) contact are found in the western portion of the area, especially in the SW 1/4 sec. 32, T. 6 S., R. 2 E., (Plate 6), in the SE 1/4 sec. 13, T. 7 S., R. 1 W., and in the NW 1/4 sec. 1, T. 7 S., R. 1 W., all in Love County, and in SE 1/4 sec. 20, T. 5 S., R. 4 W., (Plate 7). At some localities the development of the Exogyra shell agglomerate is so pronounced, especially in sec. 13, that it forms a prominent "bench" that can be traced for several miles. This agglomerate bed is in contact with the Goodland in eastern Love County and is 20 feet below the Goodland at the Red River in Cooke County, Texas. The bench expression was found no farther north than sec. 22, T. 6 S., R. 1 E. (Plate 1).

The sediments, here considered as the Walnut facies of the Fredericksburg Group, between the agglomerate bed and the overlying Goodland Limestone vary from black clay to crossbedded buff sand. In general, these sediments consist predominantly of black to olive clay occurring both as laminae in masses of crossbedded sand and as structureless deposits with laminae of silt and sand (Plate 8). At a few

PLATE 6

A. Exposure of Goodland Limestone and Walnut facies (Exogyra shell agglomerate) conformably overlying the Antlers Sand. Antlers-Goodland contact placed at base of lowest bed of biomicrudite (left side of photo); elsewhere the contact is located at the base of the lowest Exogyra shell agglomerate of the Goodland Limestone (right side of photograph); Antlers-Goodland contact rising to the north. "Bench" expression of the Exogyra shell agglomerate can be seen on the right half of the outcrop. SW1/4 sec. 32, T6S, R2E.

B. Exposure of Goodland Limestone and the Walnut facies overlying the Antlers Sand 18 miles ENE of 10-A, 1.5 miles SE of Madill at junction of State Highway 99 and U.S. Highway 70. Walnut facies shows development of clay and silt between the Exogyra shell agglomerate and the massive portion of the Goodland Limestone (compare with 6-A). Contact rising to northeast; no bench expression found because exposure is in fresh road cut.

PLATE 6

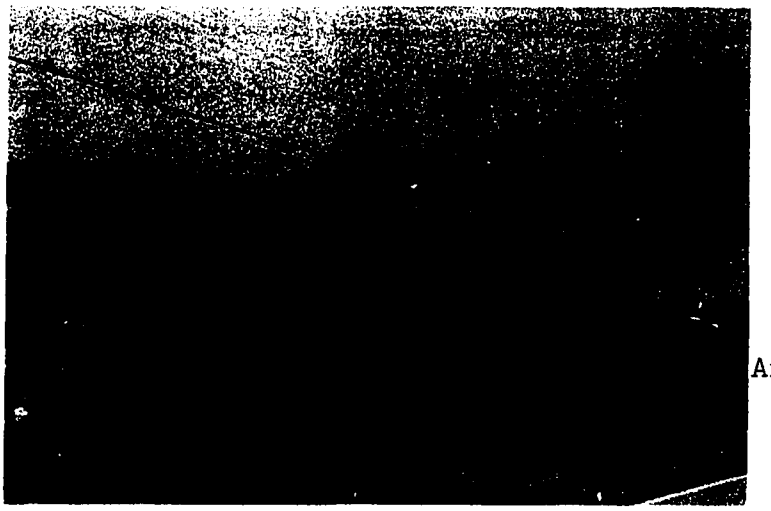
Goodland Ls.

Exogyra aggl.
Antlers Sand

A

Goodland Ls.

Exogyra aggl.



Antlers Sand

B

localities the beds consist of both lithic types intercalated. Some form or expression of this lithology is found everywhere beneath the Goodland, but in the eastern portion of the area the Exogyra shell agglomerate either does not crop out or is not separated from the overlying Goodland.

The base of the Antlers, except in the Baum limestone-facies area, is characterized by the presence of unindurated gravel or conglomerate, which is locally carbonate-, clay-, or silica-cemented. Conglomerates in the western portion are siliceous whereas those in the eastern portion of the area locally contain clay-carbonate cement. Locally, arkosic limestones are found in the Baum area. In general, the gravels and conglomerates decrease in thickness and in grade-size towards the west. One notable exception to this fact is found in the N 1/2 sec. 24, T. 6 S., R. 2 E., Love County, where the basal conglomerate consists of clay- to boulder-size material. In the eastern portion the basal conglomerates consist of material similar to the previously described Holly Creek gravel. There is also an increase in the amount of vein quartz or quartzite pebbles in the vicinity of Antlers in Pushmataha County and in Bruno in Atoka County.

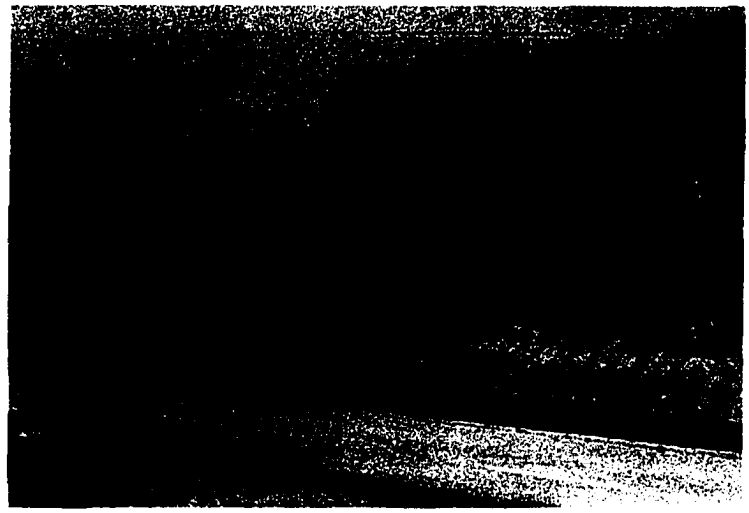
West of these villages, the percentage of chert varies, but there is a general increase, with a corresponding decrease in grade-size. The majority of fragments are sub-angular to sub-rounded and persist westward, interrupted only in the area around Tishomingo and in the area where the Baum lies directly upon rocks of Paleozoic age.

PLATE 7

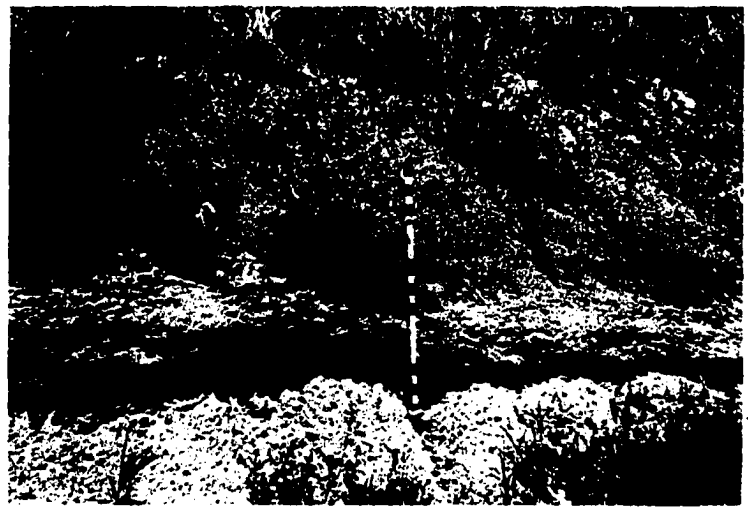
A. Exposure of Goodland Limestone-Walnut facies-*Exogyra* shell agglomerate sequence overlying the Antlers Sand. SE1/4 Sec. 20, T5S, R4E. Clay facies between Goodland Limestone and *Exogyra* shell agglomerate is at its maximum development along the exposure trend.

B. Close-up view of *Exogyra* shell agglomerate-Antlers Sand contact, located by arrow in 7-A. Black units on Jacob's Staff = 0.2 feet.

PLATE 7


Exogyra aggl.
Antlers Sand
Goodland Ls.
Covered slope
Walnut facies

A


Exogyra aggl.
Antlers Sand

B

PLATE 8

A. Where the Exogyra shell agglomerate is not exposed, a fine white clean kaolinite-rich sand is found. The resistance of the normally poorly-consolidated sand is due to locally restricted carbonate cementation.
SW1/4, SW1/4, SW1/4, Sec. 22, T6S, R1E.

B. Typical exposure of Exogyra shell agglomerate; black unit on staff = 0.2 feet.
SW1/4, SW1/4, SW1/4, Sec. 36, T6S, R1W.

PLATE 8

A

B

The Baum has a local conglomeratic facies consisting of rubble of cobble and pebble size.

In the area around Lone Grove, Carter County, the conglomerate is locally of pebble- to cobble-size. In the area south and southwest of Wilson, and south and southeast of Reck, Love County, the conglomerates are of two grade-sizes. One, near Reck, consists of coarse sands, "shale" fragments, and limestone, mainly of granule size, locally siliceous. The "shale" fragments are weathered and soft, and are composed entirely of kaolinite. The other conglomerates occur only locally, are essentially of the same composition, but normally consist of carbonate-cemented material of pebble size.

In order to determine the shoreline trends during the deposition of the Antlers, gravel orientation studies were conducted in the standard manner (Krumbein, 1939). Examination of 1,100 field-oriented pebbles, cobbles, and boulders representing 11 stations from 6 localities (Plate 1), using the standard technique of reorientation in the laboratory (Krumbein, 1939), resulted in obtaining the gravel orientation trends which are plotted on Plate 1. These plots are parallel to the shoreline at the time of deposition of that respective portion of the Antlers.

The Antlers Sand, in McCurtain County, ranges in thickness from a few feet at the north edge of its outcrop to more than 880 feet in subsurface (Davis, 1960). Towards the west, the Antlers thins to around 500 feet in eastern Choctaw County, 300 feet in western Choctaw County, and 200 feet along the southern Atoka-northern Bryan County

line. West of the central portion of Bryan County, the thickness varies reflecting the subsurface structure present in the Marshall-eastern Carter-eastern Love County area. In western Love County, the thickness of the unit ranges from a feather edge to 300-400 feet.

The lithology of the Antlers is variable. With the exception of the upper 40 to 50 feet of the formation, every outcrop encountered is characterized by a minimum of two or three types of lithology, none of which seem to persist for more than a mile. The sediments that crop out in the area of study are composed of very fine- to coarse-grained, moderately to poorly sorted, unindurated to clayey to locally carbonate-cemented, irregularly crossbedded, ferruginous sand (Plate 9). They are locally intercalated with clays and gravel lenses. The sands are varicolored and are composed almost entirely of compact quartz sand with accessory zircon, tourmaline, rutile, pyrite, leucoxene, and magnetite. At some localities there are flood amounts of leucoxene, at others, the sands are virtually devoid of heavy minerals.

The upper portion of the formation is characterized by the predominance of white to light-yellow compact quartz sand with little crossbedding. No gravel lenses were noted in the upper 50 feet of the sands which are commonly very fine to fine in size and associated with laminae of clay and/or clay fragments. In almost every case, the clays associated with these upper sands are monomineralic and consist either entirely, or dominantly, of kaolinite. Localized occurrences of asphaltic sand are found throughout the area, the largest single

PLATE 9

A. Typical exposures of Antlers Sand with irregular lenses of clay, ironstone layers, and concretions. SE1/4, SW1/4, SW1/4, Sec. 22, T6S, R2E.

B. Exposure of Antlers Sand containing typical development of laminated sand lenses; black unit on Jacob's Staff = 0.2 feet. Same locality as 9-A.

PLATE 9

A

B

occurrence is in the SE 1/4 sec. 22, T. 6 S., R. 21 E., north of Valliant, McCurtain County.

The Antlers Sand is Early Cretaceous in age and is the uppermost formation of the Trinity Group in McCurtain County (Davis, 1960; Imlay, 1940). West of McCurtain County, its age has been placed by Forgotson (1957) in the uppermost Trinity and/or lowermost Fredericksburg.

CLAY-MINERAL ZONATION OF THE TRINITY GROUP

Clay-Mineral Suites

Mineralogic identification of the clay-mineral content of clays, sands, conglomerates, and insoluble residues of limestones from the Trinity Group was determined by means of x-ray diffraction and differential thermal analysis. The clay-mineral content of each lithology change encountered was extracted, identified, and plotted (Plate 2).

The Holly Creek Formation, composed of gravels interbedded with fine sands, silt, and clay, has a clay suite consisting of predominately mixed-layer illite-montmorillonite with lesser amounts of kaolinite and illite and trace to minor amounts of chlorite.

The DeQueen Limestone, consisting of argillaceous and pellitiferous sparse biomicrudites and biomicrites interbedded with varicolored silty clays, silt, and very fine sands has a clay suite identical to the Holly Creek Formation.

The Antlers Sand, consisting of silty to sandy clays, fine- to coarse-grained, loosely consolidated orthoquartzites, with argillaceous cement, and local gravels and conglomerates contain various clay-mineral suites. Mixed-layer illite-montmorillonite pre-

dominates in the basal and eastern portions of its exposure trend, followed higher stratigraphically and farther west geographically by a transition zone containing more illite and kaolinite and trace amounts of chlorite. This suite is succeeded by a zone of montmorillonite, illite, and kaolinite with minor amounts of chlorite. Next, a suite stratigraphically higher and located in the western portion of the exposure trend consisting predominantly of montmorillonite. The final suite is at the top of the Trinity Group and consists predominantly of kaolinite with minor to trace amounts of illite and sometimes montmorillonite.

The clay minerals of each change in lithology encountered in the sediments of the Trinity Group were extracted and identified in order to determine the influence of lithology, sorting and sedimentary environment. Because no variation was encountered in the numerous lithologies of the Holly Creek, DeQueen and Antlers Formations, it was concluded that (1) there are no recognizable clay mineral-lithology relationships within the Trinity Group, (2) size sorting or alteration in different sedimentary environments were not important processes during the deposition of the clay minerals of the Trinity Group, and that (3) the areal distribution of the clay minerals is related to their paleogeographic position in the original basin of deposition and reflects variations in contributions from various source areas.

Clay-Mineral Zonation

The clay-mineral suites of the Antlers, DeQueen, and Holly Creek Formations were grouped into four major clay-mineral zones (Figure 6): (1) a mixed-layer zone consisting of the clay-mineral suite of the Holly Creek and DeQueen Formations and the basal clay-mineral suite of the Antlers Sand, (2) a transition zone lying upon the mixed-layer zone and consisting of the clay-mineral suite of the middle of the Antlers, (3) a montmorillonite zone lying above the transition zone and consisting of the upper Antlers clay-mineral suite, and (4) a kaolinite zone consisting of the clay-mineral suite of the uppermost Trinity Group. The kaolinite zone lies discordantly upon the lower three clay-mineral zones (Plate 2).

It is important to note that this uppermost (kaolinitic) zone lies discordantly upon the lower three clay-mineral zones. The lower clay-mineral zones are not gradational facies of one another but are in stratigraphic sequence. The lowest (mixed-layer) zone is everywhere found beneath the middle (montmorillonite-illite-kaolinite) zone and this middle zone, in turn, lies beneath the upper (montmorillonitic) zone. The uppermost kaolinitic zone lies in contact with each subjacent zone. In the eastern portion of the area the kaolinitic zone is in contact with the mixed-layer zone, in the central portion it lies above the transition (montmorillonite-illite-kaolinite) zone. This stratigraphic sequence is illustrated in a series of cross sections (Plate 2).

Depositional History

Published reviews of recent American literature on clay mineralogy and clay petrology of sediments (Grim, 1953, Weaver, 1959, 1960) indicate that in the nearshore site of active sedimentation there is a good relation between the geographic distribution of the clay-mineral suites of Recent shallow marine muds and source areas (Table 1). The listing of examples in Table 1 indicates that the bulk character of the marine clay suite is determined by the source material and that even the character of the dominant clay-mineral is apparently controlled by the detrital clay material derived from the land areas. These same reviews indicate that the majority of the clay minerals are not altered to any extent in a marine environment. Table 2 contains chemical data of some Recent clay fractions which indicate how relatively small the chemical modifications are between the inland or near continental (Chesapeake Bay), the nearshore, and the open marine clays. Most of this alteration is in the form of cation adsorption with little evidence of alteration of the basic lattice of the detrital clay mineral. As a result of the preceding observations, it has been assumed that the clay minerals are (1) primarily detrital in origin, (2) reflect the composition of the source area, and (3) reflect variations in contributions from various source areas.

During the early phases of deposition of the Trinity Group, the Ouachita Mountain area was the dominant feature of the sediment-source area (Pitt, 1956). In McCurtain County a considerable amount

TABLE 1. - RELATION BETWEEN CLAY MINERALS IN RECENT MARINE MUDS AND SOURCE MATERIAL (after Weaver, 1959)

Locality	Dominant Clay Mineral		
	Recent Marine Muds	Clay Detritus Carried by Rivers	Source Material
Eastern Atlantic Coast	Illite[1,2]	Illite[1,3]	Illite[1,3,10]
Eastern Gulf Coast	Montmorillonite[1,4,5]	Montmorillonite[1,4,5]	Montmorillonite[5,6]
Western Gulf Coast	Montmorillonite[7]	Montmorillonite[7]	Montmorillonite[8,10]
Southern California Coast	Montmorillonite - Illite-Kaolinite[9]	Montmorillonite - Illite-Kaolinite[9]	Montmorillonite - Illite-Kaolinite[10]

[1] Powers (1954, 1957).
[2] Murray and Sayyab (1955).
[3] Weaver (1958b).
[4] Grim and Johns (1954a, 1955, 1956).
[5] Milne and Earley (1958).
[6] Ross, Miser and Stephenson (1929).
[7] Grim and Johns (1954).
[8] Kunze (personal communication).
[9] Grim, Dietz and Bradley (1949).
[10] Weaver (1959).

TABLE 2. - DIFFERENCES IN CHEMICAL COMPOSITION BETWEEN SHOREWARD AND SEAWARD CLAYS (after Weaver, 1959)

	MgO				K_2O				Al_2O_3			Fe_2O_3		
	1	2	3	4	1	2	3	4	2	3	4	2	3	4
Shoreward	2.02	2.45	2.90	3.38	0.84	1.51	2.36	2.52	18.05	22.62	22.31	6.35	8.79	6.70
Seaward	9.04	3.37	4.16	2.11	0.84	2.36	2.51	3.43	19.02	18.14	19.98	7.07	9.89	5.56

		Shoreward	Seaward
1. Chesapeake Bay	Powers (1957)	Salinity 1 part/thousand	22-25 parts/thousand
2. W. Gulf of Mexico	Grim and Johns (1954)	Delta	Open Gulf
3. Pacific Ocean	Grim, Dietz and Bradley (1949)	Bay	13 abyssal, slope, and canyon samples
4. Gulf of California	Grim, Dietz and Bradley (1949)	River	Lower Gulf of California

of truncation of the Ouachita Mountains has occurred, removing several thousand feet of Mississippian Jackfork Sandstone and even exposing the Cambrian core of this complex (Pitt, 1956). The denuding of thousands of feet of Jackfork Sandstone from the Ouachitas would seem to have yielded adequate amounts of quartz sand for the Trinity Group clastics.

The clay suite of the Holly Creek, DeQueen and Antlers Formations of McCurtain County is mainly mixed-layer illite-montmorillonite and kaolinite along with smaller amounts of chlorite. The predominance of mixed-layer minerals with some kaolinite and chlorite reflects both the type of clay being supplied by the Ouachita sediments and the degree of weathering in the source area during the deposition of the lower Trinity Group.

After deposition of the lower portion of the Trinity Group in the McCurtain County area, the Lower Cretaceous shoreline or near-shore site of active sedimentation advanced north and northwestward as the Ouachitas became less dominant as a positive area by continued and extensive denudation.

This can be supported by (1) the presence of basal Cretaceous gravels on some of the higher levels of the Ouachita Mountains (L. M. Cline, personal communication), (2) the feasibility of the projection of present (less than 1° dip) datum planes of the Lower Cretaceous to the tops of the higher mountain peaks and above many of the others (Pitt, personal communication; Melton and McGuigan, 1928), (3) the progressive onlapping of the Trinity clastics upon the under-

lying DeQueen and Holly Creek sediments in a westward and northwestward direction, (4) the shoreline during the time of deposition of the Holly Creek trended in an east-northeast by west-southwest direction whereas in the younger Antlers west of the outcropping Holly Creek the shoreline trended in a northeast by southwest direction (Plate 1). The positive Ouachita salient appeared to act as a buttress or node to the northwestwardly advancing shoreline causing a slight clockwise rotation of the shoreline trend during deposition of the Holly Creek. As the Ouachita Mountain salient was reduced in effectiveness as a positive area the shoreline was no longer effected by a high or positive area and was not refracted to any great degree as indicated by the northeast-southwest trend west of McCurtain County (Plate 1), and (5) the clay-mineral suite that is presumed to be derived from the Ouachita Mountain source area and is dominant in McCurtain County becomes gradually less abundant to the west reflecting the decreasing influence of the Ouachita Mountain core area of McCurtain County by erosion and denudation or by partial burial in its own detritus.

The site of active sedimentation shifted to the west with the northwestward advancing shoreline which was still trending northeast-southwest near Antlers. The clay suite deposited was influenced by the type of clay locally available from the now less positive western portion of the Ouachita Mountain province, from some reworking of the eastern clay-mineral suite brought westward possibly by longshore drifting, and from the sediments from the McAlester Basin area. These

factors combined to form a transitional zone which is less a mixed-layer and more an illitic, montmorillonitic, and kaolinitic clay-mineral suite. Farther west near the Pushmataha-Atoka County line the shoreline continued to have a northeast-southwest trend and the clay suite became less transitional as the McAlester Basin sediments, rich in illite, kaolinite, and montmorillonite, became the more dominant source area. Also during this period of sedimentation chlorite, in trace to minor amounts, perhaps derived from the Stanley and Atoka Formations of the Ouachita Mountains was being deposited along with the McAlester Basin and Arbuckle Mountain sediments. The chlorite was probably being supplied from the Ouachitas in larger amounts than is evident in the surface samples. This effect is due to the masking and diluting effects of the clay suite derived from the more dominant source areas.

Active sedimentation of the Trinity Group continued to shift northwestward, and as far west as Lane, Atoka County the shoreline maintained its northeast-southwest trend. When active sedimentation reached the area near Bruno and Atoka in Atoka County both a salient or positive area and a wide low area west of Atoka was encountered. The combined effects of the extreme western portion of the Ouachitas plus the presence of the relatively lower southern portion of the McAlester Basin resulted in a slight shift of the shoreline trend in a clockwise direction as evidenced in gravel orientation plots (Plate 1). The clay suite of this central portion of the exposure trend was influenced more by the McAlester Basin and Arbuckle Mountain source area

than by the Ouachitas to the east. The basal sediments in this area contain some mixed-layer illite-montmorillonite and chlorite indicative of both Ouachita Mountain and McAlester Basin sediments. The middle portion is predominantly a mixture of montmorillonite, illite and kaolinite. The upper Trinity Group (those sediments high in elevation and apparently high in stratigraphic sequence) is characterized by a similar, but highly and even dominantly montmorillonitic, suite. This clay suite was no doubt derived from both the McAlester Basin and Arbuckle Mountain sediments, especially the richly montmorillonitic Pennsylvanian Vanoss Formation, and the Permian sediments to the west.

From Atoka County to the west edge of the exposure trend the clay suite is essentially similar to that encountered in Atoka County except that montmorillonite becomes increasingly dominant towards the west. The clay suite in this western portion was influenced more by the Arbuckle Mountain-Ardmore Basin and Red Bed Plains (undifferentiated Permian strata) sediments than by any source to the east. The Arbuckle Mountain-Ardmore Basin positive area caused the shoreline trend to regain its northeast-southwest trend. As the shoreline continued advancing northwestward this source area supplied major amounts of montmorillonite especially in the Tishomingo, Baum, and Madill areas (Plate 1), as well as illite (for example from the Ordovician Sylvan Formation) and minor amounts of kaolinite and chlorite.

As the shoreline continued its northwest advance the Criner Hills and Ardmore Basin sediments contributed dominantly mixed-layer

illite-montmorillonite and illite to the lowest or basal Trinity Group sediments in some amounts, particularly in the Lone Grove and Ardmore areas of Carter County (Plate 1). Once again after encountering the Criner Hills area of the Ardmore Basin the shoreline trend was rotated slightly clockwise (from N40E-S40W to N55E-S55W). The bulk of the clastics in the west contain montmorillonite, illite, and kaolinite with montmorillonite so dominant that the clay suite consisted entirely of montmorillonite in much of the western area.

Eventually the site of active sedimentation reached the area of what is now the western and northwestern most extent of the present day Trinity Group exposure trend. The dominant source area at this time was the Red Bed Plains consisting predominantly of Permian strata — about 4,000 feet of essentially flat-lying red and gray shale, mudstone, siltstone, sandstone, and extensive evaporites. The results of clay-mineral analyses of 45 four-inch cores and numerous outcrop samples enabled Mankin, Bellis and Kerns (1963) to subdivide these Permian strata into two mineralogic units; a lower unit characterized by illite and an upper unit whose clay suite consisted of large amounts of montmorillonite. Apparently enough montmorillonite was contributed by the Permian sediments to the site of deposition of the Trinity Group that even the basal beds, usually high in reworked and weathered material characterized by a predominance of mixed-layer illite-montmorillonite to the east, here consisted entirely of montmorillonite in much of the northwest portion of the exposure trend. Finally, the active site of sedimentation, no longer having any prominent salient or positive area

in its path extended northwest up the broad low-lying freeway of the Red Bed Plains. The last measured orientation plots indicate that the trends of the shoreline shifted from N40E-S40W in Section 26, T4S, R2E (3 miles east of Ardmore) to N50E-S50W in Section 2, T5S, R3W (20 miles west of Ardmore (Plate 1).

The final clay-mineral suite encountered was a kaolinite-rich suite occurring at the top of the Trinity Group, associated with clean white fine sand. In all cases where the Exogyra shell agglomerate was encountered the kaolinite zone was beneath this Walnut facies. Where the agglomerate bed was missing due to erosion or nondeposition the kaolinite zone was beneath the Goodland Limestone and enriched in minor amounts of illite and at places montmorillonite. An examination of this fine white sand at many outcrops revealed that this facies is highly porous and permeable. It is reasonable that kaolinite was present in the sand prior to removal of the overlying protective covering of the Walnut facies and/or the Goodland Limestone. After exposure, ground water could have leached most of the minerals and aided, along with the permeability of the sand body, in the formation of authigenic kaolinite. Another alternative process is the transportation of kaolinite or longshore drifting of clay from either the more kaolinitic eastern Gulf Coastal province or the Wichita Mountains west of study area, or both. In view of the fact that other areas within the Trinity Group exposure trend have been exposed to similar leaching and alteration and no extensive kaolinite-rich clay suites have been found elsewhere, it is felt that the major influence was longshore current

action and drifting from the eastern and western source areas. Recent studies of the Gulf of Mexico sediments have shown that longshore currents are capable of transporting clays and sands hundreds of miles (Grim and Johns, 1954).

SUMMARY

The sediments of the Trinity Group of southern Oklahoma are heterogeneous over a wide area. They represent shelf deposits laid down by a northwestward transgressing sea on the northwestern side of the Cretaceous Gulf of Mexico. The sediments strike northeastward and dip east-southeastward at less than 50 feet per mile. Field and laboratory examinations show that lithology and chemical character of the sediments vary widely both laterally and vertically. The Trinity rock units consist of poorly indurated clays, fine to coarse sands, and conglomerates, and locally marl and limestone. Approximately 95 percent of the 200-mile exposure trend is the Antlers Formation which contains no persistent marker units or diagnostic fossils.

Selected samples were analyzed using standard techniques of sieving and heavy-mineral analysis. The results yielded inconclusive correlative information. Generally, correlative data were unobtainable because (1) the majority of the sediments in the area of study are not sufficiently lithified to resist erosion and thereby provided no traceable units across the area, (2) the low (0.5-0.75°) dip of the sediments prevents exposure of basal, middle, and upper portions of the rock unit at every north-south traverse, and (3) a stable consistent

suite of heavy minerals was encountered which was not diagnostic for subdivision of the Trinity Group sediments.

Mineralogic identification of the clay-mineral content of clays, sands, conglomerates, and insoluble residues of limestones from the Trinity Group was determined by means of x-ray diffraction and differential thermal analysis. The clay-mineral content of each lithology change encountered was extracted, identified, and plotted in order to determine the influence of lithology, sorting and sedimentary environment. Because no variation was encountered in the numerous lithologies of the Holly Creek, DeQueen and Antlers Formations, it was concluded that (1) there are no recognizable clay mineral-lithology relationships within the Trinity Group, (2) size sorting or alteration in different sedimentary environments were not important processes during the deposition of the clay minerals of the Trinity Group, and that (3) the areal distribution of the clay minerals is related to their paleogeographic position in the original basin of deposition and reflects variations in contributions from various source areas.

Clay mineral analyses of 600 Trinity samples indicate four major mineral zones: a lower, mixed-layer illite-montmorillonite zone derived from the Ouachita Mountains; a middle montmorillonite-illite-kaolinite zone derived from the Ouachita and Arbuckle Mountains and the McAlester Basin; and an upper montmorillonite zone derived from the Anadarko Basin. Discordantly overlying the lower three zones is an uppermost kaolinite-rich zone possibly derived from the Appalachian and Wichita Mountains.

Interpretation of clay-mineral assemblage, provenance clay petrology, and gravel orientation studies indicate: (1) the site of active sedimentation of the Trinity Group transgressed northwestward with a northwestward sea advance, (2) the rocks of the Trinity Group become younger toward the northwest by successive onlap, (3) the general shoreline trend during deposition of the Trinity Group was southwest-northeast, not east-west as generally considered, and that (4) clay-mineral assemblages can provide effective and reliable zonations, and, in conjunction with other studies the assemblages can be used reliably to help correlate and interpret the depositional history of a section even where sediments contain no persistent units and only poorly preserved or nondiagnostic fossils.

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APPENDIX

CLAY MINERALOGY

Mineralogic identification of the clay-mineral content of more than 600 samples of clays, sands, gravels, conglomerates, and insoluble residues of limestones from the Trinity Group was determined by means of x-ray diffraction and differential thermal analysis.

Slight variations of the standard preparation techniques were employed before studying the clay mineralogy of such diversified material. The clay samples offered no difficulties other than the flocculation of some samples. Some of the sands that were strongly indurated were first crushed to granule-size fragments before further treatment was attempted. Unindurated gravel samples were wet-sieved using distilled water, and the less than 4 ϕ fraction collected for further treatment. The indurated gravels or conglomerates were crushed only enough to expose the matrix, and the individual "shale" or clay fragments present were then separated from the matrix. Clay fragments were commonly found interbedded with clay-cemented, crossbedded, and lenticular sands. These fragments were separated from the enclosing sands, split apart with a knife, and the center portion was collected and identified. This was done in order to compare the mineralogy of the clay fragment with the mineralogy of the clay cement surrounding the sand grains. The insoluble residues of the limestones were obtain- using standard laboratory procedures.

Following these preliminary treatments, all material to be studied, regardless of character, was subjected to the same standard preparation for x-ray diffraction analysis. The clay minerals were separated from all samples by dispersing the clay fraction in a beaker of distilled water with the aid of an Ultrasonic transducer-tank. Flocculated samples were washed with distilled water until complete dispersion was obtained. The dispersed less-than 8 ϕ material was sedimented upon glass slides. This allowed the clay particles to orient with their "c" crystallographic axes perpendicular to the glass slide and thus enhanced the 00ℓ reflections. The clay-water mixture was then dried in an oven at 68° to 70° C.

The dried slides were then mounted in a wide-angle North American Phillips (Norelco) x-ray diffraction goniometer with Krypton proportional counter and exposed to nickel-filtered Cu Kα radiation at 35 KV and 18 MA using a 1° slit system. The scanning speed of the goniometer was 1° 2θ per minute and rate-meter settings were varied according to the diffraction intensity. The patterns were run at a chart speed of one-half inch per minute on a Brown recording unit. Some slides were run on a Siemens-Holske horizontal x-ray diffraction goniometer using Cu Kα radiation generated by a Siemens 5 KVA constant potential unit.

Subsequent to initial x-ray analysis the slide containing the oriented clay material was then subjected to one, or several, of the following additional treatments prior to being x-rayed again: (1) the slide was placed in an ethylene glycol vapor bath (68°-72° C) for a

minimum of 4 and as much as 25 hours, (2) the slide was heated to 270° C for 1 hours, (3) the slide was heated to 300° C for 1 hours, (4) the heat-treated samples were placed in an ethylene glycol vapor bath, and (5) if the presence of kaolinite was suspected, the sample was sedimented on a porcelain slide, x-rayed, then heated to 550° C for a minimum of 0.5 hours and then x-rayed again (Figure 2).

Some samples of clay-size material were dried and ground with an agate mortar and pestle to about 80 mesh. A portion of each of these samples was subjected to differential thermal analysis using a Robert L. Stone Model DTA-13M furnace and recorder. Each sample was heated from room temperature to 1000° C at the rate of about 10° C per minute. An Inconel sample holder was used with alpha Alumina as the standard. Nitrogen was commonly employed as the purging medium, but in several instances, helium was used.

Another portion of each of these ground samples was used to prepare slides with random crystallographic orientation of the clay minerals. The slide was prepared either by packing into an aluminum sample holder or sifted through an 80-mesh sieve upon a vaseline-coated glass slide.

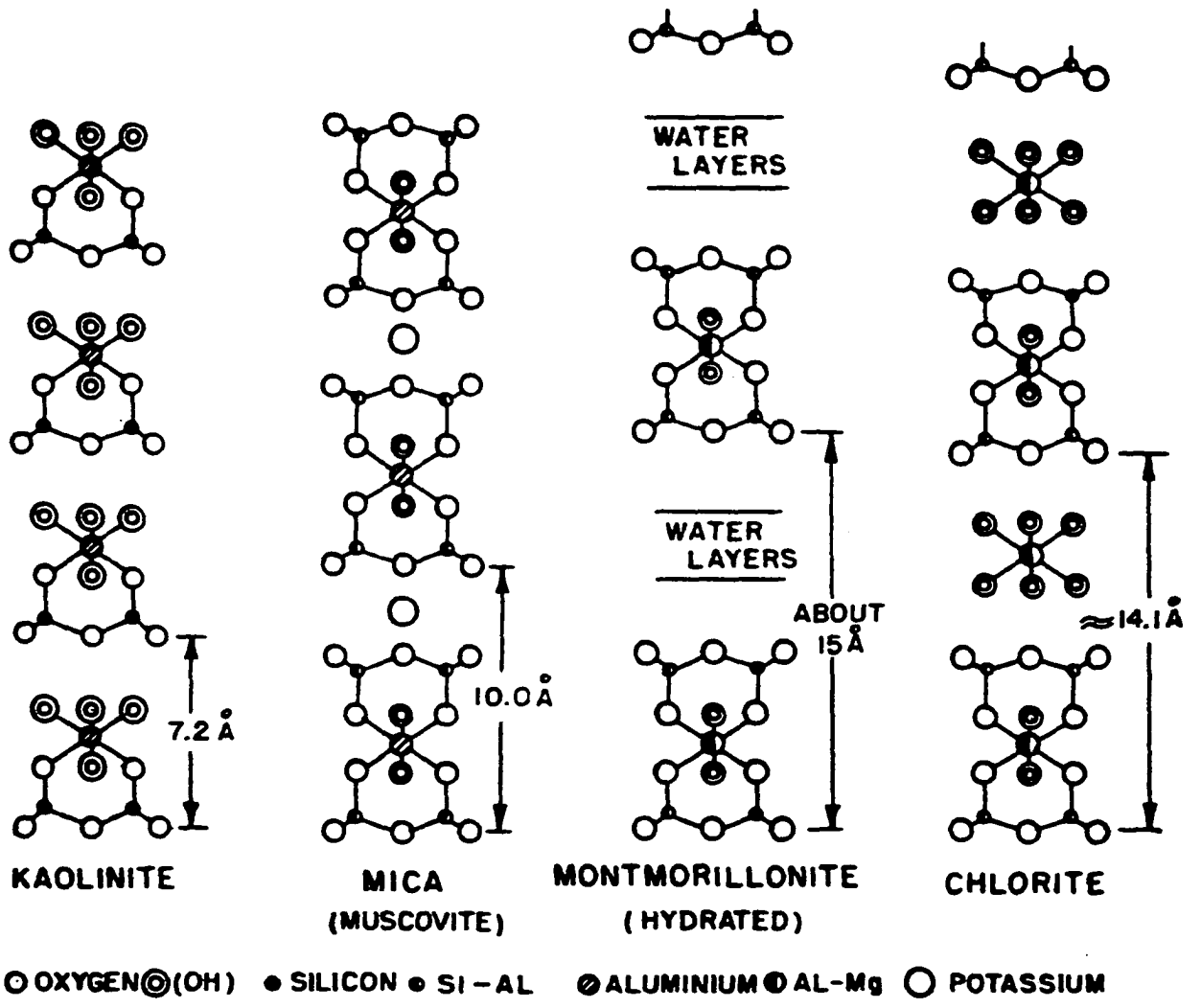
By a combination of these techniques, the main clay-mineral groups found to be present in the Trinity Group were montmorillonite, kaolinite, chlorite, illite, and mixed-layer clays (Figure 4).

Identification of Clay Minerals

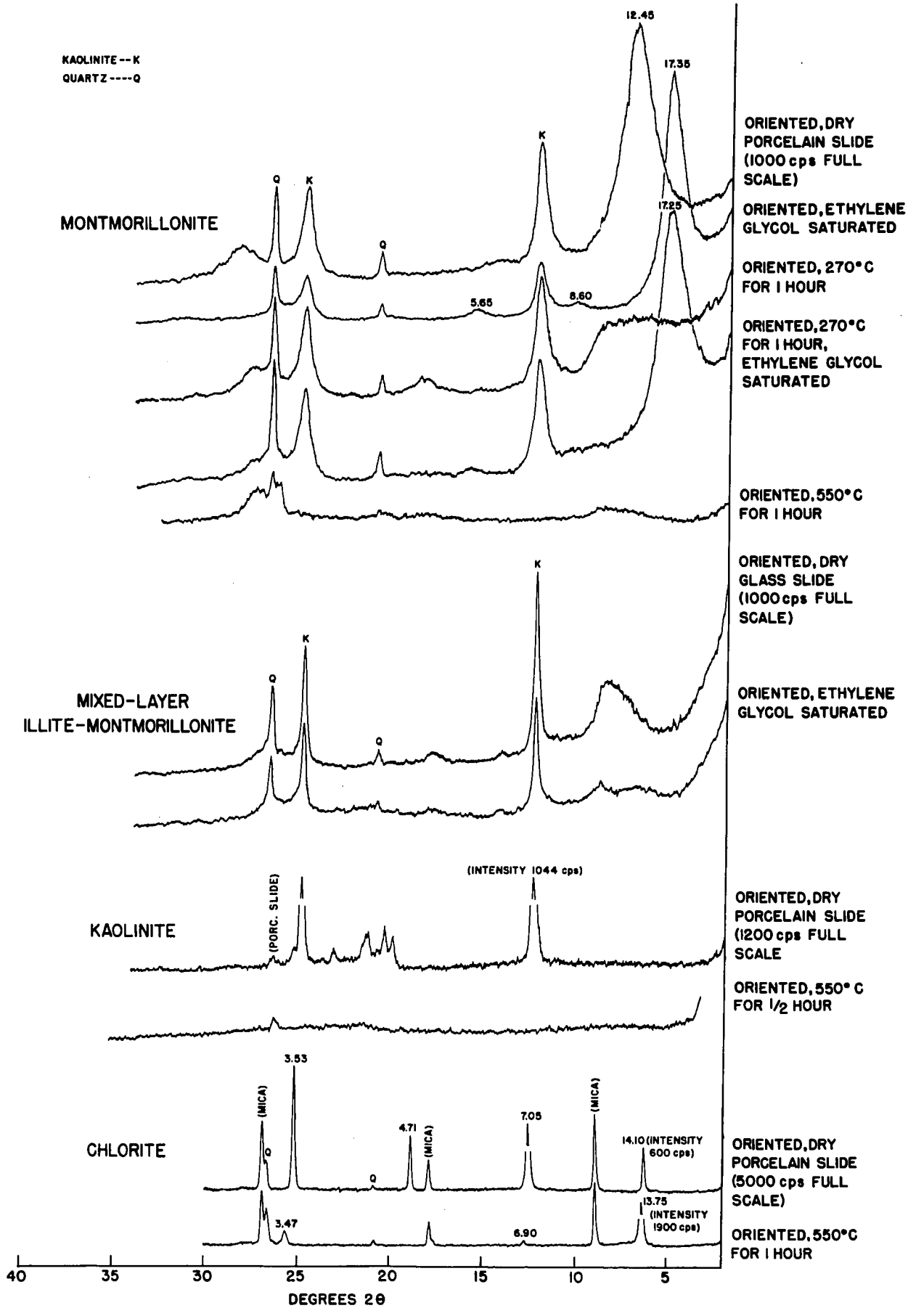
Montmorillonite: The term montmorillonite is used in this study as a group term for those three-layer clay minerals (Figure 3) which swell to approximately 17 Å after being subjected to an ethylene glycol-saturated atmosphere at 70° C for 1 hour (Bradley, 1945). The montmorillonite lattice will collapse from 12-15 Å if heated at 270° C for about 1 hour. This is shown by a decrease in both the intensity and spacing of the (001) reflection (Figure 4). In this study, almost every sample that swelled to 17 Å upon glycolation was originally 15.2-15.4 Å material. Mering in 1946 (Brown, 1961, p. 172) found that Ca-montmorillonite in later stages of hydration gives a 15.4 Å spacing which corresponds to the interlamellar water being arranged in two sheets of water molecules. With Na-montmorillonite, stationary spacings are not obtained, and the basal reflection tends to be diffuse at moderate humidities. Other than recognizing the dominance of montmorillonites with exchangeable divalent cations (predominantly Ca^{++}) and the presence of nontronite-like montmorillonite (Figure 5), no attempt was made to analyze the clays chemically in order to distinguish between individual minerals of the montmorillonite group.

Thermograms of montmorillonite subjected to differential thermal analysis are shown in Figure 5. These thermograms show three endothermic regions and an exothermic region. The first endotherm is typically in the form of a broad doublet or an asymmetrical single peak in the range from 100°-300° C. According to Kerr et al. (1951), in

FIGURE 3



DIAGRAMMATIC REPRESENTATION OF THE SUCCESSION OF LAYERS IN SOME LAYER LATTICE SILICATES

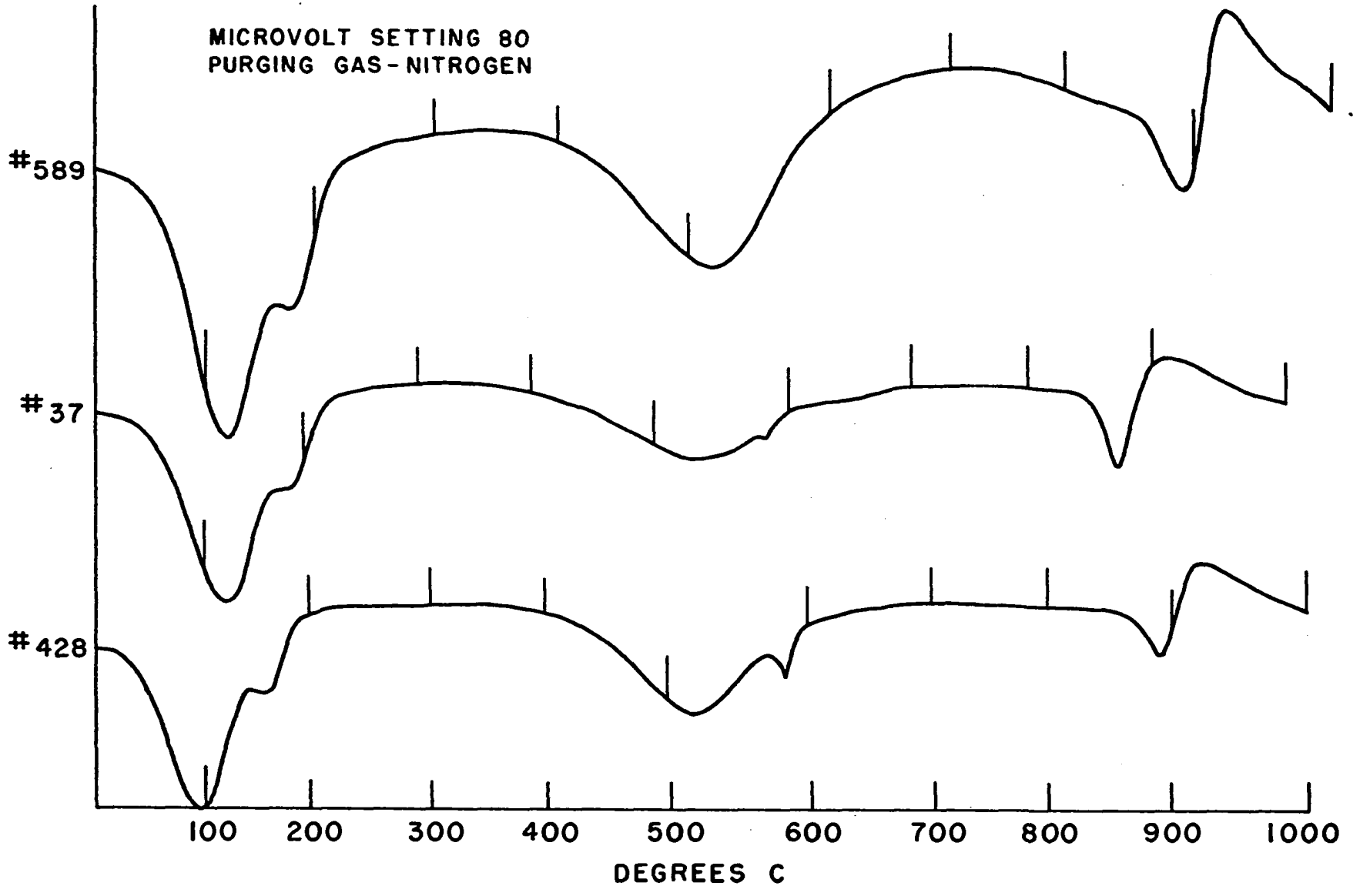


X-RAY DIFFRACTION PATTERNS
OF SELECTED MINERALS
FIGURE 4

the low humidity of the laboratory a doublet is characteristic of divalent interlayer ions rather than univalent ions such as sodium. The endotherm in the 100°-300° C range represents dehydration of sorbed water; the interlayer cations determine its shape. Montmorillonites with Li^+, Ba^{++}, Sr^{++}, Mg^{++}, or Ca^{++} as an exchangeable cation give a double endotherm in this range and montmorillonites with Cs^+, K^+, or Na^+ as exchangeable cations give a single peak in this range (Hendricks et al., 1940). In this same range, the amplitude of the peak or peaks is dependent on the humidity in which the specimens have been maintained prior to heating.

A second endothermic region, which represents decomposition due to the loss of the hydroxyl groups in the form of water, occurs in the 500°-800° C range (Kerr et al., 1951). The decomposition reaches a maximum for montmorillonite at about 700° C (Figure 5), but it varies with amount and type of substitution. In nontronite, the decomposition temperature range is 100 to 200 degrees lower (500°-600° C) (Figure 5); in hectorite the range is about 100 degrees higher. Kerr et al. (1951) feel that this is related directly to the strength of the chemical bonds with the hydroxyl, that is, it is almost exclusively a function of the octahedral cation-hydroxyl bond. As the concentration of ferric ions in aluminum positions increases, the decomposition temperature seems to decrease.

The third endothermic region ranging from 700° to 900° C (Bradley and Grim, 1951), corresponds to the final breakdown of the montmorillonite lattice and is characteristic of the montmorillonite



REPRESENTATIVE THERMOGRAMS OF NONTRONITE-LIKE MONTMORILLONITE

FIGURE 5

group (Kerr et al., 1951). Bradley and Grim (1951) and Early et al. (1953) think that this high temperature endotherm is due to the absorption of heat accompanying the change from anhydrous montmorillonite to amorphous material. In typical montmorillonite the high temperature range is from 850° to 900° C and is followed by a sharp exothermic peak which varies in temperature and shape. This high temperature endotherm representing destruction of the lattice should be affected by substitution in either the octahedral or the tetrahedral layers. The particle size and the concentration and type of interlayer cations are significant in this temperature range, but to what degree is still undetermined. The exothermic peak occurring after the last endothermic reaction is dependent upon the substitution of Al^{+++} for Si^{+++} in the tetrahedral layer (Bradley and Grim, 1951). Low octahedral Mg^{++} content tends to cause the exothermic reaction to take place immediately; high magnesium and low iron contents raise the temperature of the exothermic peak (Kerr et al., 1951). Low iron content broadens the peak; narrow particle size distribution yields an extremely sharp peak.

Kaolinite: The group name kaolinite is used here for clay minerals which exhibit a regular basal sequence of 7.2-Å, 3.56-Å, and 2.38-Å (001) spacing, plus a collapse to a nondiffracting state after heating to 550°-600° C for one hour (Brindley, 1951, see also Figure 4).

This commonly suffices for the determination of kaolinite as long as no chlorite-kaolinite mixtures are encountered. Difficulties

arise with chlorite-kaolinite mixtures because the basal sequence and collapse temperature of kaolinite are similar to those of many chlorites. However, in the majority of the samples studied, the kaolinite (003) peak at 2.38-Å was more intense than the peak of the same spacing would have been if chlorite were present. Also, in the majority of the samples the splitting of the 3.53-3.60-Å peak was not observed, which indicates that there was not both kaolinite and chlorite present throughout the area. In the majority of samples exhibiting both 14-15- and 7-Å (001) reflections, the 14-15-Å peak collapsed to a nondiffracting state after heating to 270° C for 30 minutes, and the 7-Å reflection collapsed after heating to 550° C for 30 minutes (Figure 4). For the majority of samples, these results ruled out the presence of chlorite and indicated the presence of a mechanical mixture of montmorillonite and kaolinite. A discussion of the identification procedures for samples that contained mixtures of chlorite and kaolinite is found in the section on Chlorite.

Nearly every sample contained some kaolinite; many samples had only trace amounts. When bulk samples were subjected to differential thermal analysis the presence of trace quantities of clay minerals tended to mask or alter the reactions of the dominant clay mineral that was present. It is realized that the clay fraction of the samples studied should be separated into monomineralic fractions before thermal analysis is undertaken. Because of the scope of the study only selected samples were size-fractioned by centrifugation to remove the trace amounts of minerals other than kaolinite; the remaining

samples, when studied, were analyzed in bulk. No attempt was made to determine the structural type of kaolinite.

Illite: Illite is used here as a group term for the clay minerals which contain less potassium and more water than a well-crystallized mica (Figure 3) and which have an integral sequence of basal reflections at approximately 10, 5, and 3.33-Å. Heat treatment to 600° C produces a slight sharpening of the (001 reflection and a decrease in spacing from 10.1-10.5-Å to 10.0-Å. Treatment of samples by exposure to an ethylene glycol atmosphere did not result in expansion of the lattice.

The majority of samples had some representation of illite present, mostly in trace amounts. The illite was extremely fine-sized and persisted in small amounts even when samples were size-fractioned in an attempt to obtain monomineralic fractions of kaolinite and montmorillonite. In a few instances, in and around the area of Hugo, and the bluffs along the Little River, north of Idabel, illite and kaolinite composed the entire clay-mineral assemblage.

In these localities the illite was characterized by a 10-Å reflection with a broad base or shoulder, with broadening toward the low-angle (high d-spacing) side and a steep high-angle side. In none of these instances was there any apparent indication of the presence of clay minerals with an (001) reflection higher than illite (Figure 4). Illites presenting this kind of reflection are known as degraded- or stripped-illite and are the result of the removal or stripping of potassium from the interlayer position in the illite lattice. It has been

thought (Weaver, 1959) that when degraded illite is placed in a potassium-saturated solution it absorbs potassium and reacts as if it reconstitutes as illite. In order to substantiate the presence of degraded illite, several samples were dispersed in a 0.1 N potassium chloride solution and agitated for 4 hours. The excess potassium was removed by dialysis treatment and the samples were then prepared in the standard manner for subsequent x-ray analysis. X-ray diffraction of the treated samples showed reduction of the ragged shoulder or basal broadening on the high d-spacing side; it was concluded that the material was degraded illite.

Because nearly all of the 600 samples analyzed showed illite present in only small to trace amounts no differential thermal analysis of the illite was carried out. As previously stated, illite was present, with the exception of the samples that were dominantly montmorillonite in the western portion of the area, in all samples and in all size-fractions.

Mixed-layer illite-montmorillonite: Clay minerals may be composed of a single mineral species (Grim, 1953), a mechanical mixture of two or more species, or an interstratification (mixed-layer) of two or more species (Pauling, 1930). Weaver (1956) has stated that from an examination of more than 6,000 sedimentary rock samples, ranging in age from Cambrian to Recent, that more than 70 percent of the samples contain some variety of mixed-layer clay. These so-called mixed-layer clays are the consequence of the similarity of the basic

clay mineral lattices consisting of silica tetrahedral layers and octahedral layers of oxygens and hydroxyl groups.

A mixed-layer clay can be a regular or a random interstratified mineral (Weaver, 1956). A regular mixed-layer mineral is such that the stacking along the c-axis is a regular repetition of the different layers; in random (irregular) mixed-layer minerals there is no uniform repetition of layers (Grim, 1953) (Figure 4). The mixed-layer clays of the Trinity Group are random mixed-layer minerals.

As noted in the discussion of other clay minerals, monomineralic clays exhibit a regular (00ℓ) series of x-ray reflections which are integral sequences of the (001) reflection. Random mixed-layer clays do not exhibit an integral sequence of the (00ℓ) series (Weaver, 1956), but rather average values resulting from the simultaneous scattering by both types of layers (Figure 4).

The components of the regular mixed-layer clays are determined by interpretation of the c-axis thicknesses normally after solvation. A mixing of components with c-axis thicknesses of 10 and 17-Å (after solvation) is called an illite-montmorillonite because illite has a c-axis thickness of 10-Å and montmorillonite a c-axis thickness of 17-Å. In random mixed-layer illite-montmorillonite there are no distinctive 17-Å x-ray reflections (Figure 4). The reflections are commonly broad or irregular and fall somewhere between the basal (00ℓ) sequences of each respective mineral at each successive (00ℓ) reflection position. The position of the reflection depends upon the amount of each component present (Brown and MacEwan, 1950). The randomly

interstratified expanded and nonexpanded layers of the Trinity Group mixed-layer illite-montmorillonite occur in all possible ratios.

It should be pointed out that even though mixed-layer clays can form in all possible combinations of different layers (illite-chlorite, chlorite-montmorillonite, etc.) (Weaver, 1956) only mixed-layer illite-montmorillonite was found to be present in the samples chosen for study.

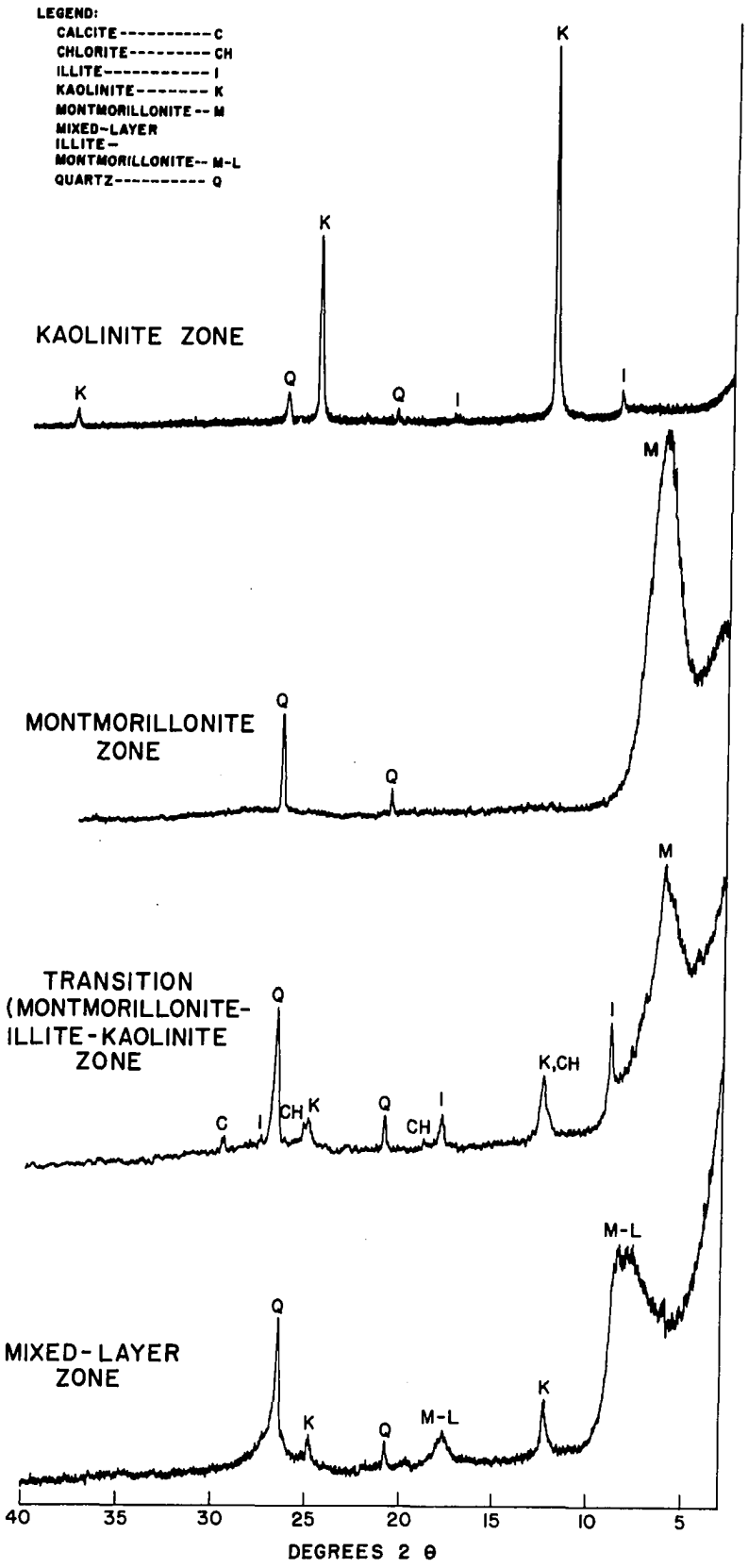
According to Weaver (1956) mixed-layer clays in most cases are derived from some form of degradation or aggradation of pre-existing clay minerals during weathering. It is not known, at the present time, if a mixed-layer clay in a sediment was formed by diagenesis in the basin of deposition, by weathering in the source area, or to what part each method plays by a combination of both factors.

Chlorite: The structure of the chlorite group of clay minerals consists of an alternating series of mica-like layers and brucite-like hydroxide layers (Bindley and Gillery, 1956) (Figure 3). Members or species of the chlorite family have the same type of structure but exceedingly varied isomorphous substitution. Aℓ ions in tetrahedral coordination and divalent Fe ions in octahedral coordination result in species which are difficult to identify by routine x-ray diffraction procedures. The identification of particular species must proceed from a consideration of the precise lattice dimensions and the intensities of reflections or structure factors (Bindley and Gillery, 1956) and, in most cases, by chemical analysis.

Chlorites have a well defined layer structure parallel to (001) (Figure 3). The (00ℓ) reflections based on a periodicity of approximately 14-Å serve for identification. Heating to 550° C for one-half hour results in the loss of all the basal peaks with the exception of the (001). This reflection is at 13.5-13.8-Å and has increased intensity (Warshaw, Rosenberg, and Roy, 1960) (Figure 4). Glycolation (Brunton, 1955) causes no change.

Chlorite is found in the Trinity Group sediments in only minor to trace amounts, is poorly crystalline, and always associated with kaolinite. This mixture caused some difficulty in identification because of similarity of the basal sequence of (00ℓ) reflections; no attempt was made to identify separate species. Chlorite was identified when splitting of the 3.53-3.60-Å peak was observed and when the 14-Å peak persisted after heating to 550° C for one-half hour (Figure 4).

The clay-mineral suites of the Antlers, DeQueen, and Holly Creek Formations were grouped into four major clay-mineral zones (Figure 6): (1) a mixed-layer zone consisting of the clay-mineral suite of the Holly Creek and DeQueen Formations and the basal clay-mineral suite of the Antlers Sand, (2) a transition zone lying upon the mixed-layer zone and consisting of the clay-mineral suite of the middle of the Antlers, (3) a montmorillonite zone lying above the transition zone and consisting of the upper Antlers clay-mineral suite, and (4) a kaolinite zone consisting of the clay-mineral suite of the uppermost Trinity Group. The kaolinite zone lies discordantly upon the lower three clay-mineral zones (Plate 2).



X-RAY DIFFRACTION PATTERNS
OF THE
CLAY-MINERAL ZONES,
TRINITY GROUP
FIGURE 6

LOCATION OF SAMPLES

Listed in the following pages are the locations of more than 800 samples collected for this study. The samples are listed by Ranges from R3W to R27E all of which are in Oklahoma. An area outside of Oklahoma is included: R33W, Townships 8S and 9S, in the southwestern part of Arkansas.

The listing of samples begins in section 1 of the northern-most township of the western-most range and continues to the southern-most township within the same range. The process is repeated for each successive range from the western portion of the study area to the eastern portion. Within each township the numbering sequence follows the section-numbering sequence. With each section the numbering sequence proceeds in a counter-clockwise direction (NE to NW to SE to SE).

Using Plate 1 with the above system it is possible to locate every sample locality to the nearest one-quarter section.

Rng. - Twp. Sec.	Smpl.
3W - 5S	
1	1
	2
2	3
	4
9	5
11	6
12	7
13	8
	9
	10
15	11
23	12
25	13
26	14
32	15
33	16
34	17
3W - 7S	
13	18
2W - 5S	
4	19
7	20
	21
	22
	23
	24
	25
9	26
16	27
17	28
21	29
29	30
	31
	32
	33
32	34
	35
2W - 6S	
8	36
16	37
17	38
2W - 7S	
3	39
18	40
1W - 4S	
28	41
29	42
32	43
36	44
	45
	46
	47
1W - 5S	
1	48
	49
	50
	51
2	52
3	53
	54
4	55
	56
7	57
10	58
	58a
	58b
	58c
	58d
12	59
	60
13	61
	62
15	63
23	64
	65
	66
	67
27	68
	69
	70
	71
1W - 6S	
29	72
1W - 7S	
1	73
	74
	75
	76
11	77
13	78
23	79
27	80
28	81
1E - 4S	
31	82
	83
	84
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32	87
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	90
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	92
1E - 5S	
5	93
18	94
19	95
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	100
	101
	102
20	103
34	104
1E - 6S	
3	105
9	106
11	107
13	108
17	109
22	110
	111
	112
	113
	114
1E - 7S	
16	115
	116
2E - 4S	
24	117
	118
	119

Rng. - Twp. Sec.	Smpl.
26	120
	120a
	120b
	120c
27	121
	122
34	123
	124
	125
36	126
2E - 5S	
8	127
9	128
10	129
2E - 6S	
1	130
8	131
19	132
22	133
24	134
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	156
	157
3E - 3S	
35	158
36	159
	160
3E - 4S	
8	161
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10	165
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35	188
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3E - 5S	
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36	218
3E - 6S	
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2	220
3	221
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8	223
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17	225
20	226
26	227
27	227a
	228
	229
36	230
3E - 7S	
4	231
5	232
7	233
17	234
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4E - 4S	
36	236
4E - 5S	
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Rng. - Twp. Sec.	Smpl.
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4E - 6S	
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34	265
4E - 7S	
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14	269
5E - 4S	
34	270
5E - 5S	
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5E - 6S	
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13	296
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	301
5E - 7S	
18	302
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22	306
	306a
23	307
	308
26	309
	310
27	311
	312
32	313
	313a
35	314
36	315
5E - 8S	
1	316
6E - 4S	
13	317
20	318
30	319
6E - 5S	
4	320
6E - 7S	
20	321
	322
	323
	324
	325
30	326
31	327
6E - 8S	
6	328
7E - 3S	
11	329
	330
12	331
23	332
26	333
7E - 4S	
5	334
6	335
16	336
17	337
18	338
	339
21	340
33	341
7E - 5S	
3	342
	343
	344
	345
5	346
8E - 3S	
18	347
22	348
26	349
28	350
30	351
35	352
8E - 4S	
11	353
14	354
24	355
9E - 3S	

Rng. - Twp. Sec.	Smpl.
12	356
25	357
	358
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32	360
36	361
9E - 4S	
1	362
2	363
5	364
	365
	366
6	367
	368
8	369
11	370
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20	372
	373
	374
	375
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22	377
23	378
27	379
	380
31	381
10E - 2S	
26	382
27	383
	384
28	385
34	386
	387

Rng. - Twp. Sec.	Smpl.
36	388
	389
10E - 3S	
1	390
	391
	392
2	393
	394
3	395
4	396
7	397
10	398
	399
19	400
24	401
25	402
31	403
	404
33	405
34	406
35	407
10E - 4S	
1	408
2	409
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5	411
6	412
11	413
	414
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13	416
14	417
	418
15	419
19	420

Rng. - Twp. Sec.	Smpl.
21	421
24	422
27	423
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30	425
	426
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	428
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	430
31	431
11E - 2S	
20	432
	433
23	434
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25	436
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27	438
28	439
29	440
32	441
33	442
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34	444
36	445
11E - 3S	
2	446
	447
3	448
	449
4	450
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Rng. - Twp. Sec.	Smpl.
6	452
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8	461
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11	464
12	465
18	466
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19	470
	471
20	472
24	473
28	474
34	475
	475a
35	476
	477
36	478
	479
11E - 4S	
1	480
	481
2	482
3	483
4	484
6	485

Rng. - Twp. Sec.	Smpl.
	486
7	487
16	488
17	489
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18	492
20	493
21	494
26	495
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27	497
	498
12E - 2S	
33	499
34	500
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	505
35	506
	507
12E - 3S	
2	508
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3	511
5	512
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9	514
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11	518
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14	522
	523
18	524
20	525
30	526
31	527
12E - 4S	
17	528
	528a
18	529
19	530
20	531
28	532
	533
	534
29	535
12E - 5S	
2	536
	537
4	538
	539
	540
13E - 3S	
18	541
20	542
22	543
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23	546
	547
13E - 5S	
22	548
14E - 3S	
19	549
27	550
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28	552
29	553
35	554
36	555
	556
14E - 4S	
3	557
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4	560
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5	562
7	563
8	564
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10	566
	567
	567a
11	568
15	569
17	570
23	571
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26	574
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27	576
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	581
34	582
14E - 5S	
10	583
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11	585
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12	588
22	589
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23	591
33	592
15E - 4S	
6	593
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19	596
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20	599
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21	603
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26	605
24	606
26	607
29	608

Rng. - Twp. Sec.	Smpl.
15E - 5S	
7	609
	610
18	611
	612
	613
16E - 3S	
35	614
	615
	616
16E - 4S	
10	617
11	618
12	619
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	621
15	622
20	623
22	624
27	635
	626
28	627
34	628
	629
16E - 5S	
3	630
	631
	632
9	633
	634
	635
10	636

Rng. - Twp. Sec.	Smpl.
17E - 4S	
13	637
	638
15	639
17	640
17E - 5S	
25	641
26	642
27	643
35	644
36	645
17E - 6S	
1	646
	647
18E - 5S	
2	648
17	649
31	650
18E - 6S	
7	651
8	652
	653
	654
	655
9	656
19E - 4S	
23	657
24	658
19E - 5S	
5	659

Rng. - Twp. Sec.	Smpl.
6	660
9	661
12	662
13	663
	664
17	665
18	666
19	667
24	668
25	669
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30	671
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31	673
34	674
	675
	676
	677
36	678
19E - 6S	
1	679
	680
3	681
5	682
6	683
7	684
	685
	686
12	687
20E - 4S	
20	688
30	689

Rng. - Twp. Sec.	Smpl.
20E - 5S	
12	690
	691
20E - 6S	
24	692
21E - 5S	
8	693
	694
	695
	696
17	697
18	698
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20	700
21	701
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27	703
28	704
33	705
34	706
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35	708
36	709
21E - 6S	
3	710
15	711
19	712
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22	714
23	715
	716

Rng. - Twp. Sec.	Smpl.
22E - 5S	
34	717
22E - 6S	
20	718
	719
21	720
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22	722
26	723
27	724
28	725
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29	729
30	730
34	731
	732
	733
	734
23E - 5S	
34	735
35	736
36	737
	738
23E - 6S	
13	739
33	740
24E - 5S	
31	741

Rng. - Twp. Sec.	Smpl.
24E - 6S	
1	742
	743
5	744
	745
6	746
	747
10	748
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12	750
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13	757
19	758
24	759
26	760
28	761
29	762
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30	764
	765
24E - 7S	
1	766
	767
8	768
	769
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	771
12	772
14	773

Rng. - Twp. Sec.	Smpl.
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	785
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19	792
25E - 6S	
6	793
	794
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7	796
9	797
10	798
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13	800
14	801
16	802
17	803
	804
	805
19	806
23	807
28	808
30	809
	810
	811

Rng. - Twp. Sec.	Smpl.
	812
	813
31	814
36	815
	816
26E - 6S	
3	817
5	818
7	819
	820
10	821
11	822
	823
	824
13	825
14	826
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18	828
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	833
	834
	835
	836
23	837
26	838
36	839
26E - 7S	
6	840

Rng. - Twp. Sec.	Smpl.	Rng. - Twp. Sec.	Smpl.	Rng. - Twp. Sec.	Smpl.	Rng. - Twp. Sec.	Smpl.
27E - 6S							
5	841						
	842						
7	854						
	844						
	845						
8	846						
	847						
	848						
9	849						
16	850						
18	851						
20	852						
	853						
22	854						
27E - 7S							
7	855						
9	856						
33W - 8S							
	857						
33W - 9S							
10	858						

DESCRIPTIONS OF SELECTED SAMPLES

Included below are field descriptions of selected samples of the various lithologies found in the Trinity Group sediments. All of the samples were analyzed for their clay-mineral content. To avoid repetition, not all of the samples whose mineralogy was determined are listed below.

The descriptive terminology follows that suggested in the Oklahoma Geological Survey Guidebook XIV (Table 6, p. 43) and the AAPG Committee on Stratigraphic Correlations.

The following abbreviations have been used:

abnt	--- abundant	ls	--- limestone
ang	--- angular	micxl	--- microcrystalline
aprox	--- approximately	mod	--- moderate
aren	--- arenaceous	olv	--- olive
bdd	--- bedded	orng	--- orange
blk	--- black	pbl, pbls	--- pebble(s)
blky	--- blocky	pk	--- pink
brn	--- brown	pos	--- possible
calc	--- calcareous	purp	--- purple
cht	--- chert	qtzt	--- quartzite
cly	--- clay, clayey	rd	--- round, rounded
clg	--- conglomerate	scat	--- scattered
xlyn	--- crystalline	sil	--- siliceous
dk	--- dark	sbang	--- subangular
fld	--- feldspar	sltst	--- siltstone
Fe	--- ferruginous	sbrd	--- subrounded
frags	--- fragments	sh	--- shale
gy	--- gray	ss	--- sandstone
ireg	--- irregular	/	--- with
lam	--- laminated	yel	--- yellow
lrg	--- large		
lt	--- light		

Other words or symbols used that require explanation are:

few	---	less than 5%
some	---	10 - 20%
much or many	---	25 - 40%
/	---	In some cases " / " not followed by an adverb, such as " /some ", or " / few ", is interpreted as " with " meaning an occurrence of, or presence of, some material or color such as pigment or stain.

Unless otherwise stated, all samples were collected from the center of each change in lithology less than 6 inches thick at any given outcrop. Units from 0.5 - 5.0 feet thick were channel sampled, whereas, thicker units were sampled at the base, middle, and top. All samples were taken from pits or trenches from 0.5 - 2.0 feet deep in order to obtain fresh material. At some localities both weathered and/or soil samples were collected along with the fresh material. The samples were placed into polyethylene freezer bags, sealed, and returned to the laboratory.

In the description of each sample the following order is used:

Sample No.	Description
1000	Rock type; Wentworth size scale, phi size (ϕ), color (after Rock-Color Chart, Goddard, et al., 1948), chemical content or stain, included terriginous material, shape of detritals, cement or matrix, field characteristics, location to the nearest one-sixty-fourth of a section (the section, township, and range of each sample is in numerical order under "Location of Samples".).

An example would be:

1000	ss; vf-f, 2.5-3.5, /some 1.5-2.0, gy-orng, Fe, /few ireg frags of gy cly, sbang, cly, bdd. NE NW SE

Sample Number	Description
1	cly; dk red-brn, Fe. SW NW SW
2	ss; vf-f, 2.0-4.0, few 1.5, yel-gy/some gy-orng, Fe stain, cly, silty, bdd. SE SE SW
4	ss; f-med, 1.0-3.0, lt-brn, Fe, sbang, bdd. NE SE SE
10	ss; f-cse, 0.5-3.0, some 3.5-4.0, dk yel-orng, Fe, sbang, silty, cly, bdd. SE SE SE
11	cly; gy-red, Fe. NW NW NE
12	ss; f-med, 1.0-2.5, some 3.0-3.5, gy-orng-pk, sbang, cly, bdd. SW SW SW
19	ss; f-med, 1.5-3.0, gy-orng-pk & yel-gy, Fe, sbang, cly, bdd. SW SW SW
20	ss; f-med, 1.5-3.0, gy-orng, sbang, cly, bdd. NW NW NW
21	ss; f-med, 1.0-2.5, few 3.0, mod red-brn & lt-brn, Fe, sbang, bdd. NW NW NW
23	ss; vf-f, 2.0-3.0, some 1.0-1.5, lt-brn, cly, conglomeratic/sbrd qtzt pbls, 6.0 mm across, lrg frags of clay, Fe, bbd. NW SW SW
24	ss; f-cse, 0.5-2.5, some 3.0-3.5, dk yel-orng, Fe, sbang, cly, contains pbls of qtzt up to 1.0 cm across, bdd. NW SW SW
25	cgl; v pale-orng, qtzt pbls up to 6.0 cm across make up 40-50% or rock, pbls cemented in matrix of f-med ss, bdd. NW SW SW

26 cly; gy-red, Fe. SW NW NW

27 ss; v-f, 3.0-4.0, v pale-orng/gy-orng & dk yel-orang, Fe stain, bdd. SW NW NW

28 ss; cse, 0.0-1.0, lt-brn, Fe, rd, some frags of qtz & cht up to 1.0 cm across, bdd. SE NE NE

29 ss; vf-med, 1.5-4.0, yel-gy/some lt-brn Fe stain, cly, silty, bdd. SW SW NW

30 ss; vf, 3.0-4.0, few 2.5, v pale-orng/some dk yel-orng Fe stain, cly, bdd. SE NE NE

31 ss; cse, 0.0-1.0, pk-gy, sil, rd/few rd granules & pbls, bdd. SE NE SE

32 ss; vf-cse, 0.5-4.0, yel-gy, rd, slty, cly, bdd. 2.0' bel W-S9. SE SE SE

33 ss; f, 2.0-3.0, few 1.0-1.5, v pale-orng, sbang, cly, bdd. SE SE SE

34 ss; vf, 3.0-3.5, v pale-orng, bdd. SE SE SE

35 sltst; pale grn-yel/some dk yel-orng Fe stain, cly, bdd. SE SE SE

36 ss; f-med, 1.0-2.5, some 3.0, lt-brn, Fe, bdd. SE SE NE

37 cly; gy-red, Fe. SW SW SW

38 ss; vf, 3.5-4.0, v pale-orng, silty, cly, bdd. SE SE SE

40 ss; f, 2.0-2.5, yel-gy/some dk yel-orng stain, Fe, slty, cly, bdd. NW SE NW

48 ss; cse-v cse, -1.0-0.5, some 1.0-2.5, dk yel-brn, cly, contains granules of pbls of cht, qtz & qtzt up to 10.0 mm across, bdd. NW SW NW

49 sltst; gy-orng, contains vf-vcse qtz grains, Fe, bdd. SW SE SE

50 ss; f-med, 1.5-3.0, some 3.5-4.0, gy-yel, Fe, sbang, cly, bdd. SE NE SE

52 ss; med-cse, 0.5-2.0, some 2.5-3.5, gy-orng, Fe, cly, few qtz grains up to 4.0 mm across, bdd. SW NE NE

55 ss; f-med, 1.5-3.0, few 3.5-4.0, dk yel-orng, Fe, sbang, cly, bdd. SW NW NW

56 ss; f, 2.5-3.0, few 3.5-4.0, gy-orng/spots of pale-brn, cly, bdd. NW SW NW

58 sltst; yel-gy, some vf qtz grains, cly, bdd. NE NE SE

58a cly; pale-olv. NE NE SE

58c cly; yel-gy, some dk yel-orng Fe stain. NE NE SE

58d cly; gy-red, Fe. NE NE SE

64 ss; f, 2.0-3.0, v pale-orng & lt-brn, Fe, sil, bdd. NW NE NE

65 ls; v pale-orng, vf xlyn, few scat vf-f qtz grains. NW NE NE

66 ss; vf-f, 2.5-3.5, yel-gy/spots dk yel-orng Fe stain, cly, slty, sbang, bdd. NW NW NW

70 ss; vf, 3.0-3.5, lt brn, Fe, cly, bdd. SW SW SW

83 ss; vf, 3.5-4.0, v pale-orng/some gy-orng Fe stain, silty, cly, bdd. SE SW SE

98 cly; wh/much gy-orng Fe stain. SW NW NE

105 ss; f-med, 1.0-2.5, v pale-orng, Fe, cly, contains irreg beds of vf-f yel-gy Fe ss bdd. SW NW SW

106 sltst; pale red-brn, Fe, many vf qtz grains, cly, bdd. NE NE SE

107 cly; pale red-brn, Fe, some vf qtz grains. SE SE SW

108 ss; f-med, 1.0-2.5, some 3.0-3.5, gy-orng, Fe, silty, bdd. NW NW NE

117 cly; pale red-brn, Fe. SW SW NW

119 ss; f, 2.5-3.0, lt-brn, Fe, bdd. SW SW SW

120b cly; gy-red, Fe. NW NE NW

120c ss; cse-vcse, -0.5-1.0, yel-gy, 40% of rock is clay matrix, fld grains, some f-med qtz grains, bdd. NW NE NW

123 ss; vf, 3.0-4.0, pale grn-yel/some gy-orng Fe stain, silty, cly, bdd. NW NE NE

124 ss; f-med, 2.0, some 2.5-3.0, lt-brn, Fe, locally contains many v cse qtz grains. SW SW SW

125 ss; f, 2.5, some vf & med, 1.0-3.5, lt-brn, Fe, cly, slty, bdd. SW SW SE

126 ss; f-med, 1.5-2.5, v pale-orng, sbang, bdd. SE SW SW

128 ss; f-cse, 0.5-3.0, gy-orng, few v cse qtz grains, contains some frags of yel-gy sltst, Fe, bdd. NE NE NE

130 ss; vf, 3.0-4.0, some 2.5, pale grn-yel/some mod-yel Fe stain, silty, cly, bdd. NW NE NW

131 ss; vf-f, 2.5-3.5, lt-brn, Fe, cly, bdd. SW NW NW

133 ss; f-med, 1.0-2.5, few 3.0, lt-brn, Fe, bdd. SW NW NE

134 ss; vf-med, 1.5-3.5, few 0.5-1.0, yel-gy/few spots of pale yel-orng Fe stain, bdd. NW SW NE

139 cly; lt olv-gy, many vf-med qtz grains. SE SW NW

140 ss; f, 2.5-3.0, many med qtz-grains, yel-gy, sbang, bdd. NE NW NW

144 cly; gy-orng, Fe, calc, some vf-f qtz grains. NW SW SW

165 cly; pale-olv/some gy orng-pk, Fe, some vf-f qtz grains. SE SE SW

173 ss; vf, 4.0, yel-gy, cly, slty, bdd. SW SW SW

174 cly; yel-gy, some dk yel-orng Fe stain.
SW SW SW

178 ss; vf, 3.5-4.0, yel-gy/few spots of dk yel-orng Fe stain, sbang, cly, bdd. SW SW NW

180 ss; vf-f, 2.5-4.0, yel-gy, slty, cly, bdd.
SE SE SW

181 ss; vf, 4.0, pk-gy, sbang, cly, bdd. SW SE SW

182 cly; dusky-yel, few vf qtz grains. SW SE SW

183 cly; dusky-red, Fe. SW SE SW

184 sltst; dusky-yel, cly, Fe. SE NE NE

185 ss; vf, 4.0, gy-orng, Fe, cly, slty, bdd.
SE NE NE

186 ss; vf, 3.5-4.0, yel-gy, sbang, cly, bdd.
NE SE SE

188 sltst; dusky-yel, cly, few vf qtz grains, bdd.
NW NE SW

189 ss; f, 2.0-3.0, gy-orng, Fe, bdd. NE NE SW

190 sltst; v pale-orng/some lt-brn Fe stain, cly, some vf qtz grains, bdd. NW NE NE

191 cly; lt olv-gy/some dk yel-orng Fe stain, calc, some vf-f qtz grains. SE SE SE

192 sltst; lt olv-gy, cly, some vf qtz grains.
SW SE SW

193 cly; lt olv-gy/some dk yel-orng Fe stain.
SW SE SW

195 ss; f-med, 1.5-3.0, v pale-orng, sbang, bdd.
SE SE SE

196 ss; f, 2.0-3.0, yel-gy, cly, slty, bdd.
SW SW SE

199 cly; lt olv-gy/dk yel-orng Fe stain, some vf-f qtz grains. NE NE SE

202 ss; vf, 3.5-4.0, wh, slty, bdd. NE NE NE

205 ss; vf, 3.5, wh/spots of pale brn, sbang, bdd.
SE SE SE

206 ss; vf-f, 2.5-3.5, v pale-orng, Fe, cly, bdd.
SE SW SW

207 ss; med-cse, 0.5-2.0, few 2.5-3.0, few -1.0-0.0, gy orng-pk/some pale yel-orng Fe stain, bdd.
SW SW SE

208 ss; f-med, 1.5-2.5, some 3.0, v pale-orng, sbang, cly, silty, bdd. SE NE NE

209 ss; vf, 3.0-4.0, few 2.5, pale red-purp, Fe, sbang, cly, bdd. SW SE SW

211 ss; f-med, 1.0-2.5, lt-brn, sbang, Fe, cly, bdd.
SW SE SE

216 ss; f, 2.5-3.0, few 3.5, pale yel-orng, Fe, sbang, bdd. SW SE SW

218 sltst; yel-gy, few vf qtz grains, cly, bdd.
SE SE NE

219 ss; vf, 3.5-4.0, pale grn-yel/some dk yel-orng Fe stain, cly, bdd. NE NW NW

230 ss; f-med, 1.5-2.5, yel-gy/dk red-brn Fe stain, silty, cly, bdd. SW SW SW

222 ss; vf, 3.0-3.5, v pale-orng, sbang, bdd. SE SE SE

223 ss; vf-f, 2.0-3.5, v pale-orng, sbang, bdd. SE SE NE

224 ss; f-med, 1.5-3.0, dk yel-orng, Fe, silty, cly, bdd. SE SE SE

225 ss; vf, 3.0-4.0, gy-orng/some dk-yel-brn Fe stain, cly, bdd. NE SE SE

226 ss; vf, 3.0-3.5, few 2.5, lt-brn/some gy-orng, Fe, bdd. NE SE SE

227a ss; vf, 3.5-4.0, lt-brn, Fe, sbang, cly, bdd. SE NE NE

228 cly; gy-red, Fe. NW NW NE

229 cly; lt olv-gy, some vf qtz grains, Fe. SW NE NW

231 ss; vf-f, 2.5-3.5, few 2.0 & 4.0, v pale-orng, sbang, cly, bdd. SE NW SE

238 sltst; yel-gy, cly, some vf qtz-grains, bdd. NW NW SE

239 cly; pale-olv/dk yel-orng Fe stain. NW NW SE

240 ss; f, 2.0-3.0, olb-gy, much cly, in part an aren cly, calc, bdd. NW NE NE

241 ss; vf, 3.0-4.0, few 2.5, gy-yel, Fe, cly, bdd. SW SE SW

243 ss; f-med, 1.0-2.5, few 3.0-3.5, gy-pk, sbang, bdd. SW SE SW

244 sltst; med lt-gy, vf silt. SE SW SE

245 ss; f-med, 1.5-3.0, some 3.5, few 1.0, dk yel-orng, Fe, cly, bdd. NE NE NE

246 cly; dusky-yel, Fe, some vf-f qtz grains, includes irreg lenses of vf-med ss. NE NE NE

247 ss; vf-f, 2.5-4.0, few 2.0, pale yel-brn cly, silty, bdd. SE NE NE

249 ss; vf-f, 2.0-3.5, pale yel-brn/dusky-yel Fe stain, cly, bdd. NW NW NW

250 cly; pale red-purp, some Fe stain, some vf qtz grains. NW SW NW

251 sltst; v pale-orng, many vf-f qtz grains, cly, bdd. SW SW NW

252 ss; vf, 3.0-4.0, some 2.5, pale yel-orng, Fe, sbang, bdd. SW NW SE

253 ss; vf-f, 2.0-3.5, some 4.0, v pale-orng, bdd. SE NE SE

254 cly; olv-gy, many vf-f qtz grains. SE NE SE

256 ss; vf, 4.0, yel-gy, cly, slty, sbang, bdd.
SE SW SE

257 sltst; lt-brn, Fe, contains some vf-med qtz-grains, cly, bdd. NW NW NW

264 ss; vf, 3.5-4.0, v pale-orng, bdd, contains irreg frags of yel-gy sltst. SE SE SE

265 ss; vf-f, 3.0, pk-gy, sbang, cly, bdd. NW NE NE

266 cly; pale-brn, some vf qtz-grains. SW SW NW

267 cly; yel-gy, some vf qtz-grains. NW NE NE

268 ss; vf-f, 2.5-4.0, lt-brn, Fe, cly, slty, bdd.
SE SE SE

269 sltst; lt-brn & gy-orng, Fe, many vf-med qtz-grains, much cly. NW NW SW

270 cly; lt olv-gy/some pale yel-orng Fe stain.
SE SE SE

272 cly; lt olv-gy, much silt, lam. C

273 cly; med dk-gy, contains irreg lenses of lt olv-gy f-grained ss. C

274 ss; vf, 3.0-4.0, lt olv-gy/some dk yel-orng Fe stain, much cly, in part an arch cly, bdd.
SW SW NW

275 ss; vf-f, 2.0-4.0, few 1.0-1.5, v pale-orng cly, bdd. SW SW NW

276 cly; olv-gy/some pale yel-orng Fe stain.
SW SW SE

277 cly; pale yel-brn, Fe. NW NW SW

279 ss; f-med, 1.5-2.5, some 3.0-3.5, v pale-orng, cly, bdd. SW SE NW

280 ss; vf-med, 1.5-3.5, yel-gy, cly, slty, bdd. SW SE NW

281 ss; vf, 3.0-4.0, pale yel-brn, cly, silty, irreg masses of vf xlyn calcite (caliche?) bdd. SE NE NE

282 cly; pale yel-brn. SE NE NE

283 ss; med, 1.0-2.0, few 2.5-3.0, pale-brn, cly, bdd. SW NW NE

284 ss; vf-f, 2.0-4.0, yel-gy/few streaks gy-orng Fe stain, cly, slty, bdd. SW NW NE

287 ss; vf-f, 2.5-4.0, yel-gy/dk yel-orng Fe stain, cly, bdd, interbdd/med-gy aren sltst. SW NE NE

290 sltst; yel-gy, some vf qtz grains, bdd. NW SW NE

306 ss; med, 1.0-1.5, some 2.0, yel-gy, bdd. NW SW NW

306a ss; vf-f, 2.5-4.0, few 2.0, mod yel-brn, Fe, calc, cly, bdd. NW SW NW

307 sltst; pale-olv/some lt-brn Fe stain, cly, many vf qtz grains, bdd. SW NW SW

308 ss; vf-med, 1.5-3.5, gy-orng/some lt-brn stain, Fe, sbang, cly, slty, bdd. SW SW SW

309 ss; f-med, 1.5-3.0, some 3.5-4.0, v pale-orng, Fe, bdd. NW NW NW

311 ss; med, 1.0-2.0, much 4.0, yel-gy/some lt-brn Fe stain, slty, cly, bdd. NW SW NW

312 cly; lt olv-gy/some mod yel-brn Fe stain, locally contains irreg masses of f-med grained ss & is in part a ss/cly matrix. NW NW SW

313 ss; vf, 4.0, yel-gy, much slt, cly, bdd. NE SE NW

313a cly; dusky yel-brn & dusky-brn, few vf qtz grains, calc/irreg masses of powdery wh calcite. NE SE NW

314 ss; vf, 3.5-4.0, dk yel-orng, Fe, slty, cly, bdd. SW NE SW

315 ss; vf, 3.5-4.0, lt-brn & yel-gy, cly, slty, Fe, bdd. NE SE SE

316 ss; f, 2.0-2.5, some 1.0-1.5 and 3.0-3.5, dk yel-orng, Fe, sbang, cly, bdd. NE NE NW

317 ss; vf-f, 2.0-4.0, gy-orng, Fe, slty, cly, bdd. SE SE NW

321 cly; mod yel-brn, irreg masses of vf xlyn calcite (caliche?). SE SE SW

324 sltst; pale yel-brn, v cly, blky. SE SE SW

326 sd; f-med, 1.5-3.0, few 3.5-4.0, gy-orng, Fe, sbang, dune sand. SW SW SW

327 ss; f-cse, 0.5-2.5, some 3.0-3.5, lt-brn, Fe, sbang, cly, bdd. SW SW NW

328 sd; f-med, 1.0-3.0, some 3.5-4.0, lt-brn & pale yel-brn, Fe, slty, cly. NW NW NE

329 cly; lt-brn, Fe. NW NE NE

330 weathered granite; gy-orng, cly & slt matrix/v cse grains of qtz, altered fld & mica, some dusky-brn asphaltic or carbonaceous matter. NW NW SW

331 ss; f-med, 1.5-3.0, few 3.5, yel-gy/much pale red-brn Fe stain, slty, cly, bdd. SW NW SW

332 sltst; yel-gy/some dk yel-orng Fe stain, some vf qtz grains, cly. SW NW NW

333 sltst; gy-orng/some dk yel-orng, Fe, some vf-f qtz grains, cly, bdd. NW SW SW

334 ss; vf, 3.0-4.0, gy orng-pk, bdd. SE SW NE

335 cly; pale olv, some vf qtz grains. NE NE SW

337 ss; vf-f, 2.5-4.0, yel-gy, sbang, cly, bdd. SE SW NE

338 sltst; mod-brn, vf slt, Fe, few vf qtz grains. NE NE SE

339 ss; f, 2.5-3.0, some 2.0 & 3.5, v pale-orng/some pale yel-orng Fe stain, sbang bdd. NW NW SE

340 ss; f, 2.0-3.0, some 3.5-4.0, lt olv-gy/lt-brn Fe stain, slty, cly, bdd. NE SE NW

341 ss; vf, 3.5-4.0, lt olv-gy/dk yel-orng Fe stain, cly, bdd. SW SW SW

342 cly; mod yel-brn, some vf-f qtz grains, Fe, calc, irreg masses of wh powdery calcite. NE NW NW

343 ss; vf, 3.5-4.0, yel-gy/dk yel-orng Fe stain cly, bdd. NE NW NW

344 cly; mod yel-brn, Fe, few scat vf qtz grains. NE NW NW

345 ss; vf-med, 1.5-4.0, dk yel-orng, Fe, cly, bdd. NE NW NW

346 ss; f, 2.0-3.0, few 3.5-4.0, v pale-orng/some pale yel-orng Fe stain, sbang, bdd. NW NE NE

348 cly; mod-brn, Fe, locally contains some vf qtz grains. SE SW SW

349 ss; vf, 3.0-4.0, gy orng-pk, silty, some mod red-orng Fe stain, bdd. NE NE SE

350 ss; vf, 3.5-4.0, v pale-orng/much pale yel-orng Fe stain, locally contains qtz & fld grains up to 1.0 cm across, bdd. NW NE NE

352 sltst; gy-yel, Fe, cly, lam. NE NE SE

353 ss; vf, 3.0-4.0, wh/some lt-brn Fe stain, slty, cly, bdd. SE SE NE

354 ss; vf-f, 2.5-3.5, yel-gy/some lt-brn Fe stain, sbang, bdd. SW SE SE

355 cly; yel-gy/some dk yel-orng Fe stain. NE SW NW

362 sltst; dk yel-orng, Fe, cly/some irreg masses of yel-gy vf-f ss, bdd. NE NW NE

363 ss; vf-f, 2.0-3.5, pale yel-brn/some mod yel-brn Fe stain, much cly, bdd. NW NW NW

370 ss; vf, 3.0-4.0, pale yel-brn & gy-orng, Fe, sbang, cly, bdd. NW NW NW

371 ss; f-med, 1.5-2.5, few 3.0, v pale-orng & gy-orng, Fe, sbang, cly, bdd. NW SW SW

377 ss; vf-f, 2.5-4.0, v pale-orng/gy-orng Fe stain, sbang, cly, slty, bdd. NE NE SE

378 ss; f-med, 1.5-3.0, v pale-orng/much dk yel-orng Fe stain, cly, bdd. SW NW SW

379 ss; f, 2.5-3.0, some 3.5, v pale-orng, sbang, cly, bdd. SE NW NE

380 cly; lt olv-gy, few vf qtz grains. SW NW NE

381 ss; vf-f, 2.5-4.0, few 2.0, olv-gy, sbang, cly, bdd. SW SE NW

382 ls; mixcl, yel-gy, slty, few f-med qtz grains. SW SW SE

399 ss; vf-f, 2.0-4.0, some -0.5-1.5, yel-gy/dk yel-orng Fe stain, cly, bdd. NE NW NW

401 ss; f, 2.0-3.0, few 1.5, lt-brn, Fe, sbang, cly, bdd. SE NE NE

405 ss; f-med, 1.5-2-5, some 3.0-4.0, mod yel-brn, Fe, cly, bdd. SW SE SE

406 sltst; yel-gy/some dk yel-orng Fe stain, cly. SW SE SE

407 cly; pale-re/some dk-yel-orng, Fe. SE SW SW

408 ss; f, 2.0-3.0, few 3.5, dk yel-orng & lt-brn, Fe, sbang, cly, bdd. SE SW SE

409 sltst; v pale-orng/gy-orng Fe stain, many vf-f qtz grains, cly, bdd. NE SW SE

410 ss; f-med, 1.5-3.0, few 3.5-4.0, lt-brn, Fe, cly, slty, bdd. NE SW SE

411 cly; lt olv-gy, many vf-f qtz grains, some Fe stain. NW NE NW

412 cly; gy-red, Fe. NW NE NE

420 ss; vf, 3.0-4.0, some 2.0-2.5, yel-gy/spots of lt-brn Fe stain, cly, bdd. SE NE NE

425 ss; f-med, 1.0-3.0, gy-orng, Fe, bdd. SE NE NE

426 cly; lt olv-gy/dk yel-orng Fe stain, locally contains many vf-f qtz grains. SE SE NE

427 ss; vf-f, 2.0-4.0, yel-gy, sbang, cly, bdd. SE SE NE

428 cly; dk yel-brn/many vf-f qtz grains. SE SE NE

429 sltst; yel-gy, some vf qtz grains, cly, bdd. SE SE NE

430 ss; f, 2.0-3.0, some 3.5-4.0, v pale-orng, sbang, cly, bdd. SE SE NE

431 cly; blk. SW SE SE

432	ss; f-cse, 1.5-3.0, some 3.5-4.0, gy-orng, Fe, slty, cly, pos worm burrows, bdd. SW SW SW
435	ss; med-cse, 0.5-1.5, some 2.0-4.0, yel-gy/much lt-brn Fe stain, cly, bdd. SE SE SE
451	ss; vf-f, 2.0-4.0, yel-gy/dk yel-orng Fe stain, sbang, cly, bdd. SW SW SW
452	ss; vf-med, 1.0-4.0, dk yel-orng, Fe, cly, slty, bdd. SE SE SE
458	ss; f, 2.0-3.0, some 3.5, v pale-orng/some dk yel-orng Fe stain, bdd. SW SE SE
459	ss; f-cse, 0.5-3.0, gy-orng, Fe, cly, bdd. SW SE SE
466	cly; gy-red/pale yel-orng, Fe, some vf-f qtz grains. NW SW NE
467	sltst; yel-gy, some vf qtz grains,much cly, bdd, weathers to dusky-yell & gy-orng. SE SW SW
469	ss; vf, 3.5-4.0, pale yel-brn, slty, cly, contains irreg frags of olv-gy cly, bdd. SW SW SW
474	cly; mod-brn, Fe, some vf-f qtz grains. SW SW NW
475	sltst; lt olv-gy/some dk yel-orng Fe stain, cly. SW SE SE
478	ss; f, 2.0-3.0, few 3.5, yel-gy/dk yel orng Fe stain, sbang, cly, bdd. NW NW NW
479	ss; vf-f, 2.5-3.5, few 4.0, pale yel-orng, Fe, sbang, cly, bdd. SW SE SW

480 ss; vf, 3.0, some 3.0-3.5, yel-gy/lt-brn & gy-orng Fe stain, slty, cly, bdd. NE NW SW

481 ss; f, 2.0-3.0, yel-gy/some gy-orng Fe stain, cly, slty, bdd. SW SW SE

482 ss; f, 2.5-3.0, some 3.5, gy orng-pk, sbang, cly, bdd. NE NW NW

483 ss; vf, 3.0-4.0, mod-brn, Fe/thin layers of mod-brn cly, cly, bdd. NE NW NW

484 ss; vf-f, 2.0-4.0, lt-brn, Fe, cly, bdd. NE NW NE

485 ss; f-med, 1.0-2.5, gy-orng/much dusky-brn stain, Fe in part, cly, bdd. SW SE SE

486 ss; med, 1.5-2.0, some 2.5-3.0, dusky yel-brn, cly, bdd. SW SE SE

488 ss; f, 2.0-3.0, few 3.5, dk yel-orng & gy-orng, Fe, sbang, interbdd/v pale-orng slty vf-f grained ss, bdd. SW SE SE

489 ss; vf, 3.0-4.0, v pale-orng/some pale yel-orng Fe stain/irreg frags of sltst, cly, bdd. NW NW NW

492 ss; vf, 3.0-4.0, mod-brn/some gy-orng, Fe, cly, bdd. SE SE NE

493 ss; vf-med, 1.5-3.5, few 4.0, v pale-orng/dk yel-orng & mod-brn Fe stain, cly, bdd. NW SW SW

494 ss; vf, 3.5-4.0, wh, slty, cly, bdd. NE NW NW

495 cly; dk red-brn, Fe. NW SW NW

497 sltst; mod-brn/some dusky-yel, Fe, few vf qtz grains, cly, bdd. SW NW NW

498 ss; f-cse, 0.5-2.5, few 3.0-4.0, dk yel-orng, Fe, bdd. SE SW SE

499 ss; f, 2.0-3.0, few 3.5-4.0, gy-orng & dk yel-orng, Fe, sbang, cly, bdd. SW SW SW

501 ss; f, 2.0-3.0, few 1.5 & 3.5, gy-orng/some dk yel-orng, Fe, sbang, bdd. SW NW NW

502 ss; f-med, 1.0-2.5, few 0.5 & 3.0, dk yel-orng Fe, slty, cly, few granules of qtzt, bdd. SW NW NW

504 ss; f-med, 1.0-2.5, some 3.0-3.5, lt-brn/some yel-gy, Fe, few cse qtz grains, cly, bdd. SW SW NW

506 cly; lt olv-gy/some lt-brn Fe stain, some vf qtz grains. NW SW SW

507 ss; f, 2.0-2.5, some 3.0-3.5, dk yel-orng & gy red-purp, Fe, sbang, cly, bdd. NW SW SW

508 sltst; pale-olv/some pale yel-orng Fe stain, v cly, bdd. SW NW SW

510 ss; vf-f, 2.5-4.0, v pale-orng, slty, cly, bdd. NW SW SW

511 ss; f-med, 1.5-2.5, dk yel-orng, Fe, cly, bdd. NW NW NE

512 ss; vf-f, 2.5-4.0, yel-gy, slty, cly, bdd. SE SE NE

514 ss; vf-f, 2.5-4.0, pale yel-brn/dk yel-orng Fe stain, much cly, bdd. SW SE SW

515 ss; vf-f, 2.0-4.0, yel-gy/some dk yel-orng Fe stain, sbang, cly, weathers to mod red-brn Fe stain, bdd. SE SE SE

518 sltst; yel-gy, some vf qtz grains, cly, bdd. SE SW NW

520 cly; pale red-brn, Fe. SW NW SE

522 cly; mod-brn, Fe. NW NE NE

523 ss; f, 2.0-3.0, some 3.5, gy-orng, Fe, sbang, cly, bdd. NE NW NW

525 ss; f, 2.5-3.0, v pale-orng, cly, slty, Fe, bdd. SW SW NW

526 ss; f-med, 1.5-2.5, few 3.0-4.0, dk yel-orng, Fe, cly, bdd. NE NE SE

527 ss; vf-f, 3.0, some 2.5, gy-orng, Fe, cly, bdd. SW SW SE

528 ss; f, 2.0-3.0, few 3.5-4.0, gy-orng, Fe, sbang, cly, bdd. SW NW NW

528a ss; med, 1.0-2.0, sk yel-orng, Fe, sbang, bdd. SW NW NW

529 ss; vf-f, 2.0-3.5, gy-orng, Fe, sbang, cly, bdd. NE NW NW

530 ss; vf-f, 2.5-3.5, mod yel-brn, Fe, much cly, in part an aren cly, bdd. SE NE NE

531 ss; vf-f, 2.5-4.0, lt-brn & dk yel-brn, Fe, cly, bdd. SW NW SW

533 cly; lt-brn & gy-orng, Fe, many vf-f qtz grains. NW SE NW

534 cly; pale yel-brn, some vf-f qtz grains. NW SE SW

535 cly; mod yel-brn, Fe, some vf-f qtz grains. NE NE NW

536 cly; dk-gy. SE SE SE

537 ss; f-med, 1.5-2.5, dk yel-orng, Fe, sbang, cly, bdd. NW SE SE

538 ss; f, 2.0-2.5, few 3.0-3.5, v pale-orng, sbang, cly, bdd. SW SW SW

539 ss; vf-f, 2.5-4.0, yel-gy, slty, cly, bdd. SW SW SW

540 cly; dusky-brn, calc, irreg masses of powdery wh calcite. SW SW SW

541 ss; vf-med, 1.5-4.0, dk yel-orng & pale yel-brn, Fe, slty, cly, bdd. NW NW SE

542 ss; vf-f, 2.5-4.0, gy-orng & dk yel-orng, Fe, much silt, cly, bdd. NW NW NE

543 ss; vf, 3.0-4.0, few 2.0-2.5, yel-gy, slty, cly/ lrg irreg lenses of aren yel-gy cly, bdd. NW SE SE

544 ss; f-med, 1.0-2.5, few 3.0-3.5, lt-brn, Fe, locally contains much cse-v cse qtz grains, few pbls up to 1.5 cm across, bdd. NW SE SE

545 ss; f-med, 1.5-2.5, some 3.0, v pale-orng/some dk yel-orng Fe stain, sbang, bdd. NW SE SE

546 cly; mod red-brn/some dk yel-orng stain, Fe.
NW SE SW

547 sltst; yel-gy, bdd, interbdd/gy-red cly.
NW SE SW

548 ss; vf, 3.0-4.0, lt olv-brn, Fe cly, bdd.
SW SW NW

549 cgl; lt-brn, Fe, pbls up to 3.0 cm across make up 50-60% of rock, matrix is sltst/some vf-cse qtz grains, bdd. SE NE SW

550 sltst; v pale-orng/some dk yel-orng Fe stain, some vf qtz grains, cly, bdd. SW SE SW

551 cly; lt olv-gy/some dk yel-orng Fe stain.
SW SE SW

552 ss; f-med, 1.0-2.5, lt-brn and gy-orng, Fe, rd, cly, bdd. SE SW SE

553 ss; f-med, 1.5.3.5, few 3.0-4.0, yel-gy/dk yel-orng Fe stain, much cly, bdd. SE NW SE

554 cly; yel-gy/some dk yel-orng Fe stain. NE SW NE

555 ss; vf, 3.5-4.0, dk yel-orng, slty, v cly, Fe, bdd. NW SW SW

556 ss; vf-f, 3.5-4.0, few 2.0, v pale-orng and gy-orng, Fe, cly, bdd. SW NE SE

557 cly; mod olv-brn. SW SW SW

558 sltst; yel-gy/some dk yel-orng Fe stain, cly, some vf qtz grains. SE SW SW

559 ss; f, 2.0-2.5, few 3.0, dk yel-orng, Fe, sbang, bdd. SE SW SW

560 ss; vf-f, 2.0-3.5, lt-brn/some v pale-orng, Fe, cly, bdd. SW SE SW

561 cly; yel-gy/much gy-red Fe stain, some vf-f qtz grains, calc. SE SW SE

562 ss; f-med, 1.0-2.5, lt-brn, Fe, cly, bdd. SE SE SW

563 cly; lt-brn, Fe. NE NE SE

564 ss; vf-f, 2.0-4.0, pale yel-brn/mod-brn and dk yel-orng Fe stain, slty, much cly, in part an aren cly, bdd. SW NW NW

565 ss; f-med, 1.5-2.5, lt-brn, Fe, sbang, cly, bdd. SE SW SW

566 ss; vf-f, 2.5-4.0, lt-brn, few med qtz grains, cly, slty, Fe, bdd. NW SW SW

567 ss; f, 2.0-2.5, dk yel-orng, Fe, sbang, cly, bdd. SE SW SE

567a ss; vf, 3.0-4.0, few 2.5, pk-gy, much silt, cly, bdd. SE SE SE

568 sltst; yel-gy/some dk yel-orng Fe stain, many vf qtz grains, cly, bdd. SW SE SW

569 cly; dusky-yel, Fe, few vf-f qtz grains. NW NE NW

570 ss; vf, 3.0-4.0, few 2.0-2.5, gy-orng, Fe, much slt, cly, bdd. NE SW NW

571 ss; f, 2.5-3.0, few 3.5, lt-brn, Fe, cly, bdd.
SE NW NW

572 ss; vf, 3.0-3.5, some 4.0, gy-yel, Fe, contains irreg frags of vf ss (see 573), bdd.
NW NW SW

573 ss; vf, 3.0-4.0, yel-gy, slty, cly, occurs as irreg frags in 572. NW NW SW

574 ss; vf-f, 2.5-3.5, some 1.5-2.0, gy-orng, Fe, sbang, cly, bdd. NW NW SW

576 ss; f, 2.0-2.5, some 3.0-3.5, gy-orng, sbang, cly, bdd. NE NE NE

577 sltst; yel-gy, cly, some vf qtz grains, bdd.
SE SE SE

579 cly; pale yel-brn, some vf-f qtz grains. SE SE SE

580 ss; vf, 3.0-4.0, some 2.5, yel-gy/dk yel-orng Fe stain, slty, cly, bdd. SE SE SE

581 ss; f-med, 1.5-2.5, few 3.0-3.5, dk yel-orng, Fe, cly, bdd. SE SE SE

582 ss; f-med, 1.5-2.5, few 3.0, lt brn, Fe, slty, cly, bdd. SW SW SE

583 ss; vf-med, 1.5-4.0, dk yel-orng, Fe, cly, bdd.
NE NE NE

584 ss; f-med, 1.0-3.0, few 3.5-4.0, dk yel-orng, Fe, cly, bdd. NE NE SE

585 cly; pale-brn, Fe. SW SE SW

586 ss; med-cse, 0.0-2.0, some 2.5-3.0, gy-orng, Fe, contains few irreg frags of dk yel-orng cly and sltst, bdd. SW SW SE

588 ss; med-cse, 0.5-1.5, dk yel-orng, Fe, cly, bdd. SW SW SE

589 ss; f, 2.0-3.0, few 1.5, brn-gy, sbang, cly, bdd. SW SE SE

590 ss; vf, 3.0-4.0, dk yel-orng, Fe, cly, bdd. SW SE SE

591 ss; vf-f, 2.5-4.0, few 2.0, dk yel-orng, Fe, much slt, cly, bdd. NE NE NE

592 ss; vf-med, 1.5-4.0, dk yel-orng, Fe, slty, cly, bdd. NW NW NE

593 sltst; yel-gy and pale red-brn, cly, few vf qtz grains, Fe, bdd. SW NW NW

594 ss; f-med, 1.5-2.5, gy-orng, Fe, sbang, bdd. NW SW SW

596 ss; med, 1.5-2.0, few 2.5, v pale-orng/some gy-orng Fe stain, sbang, slty, cly, bdd. SW NW NW

597 ss; med, 1.0-2.0, few 2.5-3.0, dk yel-orng/some gy-brn stain, Fe, cly, bdd. NW SW SW

598 ss; vf, 4.0, v pale-orng/much gy-yel Fe stain, much slt, cly, bdd. SE SW SE

599 ss; vf, 3.5-4.0, some 3.0, dk yel-orng, cly, Fe, bdd. SW SE SE

600 cly; yel-gy/some dusky-yel Fe stain, few vf qtz grains. SW SE SE

601 cly; mod-brn/some pale yel-brn, some vf qtz grains, Fe. SW SE SE

602 ss; vf, 3.5-4.0, dk yel-orng, slty, cly, Fe, few f qtz grains, bdd. SW SE SE

603 ss; f, 2.0-3.0, lt-brn, many frags of yel-gy cly and cly ss, few med qtz grains, cly, Fe, bdd. SE SW SW

605 ss; f, 2.0-3.0, dk yel-orng and lt-brn, Fe, sbang, cly, bdd. SE SE SE

606 ss; f, 2.0-3.0, few 3.5-4.0, dk yel-orng, Fe, much slt, cly, bdd. SE SE SE

607 ss; vf, 4.0, yel-gy, much slt,cly, bdd. NE NW NW

608 ss; f, 2.0-3.0, gy-brn, asph, sbang, bdd. NE NW NW

609 ss; f-cse, 0.5-2.5, few -2.0-0.0, dk yel-orng, Fe, cly, bdd. SE SW SW

610 cly; lt olv-gy/much mod-brn Fe stain, locally contains many f-med qtz grains. SE SW SW

611 ss; vf-f, 2.0-3.5, v pale-orng, sbang, sdd. NE NW NE

612 ss; vf, 3.5-4.0, yel-gy, slty, cly, bdd. NE NW NE

613 cly; lt olv-gy/dk yel-orng Fe stain, some vf qtz grains. NE NW NE

616 ss; f-med, 1.5-2.5, yel-gy, cly, NW NW SW

617 ss; f, 2.0-3.0, gy-orng, Fe, cly, bdd. NW SW SW

618 ss; f-med, 1.0-2.5, v pale-orng/some lt-brn Fe stain, cly, slty, bdd. NE NW NE

622 cly; yel-gy and dk yel-orng, Fe, many vf qtz grains. SW NW SW

623 ss; f, 2.0-3.0, yel-gy/dk yel-brn Fe stain, sbang, cly in part, thin lenses of pal-olv cly, bdd. SW SE SW

628 ss; vf, 3.0-4.0, few 2.5, dk yel-orng, Fe, cly, bdd. SW NW SW

630 ss; f-med, 1.5-2.5, lt-brn, Fe, few frags of yel-gy aren cly, bdd. NW NW SW

631 ss; f-med, 1.5-2.5, few 3.0-3.5, dk yel-orng, Fe, sbang, bdd. NW NW SW

633 ss; med, 1.0-2.0, lt-brn, Fe, cly, bdd. SE SE NE

634 ss; med, 1.0-1.5, some 2.0, lt-brn, Fe, rd, bdd. SE SE NE

635 ss; med, 1.5-2.0, few 2.5, lt-brn, Fe, cly, bdd. SE SE NE

636 ss; f-med, 1.0-2.5, some 3.0-4.0, dk yel-orng, Fe, cly, slty, bdd. SW NW SW

637 ss; f-med, 1.5-3.0, few 3.5-4.0, v pale-orng, cly, bdd. SW SW SW

640 ss; f-cse, 0.5-2.5, dk yel-orng, Fe, cly, bdd.
NE NW SW

646 ss; f, 2.5-3.0, some 3.5-4.0, gy-yel, Fe, slty, bdd.
SE NE SE

647 ss; vf, 4.0, yel-gy/mod-yel Fe stain, much silt,
cly, bdd. SE NE SE

651 ss; med-cse, 0.0-2.0, v pale-orng/much dk yel-orng
Fe stain, rd, much cly, few granules to 4.0 mm,
bdd. NW NE NE

652 ss; f, 2.0-2.5, some 3.0, lt-brn, Fe, cly, bdd.
SW NW NW

653 ss; f, 2.0-2.5, v lt-gy, some gy-orng Fe stain
coating, calc, cly, bdd. SW NW NW

654 ss; vf-f, 2.5-4.0, yel-gy, cly, slty, bdd.
SW NW NW

655 ss; vf-f, 2.0-4.0, lt-brn, Fe, slty, cly, bdd.
SW NW NW

658 ss; f-med, 1.0-2.5, lt-brn, Fe, sbang, cly, bdd.
SW SW SE

663 ss; med, 1.0-2.0, some 2.5, gy orng-pk, bdd.
NW SW NW

666 ss; f, 2.0-3.0, few 1.5, gy-orng/some dk yel-orng,
Fe, cly, bdd. SE SE SW

674 cgl; -3.0-0.0, some 0.5-1.0, dk yel-orng, Fe, cly,
bdd. SW NW NW

675 ss; med, 1.0-1.5, lt-brn, Fe, cly, bdd. SW NW NW

676 ss; med, 1.0-2.0, few 0.5 and 2.5-3.0, lt-brn and gy-orng, Fe, cly in part, bdd. SW SW NW

681 ss; f-med, 1.0-3.0, dk yel-orng, Fe, cly, bdd. NE NE NE

684 ss; med, 1.0-2.0, few 0.0-0.5, gy orng-pk/much dk-yel-orng Fe stain, cly, bdd. NW NE NW

692 ss; f, 2.0-3.0, v pale-orng/pale yel-orng Fe stain, cly, bdd. C SE

699 ss; vf, 3.5-4.0, few 3.0, v pale-orng/few spots of dk yel-orng Fe stain, cly, bdd. NE NW SE

704 ss; med, 1.0-2.0, lt-brn, Fe, cly, bdd. SE SE SE

710 ss; f, 2.0-2.5, some 1.5, gy-orng, Fe, cly, bdd. NW NW SW

711 ss; f, 2.0-3.0, some 3.5, gy-orng, Fe, cly, bdd. SW SW NW

712 ss; f, 2.0-3.0, some 3.5, dk yel-orng and lt-brn, Fe, cly, bdd. NE NE NE

713 ss; f, 2.0-3.0, some 1.5, gy-orng, Fe, sbang, cly, bdd. SE SE SE

717 ss; f, 2.5-3.0, lt-brn, Fe, bdd. SW SW SW

719 ss; f, 2.0-2.5, pale yel-brn, sbang. SE SW SE

720 ss; vf-f, 2.5-4.0, dk yel-orng, Fe, v slty, cly, bdd. NW SE NE

723 sltst; v pale-orng/some dk yel-orng Fe stain, some vf-med qtz grains, cly, bdd. SW SW SW

724 ss; f-med, 1.5-2.5, lt-brn, Fe, slty, cly, bdd.
SE SW SE

725 sltst; v pale-orng/some gy-orng Fe stain, cly, bdd.
NW SW SW

726 cly; med-gy/some dk yel-orng Fe stain. NW SW SW

727 sltst; v pale-orng/gy-orng and dk red-brn Fe stain, some vf qtz grains, cly, bdd. NW SW SW

729 ss; f, 2.5-3.0, few 3.5, gy-orng, Fe, sbang, bdd.
SE SE NE

730 ss; f-med, 1.5-2.5, dk yel-orng, Fe, sbang, cly, bdd. C

732 sltst; dk yel-orng/some gy-blk, Fe, cly, bdd.
SW SW NW

733 ss; f, 2.5-3.0, v pale-orng, sbang, slty, cly, bdd.
SE NE SE

734 ss; vf-f, 2.5-3.5, dk yel-orng, cly, Fe, bdd.
SE NE SE

737 sltst; yel-gy, v cse-grained slt, some vf qtz grains, cly, bdd. NW SE SE

740 ss; vf-f, 2.5-4.0, dk yel-orng, Fe, cly, slty, bdd.
SE SW SE

742 weathered Paleozoic sh; wh and yel-gy, flaky.
SE NE SE

743 cgl; v lt-gy/dk yel-orng Fe stain, qtzt pbls up to 5.0 cm across make up 60-70% of rock, pbls cemented in matrix of vf ss, bdd. SE SE SE

746 ss; f, 2.0-3.0, gy-orng and gy orng-pk, Fe, sbang, bdd. SE SE NE

757 ss; vf-f, 2.0-4.0, v pale-orng/some lt-brn Fe stain, cly, slty, bdd. NE SW SE

758 ss; f-med, 1.5-2.5, lt-brn, Fe, sbang, cly, bdd. SW NE NE

760 ss; med-cse, 0.0-1.5, lt-brn, Fe, few granules and pbls up to 1.0 cm across, cly, bdd. C

761 ss; f, 2.0-3.0, v pale-orng/some dk yel-orng Fe stain, sbang, slty, bdd. NE SE NE

762 ss; vf-med, 1.5-3.5, dk yel-orng, Fe, slty, cly, pos worm burrows(?), bdd. SW SW SW

764 ss; f, 1.5-2.0, lt-brn, Fe, slty, bdd. NE SE NE

765 ss; f-med, 1.0-3.0, dk yel-orng, Fe, sbang, cly, bdd. NE SE NE

769 ss; vf, 3.0-4.0, dk yel-orng, slty, cly, Fe, bdd. SW SW NE

774 ss; vf, 3.0-4.0, dk yel-orng, Fe, cly, slty, bdd. SE SE SE

776 ss; f-med, 1.5-2.5, gy-orng, sbang, Fe, bdd. SE SE SE

778 ss; vf-f, 2.0-4.0, v pale-orng/few small spots of gy-orng Fe stain, cly, slty, bdd. SE SE SE

783 ss; f-med, 1.5-2.5, few 3.0, v pale-orng, cly, bdd. SE SE SE

788 ss; f, 3.5-3.0, yel-gy/few spots of dk yel-orng Fe stain, sbang, cly, bdd. SE SE SE

791 ss; vf, 3.0-4.0, gy-orng, Fe, cly, slty, bdd. SE SE SE

796 ss; vf-f, 2.5-4.0, v pale-orng, Fe, cly, bdd. SW SW NW

809 cly; pale red-brn/dk yel-orng stain, Fe, many vf-f qtz grains. SW NW NW

811 ss; vf-f, 2.0-4.0, yel-gy/dusky-red and dk yel-orng Fe stain, slty, cly, bdd. SW NW SW

812 ss; f-med, 1.5-2.5, few 3.0, lt-brn, Fe, sbang, cly, bdd. NW NW SW

813 ss; f-med, 1.5-3.0, lt-brn, Fe, cly, bdd. SW SW SW

819 ss; vf-med, 1.5-4.0, v pale-orng/much lt-brn Fe stain, much cly, slty, bdd. NE SW NW

821 ss; vf, 3.0-4.0, dk yel-orng, Fe, cly, slty, bdd. NW SW NW

830 sltst; yel-gy, cse slt, few spots gy-orng Fe stain, some vf qtz grains, bdd. E1/2 NE

833 sltst; lt olv-gy, v cse-grained slt, cly, bdd. E1/2 NE

835 sltst; yel-gy, v cse-grained slt, cly, bdd. E1/2 NE

836 sltst; yel-gy, v cse-grained slt, cly, bdd. E1/2 NE

846 ss; vf, 3.5-4.0, some 1.5-3.0, wh, cly, bdd.
SE NE NE

847 sltst; v pale-orng and gy-orng, Fe, cly, bdd.
SE NE NE

848 ss; f, 3.0-3.5, yel-gy, cly, bdd. SE NE NE

852 ss; f, 2.5-3.0, some 3.5-4.0, v pale-orng/some dk yel-orng Fe stain, slty, cly, bdd.
SE NE NW

854 sltst; v pale-orng/lt-brn Fe stain, many vf qtz grains, cly, bdd. SE NE SW

857 weathered Paleozoic ss; vf-med, 1.0-4.0, mod orng-pk, Fe, slty, cly, bdd. C

858 ss; f-med, 1.5-3.0, few 3.5-4.0, gy-orng, Fe, slty, cly, bdd. SE SE NE

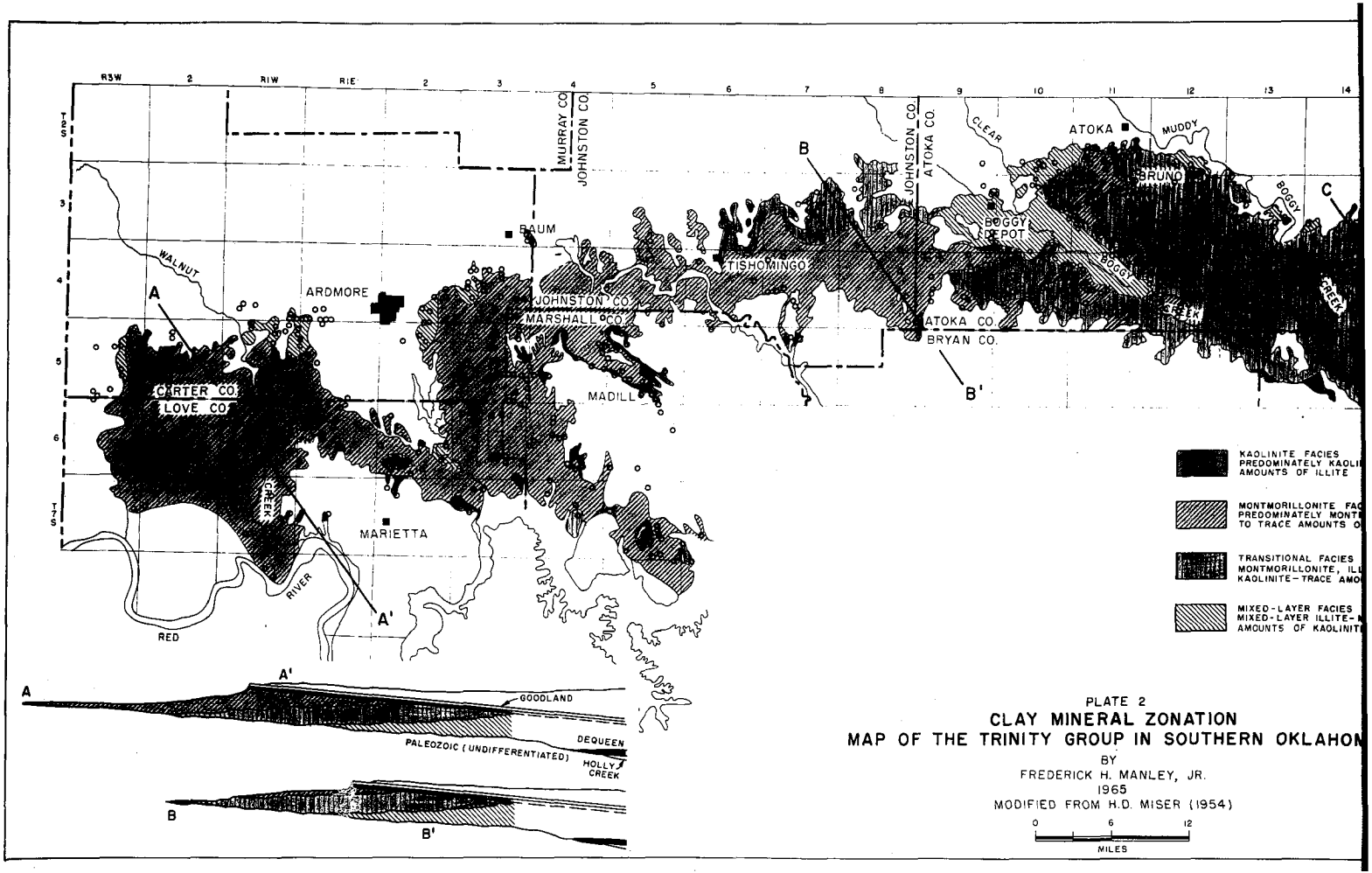


PLATE 2

CLAY MINERAL ZONATION MAP OF THE TRINITY GROUP IN SOUTHERN OKLAHOMA

BY
FREDERICK H. MANLEY, JR.

1965

MODIFIED FROM H.D. MISER (1954)

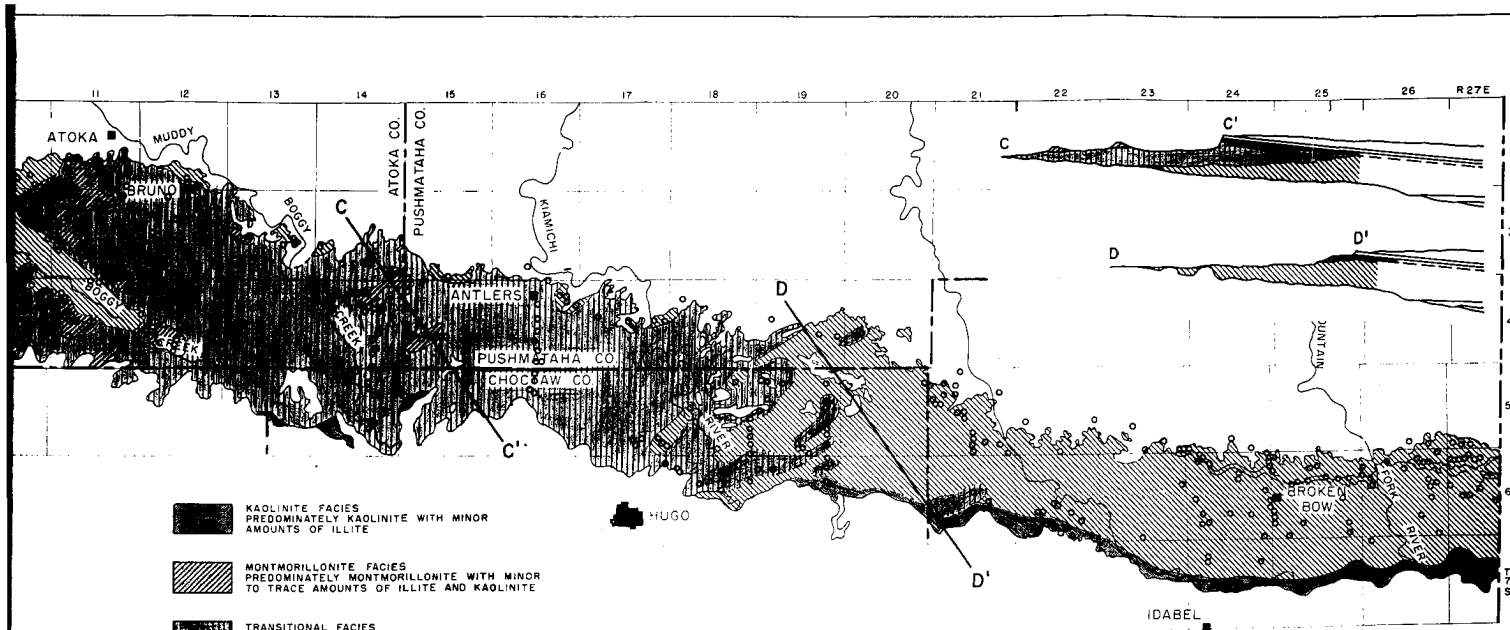


PLATE 2

MINERAL ZONATION
Y GROUP IN SOUTHERN OKLAHOMA

BY

EDERICK H. MANLEY, JR.

1965

IED FROM H.D. MISER (1954)

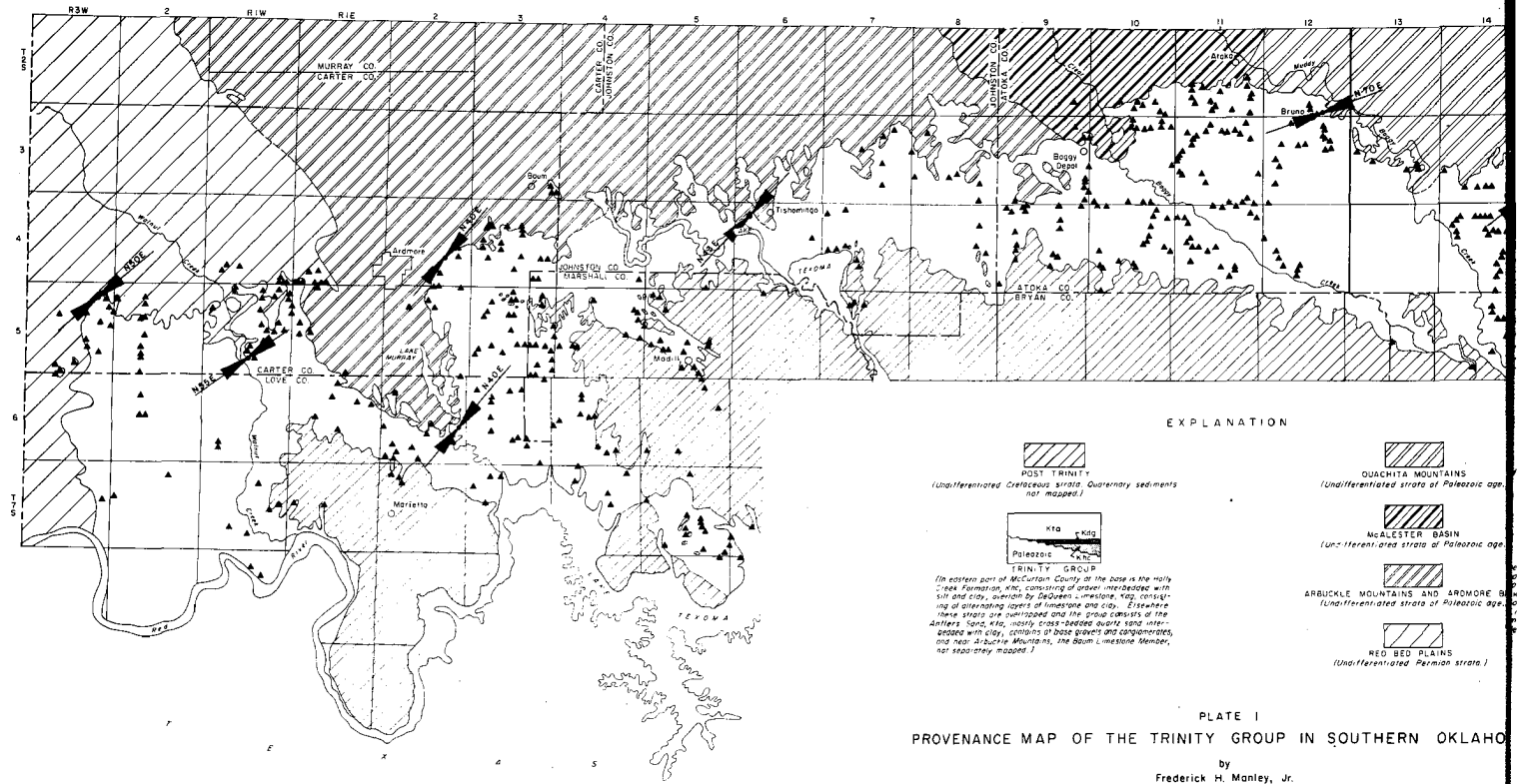


PLATE I

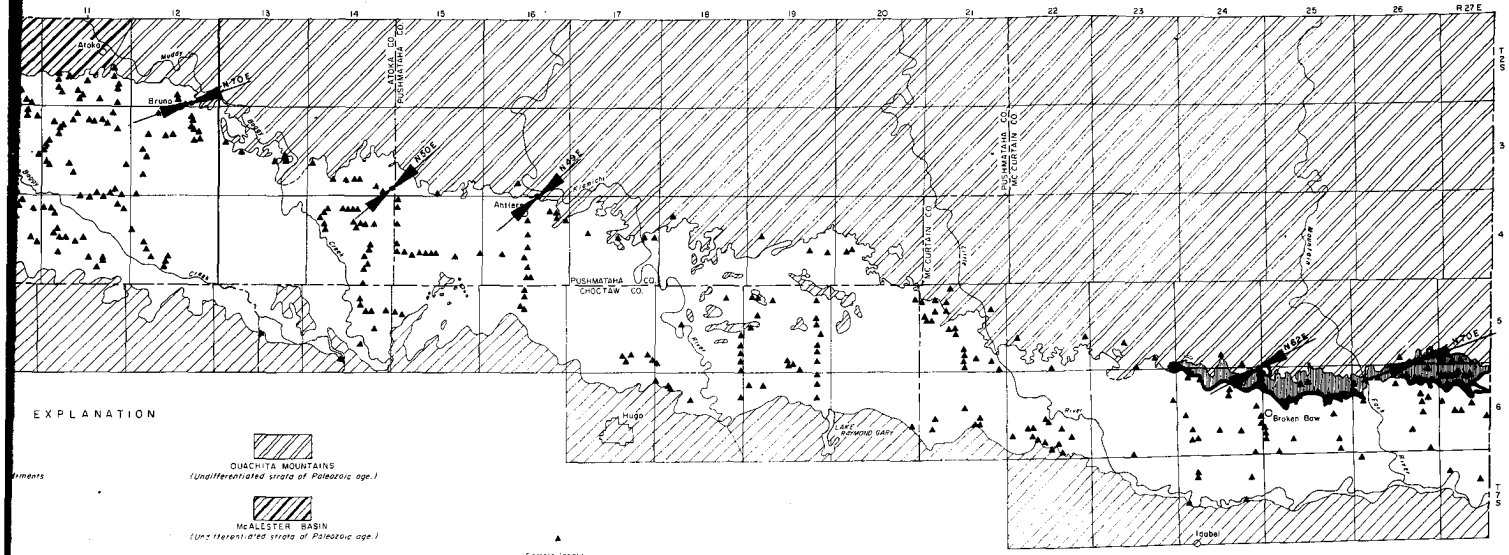
PROVENANCE MAP OF THE TRINITY GROUP IN SOUTHERN OKLAHO

by

Frederick H. Manley, Jr.

1965

Modified from H.D. Miser (1954)



EXPLANATION

OUACHITA MOUNTAINS
(Undifferentiated strata of Paleozoic age.)

McALESTER BASIN
(Undifferentiated strata of Paleozoic age.)

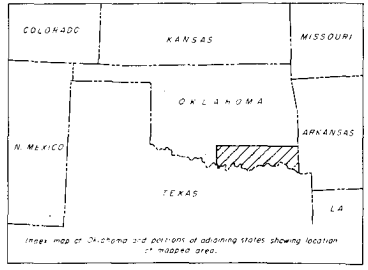
ARBUCKLE MOUNTAINS AND ARDMORE BASIN
(Undifferentiated strata of Paleozoic age.)

RED BED PLAINS
(Undifferentiated Permian strata.)

Sample locality

N 70 E

Gravel orientation plot. Shoreline trend indicated by azimuth. Sea advance from S E.



Index map of Oklahoma and portions of adjoining states showing location of mapped area.

PLATE I

TRINITY GROUP IN SOUTHERN OKLAHOMA

by

Frederick H. Manley, Jr.

1965

Modified from H.D. Miser (1954)

6 0 12

MILES