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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

PETROLOGY AND TRACE ELEMENT GEOCHEMISTRY OF THE DE QUEEN FORMATION (CRETACEOUS), SOUTHWEST ARKANSAS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

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degree of

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BURT E. HAMRIC

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PETROLOGY AND TRACE ELEMENT GEOCHEMISTRY OF THE DE QUEEN FORMATION (CRETACEOUS), SOUTHWEST ARKANSAS

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PETROLOGY AND TRACE ELEMENT GEOCHEMISTRY OF THE DE QUEEN FORMATION (CRETACEOUS), SOUTHWEST ARKANSAS

INTRODUCTION

Purpose of Investigation

The purpose of this investigation has been to make a detailed study of the carbonate and sulfate petrography, clay mineralogy, and the trace element geochemistry of the Lower Cretaceous DeQueen Formation in southwestern Arkansas. Data obtained from this study have been used in an attempt to interpret the composition and location of source rocks, the mechanical and chemical aspects of the various depositional environments, and the post-depositional history of the DeQueen sediments. Relationships between petrography and trace element geochemistry are illustrated.

The DeQueen section is well suited for detailed petrographic, mineralogic, and chemical studies due to the lack of post-depositional structural deformation and igneous activity. Recrystallization does complicate the

interpretation of many of the carbonate rocks. It is intended that the data and interpretations presented be of significant value as a model or framework for investigation of other similar stratigraphic sequences.

Location and Description of Area

The outcrop of the DeQueen Formation in southwestern Arkansas extends from about three miles south of Murfreesboro, in Pike County, to six miles west of DeQueen, in Sevier County. As is illustrated by Figure 1 and Plate 1, the exposure is a narrow, somewhat sinuous band, which is commonly less than two miles wide. The entire length of the outcrop in southwestern Arkansas is in Township 8 South, extending approximately 46 miles from Range 25 West into Range 31 West. The outcrop extends approximately 22 miles into Oklahoma.

Physiographically, the area lies within the West Gulf Coastal Plain province. Most of the land surface is gently undulating, although it is dissected by several southward-flowing streams. A rather gentle scarp is formed by the resistant DeQueen limestone beds. Along much of the outcrop belt random ledges and boulders are exposed, but the rocks are more commonly concealed by five to ten feet of

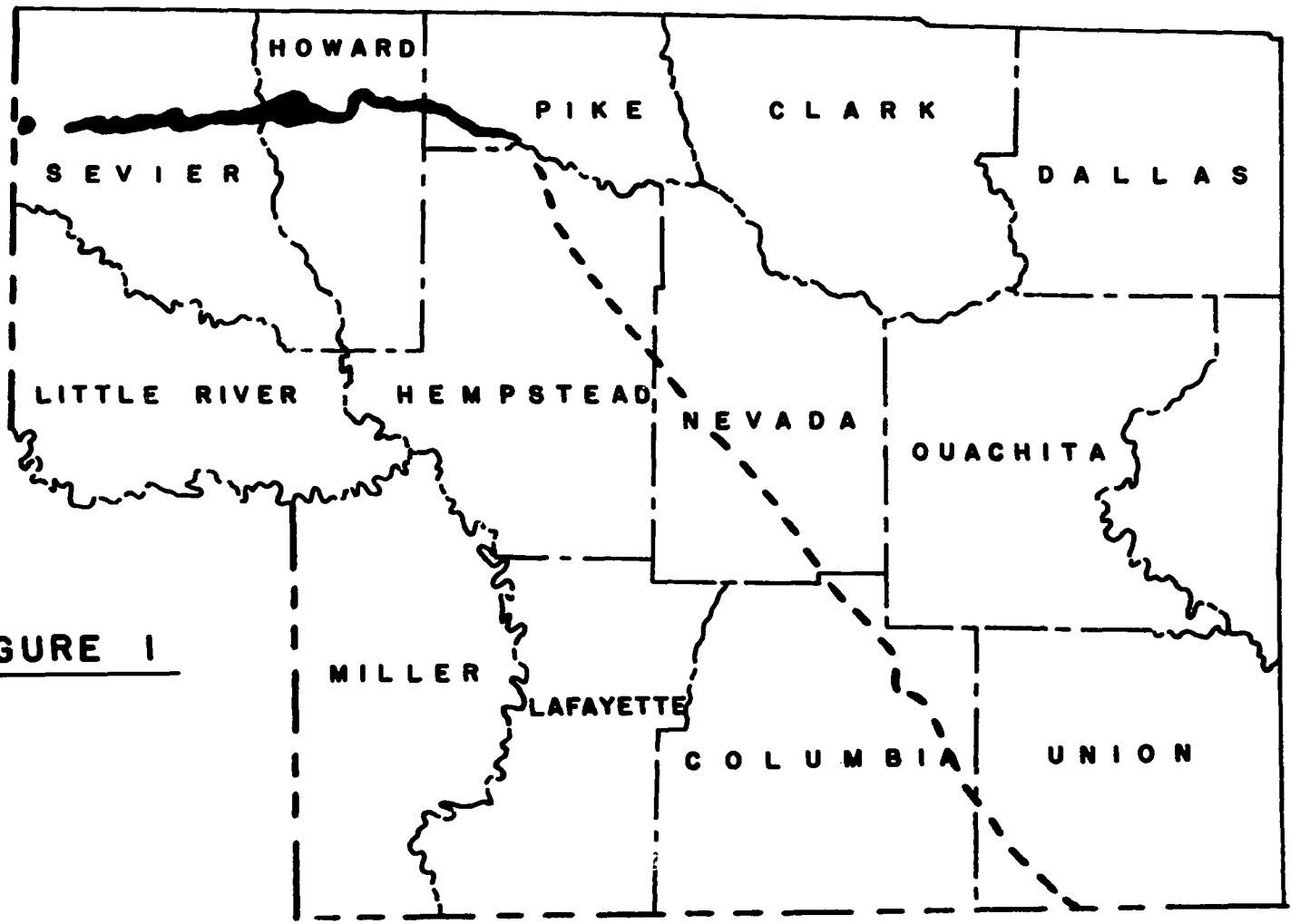


FIGURE 1

LOCATION MAP SHOWING DE QUEEN OUTCROP AND EASTERN SUBSURFACE LIMIT IN SOUTHWEST ARKANSAS.

soil cover. The soil supports pine forests and hawthorn thickets. Due to the soil and vegetation cover, detailed sampling of the formation was generally confined to road cuts, railroad cuts, and gypsum quarries. Quarries are confined to the eastern part of the outcrop belt.

Previous Investigations

Investigation of the DeQueen Formation has generally been confined to regional studies of the Trinity Group or Comanchean rocks. The writer has found no published detailed work on the petrology and geochemistry of the DeQueen Formation in southwestern Arkansas.

The "Trinity Division" was named and described by R. T. Hill in 1888. His description of the then unnamed limestone and gypsum sections within the Trinity is rather vague. A faunal list was included in his work.

The "DeQueen Member" was named in 1918 by H. D. Miser and A. H. Purdue during their study of the gravel deposits of the Caddo Gap and DeQueen quadrangles. These geologists made a most significant contribution by their mapping, lithologic description, and stratigraphic interpretation of the Trinity Group in the above mentioned quadrangles (1927 and 1929).

Paleontology of the formation was studied by H. C. Vanderpool (1928), and an investigation of Comanchean pelecypods and gastropods was completed by T. W. Stanton in 1947.

A great deal of information has been published on the subsurface portion of the Trinity Group, but equivalents of the DeQueen Formation have generally been neglected. An exception was the work of J. M. Forgotson, Jr. (1956, 1957, and 1963), which was primarily an interpretation of stratigraphy and geologic history based on electric log data. His study did, however, include some petrographic analyses of outcrop and core samples, particularly from the subsurface Ferry Lake Anhydrite.

M. E. May (1950) mapped the outcrop of the DeQueen Limestone in Oklahoma, described its physical characteristics, and listed the fossils contained in the formation.

Methods of Investigation

Initial field reconnaissance and sampling of the DeQueen Formation was performed during April and May, 1964. As previously mentioned, natural outcrops of the formation are poorly exposed, and the detailed nature of the project required close stratigraphic control. For this reason, most

of the sampling and measurement of sections was confined to artificial exposures. Field work was completed during the winter months of 1964. Representative samples were collected at intervals ranging upward from six inches, depending on variation in lithology and the nature of the exposures.

Although the study was primarily concerned with outcropping beds, electric logs from randomly located wells throughout southwestern Arkansas were used to supplement published subsurface information and to clarify stratigraphic relationships. Commercial sample logs were of little value due to their lack of detail.

Petrology of the carbonate and sulfate rocks is based mainly on thin section examination with a petrographic microscope, supplemented by the study of polished, etched, and stained surfaces. Carbonate thin sections were described using a combination of the classifications proposed by Folk (1962), and Dunham (1962). X-ray diffraction analyses were used extensively for positive mineral identification.

Mineralogy of the argillites was determined by x-ray diffraction analyses of bulk and size-fractioned samples. Six argillite thin sections were examined to determine sedimentary fabric.

Variation in exchangeable cations of the clay minerals

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Variation in exchangeable cations of the clay minerals

with respect to stratigraphic position was investigated by flame photometry.

Emission spectrographic analyses were used in trace element determinations of selected argillite samples.

STRATIGRAPHY

General

The DeQueen unit lacks lateral lithologic homogeneity, and therefore does not meet the specifications of a fundamental rock-stratigraphic unit as prescribed by the Code of Stratigraphic Nomenclature. The term "format" has been suggested by Forgotson (1957), for operational stratigraphic units such as the DeQueen, which do not completely meet the defined requirements. However, the DeQueen rocks have been given the rank of "formation" in this investigation, in compliance with present general usage.

The DeQueen Formation is stratigraphically situated in the upper part of the Lower Cretaceous (Comanchean) Trinity Group. Rocks of the Trinity Group crop out in a narrow belt extending in a westerly direction from southwestern Arkansas through southeastern Oklahoma, and southwestward into Texas. Dip of the beds in Arkansas is typically slightly greater than one degree toward the south. Thickness

of the group at its outcrop ranges from zero in extreme eastern Pike County, where it is overstepped by Upper Cretaceous strata, to more than 600 feet in the vicinity of DeQueen, near the Oklahoma border (Miser and Purdue, 1929).

A pronounced angular unconformity exists at the base of the Trinity, where the Lower Cretaceous strata overstep the truncated edges of folded and tilted Paleozoic rocks. The Trinity Group is an onlapping sequence in which each unit of strata is transgressed by the next overlying unit. Onlap and overstep is toward the north-northwest. Onlap and overstep terminology is taken from Krumbein and Sloss (p. 316, 1963).

A notable unconformity also occurs at the top of the Trinity Group. The plane of this angular unconformity truncates the formations of the Lower Cretaceous, and the Upper Cretaceous Woodbine and Tokio strata overstep toward the east as an onlapping sequence. The foregoing stratigraphic interpretations have been compiled from work by Miser (1927), Miser and Purdue (1929), Forgotson (1963), and Melton (personal communication, Geology 213, 1962). Figure 2 shows the general stratigraphic positions of the outcropping formations of the Trinity Group. Illustrated thickness of the formations is not to scale, but is intended to give a generalized

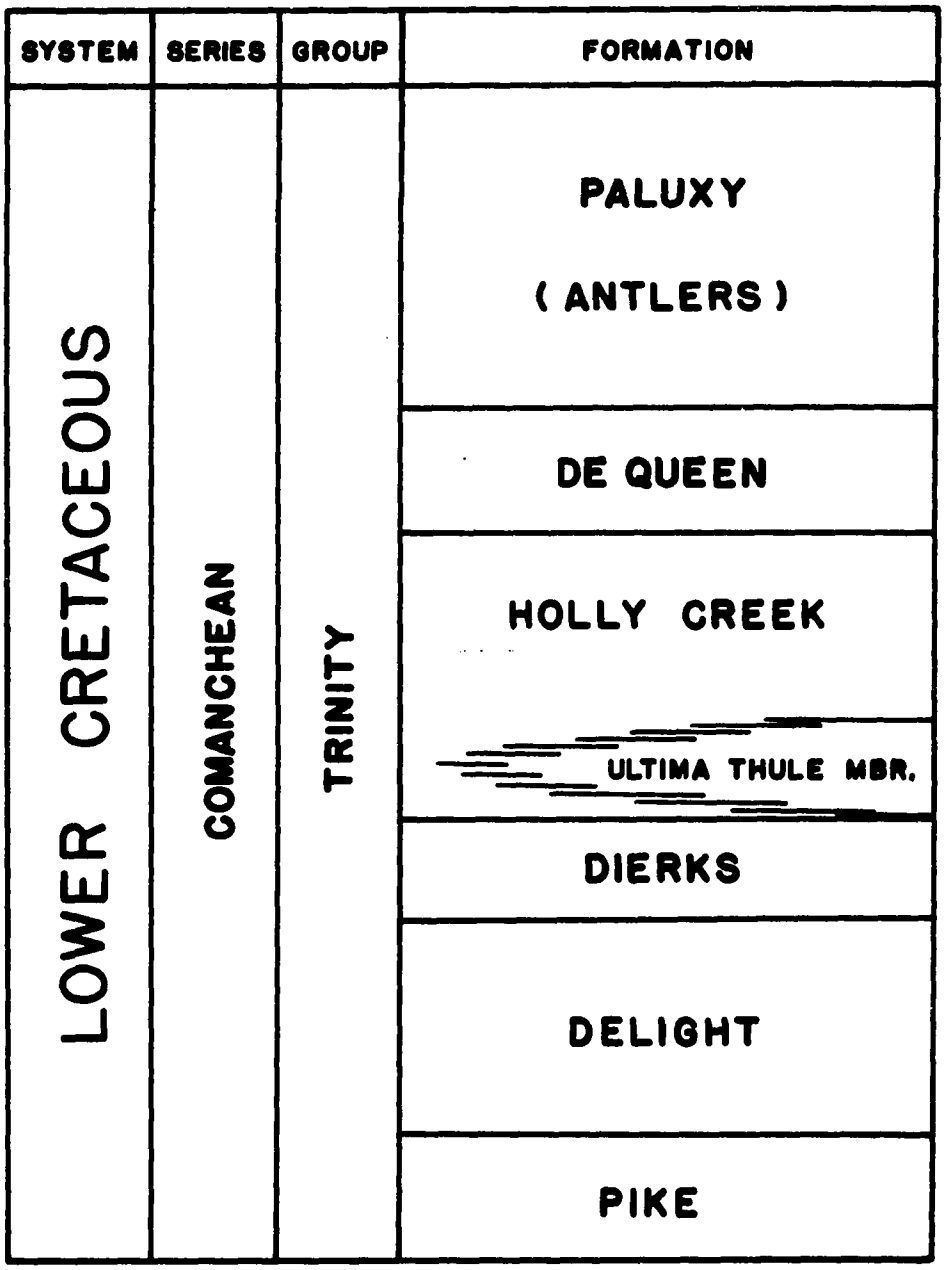


FIGURE 2 - STRATIGRAPHIC SECTION OF THE TRINITY GROUP, SOUTHWEST ARKANSAS.

idea of the relative thicknesses along the outcrop.

DeQueen Formation

Measured sections of the DeQueen Formation are described in detail in Appendix A. The outcrop pattern and measured section locations are shown on Plate 1. Columnar sections of measured sections are illustrated on Plate 2.

Thickness of the DeQueen Formation ranges from zero to 76 feet along its outcrop, and averages about 70 feet in southwestern Arkansas. Greatest thickness was observed at Measured Section 2, where the formation is exposed in an active gypsum quarry. The outcrop is limited on the east by the overstepping Upper Cretaceous rocks. At the DeQueen townsite, the thickness of the formation is 72 feet. It thins by onlap toward the west, and disappears as a "feather edge" six and one-half miles northwest of Broken Bow, Oklahoma.

Base of the formation was selected by the writer as the base of the first carbonate or sulfate bed above the varigated shales and friable sandstones of the Holly Creek Formation. An exception is illustrated by Measured Section 6, where typical DeQueen claystone lies at the base of the formation. Top of the DeQueen was selected as the top of

the first limestone below the coarse clastics of the Paluxy Formation.

The eastern portion of the outcrop area is characterized by two distinct lithologic sequences. The lower half of the formation is dominantly gypsum, whereas the upper part consists of thin limestone beds interbedded with claystone and mudstone. These two parts of the formation will hereafter be referred to as the "sulfate facies" and "carbonate facies," respectively.

In the gypsum quarries at Highland, Arkansas, the gypsum of the sulfate facies is interbedded with gray and greenish-gray claystone and mudstone (Measured Sections 1 and 2). Terminology for argillites described herein follows that of Folk (p. 127-128, 1961). The claystone and mudstone beds are generally less than 18 inches thick. These argillites are normally calcareous, and contain laminae or randomly disseminated euhedral and subhedral crystals of selenite gypsum. Detrital silt-sized quartz grains are disseminated throughout the mudstones, and are present at many places as irregular laminae within the claystones. Although there is a great deal of lateral and vertical variation from claystone to mudstone to clayey siltstone within individual beds, the non-platy, non-fissile character, and apparent lack of extensive

induration of these argillaceous rocks are nearly universal characteristics throughout the formation. The percentage of argillites throughout the formation increases toward the west.

A few thin beds and lenses of limestone are present near the center of the sulfate facies in the Highland quarries. They are commonly gypsiferous or celestite bearing, and have a fairly high clay content (5 to 15%). These carbonates grade rather rapidly into calcareous argillites and gypsum, and only one bed can be correlated between measured sections that are approximately one-half mile apart. Limestone constitutes less than three feet of the sulfate facies, which is 35 feet thick in the quarries. Seventy-five percent of the sulfate facies is composed of saccharoidal to extremely coarsely crystalline prismatic gypsum, with numerous thin beds of satin spar. Color ranges from gray to white to pink, and the bedding varies from thin to very thick. Terminology for thickness of stratification is taken from Ingram (1954).

Four miles southeast of Highland, at Plaster Bluff, Miser and Purdue (p. 83, 1929) reported 10 to 14 feet of gypsum in a single bed, with "as much as 3 feet of interbedded clay in its lower part." After examination of this poorly

exposed outcrop, it is the opinion of the writer that considerably more gypsum is present at this locality, but is covered except for a few isolated exposures. Soil cover and slump from the upper part of the bluff prohibit the identification of marker beds or sequence thicknesses which might be correlative with the section exposed in the Highland quarries.

Three miles northwest of Highland, in Section 18, Township 8 South, Range 26 West, the lower part of the De-Queen Formation is exposed in an abandoned gypsum quarry (Measured Section 3). Thickness of the exposed sulfate facies at this location is 26 feet, although the stratigraphic relationship to the Highland sections indicates that the base of the sequence lies about four feet below the quarry floor. Lithologic character of the rocks is nearly identical to the previously described gypsum beds, but less than one foot of thin-bedded limestone is present in the sulfate facies.

Gypsum is also being mined by Dierks Forests, Incorporated, at Briar Plant, in Section 10, Township 8 South, Range 27 West. The writer was unable to sample and measure the lower part of the formation in the Briar Plant quarry due to company policy which prohibits study of the mine and ore reserves by "outside groups." It was disclosed, however, that approximately 25 feet of commercial grade gypsum is

present in the quarry. The upper part of the formation is partially exposed in a railroad cut just south of the Briar Plant quarry (Measured Section 4). The only bedded sulfate observed is an extremely pure, white bed of saccharoidal gypsum, which is at least three feet thick. The lower part of the bed is covered.

The DeQueen Formation is poorly exposed along State Highway 4, three miles north of Center Point (Measured Section 5). Approximately 40 to 50 feet of the lower part of the formation is covered by soil, and thin-bedded sandy limestone is abundant as float. None is found in situ. The only sulfate observed was a two-inch bed of celestite replacing anhydrite, at the base of the exposed measured section. Although small amounts of gypsum have been reported by Miser and Purdue (1929), none was observed by the writer west of Briar Plant. The only bedded sulfates found west of Center Point are two barite-cemented sandstone beds near the base of the formation, 2½ miles north of Provo (Measured Section 6).

The carbonate facies of the DeQueen Formation overlies the sulfate facies in the eastern part of the outcrop area. The best exposures are in the quarries at Highland. At this locality 40 feet of interbedded limestone and argillites are present. The uppermost limestones form a gentle

dip slope toward the south, and it is considered that they form the top of the formation. Carbonates are actually subordinate in volume to the argillites, and constitute only 35 to 40 percent of the carbonate facies. Claystone and mudstone in the sequence are similar to those interbedded with the underlying evaporites. One bed of claystone in the central part of the carbonate facies has a characteristic light- to moderate-brown color, and can be used as a stratigraphic marker in the area between Highland and Briar Plant. It is not identified west of Briar Plant.

Carbonate rocks in the sequence consist of light- to medium-gray and buff colored limestones which weather to pale yellow and buff. Allochemical constituents are primarily pelecypods, pellets, superficial oolites, foraminifers, and ostracodes. Terrigenous silt and sand sized quartz is fairly abundant in the limestones. Authigenic gypsum or celestite is present in several of the carbonate beds. A small amount of thin-bedded, calcite-cemented siltstone and sandstone is present in the carbonate facies. Individual limestone beds are nowhere greater than 3.8 feet in thickness, and commonly range from one inch to one foot. Rapid lateral and vertical lithologic changes in individual beds are common.

The only well defined stratigraphic marker in the carbonate facies is at the top of the formation, and is a one to 2.5 foot interval of petrographically distinctive limestone. This marker can be identified throughout the outcrop.

Toward the western part of the outcrop area the carbonate facies increases in thickness at the expense of the underlying sulfates. It is the writer's opinion that gypsum is probably present in the vicinity of Provo and Center Point as thin tongues extending from the thicker beds to the east. They are probably interbedded with sediments of the carbonate facies. The gypsum tongues are not exposed at the outcrop owing to their high solubility and masking by soil and vegetation cover. At DeQueen townsite the entire formation consists of typical interbedded limestone and argillite of the carbonate facies. No sulfates were logged in a water well drilled within the city limits, and none was reported by May (1950), in his study of the DeQueen Formation in Oklahoma. The above interpretation is illustrated diagrammatically by Figure 3.

Faunal Assemblage

Only a gross faunal analysis has been made in this investigation. Thorough descriptions of faunal elements in

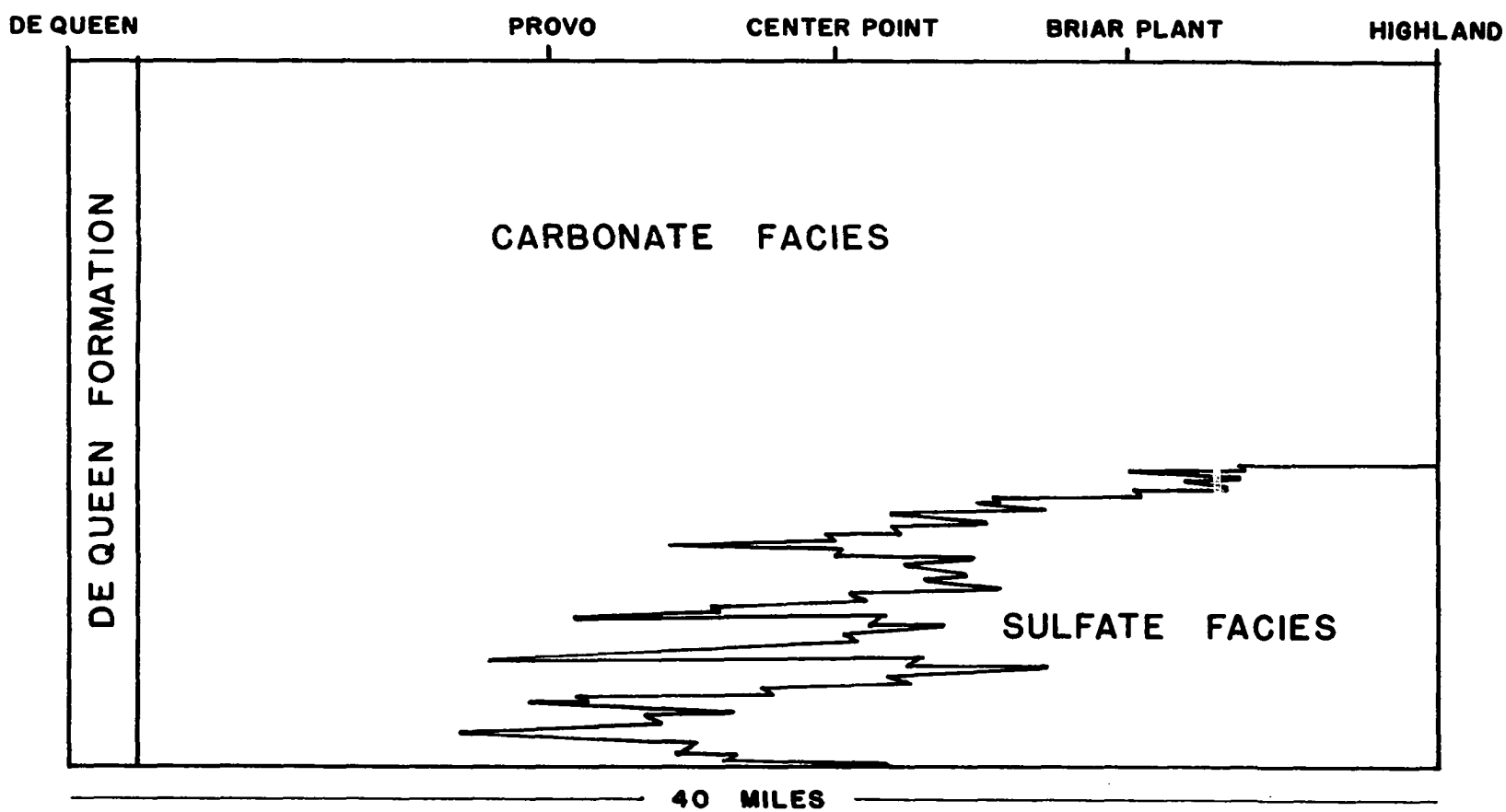


FIGURE 3 - DIAGRAMMATIC CROSS-SECTION OF THE DE QUEEN FORMATION FROM DE QUEEN TO HIGHLAND, ARKANSAS.

the DeQueen Formation are presented by Vanderpool (1928a and 1928b) and Stanton (1947).

According to Vanderpool, most of the fossil forms found in the formation also occur in the Glen Rose of Texas.

Surface - Subsurface Relationships

The subsurface geology of the Trinity Group has been studied extensively by several investigators. In this report, subsurface work has been confined to an examination of electric and commercial sample logs in order to clarify stratigraphic relationships. A petrographic analysis of several core samples and thin sections from cores of the Ferry Lake Anhydrite has also been performed. The following interpretations of the subsurface geology and its relation to outcropping beds of the DeQueen Formation is compiled primarily from the work by Imlay (1949) and Forgotson (1956 and 1957).

The sulfate facies of the DeQueen Formation is correlated with the subsurface Ferry Lake Anhydrite, whereas the carbonate facies is correlative with the lower part of the Mooringsport Formation. Well samples and logs of wells near the outcrop do not exist, and correlation is based primarily on position in the stratigraphic section and on

lithologic and genetic similarity.

The Ferry Lake Anhydrite forms a regional wedge which thickens to the south from its outcrop equivalent. In Miller County, in extreme southwestern Arkansas, it attains a maximum thickness of 250 feet, and is found at a depth of nearly 6000 feet below sea level. Greater thickness is attained farther to the south, in Louisiana. The Ferry Lake lies conformably between the Rodessa and Mooringsport Formations. Mooringsport strata have been given the rank of member by Forgotson, but will be referred to as the Mooringsport Formation herein, in accordance with Imlay and the Shreveport Geological Society.

The Mooringsport Formation consists of marine shale interbedded with clay-bearing and fossiliferous limestone. It lies above the Ferry Lake Anhydrite and below the red shales and sandstones of the Paluxy Formation. Although its lower boundary is fairly abrupt, the upper boundary is transitional. Maximum thickness in southwestern Arkansas is about 730 feet. The Mooringsport grades into the Paluxy Formation both laterally and vertically, accounting for the thinning of the typical carbonate-clay sequence toward the north. Surface exposures of the DeQueen carbonate facies in the eastern part of the outcrop area correlate with the

lower part of the Mooringsport Formation. Surface-subsurface relationships of the DeQueen Formation are illustrated diagrammatically by Figure 4.

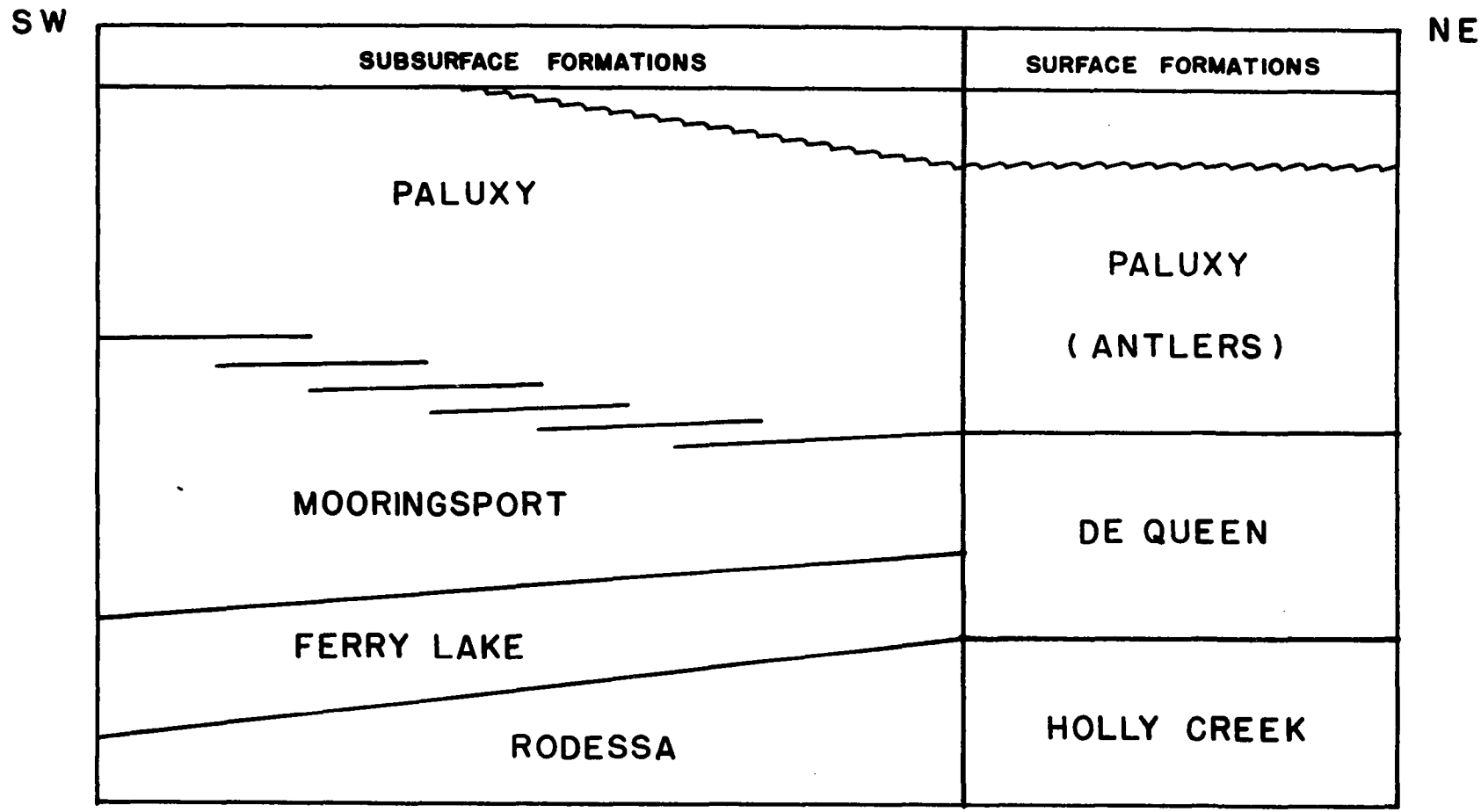


FIGURE 4 - DIAGRAMMATIC CROSS-SECTION SHOWING SURFACE-SUBSURFACE STRATIGRAPHIC RELATIONS OF THE DE QUEEN FORMATION.

CARBONATE AND SULFATE PETROLOGY

Methods and Procedures

A combination of Folk's spectral subdivision of limestone types (1962), and Dunham's classification of carbonate rocks according to depositional texture (1962), was used in the description of carbonate thin sections. Rocks with less than ten percent detrital and allochemical constituents with a micritic matrix are described as calcite- or dolomite-mudstones herein, in order to differentiate them from the mudstones of Folk's classification of mudrocks (p. 127, 1961). Grain-size scale used in all of the descriptions was taken from Folk (p. 74, 1962). Size description of constituents indicates the average or range of sizes, with the measurement having been made along the greatest dimension of the particle or crystal. Studies of polished, etched, and stained surfaces of hand specimens were used to supplement thin section analyses and field observations.

Type of cementing or matrix material, allochemical constituents, terrigenous components, lithologic variations,

and other significant features were recorded for each thin section and rock sample studied. Percentages of constituents were determined by area estimate from thin sections and polished surfaces. In many cases recrystallization and replacement prohibit an accurate estimate.

In all cases where the mineralogy was not determinable with certainty from microscopic examination, powder-pack or powder-slide x-ray diffractograms were utilized.

Descriptions of selected thin sections are included in Appendix B.

Carbonate Petrology

Carbonate rocks of the DeQueen Formation are nearly exclusively limestones, and are primarily confined to the carbonate facies. Limestone constitutes less than 5 percent of the sulfate facies.

Dolomite is absent in the carbonate facies except for a few questionable occurrences as widely disseminated, fine crystals. None was detected in the limestones by x-ray diffraction methods except for a slight trace in the uppermost bed of Measured Section 3. Examination of the thin section indicated less than one percent identifiable dolomite in the form of finely crystalline, subhedral to euhedral

rhombs. Only one example of a relatively pure dolomite rock has been found in the area of investigation. It occurs in a bed slightly less than two inches thick, lying 22 feet above the base of Measured Section 2. The rock is a very fine dolomite-mudstone, and is composed of approximately 40 percent authigenic celestite. Celestite is commonly in the form of subhedral and euhedral, medium to coarsely crystalline porphyroblasts (Plate 3A). Many crystals contain inclusions of the dolomite and have lines or zones of crystal growth. Texture of the dolomite is identical to that of a normal micrite.

A discussion of the origin of dolomite in the two samples noted would be strictly hypothetical, and in view of the lack of sufficient field and petrographic evidence, would be of little value. Let it suffice to say that the similarity of the dolomite-mudstone to common micrite could be equally well explained by the deposition of an allogenic dolomite-mud or by replacement of a calcite-mud. The celestite porphyroblasts are apparently diagenetic in origin, and are present in indistinct laminae. Lamination may be indicative of cyclic influx of strontium, deposited from downward percolating water during early diagenesis.

Limestones in the DeQueen Formation are petrographi-

cally variable both laterally and vertically within individual beds. This is due mainly to an increase or decrease in relative amounts of allogenic constituents. Characteristics of the constituents are fairly consistent throughout the formation. Nearly all of the limestones contain pellets, superficial oolites, foraminifers, ostracodes, pelecypods, and quartz grains in varying amounts. Lesser amounts of algal material and gastropods are also common. Although this is the typical allogenic assemblage, the uppermost three feet of the formation is exceptional, and notably lacking in all of the above listed constituents, with the exception of pelecypods, gastropods, and a few algal fragments (Plate 3, B and C). In addition, small amounts of echinoderm fragments are commonly present in the uppermost limestone. Only a questionable trace of echinoderm material was found in a single sample of the underlying limestone. The petrographically distinctive upper limestone is the only correlative stratigraphic marker in the formation which can be traced from the eastern limit of the outcrop to the Oklahoma boundary. Unfortunately, exposures of this marker bed are generally poor or lacking.

No depositional pattern has been established in the lower part of the carbonate facies. Variation in total

content of allogenic constituents, as well as the proportional variation within the allochemical and terrigenous assemblage is apparently random.

Depositional and Diagenetic Textures

Classification of the carbonate rocks according to depositional texture is commonly hindered by partial to extensive recrystallization of micrite matrix material. Nearly all of the DeQueen carbonates appear to be recrystallized to some extent. The dominant limestone type in the sequence, according to Dunham's classification (1962), is wackestone in the form of calcarenites and calcirudites. The allogenic grains are generally not mutually supporting, but constitute more than 10 percent of the rock. In the majority of the thin sections studied it was necessary to interpret depositional features which had been partially obliterated by recrystallization. In sparse wackestone and calcite-mudstone the interpretation is not difficult, as the constituents must have been mud supported, in accordance with modern theories on carbonate deposition. In the rocks studied, however, it is not uncommon to have gradations from mudstone to wackestone to packstone within a single thin bed. Such cases are considerably more difficult to interpret where

the rocks are recrystallized. Many of the thin sections show excellent evidence of recrystallization, but also illustrate streaks and irregular laminae of what appears to be sparry calcite-cemented grainstone. In this event, it is generally impossible to determine to what extent the intergranular sparry calcite is due to cementation or recrystallization. Disruption by burrowing organisms, which is common, further complicates the interpretation. A few of the beds appear to be disrupted by wave or current action.

Abundance of wackestone, along with lesser amounts of calcite-mudstone, packstone, and a few laminae of grainstone indicate deposition in a relatively low energy environment. Current and wave action were either too feeble to remove the lime-mud which was being deposited, or the rate of deposition exceeded the rate of removal. The small amount of grainstone is indicative of currents of removal with sufficient energy to winnow away part of the micritic ooze matrix or to prohibit its deposition in the environment.

Diagenetic fabric of the DeQueen carbonate rocks appears to be similar to that formed due to recrystallization by grain growth, as described by Bathurst (1958 and 1959). This is not intended as an endorsement or denial of his theory that the dominant type of recrystallization in

carbonates is due to reactions in the solid state, with ions being transferred between lattices without solution. This theory can be proven or disproven only by extensive laboratory experimentation in conjunction with petrographic observations. The fact remains, however, that Bathurst's description and interpretations of recrystallization in the Dinantian limestones can be correlated with the diagenetic fabrics of the DeQueen carbonates.

Evidence is present for grain growth forming fine to coarse mosaics within micritic matrix, as well as for grain growth rims around some fossil fragments. The latter form of grain growth is generally associated with echinoderm fragments as syntaxial rims, and is quite apparent in the uppermost limestones in the formation. Growth rims are also encountered, as interpreted by the writer, enclosing fragments of delicate pelecypod(?) valves in a few of the lower limestones (Plate 3D). In these cases, the sparry calcite does not form an optically continuous syntaxial rim, but occurs as a coating of prismatic to irregularly shaped crystals which have grown approximately perpendicular to the fossil surface. Growth rims at many places appear as rim cementation borders, and in some cases this is the obvious interpretation. In other cases, the growth crystals are in contact

with micritic matrix or microspar, and are definitely not void filling calcite. A few of the rims embay the surfaces of calcite-mudstone pellets. The prismatic shell structure is preserved in some of the fossils, but optical continuity with growth-rim crystals is exceptional, rather than commonplace. It is the writer's belief that the prismatic growth rims may have started developing with the conversion of aragonite shell material to calcite, assuming an original aragonitic shell. Recrystallization continued from nuclei at the shell surface, and with the growth of rim prisms and crystals, the surrounding micrite was incorporated in the lattice. The process of grain growth may have been ionic in the solid state, but pressure solution and redeposition of micrite which was originally between growth prisms and crystals does not seem illogical. Admittedly, the above interpretation lacks laboratory testing, sufficient petrographic analysis, and study of the physico-chemical conditions to thoroughly develop the idea.

Grain growth as a mosaic within micrite matrix is the most common form of recrystallization exhibited by the DeQueen carbonates. Extensive evidence for recrystallization is illustrated by petrographic thin sections, the most prominent being lack of grain support (Plate 3G). In many

samples the larger allochemical constituents appear to be mutually supporting, but close observation reveals that the fine allogenic material appears to be suspended in matrix spar. The grains were actually deposited in a micritic mud which was later recrystallized to microspar and fine- to medium-crystalline sparry calcite. Coarse sparry calcite is present as an apparent recrystallization product, but is much less abundant than the finer crystal sizes.

Most of the DeQueen carbonates contain irregular patches of calcite-mudstone grading into microspar and coarser sparry calcite. Indistinct allochem boundaries grading into matrix spar are common. Recrystallization "ghosts" of allochems are present in many of the limestones (Plate 3E). Pelecypods are nearly all recrystallized to such an extent that internal shell structure is completely obliterated. This is probably due to the conversion of primary aragonite to calcite, and is common in rocks which have undergone little diagenetic alteration.

Grain size of recrystallized matrix mosaics varies irregularly throughout the rocks. Grain boundaries are curved, rather than planar as in typical granular cement and drusy mosaics (Bathurst, 1958).

Allochemical Constituents

Pelecypod shells and fragments are the most common allochems in the DeQueen carbonate facies. They are generally less than one centimeter in greatest dimension, although a bed which lies 39 feet below the top of Measured Section 4 contains valves up to three inches in length. Limestones commonly contain a "fossil hash" of ostracodes and pelecypod fragments. These allochems are less than 0.4 millimeters in length are are contained within the micritic matrix surrounding larger allochems. In many of the calcirudites there is a general gradation from the larger pelecypod material to that contained in the fossil hash. Coarse pelecypod fragments are commonly associated with delicate unabraded valves of the same size or greater, indicating the presence of washed-in material, as well as pelecypods which were inhabitants of the depositional environment. In extensively recrystallized rocks it is difficult to distinguish matrix spar from the sparry valves of pelecypods. Fragments are angular in the majority of samples studied.

In addition to the pelecypod material described above, the uppermost limestone in the formation contains abundant pearly-brown pelecypod and gastropod shell fragments

which have not been recrystallized. These fragments are commonly moderately well rounded, although the rock apparently originated in a low energy environment (Plate 3C). Their iron content is relatively high in comparison with the other allochems, and in weathered portions of the rock they are partially oxidized to hematite and limonite. With the exception of the upper limestone, pelecypods are everywhere associated with some or all of the finer allochems and quartz grains. Identifiable gastropods are generally absent, or present in only trace amounts in the rocks underlying the petrographically distinctive uppermost limestone.

Small amounts of green algae are randomly disseminated in many of the DeQueen carbonate beds. Where present, they commonly constitute less than one percent of the rock. In cross-sectional diameter they are less than 0.4 mm. Greatest observed longitudinal section is approximately one millimeter. These algae are similar to those described by J. H. Johnson as Dasycladaceae of the Class Chlorophyta (Shimer and Shrock, p. 715-717, 1944). An unidentified platy algae is also present in varying amounts throughout the carbonate facies. As with the green algae, these generally constitute a small portion of the limestones. However, in a thin limestone 45 feet above the base of the formation in the western

Highland quarry, platy algae are the dominant allochems (Plate 3F). They comprise approximately 60 percent of the bed, which can be correlated with Measured Section 1, but has not been found west of Highland. Greatest dimension of the plates is approximately four millimeters. All are extensively recrystallized and bear a rim of algal or micritic material which appears to be impregnated into the surface of the algal plates. According to L. Griffith of Continental Oil Company (personal communication, 1965), R. G. C. Bathurst has described similar allochems as crushed pelecypod fragments. This interpretation could not be justified by the writer.

Foramanifers are present in all of the clacarenites and calcirudites of the formation, with the exception of the upper limestone marker bed. They commonly comprise from one to fifteen percent of the limestone bulk, varying throughout the formation. Size of the foraminifers observed is less than 0.3 mm in greatest diameter, generally ranging from 0.15 to 0.2 mm. Vanderpool (1928) reports only rare occurrences of foraminifers in the DeQueen Formation. He identifies those found as undetermined species of Quinqueloculina. Many of these fossils appear to be similar to the miliolid assemblage of the Glen Rose Formation in Louisiana and Texas

(Vanderpool, 1928; Shimer and Shrock, 1944; Griffith, personal communication, 1965). They are shallow water benthonic forms (R. Harris, personal communication, 1965). Minor amounts of uniserial and biserial-uniserial foraminifers were observed in a few of the carbonate beds.

Ostracodes are present throughout the formation in amounts ranging from less than one percent to approximately 15 percent. Quite commonly they are associated with fine pelecypod fragments and other unidentified fossil material within the same size range, forming the previously mentioned fossil hash. Some of the unidentified material may be prisms from the shell structures of clams (W. E. Ham, personal communication, 1965). Greatest dimension of the ostracode shells is 0.4 mm, but most of them range from 0.2 to 0.3 mm. Single valves are generally present, randomly disseminated throughout the rocks. Both valves are preserved together in a few examples. Fragmentation is common, but is not extensive. No attempt has been made in this dissertation to identify or describe the various forms present.

Nonskeletal allochems in the formation are pellets, superficial oolites, and intraclasts. The term pellet, as used herein, does not imply a faecal origin, but indicates spherical, elliptical, and rounded to subrounded, slightly

irregular grains which lack internal structure. Upper size limit for pellets has been set at 250 microns. This limit is actually more natural than arbitrary, as few of the pellets observed exceed 250 microns in diameter. They are commonly in the 100 to 200 micron range. Pellets occur throughout the carbonate facies, in calcarenites, calcirudites, and terrigenous siltstones and sandstones. They are the dominant nonskeletal allochems in the formation, comprising up to 22 percent of a few of the carbonate beds. Faecal origin of pellets is indicated in only two of the thin sections studied, where they have a constant size of approximately 80 microns. They are embedded in a partially recrystallized micrite matrix (Plate 3G). The polished hand specimen illustrates delicate laminations and cross-bedding.

Origin of the more abundant larger pellets cannot be determined with any degree of certainty. Both spherical and irregularly shaped aggregates are commonly found intermixed within a single carbonate bed, and the difference in shape is gradational. Irregular grains are similar to larger intraclasts. This similarity may be indicative that the irregular pellets are simply small intraclasts, which have been derived from the destruction of incompletely consolidated calcite-mud. Deposition followed before the particles were rounded

(Powers, 1962). Another interpretation was given by Illing (1954), who described the growth of irregular, angular aggregates *in situ*, by cementation of originally aragonite particles to sand size.

Superficial oolites are at nearly all places associated with pelletal material and foraminifers. Although superficial coatings are fairly common on pelecypod and ostracode fragments, they are much more abundant on foraminifers and apparently structureless pellets. Superficial oolites generally constitute less than 10 percent of the carbonate beds. Less than 5 percent is typical.

Petrographic evidence indicates that a gradational sequence from irregular micritic aggregates to superficial oolites is probable. The aggregates are rounded into spherical or elliptical pellets, which under favorable conditions in a slightly agitated marine environment are superficially coated. All phases of this proposed gradation are represented in the DeQueen carbonate facies. A common origin is indicated for many of the pellets, coated pellets, and coated fossil material by the fact that this assemblage is frequently partially oxidized to hematite and limonite, whereas the matrix material is not iron stained.

A minor amount of glauconite is disseminated through

the carbonate facies, but is not present in all of the limestone beds. The mineral is dominantly in the form of rounded to subrounded pellets, which in some instances bear a thin superficial coating. It is common for the glauconite pellets to be oxidized, and stained by limonite. Only a trace of demonstrably authigenic glauconite was found in the thin sections studied.

Intraclasts are sparse in the DeQueen carbonates. Those present are less than two millimeters in greatest dimension, and are composed of micrite and silty micrite. Shape of the intraclasts ranges from angular to rounded.

Terrigenous Constituents

Dominant terrigenous material within the limestones of the formation is coarse silt to fine sand-sized quartz. The mineral is present throughout the formation, with the exception of the uppermost limestone beds. It is abundant in many of the calcirudite beds, intermixed with the fine-grained allochem assemblage in the micritic and sparry calcite matrix. In calcarenites quartz is commonly one of the more abundant allogenic constituents. Gradation from extremely quartzose calcarenite to calcite cemented siltstone and sandstone is observed in several of the beds studied.

In many of the highly quartzose beds there are streaks which are characterized by lack of grain support and the presence of partially recrystallized or incompletely washed micrite matrix. The streaks commonly alternate with, or grade into grain supported siltstone or sandstone which is cemented with sparry calcite. This is indicative of fluctuation of current or wave energy at the surface of deposition. Dominant extinction type of the quartz is straight, with other types generally comprising less than 15 percent of the total quartz content. Shape of the grains is subangular to angular in most instances, but evidence of overgrowths is apparent in a few particles. Depositional shape is masked to a great extent by partial replacement of quartz by calcite. Surfaces of the quartz grains commonly have an etched and pitted appearance, and calcite replacement is evident. In some instances entire grains of quartz have been replaced, leaving a replacement "ghost" of granular calcite.

The solubility of calcium carbonate in water is highly dependent on hydrogen ion concentration, and it decreases with increasing pH. The solubility of silica in the range above pH 9 is also strongly dependent on pH, but the relationship is inverse to that of calcium carbonate (Walker, 1962). A feasible explanation for the replacement of quartz

by calcite is the presence of alkaline interstitial water, with a pH greater than 9. Solubilities of calcite and quartz are also dependent on the temperature of interstitial fluids. Through all ranges of pH the solubility of silica increases with increase of temperature, whereas calcite solubility decreases. This inverse solubility relationship suggests the definite possibility of calcite replacement due to increasing temperature with depth of burial (Walker, 1962). A combination of the above physico-chemical conditions is perhaps the best explanation for the replacement phenomenon.

Small amounts of chalcedony are intermixed with common quartz in a few of the carbonate beds. It is always less than one percent of the rock bulk, and except for its presence in the uppermost exposed limestone of Measured Section 3, is confined to the western half of the outcrop area. Most logical source of the detrital chalcedony is from the Arkansas Novaculite and cherts in the Paleozoic rocks to the north.

Detrital chert is commonly associated with quartz in trace amounts. The greatest percentage observed was five percent in fine-grained sandstone. The grains are coarse silt and fine sand sized, and are normally subangular to subrounded. Some chert is pale brown, with a pitted appearance in thin section. Nearly all of the grains are partially re-

placed by calcite. The presence of detrital chert indicates that at least part of the terrigenous material within the DeQueen Formation is derived from a sedimentary source.

Detrital orthoclase, plagioclase, tourmaline, and white mica are present in only trace amounts. Feldspar is normally moderately fresh. All of these detrital minerals, with the exception of mica, fall within the coarse silt to fine sand size range.

Non-carbonate Authigenic Minerals

Gypsum, celestite, hematite, limonite, and pyrite are the only non-carbonate authigenic minerals in the formation. Gypsum is present in only one bed, 15 feet above the base of Measured Section 2. The mineral occurs as elongate subhedral to euhedral monoclinic crystals and irregular patches in fossiliferous, partially recrystallized micrite. Sparry calcite has replaced many of the euhedral crystals, and is present as pseudomorphs after gypsum. Part of the calcite has been replaced in turn by gypsum. Although the petrographic relations are not in all cases clear, it is believed that much of the gypsum that is present was formed during the later stage of gypsum deposition. Few instances have been observed where calcite is obviously replacing

gypsum, but evidence of gypsum replacing calcite is common. Micrite, sparry calcite, pellets, and fossils have been enveloped by the gypsum. Pseudomorphs of sparry calcite commonly have more planar boundaries than the gypsum crystals. Moreover, most of the gypsum crystals are composed of irregular superindividuals (semicomposite individuals), which lack preferred orientation with the euhedral mineral boundaries. Irregular veinlets connect larger patches of gypsum, and in so doing, cut across fossil fragments within the matrix (Plate 4A). Apparently, much of the late gypsum has replaced the pseudomorphs of calcite, and presently occupies the position of the original gypsum. A trace amount of anhydrite is present as inclusions within some of the gypsum. It occurs as irregular grains and fibers which are less than 50 microns in greatest dimension. The presence of the mineral may be indicative that part of the gypsum was formed by the hydration of anhydrite. Evidence is insufficient to determine the genetic relationship with any degree of certainty.

Although none of the other carbonate rocks studied contains gypsum, pseudomorphs of calcite after gypsum are found in several of the limestone beds (Plate 4B). It is the writer's opinion that the original gypsum was deposited during early diagenesis, prior to lithification of the enclosing

micritic sediments, in a manner similar to that recently described for the formation of early diagenetic and penecontemporaneous dolomite and sulfates (Illing and Wells, 1964; Kinsman, 1964; Shinn, Ginsburg, and Lloyd, 1964). After deposition of micrite and allogenic constituents the sediments have been subaerially exposed, possibly as a supratidal mud flat, due to temporary regression of the sea. The incompletely consolidated carbonate muds were occasionally bathed by an influx of sea water, due to extraordinarily high tides or storm waves. There followed a period of subaerial exposure, during which surface evaporation increased the concentration of dissolved salts at and slightly below the exposed surface. Selenite crystals grew within the micrite by displacement and envelopment. According to Kinsman (1964), the sulfates may result from direct precipitation or from reaction of high saline water with the sediments.

Evidence for this interpretation is well illustrated by a thin bed of limestone in the middle of the formation at its type section, in DeQueen townsite (Plate 4E). The lower one inch of the bed (Unit 1, Plate 4E), consists of distorted, partially recrystallized micrite and quartzose micrite laminae containing pseudomorphs of calcite after gypsum. The upper part of Unit 1 has been disrupted and eroded.

Sparry calcite has filled the disruption voids. Unit 2 is composed of quartzose micrite containing pseudomorphs of calcite after gypsum. It is disrupted by burrowing, and contains a few intraclasts of the underlying micrite. Unit 2 is separated from the overlying, extremely quartzose micrite by a disconformable surface. Unit 3 contains no gypsum or calcite pseudomorphs. The writer believes that early diagenetic gypsum was formed in Units 1 and 2 by the previously discussed process.

Authigenic celestite was observed in 12 of the carbonate samples studied. These samples were taken from Measured Sections 1, 2, and 4. No celestite has been found in the limestones west of Briar Plant. The mineral occurs as subhedral to euhedral porphyroblasts (Plate 4C), pseudomorphs after gypsum (Plate 4, B and D), irregular patches replacing matrix spar and micrite, replacing pelecypod shells, and as solution void and disruption void fillings.

Petrographic evidence indicates that some of the celestite found within the carbonate rocks is similar in origin to the gypsum, as described above. Plate 4C illustrates porphyroblasts of celestite formed in a sparce wackestone above a thin permeability barrier. Little is present in the underlying packstone. Where the barrier had been

breached, apparently by burrowing, the strontium-bearing fluids have deposited celestite in the lower part of the bed. Porphyroblasts commonly enclose micrite and allochems.

Other forms of celestite in limestone are considered to be of later origin than the well-defined porphyroblasts. Pseudomorphs of calcite after gypsum have been partially replaced by celestite in several cases. Definite evidence of calcite replacing celestite has not been observed. A preferential replacement of sparry calcite is indicated by most of the late-deposited celestite. Although it is later than the porphyroblasts, an early diagenetic origin is proposed for the replacement celestite. This is suggested by the restriction of the mineral to certain definite horizons, which are otherwise similar to the containing sequence of rocks. Recrystallization appears to have taken place after formation of the porphyroblasts, but prior to the later replacement. Petrographic evidence is not in all cases definitive in this respect.

Source of strontium for the initial celestite was probably brines enriched in soluble strontium sulfate by evaporation. Celestite was precipitated directly, but the primary means of deposition in an unconsolidated lime-mud is considered by Kinsman (1964) to have been the replacement of

PLATE 3

PHOTOMICROGRAPHS OF CARBONATE ROCKS FROM THE DE QUEEN FORMATION

A. W 16L - Celestite bearing dolomite-mudstone. x 15.

B. HS 39 - Fine to medium calcirudite; partially recrystallized molluscan packstone and wackestone. Micrite matrix grades into patches of sparry calcite. Note the lack of pellets, foraminifers, superficial oolites, ostracodes, and detrital quartz. x 10.

C. P 16 - Fine to medium calcirudite; partially recrystallized pelecypod packstone. Dark, rounded allochems are molluscan fragments which are typical of the uppermost DeQueen limestone beds. x 15.

D. HS 11 - Fine to medium calcarenite; celestite bearing ostracode-pelecypod-foraminifer wackestone. Recrystallization rims on pelecypod(?) fragments project into the micrite and microspar matrix. Matrix micrite grades into microspar. x 12.5.

E. RR 2 - Fine to medium calcirudite; extensively recrystallized pelecypod wackestone. Note the gradational boundaries between pelecypod fragments and matrix spar. x 30.

F. W 28U - Coarse calcarenite to fine calcirudite; extensively recrystallized, celestite bearing, pelecypod-algal grainstone and packstone. x 10.

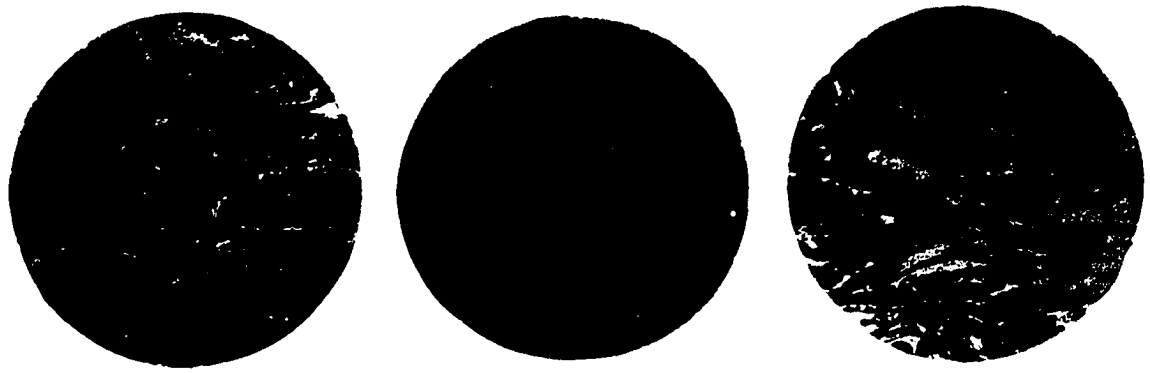
G. HS 16 - Very fine calcarenite; faecal pellet wackestone with clay and micrite filled borings. x 12.5.

H. HS 18 - Fine to medium calcirudite; extensively recrystallized pelecypod wackestone. Fine allochems lack mutual grain support. x 12.5.

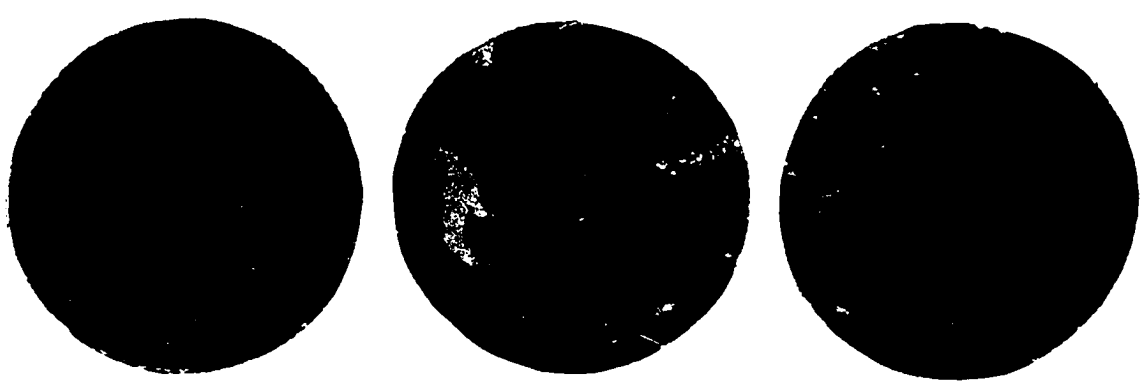
I. W 23U - Fine calcarenite; sandy, fossiliferous and pelletiferous grainstone. Typical fine allochem assemblage. x 25.



A B C



D E F



G H I

PLATE 3

PLATE 4

PHOTOGRAPHS AND PHOTOMICROGRAPHS OF ROCKS

FROM THE DE QUEEN FORMATION

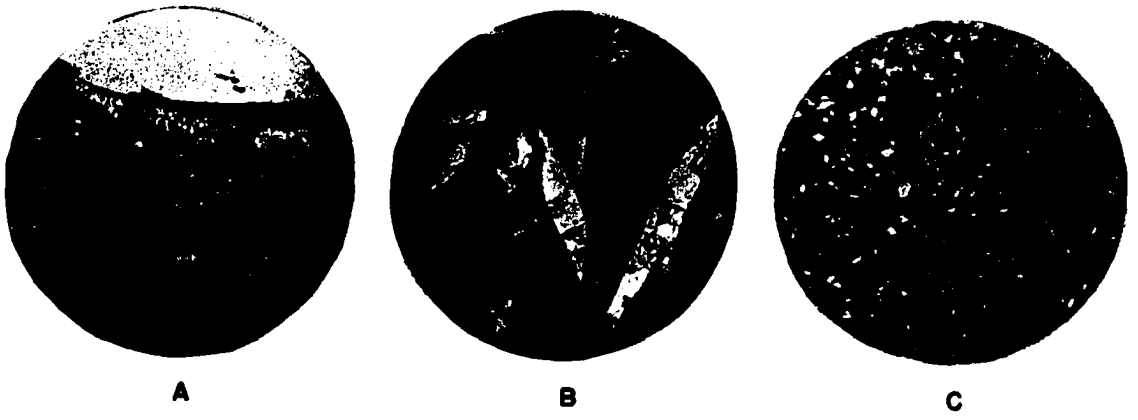
A. W 10 - Fine calcarenite; partially recrystallized, fossiliferous wackestone, containing gypsum and pseudomorphs of calcite after gypsum. Note the large gypsum crystal in the upper part of the picture and the calcite pseudomorph in the lower right quadrant. A veinlet of gypsum cuts across fossil fragments. x 12.5.

B. HS 23 - Calcilutite; calcite-mudrock containing pseudomorphs of calcite and celestite after gypsum. x 5.

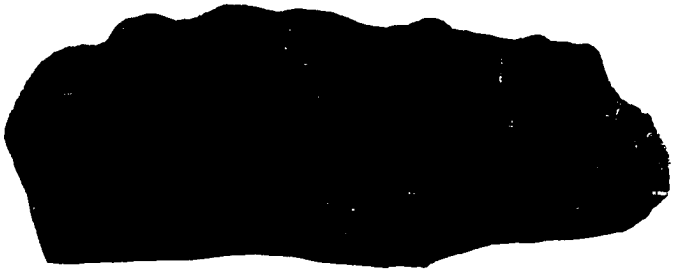
C. HS 21 - Fine calcarenite; extensively recrystallized, celestite bearing, ostracode-foraminifer-superficial oolitic wackestone and packstone. Celestite porphyroblasts are abundant in the upper wackestone, but are absent below the apparent permeability barrier. x 12.5.

D. HS 23 - Polished hand specimen. Light upper part is calcite-mudstone as described above. Dark lower part is celestite-bearing wackestone. x 0.8.

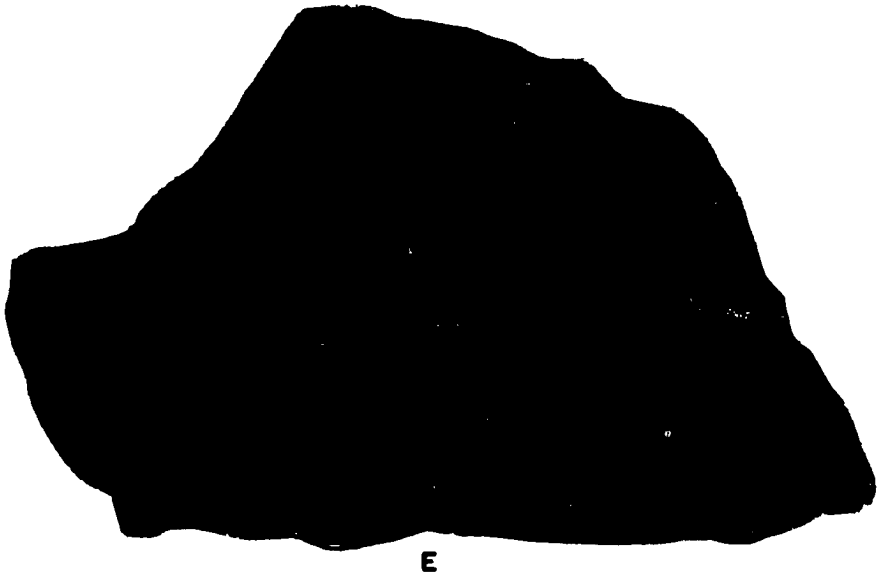
E. RR 1 - Polished hand specimen. Interbedded calcite-mudstone and wackestone. Description and genetic relations are given in the text. x 0.8.



A B C



D



E

PLATE 4

high-strontium aragonite sediments. Later diagenetic celestite within the sulfate facies may have originated from the deposition of strontium which had been released by anhydrite upon gypsification. Sufficient strontium may have been released by conversion of aragonite to calcite in order to form the later diagenetic replacement celestite in the carbonate facies (Rankama and Sahama, 1950).

Minor amounts of authigenic pyrite, hematite, and limonite are found throughout the formation. Pyrite is commonly present in trace amounts as small, irregular patches and a few euhedral crystals which are less than 50 microns in diameter. It is locally found as thin laminae of euhedral crystals at the base or top of carbonate beds. Hematite is present in trace amounts as irregular patches, tiny disseminated specks, and as a staining pigment within and surrounding oxidized iron-bearing allochems. In the uppermost limestones hematite constitutes up to five percent of the rock. It appears to have been derived from the weathering of included molluscan fragments. Limonite stain is moderately abundant in the weathered portions of limestones, claystones and mudstones of the formation.

Sulfate Petrology

In the subsurface the DeQueen sulfate facies is represented by the Ferry Lake Anhydrite, which reaches its greatest thickness in northwestern Louisiana. Toward the south, in central Louisiana, the sulfate sequence thins, and grades into porous limestone (Forgotson, 1963). According to Forgotson, the limestone represents biohermal development along a tectonic sill which formed along the tectonic hinge. The biohermal development and sill served as the restrictive barrier which impeded circulation between the area of sulfate deposition and the open sea.

The physical and chemical environments which favor the precipitation of anhydrite or gypsum have been studied for many years. Much of the recent evidence suggests that under most surface conditions gypsum should be the primary sulfate product of evaporation of sea water. A short synopsis of physico-chemical evidence leading to this conclusion is presented by Murray (1964). Only gypsum or hemihydrate is produced by evaporation of sea water in modern laboratory experiments. Gypsum, and not anhydrite, is forming in present-day lagoons (Ham, 1962).

Although no well-defined evidence is found in the bedded sulfates of the DeQueen Formation, it is assumed herein

that the primary deposits were dominantly gypsum.

The two dominant mineral species of the sulfate facies are gypsum and anhydrite. Much lesser amounts of celestite and barite form beds which crop out in southwestern Arkansas. No bedded anhydrite is found along the present-day outcrop.

Gypsum

Gypsum is the principal mineral of the sulfate facies along the DeQueen outcrop. Minor amounts of calcite, anhydrite, clay, and celestite are also found in the gypsum beds, but commonly constitute less than five percent of each rock unit. Some of the purer layers of gypsum contain less than one percent of the above mentioned minerals.

All of the gypsum beds studied are similar in lithologic character. They consist of medium to extremely coarsely crystalline, subhedral to anhedral alabaster and selenite. Color ranges from flesh-pink to gray to white. Porosity is high, and the surface exposures commonly have an irregular, lumpy, mottled to dirty-gray aspect. This aspect is typical even in quarries where the beds have been exposed for only a few years. This is due to the high porosity and solubility of the gypsum, in which are contained distorted

and disrupted laminae of calcite and clay minerals.

The outcropping gypsum apparently has a complex history, and has been formed by the hydration of anhydrite. Two growth stages of gypsum are found in all of the thin sections studied. The earliest is represented by alabaster, which consists of approximately equidimensional subhedral porphyroblasts, ranging from 50 to 250 microns in greatest dimension (Plate 5B). Patches of alabaster are intercalated with the dominant selenitic gypsum, and commonly illustrate apparent flow structure due to recrystallization. This first stage of gypsum growth is believed to be a direct conversion from anhydrite. No earlier form of gypsum has been detected. Selenitic gypsum represents the second growth stage, and is the principal constituent of the beds. It commonly consists of anhedral to subhedral, elongate, irregular porphyroblasts ranging from one to four millimeters in greatest dimension (Plate 5D). The selenitic porphyroblasts are generally superindividuals, appearing similar to elongate semicomposite quartz grains. There are slight differences in optical orientation between the individuals making up each porphyroblast. The porphyroblasts are oriented subparallel to one another, and are commonly perpendicular to the bedding. A few anastomosing rosettes of elongate selenite crystals were

observed. The alabaster and selenite form a tightly interlocking mosaic of porphyroblasts with well-defined boundaries.

Selenite grades into alabaster, appearing to envelop the smaller material. Inclusions of alabaster in selenite are common (Plate 5C). As porphyroblasts of selenite continue to grow, the inclusions become more and more indistinct, and are finally completely recrystallized into the selenite structure. An apparent third stage of crystal growth is represented by traces of euhedral selenite crystals in a few of the thin sections studied. These may, however, have been formed in conjunction with the second growth stage.

Residual anhydrite inclusions occur in both the alabaster and selenite. The inclusions take the form of fibers parallel to cleavage planes, and irregularly shaped minute crystalline masses. Their size is generally less than 30 microns, but a few up to 60 microns in greatest dimension were observed. The anhydrite inclusions are considered to be residue left after incomplete hydration of anhydrite to gypsum. None of the gypsum beds studied contained more than one percent anhydrite.

Micrite, sparry calcite and clay material are present within the gypsum beds as irregular patches and thin disrupted and distorted laminae (Plates 5A and 6A). Micrite is

generally recrystallized to very fine- to medium-crystalline sparry calcite. Some of the micrite contains skeletal material, pellets, superficial oolites, and pseudomorphs of calcite after gypsum. The laminae are commonly discontinuous, appearing in thin section as disconnected calcite patches. Calcite and clay originated as even laminae of micrite and argillaceous mud deposited in a quiet water environment. Continued precipitation of gypsum was evidently prohibited by an influx of sea water or terrestrial water. The present disrupted, distorted and recrystallized nature of the sediments is attributed to diagenetic changes. These changes and processes will be discussed later.

Celestite is found in a few of the gypsum samples as small patches or rosettes of tiny bladed crystals. They are less than 150 microns in greatest dimension, and are relatively rare in the DeQueen gypsum beds. These accumulations of celestite have probably been derived from strontium which has substituted for calcium in the anhydrite lattice. Upon hydration of the anhydrite to gypsum the strontium, which is compatible to the gypsum lattice in only small amounts, was free to form celestite (Rankama and Sahama, 1950).

Irregular patches of pyrite are present in the gypsum beds. This mineral is commonly present in trace amounts,

but a few samples contain up to one percent.

Anhydrite

Bedded anhydrite does not crop out in the surface exposures of the DeQueen Formation. The subsurface equivalent of the sulfate facies, the Ferry Lake Anhydrite, consists of white anhydrite interbedded with dark-gray to black shale and a small amount of limestone. Individual anhydrite beds range up to 50 feet in thickness (Forgotson, 1956). Stratigraphic relations and lithologic variations of the Ferry Lake Anhydrite were studied by Forgotson in his analysis of the Trinity Group (1956, 1957, and 1963). Several of Forgotson's thin sections and cores from the formation have been examined by the writer. Nearly all of the samples are similar in lithologic character. Anhydrite is the dominant mineral of the subsurface beds. Micrite and clay form distorted and disrupted laminae injected throughout the white anhydrite (Plate 5E and Plate 6, B and C). These irregular laminae or apophyses (Forgotson's terminology) correspond to the same features in the DeQueen gypsum beds. The micrite has been extensively recrystallized in many of the gypsum beds. Recrystallization is much less extensive in the subsurface anhydrite beds. The degree of recrystallization is

evidently dependent upon diagenetic conversion between the two mineral species.

The Ferry Lake Anhydrite is commonly fine- to medium-crystalline. Three stages of crystal growth have been observed. The most abundant crystal form is apparently the last stage of development, and consists of felted masses of fibrous to prismatic, subhedral to euhedral porphyroblasts (Plate 5F). Size of the elongate crystals ranges from 25 to 250 microns in greatest dimension. Dominant size range is from 100 to 150 microns. The porphyroblasts are generally oriented subparallel to one another, appearing to form flow structure within the felted masses. Adjacent to the irregular micrite and clay laminae the porphyroblasts are oriented subparallel with the laminae (Plate 5E).

The first growth stage represented is a fine mosaic of equidimensional subhedral to euhedral crystals. Their size range is generally from 15 to 25 microns (Plate 5G). There is a continuous gradation from this first stage into the dominant fibrous and prismatic masses. An apparent intermediate stage of crystal growth is indicated by the presence of equidimensional to rectangular porphyroblasts, ranging from 100 to 300 microns in greatest dimension. These are subhedral, and are commonly partially to completely

replaced by fibrous and prismatic crystals of the felted masses in which they occur. They are much less abundant than the forms previously described. In a few of the thin sections they are preserved unaltered within the micritic laminae. Petrographic relations between these porphyroblasts and those of the first growth stage are indistinct. Formation of the two may have been contemporaneous.

According to Forgotson, the Ferry Lake Anhydrite was originally deposited as gypsum, and its typical mosaic or "chicken wire" structure observed in cores is due to the dehydration of gypsum to anhydrite. Expulsion of molecular water resulted in shrinkage of the beds as dehydration continued. The expelled water could then saturate the surrounding non-evaporite deposits, causing them to become plastic and to invade the shrunken and disrupted anhydrite. The dehydration supposedly took place at a depth of several hundred feet (Forgotson, 1956). Riley and Byrne (1961), have shown with experimental models that the mosaic structure may be formed by flowage resulting from density variations between sulfate and non-sulfate beds. They propose that the distortion took place near the depositional interface, and that the original evaporite was anhydrite. The latter mechanism for origin of the structure is favored by the writer, but

the chemical improbability of primary anhydrite indicates that the deformation took place in bedded gypsum, or possibly during an early diagenetic dehydration to anhydrite. Early diagenetic formation of anhydrite is also suggested by Ham (1962) in his study of the Blaine evaporites.

Celestite and Barite

Although celestite is a common authigenic constituent of limestone in the DeQueen Formation, it is found in only two thin beds as the rock-forming mineral. Miser and Purdue (p. 83, 1929) stated that:

> Coarsely granular white to pink celestite occurs in clay in the lower part of the member, in some places as short lenses and in others as a single layer from 1 to 6 inches thick.

No bedded celestite was found by the writer in the sulfate facies of the formation. The two occurrences reported herein are thin beds, less than two inches thick, within the carbonate sequence (samples B 14 and C 1, Plate 2). In both instances celestite has replaced a deformed layer of anhydrite containing irregular laminae of micrite and recrystallized micrite (Plate 6D). The celestite is very coarsely crystalline, equidimensional to elongate, anhedral to subhedral, and contains residual anhydrite. Anhydrite occurs as irregular grains up to 100 microns in greatest dimension, and

comprises approximately five percent of the rock (Plate 5H). Relic flow structure of the anhydrite is preserved. At the Briar Plant outcrop the underlying micrite contains pseudomorphs of calcite and celestite after gypsum. This fact leads to the inference that the original sulfate was in the form of gypsum, and lends support to the idea of an early diagenetic change from gypsum to anhydrite.

Barite is present as poikilitic cement in two beds of coarse siltstone to medium sandstone in the lower part of Measured Section 6. Part of the rock lacks grain support. This may be indicative that terrigenous quartz grains were separated due to crystal growth, and the poikilitic barite is the original matrix mineral. Another explanation is that the grains were deposited in a micritic matrix, but the micrite was later replaced by barite. The latter is probably valid, as both beds contain at least five percent matrix clay. It is logical that the clay would have been winnowed out with the rest of the fine matrix material prior to cementation.

Source of strontium and barium may have been aragonite, in which these elements substituted for calcium. These elements are incompatible to the calcite lattice due to their relatively large ionic diameters. Upon conversion of aragonite to calcite they were released in the form of soluble

sulfates and bicarbonates, which later formed epigenetic celestite and barite. Strontium may have also been derived in a similar manner by the hydration of strontium-rich anhydrite to gypsum (Rankama and Sahama, 1950).

PLATE 5

PHOTOMICROGRAPHS OF ROCKS FROM THE DE QUEEN FORMATION AND FERRY LAKE ANHYDRITE

A. W 8 - Disrupted and distorted lamina of micrite and sparry calcite in gypsum. x 5.

B. HS 12 - Alabastrine gypsum. Crossed nicols, x 30.

C. HS 12 - Selenitic gypsum grading into alabaster. Note alabaster inclusions in selenite. Crossed nicols, x 12.5.

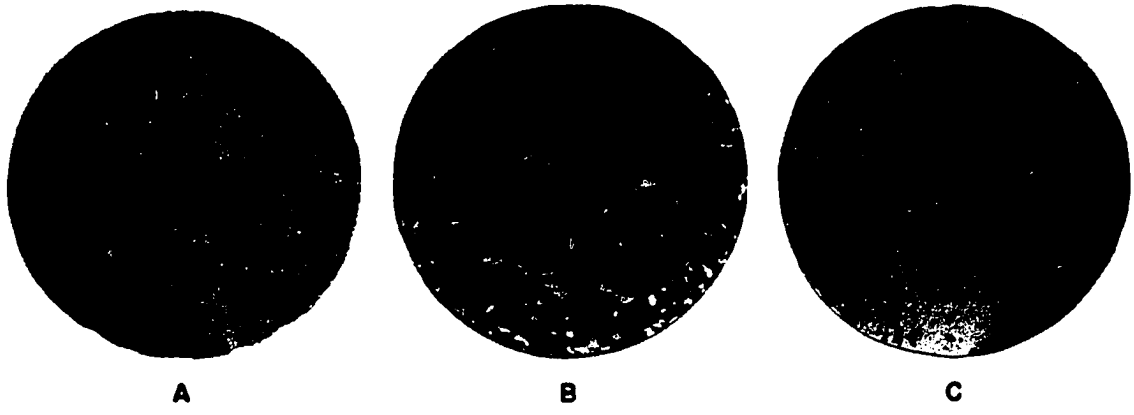
D. W 6 - Selenitic gypsum. Crossed nicols, x 12.5.

E. 12 v - Micrite lamina in anhydrite. Note orientation of anhydrite crystals parallel to lamina. x 5.

F. 15 h - Felted mass of prismatic and fibrous anhydrite. Last stage of crystal development. x 125.

G. 14 h - Equigranular anhydrite. Initial stage of crystal development. x 125.

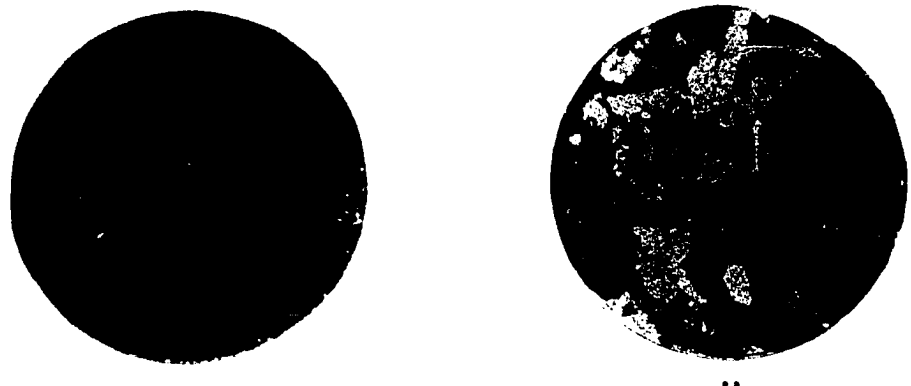
H. C 1 - Celestite crystals with residual anhydrite. Crossed nicols, x 6.25.



A B C



D E F



G H

PLATE 5

PLATE 6

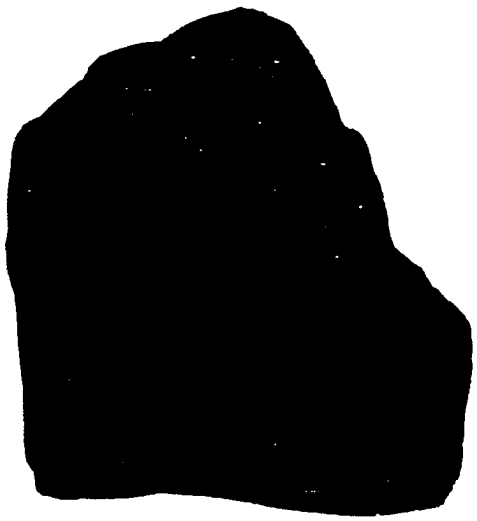
PHOTOGRAPHS OF ROCKS FROM THE DE QUEEN FORMATION AND FERRY LAKE ANHYDRITE

A. W 16 - Polished surface of gypsum cut perpendicular to bedding. Shows disrupted and distorted laminae of dark calcite ("chicken wire" structure of Forgotson, 1956). x 0.8.

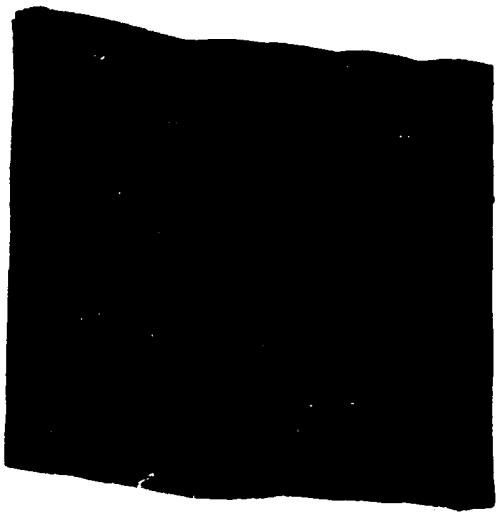
B. Polished surface of Ferry Lake Anhydrite core, cut perpendicular to bedding. Typical mosaic or "chicken wire" structure formed by disrupted and distorted laminae of dark micrite. x 0.8.

C. Polished surface of Ferry Lake Anhydrite core, cut parallel to bedding. x 0.8.

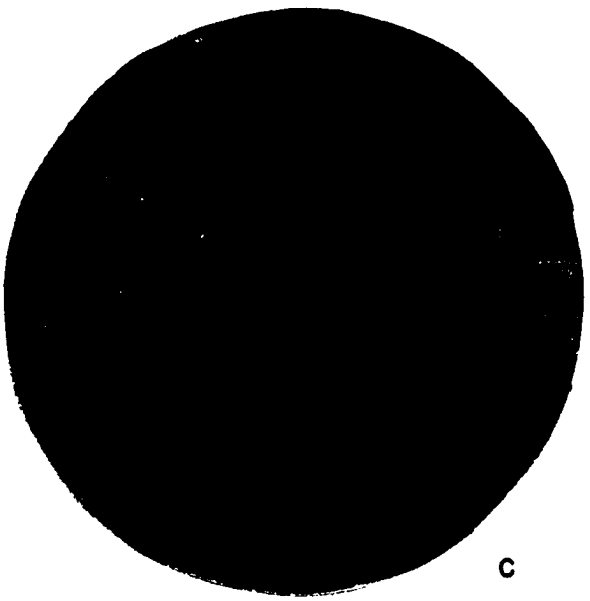
D. B 14 - Polished surface of celestite (light gray), and micrite (dark gray), showing flow structure. Very dark material is pyrite. Celestite has replaced anhydrite subsequent to deformation. x 0.8.



A



B



C



D

PLATE 6

ARGILLITE PETROLOGY

Methods and Procedures

Seventy-three spot samples of claystone, mudstone, siltstone, and clay-bearing sandstone were collected throughout the DeQueen Formation. A few samples were also taken from the beds which overlie and underlie the formation. Each of the samples was studied and described by use of a non-polarizing binocular microscope. Six of the argillites were examined in thin section with a polarizing petrographic microscope.

Gross mineralogy was determined through the analysis of x-ray diffraction patterns. Powder packs or powder-on-vaseline slides were prepared from each of the bulk samples in order to examine the total mineral content. Norelco and Siemens equipment were used for the x-ray analyses.

In the study of clay mineralogy oriented sedimentations of material less than 4 microns in diameter were examined before and after treatment with ethylene glycol. All

size fractionation was based on settling velocities according to Stoke's Law. Various size fractions of clay minerals were studied in 18 of the samples collected. Twelve of the samples were fractionated to particle sizes ranging from 1 to less than 0.1 micron by use of continuous flow centrifuge. This was done primarily in an attempt to separate the various clay mineral species, thereby enabling accurate chemical analyses and calculation of theoretical structural formulas. Unfortunately, the clay minerals could not be separated by size fractionation.

The presence of several clay minerals within each sample restricted the use of differential thermal analysis as a primary tool for investigation. DTA was used principally for detection of non-clay minerals in samples after examination by flame photometry.

Visual Determinations

Argillaceous rocks of the DeQueen Formation are dominantly claystone and mudstone, although lesser amounts of siltstone are present. Color of the rocks generally ranges from yellowish-gray to greenish-gray. A persistent brown layer is present in the carbonate facies in the eastern part of the outcrop area. Fresh surfaces of the

claystone commonly have a smooth to waxy appearance. Most of the argillites are fairly calcareous, and many contain irregular sucrosic grains and euhedral crystals of gypsum. Carbonaceous material is present as specks, patches, and irregular films. Staining by limonite is common near weathered surfaces. Thin sections commonly illustrate irregular vague laminae of clay and silty clay. Some streaks and patches of silty clay are discordant with the bedding, and clasts of pure clay are commonly found within silty clay. It is fairly obvious that disruption at or near the depositional interface took place prior to compaction. The disruption resulted from burrowing organisms and extraordinary wave or current action. A few of the claystones and mudstones are cross-laminated. Traces of muscovite, tourmaline, hematite, carbonaceous material, authigenic pyrite, and fossils are common in the thin sections studied. Small amounts of authigenic dolomite and siliceous material are infrequently found.

Clay material is commonly aphanocrystalline to very finely crystalline, and clay mineral species are indistinguishable in thin sections. Flakes of clay material are oriented subparallel to the bedding, except where disruption or draping around clasts is evident. Two of the thin sections

show cross-cutting veinlets or zones of what appears to be recrystallized clay mineral.

Mineralogy

The dominant non-clay mineral in the argillites is quartz, and in many of the diffractograms studied it is the only non-clay mineral detected. Calcite was found in 46 of the argillite samples examined by x-ray diffraction, but it is nearly always subordinate to quartz. Dolomite is present in detectable amounts on only eight of the diffraction patterns. It is the dominant non-clay mineral in three samples. The percentages of non-clay minerals present in argillites of the formation are illustrated in Appendix C. Values shown represent percentages based on diffractogram peak heights of the dominant peaks for quartz, calcite, and dolomite. Diffractability of the various minerals has been considered to be equal. Although this is obviously not a correct assumption, the table does give a semi-quantitative idea of the variations encountered. The proportion of quartz in the argillites increases from east to west along the DeQueen outcrop.

The four clay minerals identified in the samples studied are illite, kaolinite, montmorillonite, and a non-

expandable 14 angstrom mineral which is believed to be poorly-crystalline chlorite. Principal means of identification of these minerals was by their basal reflections illustrated on x-ray diffractograms. Representative diffraction patterns of the DeQueen clays are shown on Figure 5.

Illite

The most abundant clay mineral in the formation is illite. The (001) reflections of the illites indicate a d-spacing range from 10.0 to 10.1 angstroms. The most common spacing is 10.04 angstroms. Diffractogram peaks for the first-order basal reflections of all samples which have not been chemically treated with ethylene glycol or potassium chloride solution are asymmetrical. All have (001) peaks which broaden at the base toward higher "d" values (Figure 5 and Figure 6A). Asymmetry of illite peaks is generally attributed to one of two causes. One possibility is that the clay is a random interstratification of illite and montmorillonite or illite and vermiculite (Weaver, 1956). Another explanation is that potassium ions have been leached from interlayer positions of the illite lattice during weathering. The vacant interlayer positions may subsequently have been occupied by other ions (Johns and Grim, 1958). Illites of

this type are referred to as "stripped" or "degraded." Both of the above possibilities were investigated by the writer.

In mixed-layer structures the basal reflections are composites of the adjacent reflections of the mineral species which are interstratified. Position and intensity of composite reflections vary with the relative abundance of the different layers (Grim, 1953). All of the DeQueen illites have relatively constant maxima positions of the (001) diffraction peaks. The d-spacing values observed are well within the range for illites as indicated by Grim (1953) and Brown (1961). Treatment of sedimented slides with ethylene glycol caused no shift in maxima of the (001) peaks. The treatment did, however, increase the symmetry of the diffraction peaks.

According to Johns and Grim (1958), degraded illite may absorb potassium from solution, thereby regrading to a well-crystalline illite. Several samples of various size fractions were placed in 0.1 N solutions of potassium chloride. The suspensions were agitated for one to three hours. In most cases x-ray diffraction patterns of the reconstituted clay showed a reduction of basal broadening and increased intensity of the peak. Complete reconstitution of the illite was never attained, and the ragged character of the low angle

side of the diffraction peak remained (Figure 6B). Treatment of regraded illite with ethylene glycol caused a definite sharpening of the peak, and decreased its intensity (Figure 6C).

Based on the above experimental observations, it was concluded that the dominant clay mineral of the formation is degraded illite. It is the writer's opinion that sharpening of the diffraction peaks and increase of their symmetry by treatment with ethylene glycol is the result of removal of highly polar water molecules from interlayer positions. The ethylene glycol molecules have drawn the water molecules out of the lattice. This has been illustrated experimentally by Raymond Kerns (graduate student at the University of Oklahoma, personal communication, 1965). DTA patterns show an endothermic reaction at temperatures of 75 to 150°C, representing interlayer dehydration.

Positions of the (060) diffraction peaks indicate that the DeQueen illites are dioctahedral micas. Comparison of x-ray data with that illustrated by Brown (1961) shows that both 1M and 2M polymorphic forms of illite are present. 2M illite is dominant.

Ionic substitutions in the octahedral layer of illites cause large intensity variations of the basal

diffraction peaks. High ferric iron content for the illites studied is indicated by comparison of intensity ratios with standard curves illustrated by Brown (1961).

Kaolinite

The first order basal kaolinite reflection was found between 7.14 and 7.2 angstroms for almost all of the samples studied. The mineral is present in all of the clays analyzed by x-ray diffraction, generally ranking second in abundance to illite. Basal broadening of peaks and weak reflections indicate poor crystallinity of the DeQueen kaolinites.

Small amounts of chlorite are present throughout the section. Several clay samples were treated with warm dilute hydrochloric acid in an attempt to dissolve the chlorite. Only partial dissolution of chlorite was attained. The (001) peak of kaolinite which coincides with the (002) peak of chlorite was not affected. Heat treatment to differentiate between the two minerals was unsuccessful, as the chlorite structure was destroyed along with the kaolinite.

In many of the argillites in the western part of the outcrop area kaolinite is the dominant clay mineral. It was found to be the most abundant clay mineral in beds of the Trinity Group lying above and below the DeQueen.

Chlorite

Poorly crystalline chlorite is common in minor amounts throughout the DeQueen Formation. Solvation of samples with ethylene glycol is generally necessary to detect the mineral by x-ray analysis. In cases where montmorillonite and chlorite occur together the minerals cannot be differentiated in the untreated sample. The first-order basal reflection frequently forms a diffuse peak or series of peaks between d-spacings of 12.5 and 14.3 angstroms. Higher order basal reflections are absent or represented by ragged shoulders on the high-angle side of illite and kaolinite peaks. Chlorite content increases from east to west along the outcrop.

Montmorillonite

Montmorillonite is present in small amounts in many of the samples studied. The only diffractogram peak observed for the mineral in the untreated samples was the first-order basal reflection. Poor crystallinity is indicated by the diffuse nature of the peak. Observed (001) d-spacings lie between 14 and 15 angstroms for untreated samples. Upon solvation with ethylene glycol the first-order basal d-spacing expands to about 17 angstroms.

FIGURE 5

X-RAY DIFFRACTION PATTERNS OF REPRESENTATIVE CLAY SAMPLES FROM THE DE QUEEN FORMATION

Humidified sedimented slides of less than 4 micron size fraction. Copper radiation.

A. Measured Section 2, sample W 14.

B. Measured Section 2, sample W 12.

C. Measured Section 1, sample HS 26.

D. Measured Section 2, sample W 29.

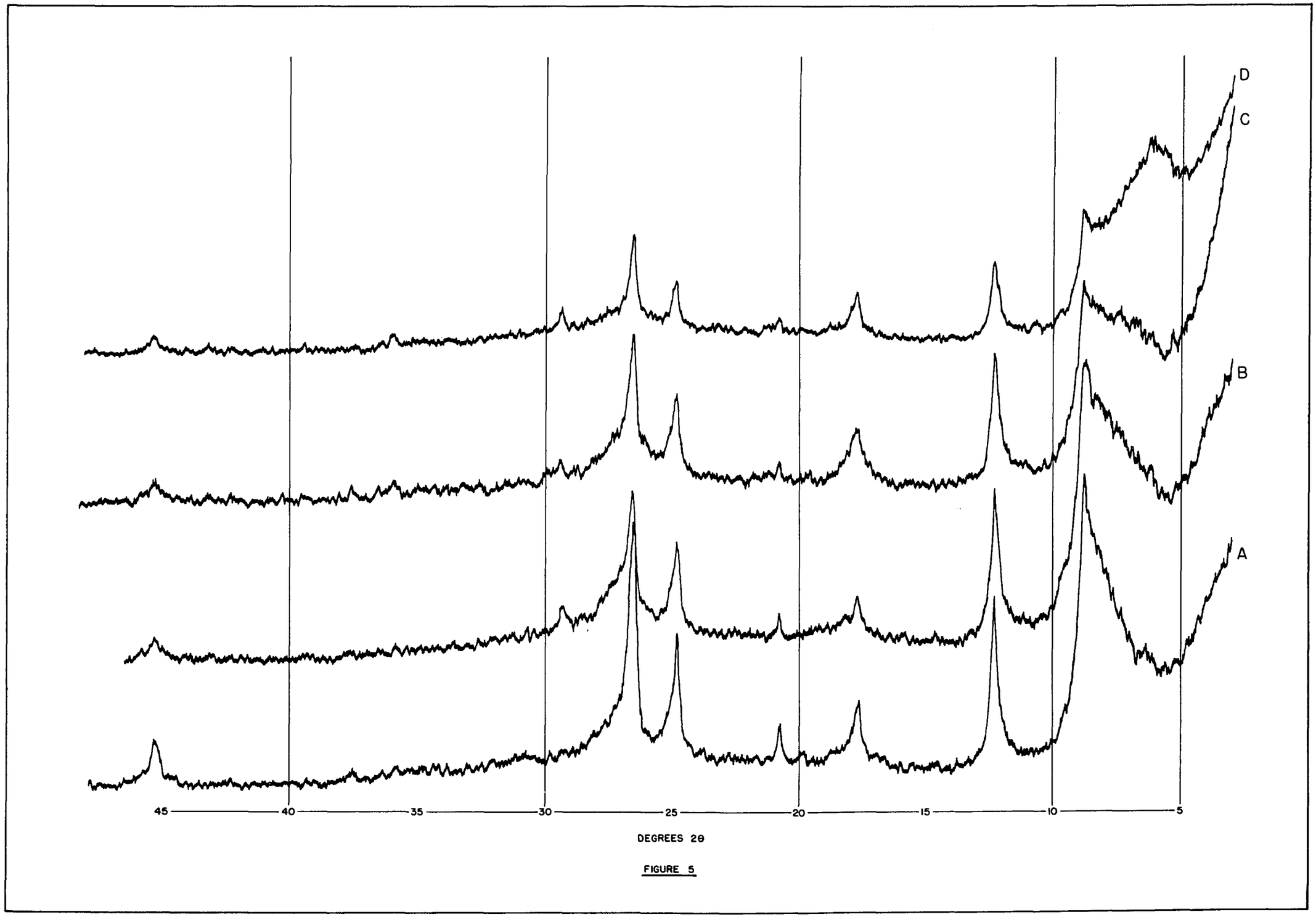


FIGURE 5

FIGURE 6

X-RAY DIFFRACTION PATTERNS SHOWING THE EFFECTS OF RECONSTITUTION AND SOLVATION ON THE (001) PEAK OF ILLITE

Sedimented slides of less than 4 micron size fraction. Copper radiation.

A. Sample W 12, humidified.

B. Sample W 12, after agitation in 0.1 N solution of KCl for three hours.

C. Sample W 12, after above treatment in KCl solution and subsequent solvation with ethylene glycol.

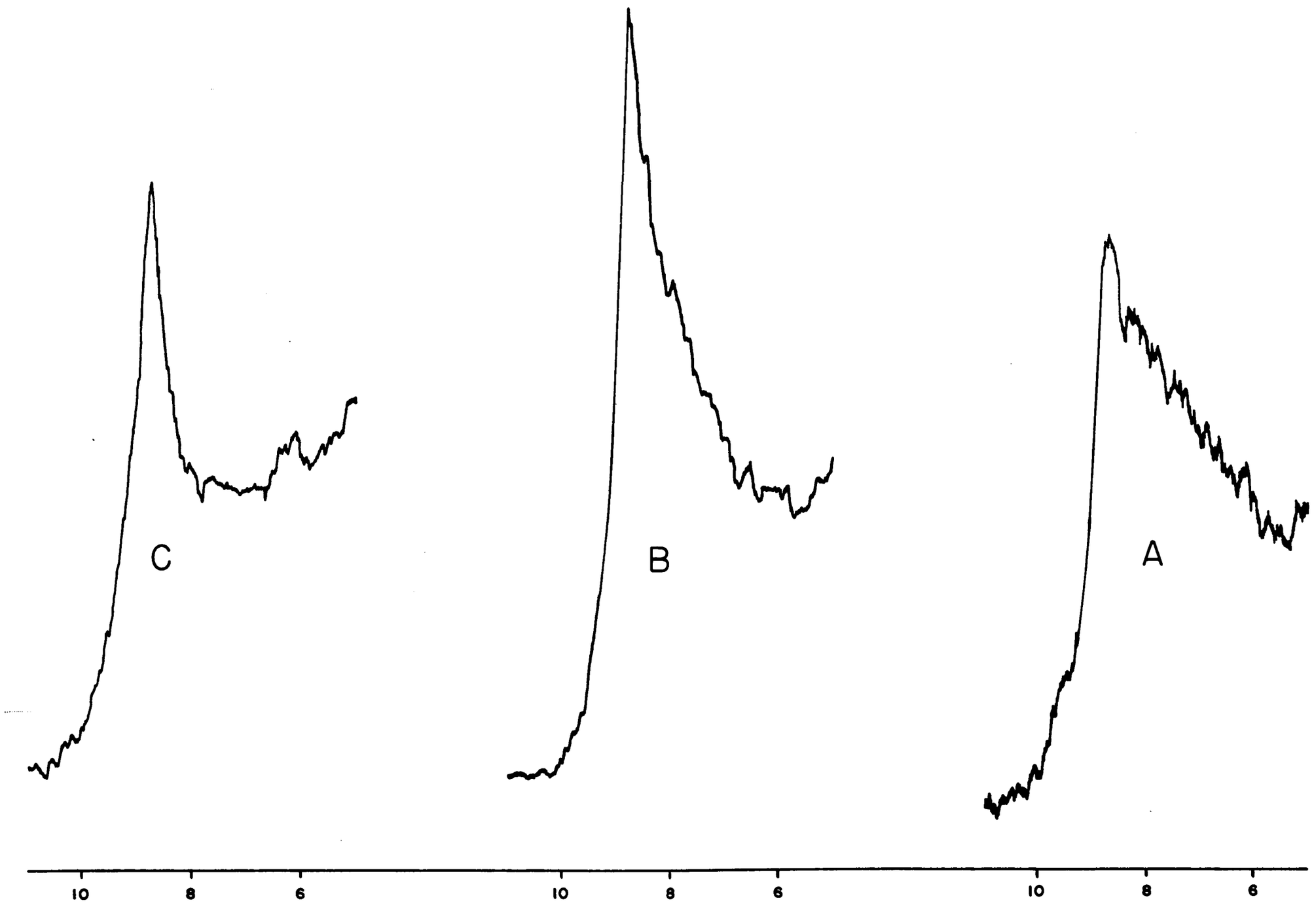


FIGURE 6

Several of the clay samples were dispersed in a solution of Calgon (sodium hexametaphosphate), in order to prevent flocculation during size fractionation. The basal d-spacing of montmorillonite treated in this manner was decreased, ranging from about 11.3 to 12.3 angstroms. It is believed that sodium montmorillonite resulted from exchange of interlayer cations during the treatment with Calgon. Decrease in d-spacing is probably due to the difference in hydration of the various interlayer cations.

Variations in Abundance of Clay Minerals

Percentages of various clay minerals in the samples studied are shown in Appendix C. Peak heights of solvated samples were used to estimate the relative changes in clay mineral proportions. Mechanical mixtures of varying proportions of relative pure clay minerals were examined by x-ray diffraction. It was found that the (001) peaks of illite, kaolinite, and chlorite have nearly the same basal diffractability. The first-order basal reflections of chlorite are so small in most of the samples studied that interference by the (002) reflection was ignored. This procedure was also followed by Degens, Williams, and Keith (1957). Diffractability of basal planes of montmorillonite was found to vary

considerably from that of illite. A standard curve showing the variation of peak height ratio with respect to weight percent of montmorillonite was constructed and used in calculation of the proportions of montmorillonite present. The writer realizes that the diffractability of the standard clays differs from that of the DeQueen clays, but isolation of individual clay mineral species of the DeQueen Formation for use as standards could not be accomplished by size fractionation.

The variation of clay mineral percentages with grain size was not studied in detail. The broadening and increase of ragged appearance of the diffraction peaks with grain size decrease prohibited accurate estimation of clay proportions. The change in character of the diffraction peaks is probably due to decreasing crystallinity with decreasing grain size.

While illite is the principal clay in the eastern part of the outcrop area, there is an apparent increase in kaolinite toward the west, where it is the dominant clay mineral in many of the samples examined. This observation is based primarily on random spot samples, as the clay outcrops are generally poor in the area west of Briar Plant.

Illite:kaolinite ratios have been used by Degens,

Williams, and Keith (1957) as indicators of variation in depositional salinity. A definite increase in the ratio was observed from fresh-water to marine shales in their work. Figure 7 illustrates the variations in illite:kaolinite ratio encountered in the DeQueen Formation at Highland, Arkansas. No overall pattern of clay-mineral variation is apparent between the measured sections, which are approximately one-half mile apart. Average illite:kaolinite ratio in the sulfate facies is 1.75. In the carbonate facies the ratio is 1.28. These results are similar to those obtained by Degens, Williams, and Keith, whose work indicates an increase in illite:kaolinite ratio with increasing salinity.

Chlorite:illite ratios have also been used as indicators of salinity variation in depositional environments (Everett, 1962). Mutual interference of montmorillonite and chlorite diffraction peaks from the DeQueen argillites limits the accuracy of percentage estimates. This fact, along with the poor crystallinity of chlorite present, restricts the value of chlorite:illite ratios.

Origin of Clay Minerals

Lithologic similarity of argillites in the DeQueen Formation may indicate that the environment of deposition

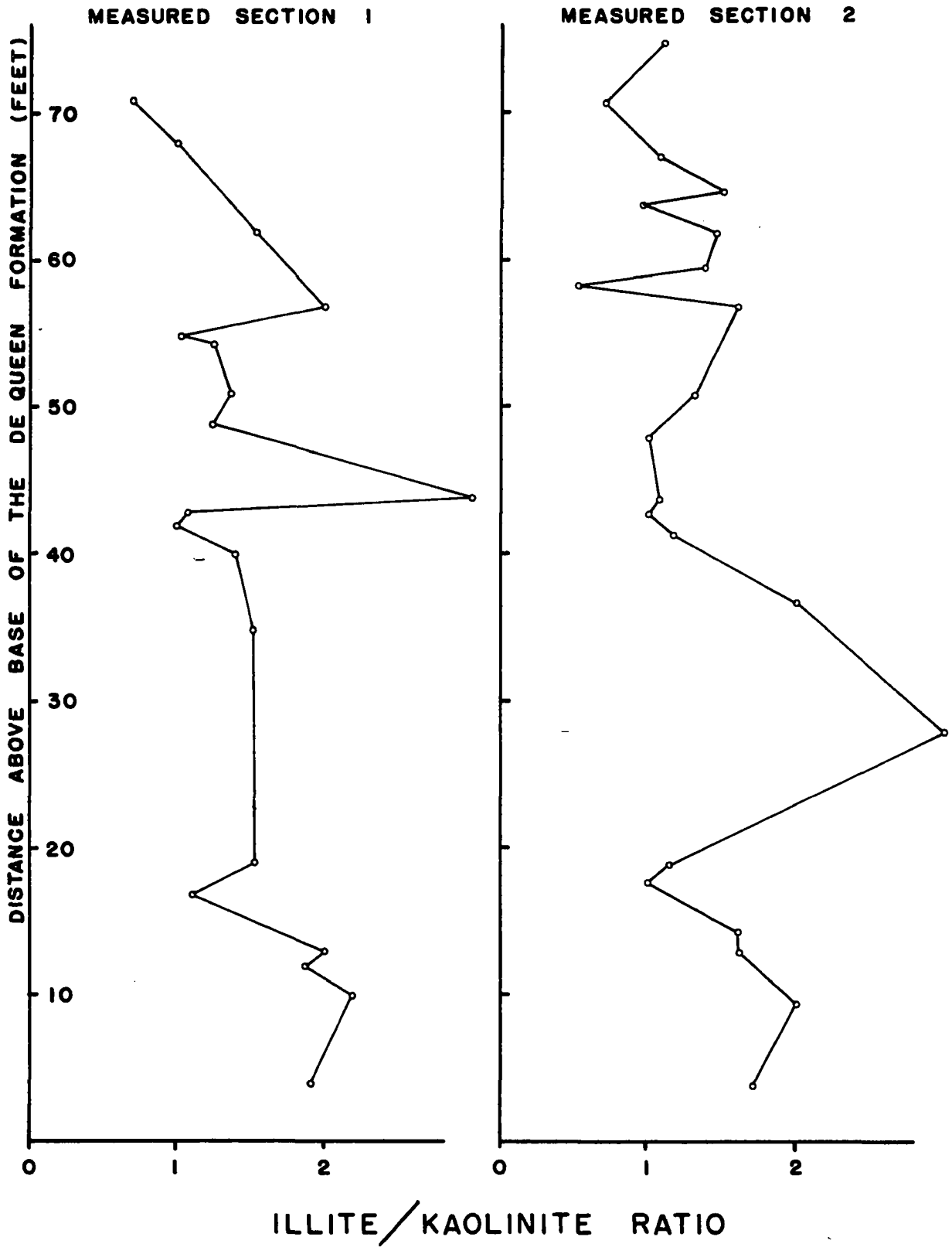

MEASURED SECTION 1
MEASURED SECTION 2
DISTANCE ABOVE BASE OF THE DE QUEEN FORMATION (FEET)
70
60
50
40
30
20
10
0
1
2
0
1
2
ILLITE / KAOLINITE RATIO

FIGURE 7

was similar, from a physico-chemical point of view, for clays throughout the formation. Another explanation is that the chemical aspects of the depositional environment had little effect on the clays, and the clay mineralogy was dominantly controlled by the nature of source rocks and the environment of erosion. While neither theory can be proven with certainty, the latter seems to be the most feasible. This interpretation is supported by the lack of meaningful variation between illite:kaolinite ratios from the sulfate and carbonate facies.

A logical source of detrital sediments is the Ouachita Mountain area, lying a short distance north of the outcrop. This is substantiated by the abundance of degraded illite and smaller amounts of degraded chlorite in the DeQueen Formation. 2M illite, chlorite, and smaller amounts of kaolinite are present in the Paleozoic rocks of the Ouachitas (Wong, 1964). The relatively small amount of 1M illite in the DeQueen argillites may have been formed authigenically (Weaver, 1959). Montmorillonite probably originated as a weathering product of shale in the Ouachitas or as detritus from the weathering of exposed Permian rocks in which the mineral is fairly abundant. The proportion of kaolinite in the DeQueen clay suite is greater than in the proposed source

rocks of the Ouachita belt. The mineral was apparently more stable in the environment of erosion than the associated chlorite, which is much less abundant in the formation. It is doubtful that authigenic kaolinite is present in the clay minerals examined, as the high calcium content in the depositional and diagenetic environments would probably restrict its formation (Grim, 1953).

GEOCHEMISTRY

Geochemical analyses were confined to the clay minerals and bulk argillites of the DeQueen Formation. The primary purpose was to determine what chemical variations exist between clay minerals of the sulfate facies and those of the carbonate facies. Two basic approaches were used. The first was a study of the exchangeable cations of the clay minerals by use of flame photometry. Secondly, an emission spectrographic analysis of the trace elements in the clays was performed.

Variations in Exchangeable Cations

Variations in exchangeable cations were examined in nine representative clay samples from the formation. In order to avoid contamination by non-clay impurities the samples were size fractionated, and material ranging from 0.1 to 0.25 microns in diameter was used in the determinations. X-ray diffraction patterns revealed no non-clay minerals in this size range. Each sample was stripped of its interlayer

cations by agitation in 20 percent reagent grade hydrochloric acid for three to four hours. The leachates were diluted and filtered off, and stored in plastic bottles. Distilled water was used in size fractionation, stripping, and dilution to insure against introduction of cations during experimental procedure.

Standard curves for various concentrations of sodium, potassium, and calcium were prepared, and each of the leachate samples was analyzed by flame photometric means. Five to ten readings were averaged for each sample. Concentrations of the three above listed elements were determined by comparison with standard curves. Figure 8 shows the variation in cation ratios with respect to stratigraphic position. Concentration ratios are given in Appendix D.

Concentrations of Na_2O and K_2O in the leachates show little variation. Na_2O ranges from 0.56 to 1.49 ppm, whereas K_2O concentration ranges from 7.13 to 8.63 ppm. CaO content was somewhat more variable, ranging from 4.1 to 20.8 ppm.

No definitive pattern of exchangeable cation variation is apparent between rocks of the sulfate facies and the carbonate facies. The K:Na ratios all fall between 6.35 and 13.75. Samples whose leachates were anomalously high in calcium content were studied by differential thermal analysis.

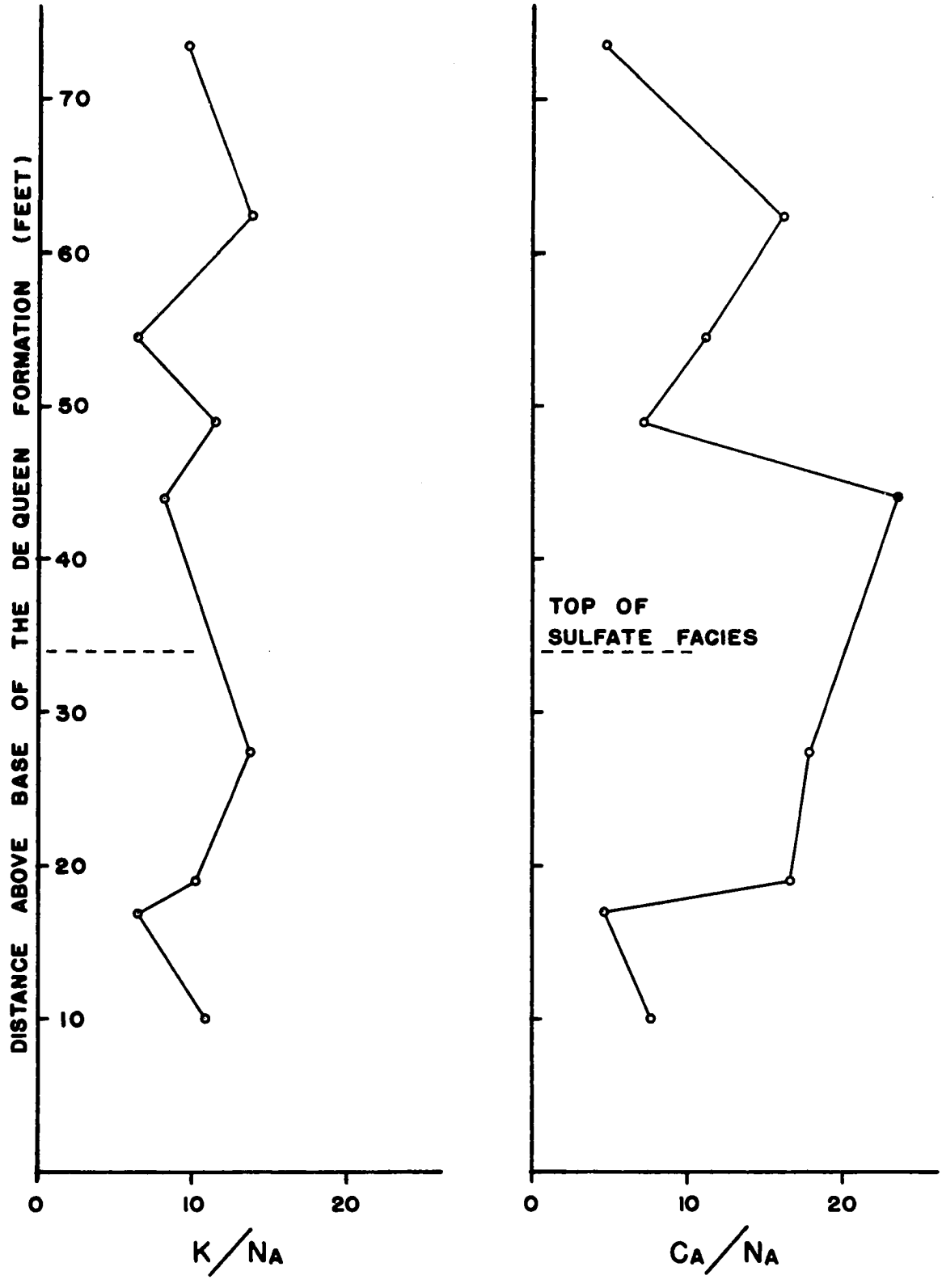

DISTANCE ABOVE BASE OF THE DE QUEEN FORMATION (FEET)
70
60
50
40
30
20
10
0
10
20
K / NA
TOP OF
SULFATE FACIES
0
10
20
CA / NA

FIGURE 8

Small amounts of gypsum were found to contaminate each of the anomalous samples, and the calcium ion exchange data were discarded.

The obvious lack of variation of the K:Na ratio with stratigraphic position may indicate that the chemical environment was similar during deposition of the argillites contained in the sulfate and carbonate facies. Other possibilities are that the depositional environment had little effect on the clays, or the exchangeable cation suite is the result of diagenetic changes.

Trace Element Analyses

Qualitative and semiquantitative emission spectrographic analyses of 16 selected argillite samples were performed by Kenneth Sargent (graduate student, University of Oklahoma). Ten of the samples were bulk material and six were various size fractions of less than one micron in diameter.

Trace elements detected by qualitative analysis include boron, strontium, gallium, chromium, vanadium, copper, zirconium, hafnium, arsenic, phosphorus, thallium, yttrium, sodium, potassium, cadmium, nickel, and thorium. Semiquantitative analyses were performed on the first six of these

elements. Study of the spectrographic pattern indicated that the remainder of the trace elements were not present in sufficient quantities for reliable semiquantitative analysis (Kenneth Sargent, personal communication, 1965), or would be of little value in interpretation of depositional history.

Gallium content was found to be less than 5 ppm, and strontium concentration was less than 10 ppm for all of the samples studied. The remainder of the semiquantitative results are tabulated on Table 1. No definite pattern of variation in concentration was detected for the elements. Comparison of semiquantitative with quantitative results for boron leads the writer to believe that the accuracy of semiquantitative analyses is generally insufficient for determination of concentration variation within the range of values indicated by quantitative analyses.

The applicability of boron as an indicator of paleosalinity has been confirmed by several investigators since the theory was suggested by Landergren in 1945. Studies by Frederickson and Reynolds (1960) indicate that in the clay minerals, boron is preferentially associated with illite. Rubidium, lithium, and gallium have also been used as indicators of paleosalinity, but only the last has been detected in the DeQueen argillites.

Quantitative analyses for boron were performed on 12 clay samples by personnel of the Pan American Petroleum Corporation. Ten of the samples were clay material of less than 0.1 micron in diameter, whereas the other two samples were in the 0.25 to 0.1 micron range. Results of the analyses are given on Table 1. Concentrations range from 200 to 450 ppm.

Because boron content of a sample varies in proportion to the amount of illite contained therein, a ratio of boron concentration to percentage of illite was determined for each sample. Figure 9 shows a plot of the boron:illite ratios with respect to stratigraphic position of samples in the DeQueen Formation. All of the included samples are from the Highland quarries. Although an overall decline in the ratio is apparent from the bottom to the top of the section, the variation is rather erratic in the lower 42 feet. In the overlying part of the formation a relatively constant decline of the boron:illite ratio is illustrated, which is interpreted to be an indication of decreasing salinity in the depositional environment. Variation in salinity was much more pronounced during the deposition of the argillites contained in the sulfate facies and the lower part of the carbonate facies. These observations and interpretations substantiate

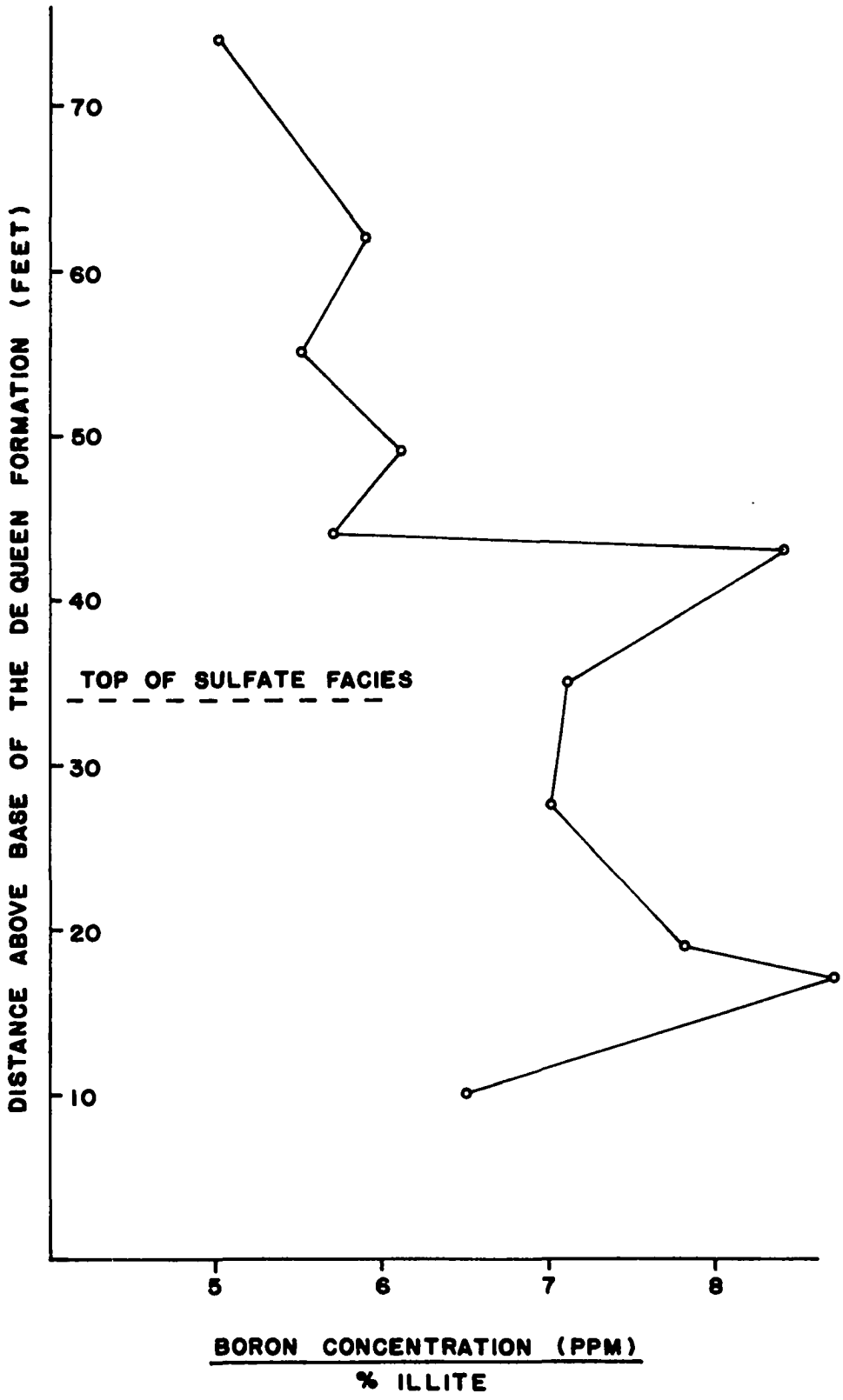

DISTANCE ABOVE BASE OF THE DE QUEEN FORMATION (FEET)
70
60
50
40
TOP OF SULFATE FACIES
30
20
10
5
6
7
8
BORON CONCENTRATION (PPM)
% ILLITE

FIGURE 9

the writer's interpretation of the depositional history of the DeQueen Formation.

Average value of the boron:illite ratio in the sulfate facies is 7.5, compared with 6.2 in the carbonate facies.

Table 1 - Trace Element Analyses of Argillites

Sample Number	Size (microns)	Concentration of Elements (ppm)					
		B*	B	Cu	V	Zr	Cr
HS 5	bulk		300	10	<10	100	300
"	0.5-1		350	50	10	100	400
"	0.25-0.5		400	10	100	tr	500
"	0.1-0.25		350	300	10	ND	500
"	<0.1	370	400	300	10	ND	400
HS 8	bulk		400	100	10	10	300
"	<0.1	390					
HS 10	bulk		400	10	500	100	300
"	<0.1	410					
W 19	bulk		400	10	100	10	400
"	<0.1	450					
HS 15	0.1-0.25	392					
W 26	<0.1	285					
HS 22	bulk		400	100	<10	ND	300
"	0.25-1		400	100	10	10	400
"	0.1-0.25		400	300	100	10	400
"	<0.1	375	400	100	10	ND	400
HS 25	bulk		300	10	10	10	300
"	<0.1	295					

Table 1 - Continued

Sample Number	Size (microns)	Concentration of Elements (ppm)					
		B*	B	Cu	V	Zr	Cr
W 32	bulk		200	300	10	100	200
"	0.1-0.25	255					
"	<0.1	300					
W 39	bulk		400	100	<10	10	400
"	<0.1	345					
W 46	bulk		200	10	<10	100	200
"	<0.1	200					

B* indicates quantitative analysis for boron; the remainder of the tabulated data is from semiquantitative analysis.

ND indicates none determined.

tr indicates a concentration of less than 5 ppm.

Semiquantitative analyses by Kenneth Sargent, University of Oklahoma, Norman, Oklahoma.

Quantitative analyses by personnel of Pan American Petroleum Corporation Research Center, Tulsa, Oklahoma.

GEOLOGIC HISTORY

The interpretations of detailed petrographic and chemical analyses from this study have been incorporated with stratigraphic interpretations of previous authors in an attempt to arrive at the most logical geologic history for the DeQueen Formation.

Depositional Environments

Studies of the stratigraphy and geometric relations of the outcropping Trinity Group by F. A. Melton indicate that lower and middle Trinity sediments were deposited in a transgressing sea (personal communication, 1962). The sediments form an onlapping sequence which overstepped the peneplaned surface of Paleozoic rocks. Direction of transgression was apparently in a northwesterly direction in southwestern Arkansas. This direction of transgression is substantiated by a study of pebble orientations by Frederick Manley of Pan American Petroleum Corporation (personal

communication, 1965). Sediments were deposited on a broad unstable shelf, which lay between the craton to the north, and the Gulf Coast geosyncline to the south (Forgotson, 1963).

During the time of upper Rodessa-Holly Creek deposition there was extensive biohermal development along the tectonic hinge of the shelf in central Louisiana. This produced sufficient restriction to cause deposition of evaporites. Continued biohermal development and gentle downwarping of the shelf area produced a shallow, elongate, saucer shaped lagoon of great areal extent, into which the Ferry Lake-DeQueen evaporites were deposited (Forgotson, 1963). The initial evaporites were in the form of carbonates, and are represented by the limestones in the uppermost part of the Rodessa Formation. Evaporation continued at a faster rate than the influx of normal marine and run-off water, resulting in the initial deposition of the Ferry Lake-DeQueen beds of calcium sulfate. Salinity of the water was apparently fairly constant throughout deposition of the sulfate facies, as calcium sulfate and calcium carbonate are the only bedded chemical deposits present. According to Clarke (1924), the absence of sodium chloride indicates salinities of less than 332 parts per thousand. Maintenance of this salinity range may be explained by stratification of the restricted lagoonal

water, and flowage of the underlying, denser, highly saline brines into the open sea through channels in the restricting barrier (Scruton, 1953). Another explanation may be that the concentration of highly saline brines by stratification was prohibited by wave action. This mixing would probably require a relatively shallow depth of water over the restricted shelf area. Oxidation-reduction potentially probably ranged from 0.0 to +0.1 in the depositional environment, and the pH range was about 8 to 9 (Krumbein and Garrels, 1952).

Recent experimentation indicates that gypsum is the most probable primary calcium sulfate precipitate, and the writer assumes this to be true in the case of the DeQueen evaporites (Murray, 1964, and Ham, 1962).

The southwest-northeast trending shoreline was apparently stationary, except for minor fluctuations, during deposition of the outcropping DeQueen gypsum. Subsurface relationships indicate that the shoreline was not far beyond the present outcrop limit (Forgotson, 1956 and 1963). This is also indicated by stratigraphic and petrographic evidence along the outcrop. The DeQueen sulfate facies is confined to the eastern half of the outcrop, and is stratigraphically equivalent to the limestones and clays in the lower part of

the formation in the western portion of the outcrop. The relatively stationary nature of the shoreline is indicated by the fact that the facies change from sulfates to interbedded limestones and clays takes place over a distance of less than 20 miles. The distance may be much less, but stratigraphic evidence is lacking due to poor exposures.

The lower part of the formation appears to be a perfect example of evaporite basin margin deposition as described by Sloss (1953). The limestone-clay equivalent of the evaporite facies was deposited in a near-shore brackish environment resulting from dilution of the hypersaline water by run-off water. The proportion of clastics in the formation increases toward the west. There is also a proportional increase in kaolinite content of the claystones and mudstones from east to west. This is due either to a preferential flocculation of kaolinite when the sediment-laden run-off water flowed into the more saline environment, or the fact that the larger kaolinite particles had a faster settling velocity than the other clay minerals.

With the exception of the uppermost beds, nearly all of the DeQueen carbonates are petrographically similar to the brackish-water equivalent of the sulfate facies. The depositional environments were apparently similar during

deposition of most of the carbonate sequence. Sediments which are younger than the outcropping evaporites were probably deposited in a brackish water environment which was transitional from hypersaline to normal marine conditions. It is also possible that the brackish water sediments in the upper part of the formation are genetically similar to those in the lower part, and are stratigraphically equivalent to subsurface sulfate deposits. The variation in boron concentration of the clays indicates that the former explanation is the most feasible. Brackish conditions of deposition are also indicated by the faunal assemblage of the formation (Miser and Purdue, 1929).

All of the DeQueen limestones appear to have been deposited in a low to moderate energy, shallow water environment. Evidence of subaerial exposure and erosion is fairly common throughout the section. A few examples of well preserved carbonate boxwork overlying hematite and limonite stained argillites have been observed. Erosion within the formation was not extensive, and it was generally confined to small exposed areas. A shallow water environment of deposition is also indicated by the faunal assemblage (Miser and Purdue, 1929; R. W. Harris, personal communication, 1965).

Argillite beds throughout the section are lithologi-

cally similar. There is little variation of exchangeable cations or trace elements in the clays. It is the writer's opinion that the depositional environments of nearly all of the argillite beds in the formation were physically and chemically similar. The clays were deposited in a brackish environment caused by an influx of clastic-laden run-off water from the craton. Deposition and availability of the fine clastics were probably climatically controlled. The argillite beds were formed during times of increased humidity and rainfall. This would explain the relative lack of variation between claystones and mudstones of the sulfate facies and those of the carbonate facies. The argillites of the sulfate facies are generally highly calcareous due to the decrease of salinity into the range of carbonate deposition upon influx of run-off water.

Source of the detrital sediments was north and northwest of the present-day outcrop. The sedimentary Paleozoic rocks of the Ouachita belt produced the greatest portion of the DeQueen clastics.

Diagenetic Changes

Primary gypsum deposits of the DeQueen Formation were interbedded with beds and laminae of micrite and

argillaceous muds. It is believed that the initial conversion of gypsum to anhydrite began a short distance below the depositional interface, as has been proposed for the Blaine evaporites (Ham, 1962). The theory has not been substantiated by chemical analyses of the DeQueen sulfates. Flowage, distortion, and injection of the unconsolidated non-sulfates into the sulfate beds was caused by shrinkage of the gypsum due to dehydration to anhydrite, in conjunction with density variations in the sequence of sediments. The typical "chicken wire" or mosaic character of the sulfates resulted from this process. Completion of the change from gypsum to anhydrite occurred with continued burial. The gypsum in the present-day outcrop was formed by hydration of anhydrite when the area was uplifted and eroded. It may represent hydration of the original anhydrite. There is a definite possibility that the outcropping gypsum is a third generation of the mineral, and the original anhydrite was previously converted to gypsum during the period of erosion which followed deposition of the Lower Cretaceous rocks. Upon burial by Upper Cretaceous sediments the second generation of gypsum would probably have reconverted to anhydrite, which in turn would be rehydrated to form the gypsum which is exposed along the present DeQueen outcrop. Petrographic evidence is lacking

for the formulation of a positive conclusion.

Most of the authigenic minerals within the carbonates were apparently formed during early diagenesis. Although the Eh of the environment of deposition was apparently slightly positive, the presence of randomly disseminated and laminated pyrite indicates reducing conditions below the depositional interface. Pyrite was formed prior to consolidation of the enclosing sediments.

Hematite and limonite appear to have resulted primarily from oxidation during weathering, and are considered to be late diagenetic in origin.

Petrographic evidence indicates a fairly early diagenetic recrystallization of carbonates.

CONCLUSIONS

The outcropping DeQueen Formation in southwestern Arkansas is composed of two distinct lithofacies. In the eastern half of the outcrop area the lower part of the section consists primarily of gypsum interbedded with lesser amounts of argillites and carbonate rocks. The gypsum sequence grades laterally toward the west into interbedded limestones and argillites. The upper part of the formation is lithologically similar to the underlying part of the carbonate facies.

The DeQueen Formation is correlative with the subsurface Ferry Lake Anhydrite and the lower portion of the Mooringsport Formation.

Carbonates of the formation are dominantly thin- to medium-bedded calcarenites and calcirudites. Although recrystallization commonly obliterates the depositional texture, they are primarily classified as wackestones and packstones. Common allochemical constituents are pellets,

pelecypods, ostracodes, foraminifers, superficial oolites, and algal material. Early diagenetic celestite, gypsum, pyrite, and pseudomorphs of calcite after gypsum are authigenic constituents of many limestone beds.

Outcropping gypsum beds are the end-product of a complex diagenetic history involving dehydration, rehydration, and recrystallization of the primary gypsum deposits. Irregularly prismatic selenite is the dominant form of gypsum, although alabaster is nearly always present in small amounts. Distorted and disrupted laminae or "apophyses" of calcite and clay are present throughout the DeQueen gypsum beds.

Argillites of the formation are typically non-platy claystones and mudstones. Clay minerals comprising the argillites are illite, kaolinite, chlorite, and montmorillonite. Illite is the dominant clay mineral in the formation. Kaolinite content increases from east to west, and in many of the beds in the western half of the outcrop it is the most abundant clay mineral. The relative amount of detrital quartz contained in the argillites also increases toward the west, as does the total percentage of argillites in the formation.

Flame photometric analyses indicate no detectable

pattern of variation in the proportions of exchangeable cations between clay minerals from the sulfate and carbonate facies of the DeQueen Formation. Quantitative emission spectrographic analyses show an overall decrease in boron content of clays from the bottom to the top of the formation. Variations of boron concentrations are erratic in the lower 42 feet of the formation, but a fairly constant decline is apparent in the overlying beds.

The original gypsum of the sulfate facies was deposited in a hypersaline, restricted lagoon, formed by biohermal development along a tectonic sill. Salinity of the water never exceeded the threshold value for precipitation of sodium chloride, but it apparently fluctuated between the ranges of carbonate and sulfate precipitation. During formation of the sulfate facies, interbedded limestones and argillites were being deposited farther to the west, near the ancient shoreline. The entire carbonate facies was deposited in a low- to moderate-energy, shallow, near-shore, brackish-water environment. Except for minor fluctuations, the position of the shoreline was fairly constant during DeQueen deposition. The carbonates that are stratigraphically equivalent to the sulfate facies are evaporite basin margin deposits. The overlying portion of the carbonate

facies was deposited in a brackish-water environment which was transitional from hypersaline to normal marine with time. Salinity of the environment was considerably greater during deposition of the beds directly above the sulfates than it was during the deposition of those near the top of the formation.

Argillites of the formation were deposited in brackish water during periods of increased rainfall and influx of clastic-laden run-off water.

Primary source of the DeQueen clastics was from the Ouachita belt lying to the north and northwest of the present outcrop.

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APPENDIX A

MEASURED SECTIONS

Measured Section 1

Section measured in the southern Highland quarry, center of sec. 22, T. 8 S., R. 26 W., Pike County, Arkansas.

	Thickness (feet)
DeQueen Formation (top of exposure)	
Limestone, dark bluish-gray weathering to moderate yellowish-brown, fossiliferous, hematitic, fine to medium calcirudite	0.5
Claystone, dusky-yellow, calcareous, soft, waxy to gummy, chunky, with carbonaceous film and stain; thin sandy limestone bed one foot from the top	3.7
Interbedded siltstone, claystone, and thin bedded sandy limestone. Siltstone is grayish-yellow to dusky-yellow, calcareous, slightly carbonaceous; with greenish-gray claystone and yellowish-gray, clay-bearing, carbonaceous, irregularly bedded, very fine calcarenite	3.6
Claystone, light olive-gray, calcareous, gypsum-bearing, crumbly, chunky; with thin bed of limestone near top	2.8

Measured Section 1 (continued)	Thickness (feet)
Limestone, pale yellowish-brown, fossiliferous, fine calcarenite grading upward into yellowish-gray, celestite-bearing, disrupted calcilutite	0.3
Same claystone as above; interbedded with limestone, yellowish-gray, clay-bearing, silty, thin-bedded, cross-laminated calcilutite and calcarenite with some disruption of bedding	3.5
Claystone, dusky-yellow to light olive-gray, calcareous, very gypsiferous, slightly carbonaceous, soft, chunky	1.9
Limestone, light-gray, fossiliferous, clay-bearing, disrupted, fine calcarenite	1.0
Claystone, dusky-yellow to light olive-gray, silty, calcareous, gypsiferous, slightly fossiliferous, slightly carbonaceous, soft, platy to chunky	0.6
Clay shale, light to medium greenish-gray, very calcareous, pyritic	0.8
Claystone, greenish-gray, carbonaceous, gypsiferous, chunky to blocky; interbedded with thin-bedded limestone, light-gray, clay- and sand-bearing, burrowed, very fine calcarenite	3.8
Claystone, pale-brown, chunky, waxy to smooth	3.6
Limestone, yellowish-gray, fossiliferous, disrupted(?), fine to medium calcirudite	1.0
Claystone, greenish-gray, calcareous	1.4
Limestone, light-gray, celestite-bearing, fossiliferous, fine calcirudite	0.5

Measured Section 1 (continued)	Thickness (feet)
Claystone, greenish-gray, calcareous, slightly gypsiferous, smooth, chunky to blocky	0.5
Limestone, yellowish-gray to light olive-gray, fossiliferous, celestite-bearing, limonite-stained, fine calcarenite	0.4
Clay shale, medium-gray, smooth, soft, chunky to platy; grading upward into claystone, light-gray, silty, calcareous, slightly gypsiferous and carbonaceous	2.3
Limestone, light olive-gray, fossiliferous, poorly sorted, fine to medium calcirudite	0.5
Clay shale, medium dark-gray, smooth, soft, platy; with limestone, medium-gray to light olive-gray, fossiliferous, thin-bedded, fine calcirudite	3.0
Limestone, light-gray, cross-laminated, sparsely fossiliferous, fine calcarenite	0.5
Claystone, very light-gray, very calcareous, hard, smooth, blocky	2.8
Gypsum, white to medium light-gray alabastrine and selenitic, medium-bedded; with interbedded, very thin-bedded calcareous clay, satin spar, and disrupted laminae of clay and calcite	3.4
Gypsum, white to medium light-gray, alabastrine and selenitic, massive; with disrupted laminae of clay and calcite	4.4
Gypsum, white to medium light-gray, selenitic, thin- to medium-bedded; with very thin-bedded calcareous clay and disrupted laminae of clay and calcite	5.2

Measured Section 1 (continued)	Thickness (feet)
Limestone, light-gray to pale yellowish-brown, fossiliferous, porous, fine to medium calcarenite	1.8
Claystone, dark greenish-gray, slightly gypsiferous, soft	1.0
Gypsum, white to light-gray, alabastrine and selenitic; with disrupted laminae of clay and calcite	0.3
Claystone, medium greenish-gray, waxy, chunky to blocky, tough	1.5
Gypsum, white to light-gray, alabastrine and selenitic, thin- to medium-bedded; with disrupted calcite and clay laminae; interbedded with thin-bedded clay	3.0
Claystone, medium greenish-gray, waxy, chunky to blocky, tough	0.5
Mudstone, yellowish-gray, very calcareous, carbonaceous, limonite-stained, soft; grading upward into calcite boxwork, grayish-yellow, medium-crystalline; overlain by 2 inches of gypsum	0.4
Claystone, greenish-gray, smooth to waxy, blocky, tough	3.3
Gypsum, white to light-gray, alabastrine and selenitic, medium- to thick-bedded; with disrupted laminae of clay and calcite; interbedded with thin-bedded satin spar and clay laminae	4.3
Claystone, dark greenish-gray, calcareous, smooth, soft, chunky	0.5

-- Base of exposure --

Measured Section 1 (continued)	Thickness (feet)
Gypsum, (core data)	3.0
Clay, (core data)	0.5
Gypsum, (core data)	0.5
--Base of DeQueen Formation --	
Total thickness	72.6

Measured Section 2

Section measured in western Highland quarry,
W/2 NW/4 sec. 22, T. 8 S., R. 26 W.,
Pike County, Arkansas.

DeQueen Formation (top of exposure)	Thickness (feet)
Claystone, moderate yellowish-brown, silty, calcareous, waxy	0.8
Limestone, dark bluish-gray weathering to moderate yellowish-brown, fossiliferous, fine to medium calcirudite; interbedded clay in lower part	2.7
Claystone, dusky-yellow to light olive-gray, soft, waxy, chunky	2.0
Limestone, moderate yellowish-brown, sandy, hematitic, burrowed, thin-bedded, fine to medium calcarenite	1.5
Claystone, light olive-gray, soft, waxy, chunky	3.0
Limestone, moderate yellowish-brown, fossiliferous, clay-bearing, hematitic, carbonaceous, fine calcirudite	0.4

Measured Section 2 (continued)	Thickness (feet)
Claystone, yellowish-gray, calcareous, slightly fossiliferous, soft, chunky to platy; with a few silty laminae	1.0
Sandstone, pale yellowish-brown, calcite-cemented, thin-bedded, very fine ortho-quartzite and very silty limestone; inter-bedded with claystone, greenish dusky yellow, calcareous, silty, soft, platy to chunky	1.7
Mudstone, light olive-gray, clacareous, very gypsiferous, soft, chunky	1.9
Limestone, yellowish-gray, clay-bearing, fossiliferous, fine calcarenite	1.1
Claystone, greenish- to yellowish-gray, very calcareous, gypsiferous, silty, chunky	0.7
Mudstone, dark yellowish-orange, very gypsiferous, calcareous, hematitic, limon-ite stained, carbonaceous, soft, crumbly; with carbonate nodules	0.8
Mudstone, yellowish-gray, very calcareous, hematitic, hard, chunky; with a few thin beds of limestone; partially covered	4.4
Claystone, moderate-brown, calcareous, waxy, soft, chunky	4.3
Limestone, light-gray, fossiliferous, clay-bearing, fine to medium calcarenite and fine calcirudite	0.7
Claystone, olive-gray to moderate yellowish-brown, calcareous, gypsiferous, soft, chunky; with silty laminae	0.9

Measured Section 2 (continued)	Thickness (feet)
Limestone, yellowish-gray to light olive-gray, fossiliferous, clay-bearing, medium-bedded, coarse calcarenite and fine calcirudite; interbedded with claystone	3.0
Claystone, medium-gray, gypsiferous, calcareous, waxy; extensively limonite stained in lower 6 inches	2.2
Limestone, light olive-gray, fossiliferous, clay-bearing, fine to medium calcirudite	0.5
Claystone, medium light-gray, chunky to platy; interlaminated with mudstone, grayish-orange, calcareous, silty, gypsiferous, fossiliferous	1.2
Limestone, light- to medium-gray, clay-bearing, slightly fossiliferous, thin- to medium-bedded calcarenite and fine calcirudite; interbedded with claystone	2.4
Claystone, very light-gray, very calcareous, blocky, hard	3.2
Gypsum, white, alabastrine to selenitic, very coarsely crystalline, massive; with disrupted laminae of clay and calcite	2.7
Gypsum, white to light-gray, selenitic, thin-bedded; containing disrupted laminae of calcite and clay; with interbedded thin beds of claystone	3.0
Claystone, greenish-gray, phosphatic, gypsiferous, chunky, smooth, soft	1.9
Gypsum, white to light-gray, selenitic, extremely coarsely crystalline, thin- to medium-bedded; with disrupted laminae of clay and calcite; interbedded with thin laminae of claystone	3.9

Measured Section 2 (continued)	Thickness (feet)
Gypsum, white, alabastrine to selenitic, massive; with 1½ inches of celestite-bearing dolomite near the center of the unit	2.0
Limestone, greenish-gray, clay-bearing, silty, irregularly bedded, fine to medium calcarenite	1.5
Claystone, medium greenish-gray, slightly calcareous, soft, smooth, chunky	1.2
Gypsum, white to grayish-yellow, selenitic, extremely coarsely crystalline; with disrupted laminae of clay and calcite	0.4
Claystone, dark greenish-gray, soft, smooth, chunky; with few laminae of calcareous siltstone	1.1
Gypsum, white, alabastrine to selenitic, thin- to medium-bedded; with disrupted laminae of clay and calcite, and a few thin beds of claystone	1.6
Limestone, yellowish-gray, fossiliferous, gypsiferous, clay-bearing, thin-bedded, calcarenite and silty calcarenite; interbedded with clay shale, light-gray, slightly fossiliferous, calcareous, hard, chunky	2.0
Gypsum, white to grayish orange-pink, alabastrine and selenitic; with disrupted clay and calcite laminae and a few laminae of satin spar	0.6
Claystone, medium greenish-gray, smooth, soft, chunky; with calcareous, silty laminae	0.5
Gypsum, white to moderate orange-pink, alabastrine and selenitic, massive	1.2

Measured Section 2 (continued)	Thickness (feet)
Claystone, light olive-gray to greenish-gray, calcareous, soft, smooth, chunky; with lenticular, clay-bearing limestone and satin spar near the top	3.5
Gypsum, white, selenitic, extremely coarsely crystalline, thin- to medium-bedded; interlayered with claystone and satin spar	4.2
Claystone, medium-gray, calcareous; inter-laminated with shale, light gray, silty, calcareous, platy	0.3
Gypsum, white to light-gray, selenitic, very coarsely crystalline, massive; with disrupted thin laminae of calcite, and few thin laminae of satin spar	2.7
Claystone, medium-gray, calcareous	0.5
-- Base of exposure --	
Gypsum, (core data)	0.5
-- Base of DeQueen Formation --	
Total thickness	75.7

Measured Section 3

Section measured in abandoned gypsum quarry, 2½ miles WNW of Highland, NE/4 sec. 18, T. 8 S., R. 26 W., Pike County, Arkansas.

DeQueen Formation (top of exposure)	Thickness (feet)
Limestone, pale yellowish-brown, silty, slightly fossiliferous, thin-bedded, porous, irregularly-laminated, very fine calcarenite; overlain by reddish soil cover	0.9
Clay shale, light olive-gray to dusky-yellow, slightly calcareous, carbonaceous, platy, smooth; with interlaminated streaks of siltstone, light gray, very calcareous, limonite-stained	0.8
Limestone, yellowish-gray, very sandy, clay-bearing, slightly fossiliferous, burrowed, fine calcarenite	0.5
Clay shale, same as above	2.7
Limestone, yellowish-gray to grayish yellow, fossiliferous, silty, clay-bearing, disrupted, irregularly bedded, medium calcirudite	0.7
Claystone, light olive-gray to dusky-yellow, silty, slightly calcareous	1.0
Limestone, yellowish-gray to grayish-yellow, slightly silty, clay-bearing, fossiliferous, partially disrupted, fine to medium calcirudite	1.2
Siltstone, yellowish-gray, extremely calcareous, hard, chunky to blocky; with a few thin lenses of limestone, light bluish-gray, silty, clay-bearing, slightly fossiliferous, cross-laminated calcarenite	2.8

Measured Section 3 (continued)	Thickness (feet)
Covered	3.0
Gypsum, white to grayish-orange, selenitic, coarsely crystalline; containing disrupted laminae of calcite	0.8
Claystone, yellowish-gray, calcareous, smooth to waxy, chunky	1.3
Claystone, dusky-yellow to moderate yellowish-brown, calcareous, hematitic, smooth, chunky; with very thin beds and laminae of gray alabastrine gypsum and satin spar gypsum in upper 9 inches	1.1
Gypsum, white to light-gray, selenitic, extremely coarsely crystalline, massive; with disrupted laminae of clay and a small amount of calcite	3.7
Claystone, greenish-gray	0.3
Gypsum, white to light-gray; upper 18 inches same as above. Lower part of the unit is coarsely crystalline, more regularly bedded, selenite and alabaster with disrupted laminae of calcite	2.4
Claystone, greenish-gray, slightly calcareous, waxy, chunky	2.3
Gypsum, white to gray, selenitic and alabastrine	0.3
Claystone, olive-gray, slightly calcareous, gypsiferous; with very thin laminae of gypsum, white, calcareous, slightly silty, alabastrine	1.2
Gypsum, white to light-gray, selenitic; with disrupted laminae of dark-gray calcite and clay	0.7

Measured Section 3 (continued)	Thickness (feet)
Claystone, greenish-gray	0.6
Limestone, yellowish-gray, hematitic, slightly fossiliferous, clay-bearing, calcirudite	0.2
Claystone, mottled yellowish-gray to moderate yellowish-brown, very calcareous, hematitic; grading upward into 2 inches of carbonate boxwork, yellowish gray, clay-bearing, hematitic	0.3
Limestone, light olive-gray to greenish-gray, sandy, fossiliferous, medium calcirudite; disrupted in upper part	0.3
Clayey siltstone, greenish-gray to dark greenish-gray, gypsiferous, carbonaceous; with laminae and small patches of sucrosic gypsum. Gypsum laminae especially abundant in lower 10 inches	2.0
Gypsum, white to light-gray, selenitic; with abundant disrupted laminae of calcite and clay. Lower part of the unit is massive but upper 8 inches is thin bedded with interlaminated claystone	1.8
Claystone, greenish-gray, slightly fossiliferous, calcareous; with irregular laminae and small patches of very calcareous siltstone	2.0
Gypsum, white to moderate orange-pink, selenitic; with disrupted laminae of calcite and clay, and 2 inches of satin spar at the base	0.7
Claystone, greenish-gray, calcareous	0.6

Measured Section 3 (continued)	Thickness (feet)
Gypsum, white to moderate orange-pink, selenitic to alabastrine, massive; with disrupted laminae of calcite and clay, and a few thin beds of satin spar near the base	3.5
-- Base of exposure --	
Total thickness	39.7

Measured Section 4

Section measured in railroad cut southwest of Briar Plant quarry, E/2 sec. 10, T. 8 S., R. 27 W., Howard County, Arkansas.

DeQueen Formation (top of exposure)	Thickness (feet)
Claystone, yellowish-gray to grayish-yellow; containing thin-bedded, interbedded, silty limestone, which is abundant as float along the outcrop. Poor exposure	9.0
Limestone, light olive-gray to yellowish-gray, sandy, cross-laminated, very fine calcarenite; with smaller amount of interbedded claystone as below	1.4
Claystone, light olive-gray to greenish-gray, slightly silty, calcareous, chunky	1.5
Limestone, yellowish-gray, sandy, celestite-bearing, fossiliferous, thin- to medium-bedded, medium calcirudite	1.2
Claystone, as above	0.3

Measured Section 4 (continued)	Thickness (feet)
Celestite, white to yellowish-gray, pyritic, porous, irregularly bedded; with irregular, disrupted laminae of light olive-gray limestone	0.5
Claystone, light olive-gray, calcareous, carbonaceous, chunky, poorly exposed	2.0
Limestone, yellowish-gray, sandy, dense, fine calcarenite	1.0
Limestone, yellowish-gray, marly, silty, crumbly, irregularly bedded, fine calcarenite	2.8
Sandstone, light olive-gray, finely laminated, dense, fine-grained, with inter-laminated clay in the upper part, and mud crack impressions on the bottom of the unit ...	0.4
Claystone, light olive-gray to dusky-yellow, calcareous, chunky; containing carbonaceous specks and films, and a few laminae of lime-stone. Some red stain within the claystone ...	2.1
Claystone, yellowish olive-gray, slightly calcareous, soft, smooth, chunky	2.0
Claystone, light olive-gray to dusky-yellow, calcareous, carbonaceous, soft, chunky	1.0
Claystone, light olive-gray, slightly calcareous, gypsiferous, chunky; containing laminae of gypsiferous, calcareous mudstone, and interbedded with thin-bedded limestone and sandstone. Limestone is light olive-gray to dusky-yellow, fossiliferous, sandy, fine to medium calcirudite. Sandstone is light olive-gray, very fine- to fine-grained, and commonly cross-laminated	5.2

Measured Section 4 (continued)	Thickness (feet)
Limestone, light olive-gray, fossiliferous, porous, fine to medium calcirudite in lower 2 inches; grades upward into sandy, burrowed, very fine calcarenite	0.5
Claystone, yellowish olive-gray, gypsiferous, smooth to waxy, chunky	1.1
Limestone, yellowish-gray, marly, silty, irregularly bedded, slightly fossiliferous, fine calcarenite	0.5
Limestone, light olive-gray, sandy, cross-laminated, thin-bedded, very fine to fine calcarenite	1.0
Claystone, yellowish-gray	0.3
Limestone, yellowish-gray, clay- and celestite-bearing, very fossiliferous, slightly sandy, very coarse calcirudite	0.5
Claystone, yellowish-gray, poorly exposed	0.5
Covered	16.0
Claystone, light olive-gray; with streaks and patches of dusky-yellow. Upper 16 inches contain interbedded, thin-bedded, sandy limestone and calcareous fine sandstone	3.0
Gypsum, white, alabastrine, massive, very pure	3.0
-- Base of exposure --	
Total thickness	56.8

Measured Section 5

Section measured in road cut of Arkansas State Highway 4, 2¼ miles NNW of Center Point, along the boundary between sections 15 and 16, T. 8 S., R. 28 W., Howard County, Arkansas. This is a poorly exposed section.

DeQueen Formation (top of exposure)	Thickness (feet)
Limestone, yellowish-gray, slightly fossiliferous, sandy, disrupted, very fine to fine calcarenite	0.7
Mudstone, yellowish-gray, very calcareous, carbonaceous, chunky, crumbly	0.5
Covered	4.0
Limestone, yellowish-gray, sandy, clay-bearing, disrupted, massive, very fine to fine calcarenite	3.0
Silty claystone; pale-olive, very calcareous, slightly carbonaceous, crumbly, chunky	1.0
Covered	7.0
Limestone, yellowish-gray, clay-bearing, silty, slightly fossiliferous, disrupted, fine calcarenite	1.0
Claystone, light olive-gray, calcareous	1.5
Celestite, white to light-gray, very coarsely crystalline, irregularly bedded; containing disrupted laminae of clay and calcilutite	0.2
Limestone, light-gray to pale-olive, clay-bearing, irregularly bedded, calcilutite	0.2
-- Base of exposure --	
Total thickness	19.1

Measured Section 6

Section measured in road cut, 1½ miles north of Provo, SE/4 sec. 17 and NE/4 sec. 20, T. 8 S., R. 29 W., Sevier County Arkansas. Argillites are poorly exposed.

DeQueen Formation (top of exposure)	Thickness (feet)
Limestone, medium-gray weathering to dusky-yellow, fossiliferous, compact, fine to medium calcirudite	0.5
Claystone, pale-olive; with interbedded, thin-bedded, limestone and sandy limestone. Poorly exposed	7.0
Limestone, grayish dusky-yellow, porous, clay gall-bearing, sandy, indistinctly laminated, thin- to medium-bedded, very fine to fine calcarenite	1.0
Claystone	2.0
Limestone, yellowish-gray to grayish-yellow, very sandy, clay-bearing, hematitic, very fine to fine calcarenite	0.5
Covered ..... (approximately)	12.0
Limestone, yellowish-gray, hematitic, very sandy, porous, thin-bedded, very fine to fine calcarenite; with interbedded grayish-yellow claystone	1.5
Mudstone, yellowish-gray, chunky, crumbly. Poorly exposed	1.3
Limestone, light-gray, silty, clay-bearing, slightly fossiliferous, burrowed, fine calcarenite	0.5
Claystone, poorly exposed	1.0

Measured Section 6 (continued)	Thickness (feet)
Limestone, light-gray, abundantly fossiliferous, disrupted, fine to medium calcirudite	0.6
Silty claystone, light olive-gray to dusky-yellow, calcareous, carbonaceous, hematitic, chunky, crumbly; with thin-bedded, interbedded limestone and sandy limestone	5.5
Limestone, yellowish-gray to light olive-gray, very sandy, indistinctly laminated, calcarenite; with clay and silt in the upper 1 inch	0.4
Claystone, yellowish-gray	1.2
Limestone, medium dark-gray weathering to dusky-yellow, slightly fossiliferous, medium calcarenite	0.3
Limestone, yellowish-gray, silty, marly, irregularly bedded, thin-bedded, calcarenite	0.5
Covered ..... (approximately)	27.0
Sandstone, yellowish-gray to grayish-yellow, clay-bearing, barite-cemented	0.5
Mudstone, yellowish-gray to moderate yellowish-brown, sandy, hematitic, chunky	0.9
Sandstone, same as above	0.8
Silty claystone, dusky-yellow, chunky, tough; with abundant carbonaceous material in patches and as film along indistinct bedding planes	6.5
-- Base of DeQueen Formation --	
Total thickness ..... (approximately)	70.6

Measured Section 7

Section measured in road cut of U. S. Highway 71 in DeQueen Townsite, along the boundary of sections 19 and 20, T. 8 S., R. 31 W., Sevier County, Arkansas.

Sandstone, dark yellowish-orange, very friable, medium-grained, subrounded to rounded, very porous. Located 12 feet above the top of the DeQueen Formation.

-- Top of DeQueen Formation --

	Thickness (feet)
Limestone, dusky-yellow to light olive-gray, fossiliferous, clay-bearing, disrupted, fine to medium calcirudite	0.7
Claystone, mottled yellowish-gray and dark yellowish-orange, abundantly fossiliferous, slightly carbonaceous and silty	2.0
Limestone, same as above	0.5
Covered, with only a few isolated limestone outcrops and float ..... (approximately)	68.0
Limestone, light-gray weathering to dusky-yellow, very sandy, fossiliferous, irregularly laminated; grading downward into 2½ inches of calcareous sandstone	0.9

-- Base of DeQueen Formation --

Total thickness ..... (approximately)	72.1

Claystone, yellowish-gray, slightly silty, waxy, chunky; 2 feet below base of the DeQueen Formation.

Sandstone, pale yellowish-orange, very friable, fine- to medium-grained, subangular to subrounded, poorly sorted, porous, clay-bearing; 7 feet below base of DeQueen Limestone.

Measured Section 8

Section measured in railroad cut in DeQueen Townsite, sections 19 and 30, T. 8 S., R. 31 W., Sevier County, Arkansas.

DeQueen Formation (top of exposure)	Thickness (feet)
Limestone, yellowish-gray, fossiliferous, thin to medium, irregularly bedded; with some cross-laminated, calcarenite interbedded with fine to medium calcirudite	2.6
Claystone, greenish-gray. Poorly exposed	3.0
Covered	7.0
Limestone, light-gray to yellowish-gray, clay-bearing, very sandy, burrowed, very fine calcarenite	0.4
Limestone, light-gray to light olive-gray, fossiliferous, sandy, burrowed, finely laminated to thin-bedded, fine calcarenite to coarse calcirudite	3.4
Claystone, gray. Poorly exposed	2.7
Limestone, light olive-gray weathering to grayish-yellow, abundantly fossiliferous, slightly sandy, fine to medium calcirudite	1.3
Clay shale, gray, platy to chunky, poorly exposed	2.3
Limestone, medium dark-gray to light-gray, extremely sandy, thin-bedded, very fine calcarenite	0.5
Covered ..... (approximately)	15.0

Measured Section 8 (continued)	Thickness (feet)
Limestone, yellowish-gray to grayish-orange, sandy, pyritic, burrowed, interlayered calcarenite and calcilutite; showing some disruption of bedding due to flowage	0.3
-- Base of exposure --	
Total thickness ..... (approximately)	38.5

APPENDIX B

SELECTED THIN SECTION DESCRIPTIONS

Format of carbonate rock descriptions:

1. Sample number - formation, measured section where sample was taken, brief description of sampled bed, stratigraphic position of sampled bed.

2. Descriptive rock name.

3. Allogenic constituents: percentage, description.

4. Authigenic constituents: percentage, description.

5. Matrix and/or cement.

6. Significant features.

Format of sulfate rock descriptions:

1. Sample number - formation, measured section where sample was taken, brief description of sampled bed, stratigraphic position of sampled bed.

2. Descriptive rock name.

3. Mineralogy: percentage, description.

4. Significant features.

1. HS 16 - DeQueen Formation, Measured Section 1, 0.5 feet of limestone, 37 feet above the base of the formation.

2. Very fine to fine calcarenite: moderately sorted, extensively recrystallized, burrowed, pelletiferous wackestone.

3. Allochems constitute approximately 25% of the thin section. Closer estimate is prohibited by extensive recrystallization, which has obliterated many of the allochems.

   Faecal(?) pellets: 21%, 0.05 to 0.1 mm in greatest dimension.

   Foraminifers: 2%, 0.15 to 0.25 mm in diameter.

   Pelecypods and ostracodes: 2%, less than 0.3 mm in greatest dimension; a few composed of phosphatic material.

   Clay: 1 to 2%, occurring principally as clay-micrite mixture in borings.

   Quartz: 1%, silt and very fine sand sized, angular, randomly disseminated, partially replaced by calcite.

   Carbonaceous material: less than 1%, randomly disseminated specks and patches, less than 0.1 mm in greatest dimension.

   White mica: trace, in blades from 0.1 to 0.15 mm in length.

4. Calcite: replacing quartz.

5. Matrix is finely crystalline sparry calcite, which grades into a few indistinct patches of micrite.

6. Significant features: textural immaturity; sparse allochems, definitely lacking grain support; recrystallization ghosts and gradational boundaries of allochems; micrite grading into sparry calcite;

HS 16 (continued)

clay and micrite filling borings; replacement of quartz by calcite; cross-laminations obvious in hand specimens.

1. HS 21 - DeQueen Formation, Measured Section 1, 0.4 feet of celestite-bearing limestone, 43 feet above the base of the formation.

2. Fine calcarenite: extensively recrystallized, celestite-bearing, superficial oolitic, foraminifer wackestone and packstone.

3. Allochems vary from 10 to 30% of the thin section, averaging 25%. They are extensively obliterated by recrystallization.

   Foraminifers and superficial oolites: approximately 20%, 0.1 to 0.2 mm in diameter; superficial coatings are brown, yielding iron stain on oxidation; nuclei of oolites are commonly unidentifiable.

   Pelecypod fragments: 4%, 0.3 to 3.5 mm in greatest dimension; many small fragments are well rounded and coated; few phosphatic fragments.

   Ostracodes: 1%, 0.15 to 0.33 mm in greatest dimension.

   Green algae: trace, less than 0.2 mm in greatest dimension.

   Quartz: 5%, coarse silt to fine sand sized, subangular to angular with a few of the larger grains subrounded, randomly disseminated, partially replaced by calcite.

   Carbonaceous material: trace, irregular specks and fragments.

4. Celestite: approximately 20%, subhedral to euhedral, prismatic porphyroblasts, ranging from 0.02 to 0.6 mm in greatest dimension; porphyroblasts enclose allochems and granular calcite.

HS 21 (continued)

Hematite and limonite: as oxidation products of coated grains.

Calcite: replacing quartz.

5. Matrix is composed of very fine to finely crystalline sparry calcite, which grades into a few small patches of micrite.

6. Significant features: textural immaturity; some lack of allochem grain support; recrystallization ghosts of allochems, and gradational boundaries of allochems; micrite matrix grading into sparry calcite; iron stain originating from oxidation of oolitic coatings; abundance of celestite porphyroblasts; fairly abundant detrital quartz.

1. HS 27 - DeQueen Formation, Measured Section 1, 0.2 feet of sandy limestone, 53 feet above the base of the formation.

2. Very fine calcarenite: clay-bearing, sandy, burrowed, partially recrystallized, pelletiferous wackestone.

3. Allochems form approximately 25% of the thin section.

Pellets: 22%, less than 0.1 mm in greatest dimension.

Foraminifers: 2%, 0.1 to 0.2 mm in diameter; many of the smaller forms have superficial coatings.

Ostracodes: 1%, 0.15 to 0.3 mm in greatest dimension; single valves preserved.

Quartz: 10%, coarse silt to fine sand sized, subangular to angular, dominantly straight extinction, extensively replaced by calcite.

Clay: associated with burrows and disseminated throughout the carbonate matrix.

HS 27 (continued)

Carbonaceous material: trace, randomly distributed.

4. Pyrite: trace, irregular patches, less than 1 mm in greatest dimension.

   Calcite: replacing quartz.

5. Matrix consists of very fine- to finely-crystalline sparry calcite, and patches of micrite.

6. Significant features: textural immaturity; lack of mutual grain support; micrite grading into sparry calcite; recrystallization ghosts of allochems, and gradational boundaries of allochems; discordant streaks of sandy clay and micrite; abundant detrital quartz; calcite replacing quartz; abundance of pellets.

1. HS 30 - DeQueen Formation, Measured Section 1, 1 foot of limestone, 56 feet above the base of the formation.

2. Fine calcarenite: clay-bearing, slightly sandy, disrupted, partially recrystallized, pelletiferous wackestone.

3. Allochemical constituents form 25 to 30% of the thin section. Closer estimate is prohibited by recrystallization.

   Pellets: 16%, generally ranging from 0.07 to 0.15 mm in diameter; some are glauconitic.

   Ostracodes and pelecypods: 5%, 0.07 to 5.0 mm in greatest dimension; fragments are typically delicate and extensively recrystallized; small pelecypod and ostracode fragments are commonly indistinguishable; a few of the small fragments are phosphatic.

   Foraminifers: 3%, 0.15 to 0.3 mm in diameter.

HS 30 (continued)

Superficial oolites: less than 1%, 0.15 to 0.3 mm in diameter, brown, generally with fossil fragment nuclei.

Intraclasts: trace, less than 2 mm in greatest dimension, dark micritic.

Quartz: 5%, coarse silt to fine sand sized, subangular to angular, dominantly straight extinction, partially replaced by calcite.

Glauconite: 1%, in the form of pellets and irregular grains.

Carbonaceous material: slight trace.

4. Pyrite: slight trace, irregular patches, less than 0.2 mm in greatest dimension.

   Hematite: trace, irregular patches, less than 0.2 mm in greatest dimension.

5. Matrix consists primarily of very fine- to finely-crystalline sparry calcite. Micrite is preserved with clay in patches throughout the thin section. Clay is most prominent in apparently burrowed portions of the rock.

6. Significant features: textural immaturity; lack of mutual grain support; micrite grading into sparry calcite; recrystallization ghosts and gradational boundaries of allochems; clay and micrite in irregular patches; glauconitic pellets; replacement of quartz by calcite; general lack of lineation.

1. HS 36 - DeQueen Formation, Measured Section 1, 0.1 feet of sandy limestone, 64 feet above the base of the formation.

2. Very fine calcarenite: moderately sorted, sparsely fossiliferous, extremely sandy, partially recrystallized packstone.

HS 36 (continued)

3. Fossils constitute only 5% of the thin section, and consist of approximately equal amounts of pelecypod fragments, foraminifers, and ostracodes; green algae is present in trace amounts.

   Intraclasts: 7 to 10%, less than 3 mm in greatest dimension, micrite and sandy micrite; boundaries of the intraclasts are commonly vague and indistinct.

   Pellets: 1%, less than 0.2 mm in diameter.

   Quartz: varies from 30 to 40%, coarse silt to very fine sand sized, subrounded to angular, dominantly straight extinction, extensively replaced by calcite, randomly disseminated.

   Chert: less than 1%, coarse silt to fine sand sized, subrounded to subangular, extensively replaced by calcite.

   Orthoclase and muscovite: trace amounts, less than 0.15 mm in greatest dimension.

4. Hematite: 1 to 2%, as irregular patches replacing matrix.

   Calcite: replacing quartz.

5. Matrix is composed of micrite which is extensively recrystallized to very fine and fine sparry calcite.

6. Significant features: some lack of mutual grain support; recrystallization ghosts and gradational boundaries of allochems; micrite grading into matrix spar; textural immaturity; abundant silt and sand sized quartz; extensive replacement of quartz by calcite; presence of detrital chert.

1. HS 39 - DeQueen Formation, Measured Section 1, 0.5 feet of limestone, top of the exposed section.

2. Fine to medium calcirudite: poorly sorted, partially recrystallized, hematitic, pelecypod packstone and grainstone.

3. Pelecypods: 50 to 55%, fragments and valves ranging from less than 0.2 to 9.0 mm in greatest dimension; composed of pearly and sparry calcite; mixture of well rounded fragments and delicate, unbroken valves; few phosphatic fragments.

   Gastropod fragments: approximately 5%, pearly and recrystallized calcite; difficult to distinguish many fragments of gastropods and pelecypods.

   Echinoderm plates and fragments: 1%, less than 0.3 mm in greatest dimension, with syntaxial rims.

   Carbonaceous material: trace.

4. Hematite: 5%, as irregular patches replacing matrix and fossil fragments.

5. Matrix is primarily micrite which has been partially recrystallized to microspar. Some medium to coarsely crystalline sparry calcite is apparently pore filling cement.

6. Significant features: textural immaturity; lack of pellets, foraminifers, ostracodes, and quartz; apparently winnowing of some matrix micrite; micrite grading into microspar; mixture of delicate, fairly well preserved pelecypod material with coarse, rounded fragments.

1. W 25 - DeQueen Formation, Measured Section 2, 0.5 feet of silty limestone, 42 feet above the base of the formation.

2. Fine to medium calcirudite: extensively recrystallized, clay-bearing, slightly silty, pelecypod wackestone.

3. Allochems constitute approximately 40% of the thin section. Recrystallization has obliterated many of the allochems.

   Pelecypod fragments: 20%, 0.1 to 8.0 mm in greatest dimension, recrystallized; some of the coarse fragments have been broken more extensively than some of the delicate pelecypods.

   Ostracodes: 5%, less than 0.3 mm in greatest dimension.

   Superficial oolites and pellets: 12%, less than 0.2 mm in diameter; some pellets composed of glauconite.

   Foraminifers: 3%, 0.15 to 0.3 mm in diameter.

   Quartz: 5%, coarse silt to fine sand sized, subangular to angular, straight extinction, partially replaced by calcite; though present throughout the rock, the quartz is concentrated in indistinct laminae.

   Carbonaceous material: trace, irregular specks.

4. Hematite and pyrite: slight trace.

   Calcite: replacing detrital quartz.

5. Matrix consists of very fine- to finely-crystalline sparry calcite with a few patches of micrite.

6. Significant features: textural immaturity; mutual grain support is questionable; recrystallization ghosts of allochems and gradational boundaries between sparry calcite and allochems; few patches of micrite grading into microspar; lack of orientation of fossil fragments; some coarse pelecypods are more fragmental than the more delicate ones.

1. W 28L - DeQueen Formation, Measured Section 2, 0.4 feet of limestone, 45 feet above the base of the formation.

2. Fine calcirudite: poorly sorted, partially recrystallized, disrupted, pelecypod-superficial oolitic wackestone.

3. Allochems constitute 25 to 30% of the rock. A closer estimate is prohibited by recrystallization.

   Superficial oolites: 14%, 0.1 to 0.3 mm in diameter; nuclei are commonly foraminifers and ostracode valves, but many are unidentifiable; iron contained in superficial coatings has been oxidized to iron oxide in many of the grains.

   Pelecypods: 11%, fragments and complete valves ranging from 0.1 to 7.0 mm in greatest dimension; many of the smaller grains (less than 0.3 mm), are rounded, and some have a brown superficial coating; pelecypod material is sparry calcite.

   Uncoated ostracodes and foraminifers: 2%, 0.2 to 0.5 mm in greatest dimension; ostracodes are commonly nonfragmental, and often both valves are preserved together.

   Intraclasts: trace, less than 0.4 mm in greatest dimension, micritic.

   Green algae: trace

   Quartz: 4 to 5%, coarse silt to fine sand sized, subangular to angular with a few coarse grains subrounded, dominantly straight extinction, randomly disseminated, partially to completely replaced by calcite.

4. Hematite and magnetite(?): in a few randomly distributed clusters of individual grains, less than 0.08 mm in diameter; hematite and limonite stain is common.

5. Matrix is very fine- to finely-crystalline sparry calcite, grading into a few patches of micrite.

W 28L (continued)

6. Significant features: textural immaturity; lack of mutual grain support; recrystallization ghosts, and gradational boundaries of allochems; matrix micrite grading into sparry calcite; abundance of brown superficial oolites in apparently immature rock; disruption by burrowing; calcite replacing detrital quartz.

1. W 28U - DeQueen Formation, Measured Section 2, 0.7 feet of limestone, 46 feet above the base of the formation.

2. Coarse calcarenite to fine calcirudite: poorly sorted, extensively recrystallized, celestite-bearing, pelecypod-algal grainstone and packstone.

3. Allochems constitute approximately 70% of the thin section. Most of the fossil fragments have been recrystallized, and have thin coatings or impregnations of algal or micritic material.

   Platy algae and pelecypods: 60%, 1.0 to 4.0 mm in greatest dimension; algae are dominant, but in many instances cannot be differentiated from recrystallized pelecypod valves.

   Superficial oolites and foraminifers: 5 to 7%, less than 0.2 mm in diameter, randomly disseminated; nuclei of oolites commonly indistinct; coatings are brown, with some iron oxidation.

   Ostracodes: 1 to 2%, less than 0.4 mm in greatest dimension.

   Intraclasts: less than 1%, less than 1.0 mm in greatest dimension, dark micritic, partially recrystallized.

   Quartz: less than 1%, coarse silt to coarse sand sized, subangular to subrounded, some overgrowths, commonly straight extinction, partially replaced by calcite.

W 28U (continued)

Carbonaceous material: trace, irregular fragments.

4. Celestite: 2 to 3%, in irregular patches, less than 1.0 mm in greatest dimension, good cleavage; appears to be confined to indistinct zones; incipient replacement by calcite(?).

   Pyrite: trace, clusters of anhedral patches which are less than 0.1 mm in greatest dimension; some oxidation to hematite.

   Calcite: replacing quartz and celestite.

   Dolomite(?): trace.

5. The rock is cemented with pore filling sparry calcite, but a small amount of micrite and apparently recrystallized micrite is present.

6. Significant features: poor sorting; apparently incomplete winnowing of original matrix micrite; extreme recrystallization; superficial coatings or impregnations on nearly all allochems; presence of celestite; recrystallization ghosts and gradational boundaries of some allochems; few dark micritic intraclasts; calcite replacing quartz and celestite.

1. A 7 - DeQueen Formation, Measured Section 3, 0.3 feet of sandy limestone, 10½ feet above the base of the exposure.

2. Medium calcirudite: poorly sorted, slightly recrystallized, sandy, pelecypod packstone.

3. Allochems constitute 55% of the thin section.

   Pelecypod valves and fragments: 33%, 0.5 to 12.0 mm in greatest dimension; all are composed of sparry calcite, and some have been obliterated by recrystallization of matrix; surface of most pelecypods is impregnated with micrite or algal material.

A 7 (continued)

Ostracodes: 7%, less than 1.0 mm in greatest dimension, partially recrystallized; both valves are commonly present.

Pellets: 6%, less than 0.25 mm in diameter; both rounded and irregularly shaped, and some apparently differ from the larger intraclasts only in size; partially recrystallized.

Intraclasts: 3%, 0.25 to 0.6 mm in greatest dimension, subrounded to angular, micritic.

Foraminifers: 5%, 0.1 to 0.3 mm in diameter, randomly disseminated; some are filled with micrite; a few are partially recrystallized.

Quartz: 20%, fine sand sized, subangular to angular with a few subrounded and rounded grains, dominantly straight extinction, partially replaced by calcite; most abundant in the upper and lower part of the bed.

Chert: 1%, fine sand sized, subangular to subrounded.

4. Hematite: trace, irregular small patches and specks, less than 0.3 mm in greatest dimension, randomly disseminated.

   Calcite: replacing detrital quartz.

5. Matrix consists of micrite which has been partially recrystallized to microspar. Some pore-filling sparry calcite is present in the lower one inch of the bed.

6. Significant features: textural immaturity; matrix micrite grading into microspar; some sand grains and pellets lacking grain support within the matrix; recrystallization ghosts of allochems; abundance of quartz sand; micrite or algal material impregnating the surface of pelecypod fragments; pellets and intraclasts apparently differ only in size; apparent winnowing of micrite in the lower part of the bed; burrowing along the upper surface of the bed (hand specimen).

1. A 19 - DeQueen Formation, Measured Section 3, 0.8 feet of slightly sandy limestone, 34 feet above the base of the exposure.

2. Medium calcirudite: unsorted, clay-bearing, slightly sandy, burrowed, partially recrystallized, wackestone.

3. Allochems constitute approximately 35% of the thin section.

   Pelecypod fragments and valves: 14%, less than 5.0 mm in greatest dimension, angular, composed of sparry calcite; both coarse and delicate forms present.

   Ostracodes and unidentified fine fossil hash: 9%, less than 0.25 mm in greatest dimension, lacking lineation and grain support.

   Pellets: 6%, less than 0.25 mm in greatest dimension; most of the pellets are rounded, but some are irregularly shaped, differing from intraclasts only in size.

   Foraminifers: 4%, generally less than 0.2 mm in greatest dimension, randomly disseminated.

   Intraclasts: less than 1%, 0.25 to 0.5 mm in greatest dimension, irregularly shaped, dark micritic.

   Superficial oolites: trace, less than 0.2 mm in diameter, dark micritic.

   Green algae and platy algae: trace.

   Quartz: 6 to 7%, silt to very fine sand sized, angular to subangular with a few subrounded grains, some overgrowths, dominantly straight extinction, partially replaced by calcite.

   Chert: trace, silt to very fine sand sized, subrounded.

   Clay: disseminated throughout micrite, and associated with burrows.

A 19 (continued)

4. Hematite: less than 1%, specks and irregular patches in matrix; oxidation along clay laminae.

   Calcite: replacing detrital quartz.

5. Matrix consists of clay bearing micrite which has been partially recrystallized to finely-crystalline sparry calcite.

6. Significant features: textural immaturity; lack of mutual allochem support; micritic matrix grades into sparry calcite; abundant clay in matrix; lack of lineation due primarily to burrowing; angularity of pelecypod fragments; fairly abundant quartz with some detrital chert; similarity of irregular pellets and intraclasts.

1. A 22 - DeQueen Formation, Measured Section 3, 0.9 feet of sandy limestone, top of the exposed section.

2. Very fine calcarenite: extremely recrystallized, sandy, fossiliferous wackestone.

3. Allochems constitute approximately 15% of the rock. Extensive recrystallization prohibits close estimation.

   Pellets: 6%, generally less than 0.1 mm in greatest diameter, micritic, some iron oxide stained, randomly disseminated; recrystallization ghosts are common.

   Foraminifers: 4%, less than 0.2 mm in diameter, randomly distributed, recrystallization ghosts common.

   Ostracodes and unidentified fine fossil hash: 30%, generally less than 0.3 mm in greatest dimension, recrystallized.

   Quartz: ranging from 15 to 20%, very fine sand sized, angular to subrounded, dominantly straight extinction, partially replaced by calcite.

A 22 (continued)

Chalcedony: 1%, very fine to fine sand sized.

Microcline, orthoclase and white mica: trace.

4. Hematite: 1%, irregular patches, less than 0.5 mm in greatest dimension, randomly distributed; yellow iron stain common.

   Calcite: replacing detrital quartz.

   Dolomite: less than 1%, finely-crystalline, subhedral to euhedral rhombs, randomly scattered.

5. Matrix consists dominantly of recrystallized medium- and coarsely-crystalline sparry calcite.

6. Significant features: lack of grain support; recrystallization ghosts common; absence of micrite; poor lineation; porous streaks; abundant quartz; small amounts of chalcedony, feldspar and white mica; fairly uniform matrix spar.

1. B 14 - DeQueen Formation, Measured Section 4, 0.5 feet of thin bedded limestone and celestite, approximately 42 feet above the base of the exposure.

2. Calcilutite: pyritic, celestite-bearing, partially recrystallized mudstone, with pseudomorphs of calcite and celestite after gypsum. The calcilutite is interbedded with celestite: very coarsely crystalline, secondary, containing disrupted laminae and inclusions of micrite and fine sparry calcite.

3. No allogenic constituents are present.

4. Pyrite: 2%, irregular patches, less than 2 mm in greatest dimension; the hand specimen shows a lamina of pyrite above the celestite.

B 14 (continued)

Celestite: comprises 25% of the mudstone, where it forms irregularly shaped patches and elongate pseudomorphs after gypsum. Bedded celestite consists of anhedral, irregularly shaped, unoriented, subequidimensional crystals which form an interlocking mosaic; the crystals show good cleavage.

Anhydrite inclusions: absent in celestite of the calcilutite, but comprise 5% of the bedded celestite; irregularly shaped replacement residue, less than 0.05 mm in greatest dimension; vague relic flow structure of anhydrite; replacement ghosts of anhydrite common in the celestite.

5. Matrix: micrite and celestite.

6. Significant features: lack of allogenic constituents; pseudomorphs of celestite and calcite after gypsum; anhydrite inclusions in the bedded celestite; distinct depositional interface between celestite and calcilutite; deformation and flowage of sulfates; fairly abundant pyrite; apparent replacement of celestite pseudomorphs by calcite; disrupted calcite laminae in bedded celestite.

1. P 7 - DeQueen Formation, Measured Section 6, 0.8 feet of limestone, approximately 36 feet above the base of the formation.

2. Medium calcarenite: poorly sorted, partially recrystallized, pellet-pelecypod-foraminifer packstone.

3. Allochems constitute approximately 50% of the thin section; many are coated grains.

Foraminifers: 13%, less than 0.3 mm in diameter, dark brown to black colored, some partially to completely recrystallized, micritic filling common; high iron content is indicated by iron oxide stain in weathered part of the rock.

P 7 (continued)

Pellets and superficial oolites: 12%, generally less than 0.2 mm in diameter, dark micritic oxidized to reddish brown, subrounded to rounded with a few irregularly shaped grains, partially recrystallized.

Ostracodes, pelecypods and unidentified fossil hash: 20%, commonly less than 0.5 mm in greatest dimension with a few delicate pelecypod fragments ranging to 5.0 mm; many of the small fragments are well rounded; most of the material is partially to completely recrystallized.

Green algae: 3%, less than 0.3 mm in greatest dimension.

Intraclasts: 1 to 2%, 0.5 to 2.0 mm in greatest dimension, dark micritic, slightly fossiliferous, irregularly shaped and commonly angular.

Quartz: 2%, fine sand sized, subangular to angular, dominantly straight extinction, partially replaced by calcite.

4. Hematite: oxidized pellets and fossils.

   Glauconite: slight trace.

5. Matrix is primarily finely-crystalline sparry calcite, which grades into a few small patches of micrite. Some recrystallization of micrite to sparry calcite is evident, but most of the spar is believed to have resulted from pore filling.

6. Significant features: poor sorting; recrystallized ghosts of allochems; gradational boundaries of allochems; micrite patches grading into sparry calcite; mixture of rounded and superficially coated small fossil fragments with larger, delicate pelecypod fragments; angular intraclasts; calcite replacing quartz; abundance of superficially coated grains.

1. P 16 - DeQueen Formation, Measured Section 6, 0.5 feet of limestone, top of the exposed section.

2. Fine to medium calcirudite: partially recrystallized, pelecypod packstone.

3. Allochems vary from 45 to 55% of the thin section.

   Pelecypod valves and fragments: 48%, 0.2 mm to 2 cm in greatest dimension, most commonly less than 1 cm; shell material is dominantly sparry calcite, but some fragments are pearly; pearly fragments are generally well rounded and less than 2.0 mm in greatest dimension, while the recrystallized fragments are larger and more angular; iron content of pearly material is evidently fairly high, as they are reddish brown and yellow stained where oxidized.

   Gastropod fragments: 2%, pearly and sparry calcite.

   Platy algae: 1%, less than 1 mm in greatest dimension, recrystallized, with the outer surface impregnated with micrite or algal material.

   Echinoderm fragments: trace, less than 1 mm in greatest dimension, with syntaxial growth of calcite.

   Quartz: trace, very fine sand sized, angular, straight extinction.

4. Hematite: irregular small patches in the matrix; hematite and limonite also formed by oxidation of pearly pelecypod fragments.

5. Matrix is composed of uniform microspar, with crystal size less than 10 microns.

6. Significant features: lack of allochems typically found in the underlying beds; abundance and character of the pelecypods; uniformity of matrix microspar; recrystallization ghosts and gradational allochem boundaries; upper one inch of the bed is apparently burrowed; high iron content of pearly pelecypod fragments.

1. HS 2 - DeQueen Formation, Measured Section 1, 1.5 feet of gypsum, 5 feet above the base of the formation.

2. Gypsum: medium to very coarsely crystalline, alabaster and selenitic gypsum with thin, disrupted laminae and apophyses of calcite.

3. Gypsum: 95%, elongate and equidimensional anhedral crystals, 0.06 to 3.0 mm in greatest dimension, forming an interlocking mosaic; many of the crystals appear to be superindividuals, composed of numerous grains differing slightly in optical orientation; elongate crystals are commonly subparallel, oriented approximately perpendicular to bedding or in anastomosing masses; alabastrine aggregates commonly illustrate an apparent flow structure bordering the selenitic gypsum; inclusions of calcite and anhydrite are present in the gypsum crystals.

   Anhydrite: approximately 1%, residual replacement inclusions in gypsum, less than 0.05 mm in greatest dimension; inclusions are in the form of irregularly shaped grains and also as fibers along the cleavage planes of gypsum.

   Calcite: 5%, very fine to medium crystalline sparite in disrupted laminae and apophyses; pseudomorphs of calcite after gypsum in very fine sparry calcite matrix.

   Clay: associated with calcite laminae; constitutes less than 1% of the thin section.

4. Significant features: variation in gypsum crystal size; orientation of crystals; disrupted laminae and apophyses of sparry calcite; lack of micrite; superindividual character of gypsum crystals; apparent flow structure of alabaster; inclusions of anhydrite residue.

1. W 6 - DeQueen Formation, Measured Section 2, 1.2 feet of gypsum, 12 feet above the base of the formation.

2. Gypsum: fine to extremely coarsely crystalline, alabaster and selenitic gypsum.

3. Gypsum: 99%, equidimensional alabaster and elongate to irregularly-shaped selenitic anhedral crystals forming a tightly interlocking mosaic; larger crystals are generally elongate and subparallel, oriented approximately perpendicular to the bedding or in a radial pattern; inclusions of calcite, anhydrite, and alabaster are common in the larger selenitic gypsum crystals; alabaster commonly exhibits flow structure near the selenitic masses of gypsum; superindividual crystals are apparent under crossed nicols.

   Anhydrite: 1%, residual inclusions in gypsum due to incomplete replacement; anhydrite is in the form of irregularly shaped grains, and also as fibers parallel to gypsum cleavage; size of inclusions is less than 0.05 mm in greatest dimension.

   Calcite: less than 1%, microspar to medium crystalline sparry calcite in disrupted laminae and apophyses, and as inclusions in gypsum; gradation from microspar to coarser sparry calcite is common.

4. Significant features: abundance of alabaster inclusions in selenite; otherwise very similar to HS 2.

1. 7 h - Ferry Lake Anhydrite, core sample from Skelly #3 Baldwin well in Cass County, Texas. Exact stratigraphic position of the sample is unknown.

2. Anhydrite: fine to medium crystalline, with disrupted laminae and apophyses of clay-bearing micrite.

3. Anhydrite: 85%, in felts of randomly oriented blades and fibers; partially recrystallized grains and patches of prismatic to blocky anhydrite crystals, as well as recrystallization ghosts of the crystals are common in the fibrous and bladed masses; some euhedral to subhedral crystals are present in the micrite laminae and injections.

   Calcite: 15%, micritic, clay bearing, as disrupted laminae and apophyses within the anhydrite; containing blocky to prismatic anhydrite.

   Dolomite: less than 1%, very fine crystalline, subhedral to euhedral, occurring primarily in fibrous anhydrite bordering micrite.

4. Significant features: presence of two distinct growth stages of anhydrite; distinct anhydrite crystals preserved in micrite; orientation of felted masses parallel to micritic laminae and apophyses near the boundaries of the two minerals; presence of dolomite.

1. 14 h - Ferry Lake Anhydrite, core sample from Skelly #3 Baldwin well in Cass County, Texas. Exact stratigraphic position of the sample is unknown.

2. Anhydrite: very fine to finely crystalline, with disrupted laminae and apophyses of clay.

3. Anhydrite: 98%, composed almost entirely of a felted mass of fibrous to prismatic superindividual crystals; grains of tabular to prismatic, partially recrystallized anhydrite, as well as anastomosing clusters and rosettes occur in the felted mass; fibers and prisms are commonly parallel to clay laminae and apophyses near the boundaries of the two minerals.

   Clay: 1 to 2%, submicroscopic, dark brown to black, as disrupted laminae and apophyses.

   Pyrite: trace, very fine subhedral and euhedral crystals; isolated crystals or clusters, generally within or bordering clay; a few anhedral masses also present.

   Dolomite(?): trace, very fine crystalline, subhedral to euhedral.

4. Significant features: very similar to thin section 14 h.

1. C 1 - DeQueen Formation, Measured Section 5, 0.2 feet of celestite with interlaminated calcite, base of the exposure.

2. Celestite: extremely coarsely crystalline, secondary, with disrupted laminae and apophyses of calcite.

3. Celestite: approximately 60%, extremely coarsely crystalline, subhedral, elongate to equidimensional, randomly oriented crystals forming an interlocking mosaic; contains abundant inclusions of micrite, sparry calcite, and anhydrite.

   Calcite: 35%, as disrupted laminae and inclusions in celestite; comprises micrite and coarse sparry calcite; a few fossil fragments are present in the micrite.

   Anhydrite: 5%, replacement residue; consists of irregularly shaped grains, less than 0.1 mm in greatest dimension; abundant as inclusions in celestite crystals.

4. Significant features: inclusions of micrite and sparry calcite in celestite; inclusions and replacement ghosts of anhydrite in celestite; relic flow structure of original anhydrite is preserved; gradation from micrite to sparry calcite; disrupted laminae of calcite; straight crystal boundaries between celestite and sparry calcite are common.

1. B 4 - DeQueen Formation, Measured Section 6, 0.8 feet of barite cemented sandstone, 7 feet above the base of the formation.

2. Coarse siltstone to medium sandstone: poorly sorted, submature, poikilitic barite-cemented orthoquartzite, containing a small amount of matrix clay.

3. Quartz: 50%, coarse silt to medium sand sized, subangular to angular; many of the larger grains are subrounded; dominant extinction type is straight, with some slightly undulose, and a small amount of strongly undulose grains; vacuoles and/or microlites are present in about half of the grains; some quartz overgrowths are evident.

   Chert: 5%, very fine to fine detrital grains, subrounded to rounded, with a pitted appearance.

   Tourmaline: trace, fine to medium sand sized, subangular, green to brown.

   Microcline and orthoclase: trace, detrital.

   Barite: 40%, poikilitic cement.

   Clay: 4%, as patches of matrix throughout the thin section.

   Hematite: less than 1%, as irregular authigenic patches and stain.

4. Significant features: some lack of grain support; poikilitic barite cement; matrix clay present; extreme variation in size and shape of quartz; presence of detrital chert; general lack of feldspar.

APPENDIX C

MINERAL PERCENTAGES IN ARGILLITES

Sample Number	Clay Mineral Percentages				Non-clay Mineral Percentages		
	Illite	Kaolinite	Chlorite	Mont-morillonite	Quartz	Calcite	Dolomite
HS 1	58	30	5	7	90	10	--
HS 5	57	26	17	tr	33	--	67
HS 6	56	30	9	5	79	21	--
HS 7	65	33	tr	tr	95	5	--
HS 8	45	40	13	2	100	--	--
HS 10	54	35	11	--	100	--	--
HS 15	55	36	--	9	28	29	43
HS 17	46	33	6	15	95	5	--
HS 19	43	43	7	7	93	7	--
HS 20	39	36	8	17	70	30	--
HS 22	66	22	12	--	87	13	--
HS 25	48	39	13	tr	86	14	--
HS 26	51	37	12	tr	89	11	--

Sample Number	Illite	Kaolinite	Chlorite	Mont-morillonite	Quartz	Calcite	Dolomite
HS 28	53	42	5	--	86	14	--
HS 29	39	38	7	16	81	19	--
HS 31	57	28	14	tr	100	--	--
HS 34	57	37	3	3	86	14	--
HS 37	45	45	7	3	89	11	--
HS 38	29	43	11	17	85	15	--
W 2	60	35	tr	5	97	3	--
W 4	57	28	14	tr	57	14	29
W 7	61	38	tr	tr	95	5	--
W 9	53	33	13	tr	84	16	--
W 12	45	45	10	tr	87	13	--
W 14	49	43	8	--	100	--	--
W 19	65	22	12	tr	64	28	8
W 22	52	26	13	9	42	23	35
W 24	40	34	11	15	95	5	--

Sample Number	Illite	Kaolinite	Chlorite	Mont-morillonite	Quartz	Calcite	Dolomite
W 26	34	34	13	19	95	5	--
W 27	42	39	9	10	100	--	--
W 29	40	40	12	8	80	20	--
W 31	49	37	14	--	86	14	--
W 32	56	35	9	--	5	1	94
W 33	28	55	6	11	100	--	--
W 34	44	32	8	16	68	32	--
W 36	57	39	4	tr	100	--	--
W 37	46	50	--	4	84	16	--
W 39	58	39	3	tr	82	18	--
W 41	45	42	7	6	100	--	--
W 43	39	52	5	4	100	--	--
W 46	40	36	8	16	85	15	--
A 2	71	19	10	tr	45	32	23
A 4	48	36	11	5	83	17	--

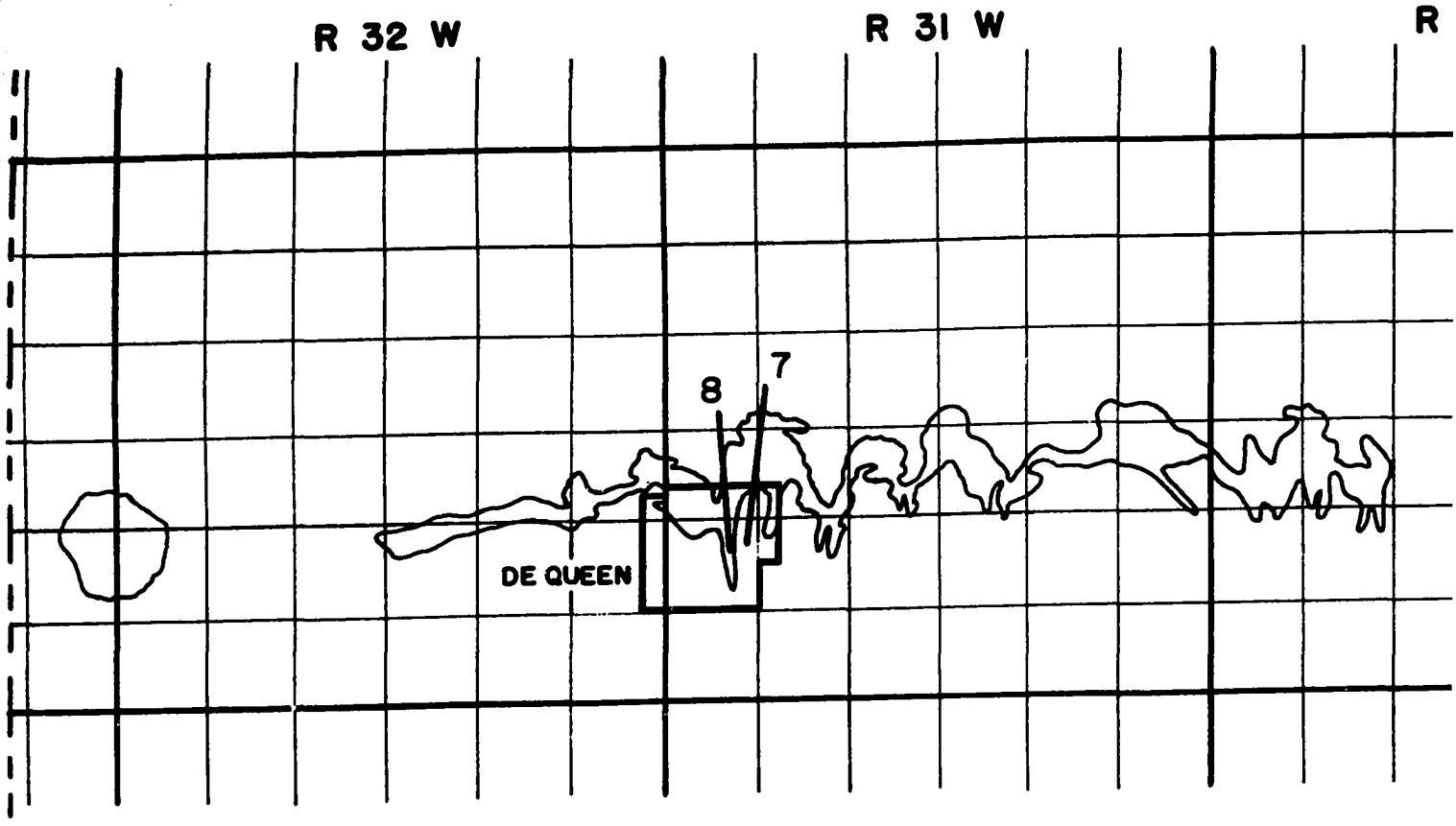
Sample Number	Illite	Kaolinite	Chlorite	Mont-morillonite	Quartz	Calcite	Dolomite
A 6	48	36	12	4	100	--	--
A 8	52	28	20	tr	38	62	--
A 10	44	44	10	2	100	--	--
A 11	52	40	5	3	100	--	--
A 14	31	51	12	6	30	65	5
A 15	58	29	13	--	74	26	--
A 17	36	29	tr	35	57	43	--
A 20	34	44	7	15	100	--	--
B 6	39	28	17	16	100	--	--
B 8	42	44	3	11	75	25	--
B 10	45	35	20	tr	100	--	--
B 11	47	41	9	3	90	10	--
B 16	57	36	7	--	34	66	--
C 3	50	34	6	10	100	--	--

Sample Number	Illite	Kaolinite	Chlorite	Mont-morillonite	Quartz	Calcite	Dolomite
C 5	32	54	tr	14	66	34	--
P 1	30	54	16	tr	100	--	--
P 2	36	27	36	3	100	--	--
P 3	46	34	10	10	100	--	--
P 5	24	35	41	--	100	--	--
P 9	40	19	25	16	50	50	--
P 13	19	58	10	13	82	18	--
P 17	21	58	21	--	100	--	--
P 18	16	40	40	4	100	--	--
D 2a	29	48	9	14	87	13	--
D 4	18	46	35	tr	100	--	--
D 5	9	59	9	23	100	--	--
RR 4	33	55	tr	11	97	3	--

APPENDIX D

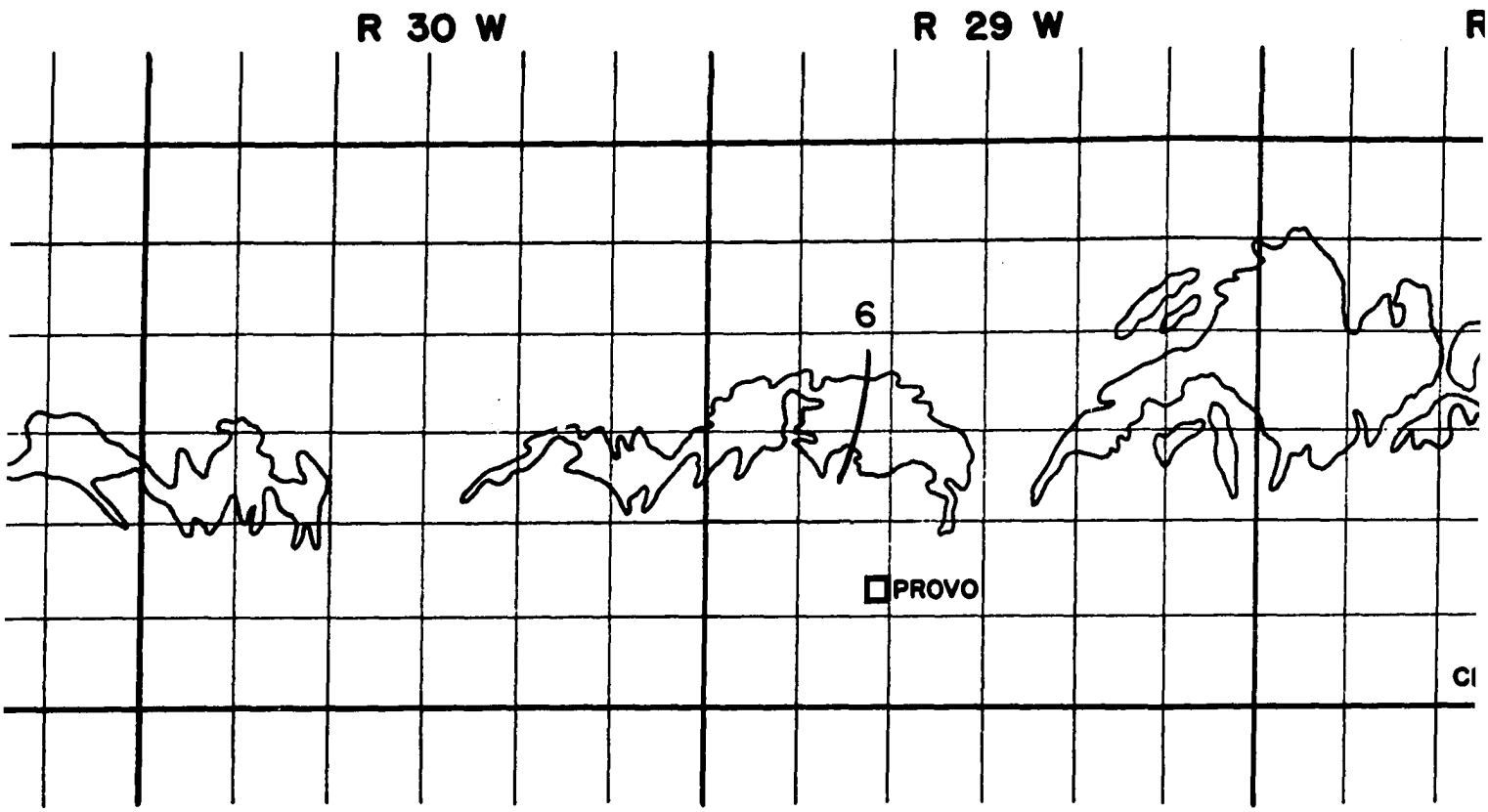
CONCENTRATION RATIOS OF EXCHANGEABLE CATIONS IN LEACHATES

Sample Number	K/Na	Ca/Na	Ca/K	Ca/(Na + K)
HS 5	10.85	7.70	0.707	0.647
HS 8	6.35	4.50	0.71	0.613
HS 10	10.02	16.7	1.64	1.49
W 19	13.5	17.5	1.29	1.20
HS 22	8.1	23.6	2.92	2.60
HS 25	11.3	6.95	0.617	0.567
W 32	5.62	10.8	1.92	1.63
W 39	13.75	15.9	1.14	1.07
W 46	9.65	4.65	0.48	0.436



AFTER MISER AND PURDUE, 1929.

PLATE I



OUTCROP MAP OF THE DE QUE
IN SOUTHWESTERN ARK

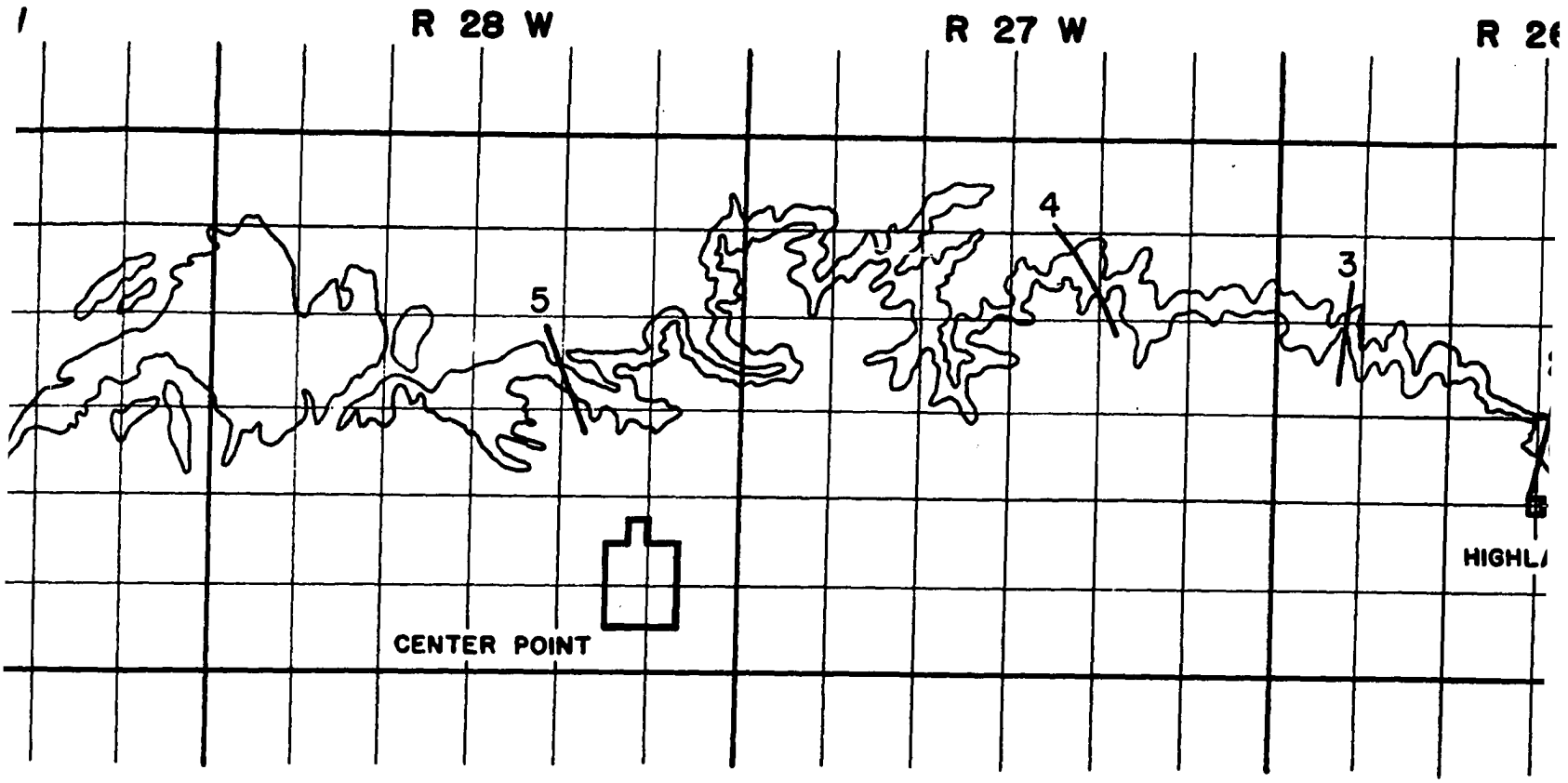
BY

BURT E. HAMRIC PH. D. 19

0 3

MILES

PLATE I



OF THE DE QUEEN FORMATION

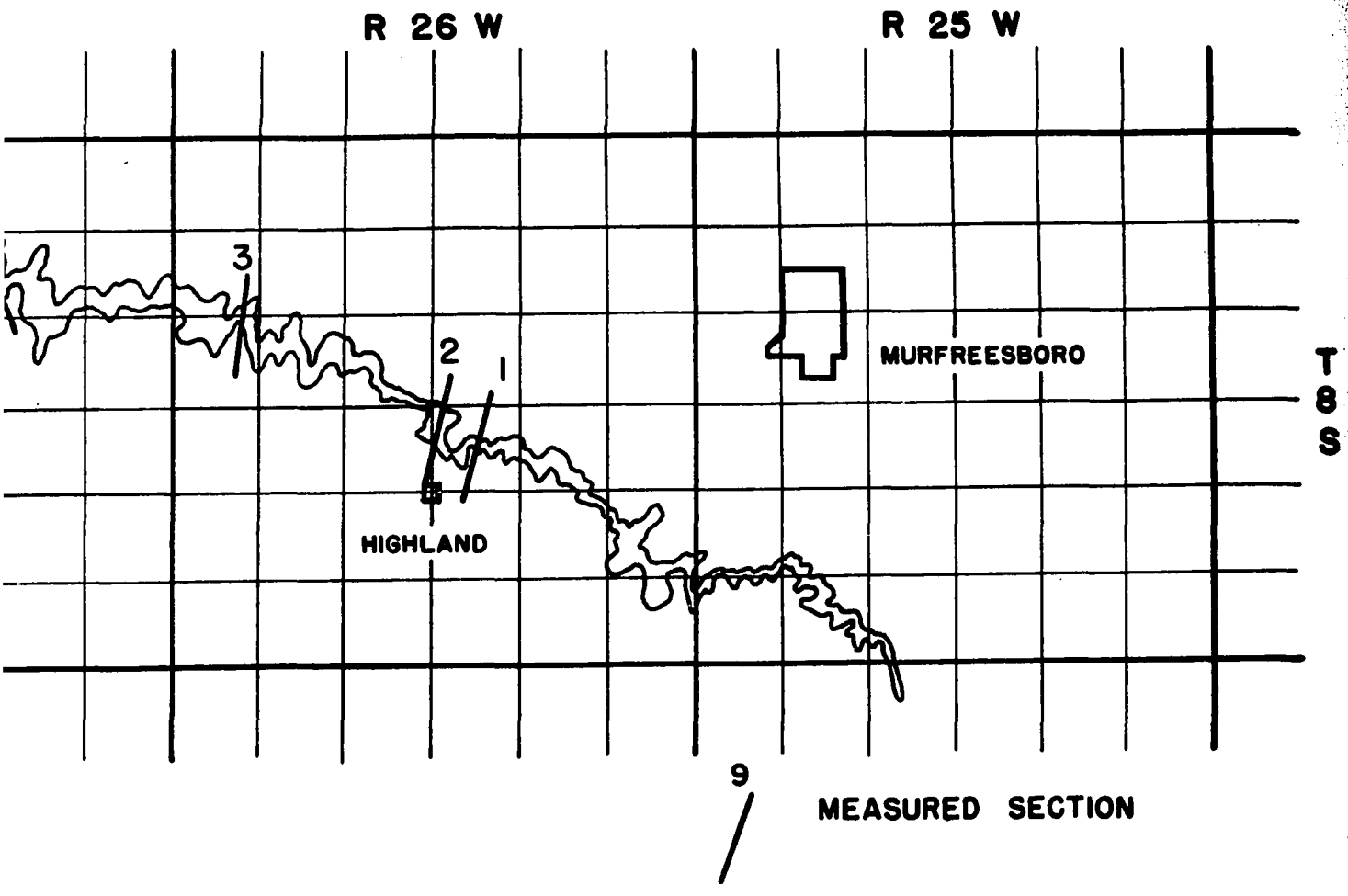
HWESTERN ARKANSAS

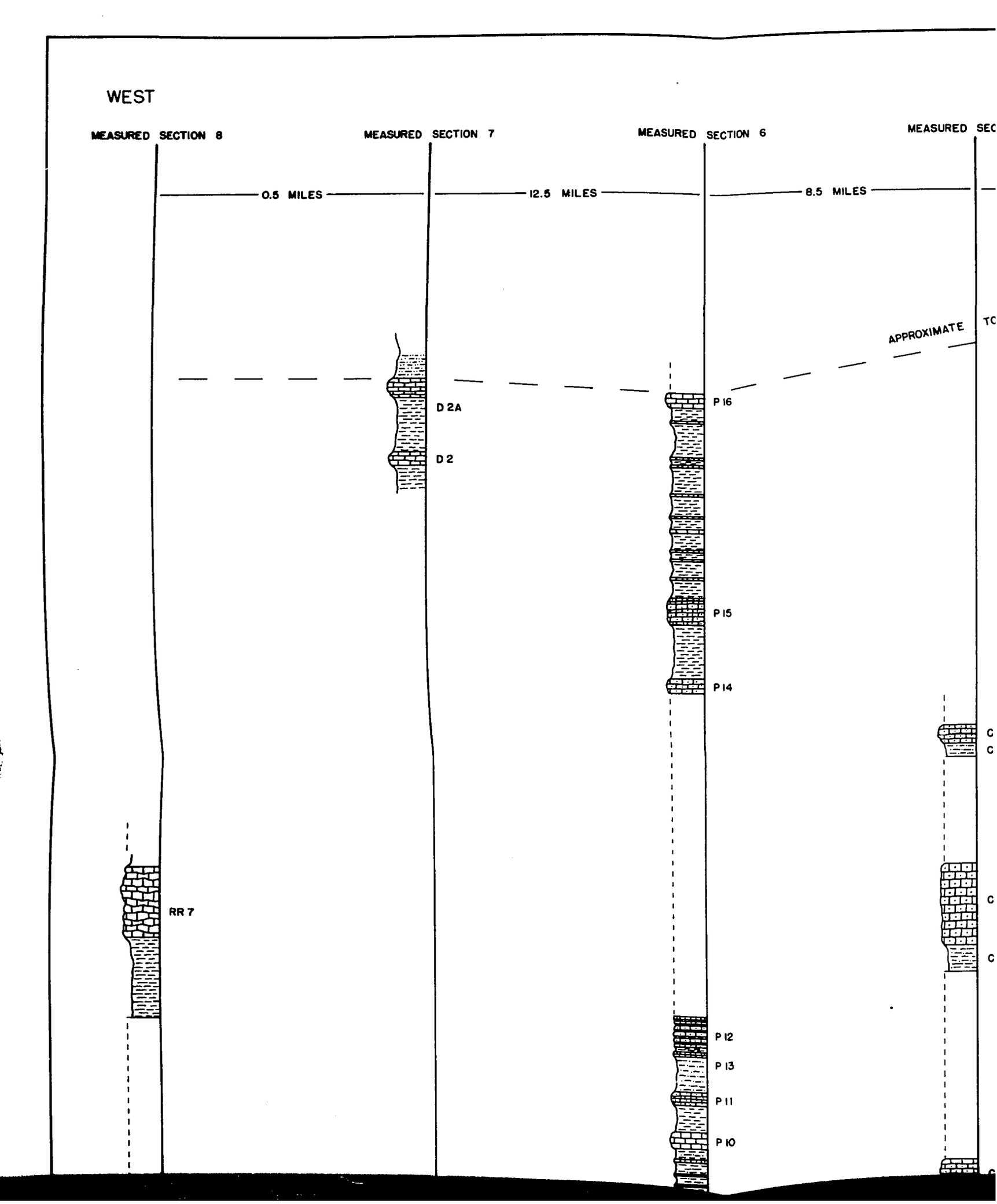
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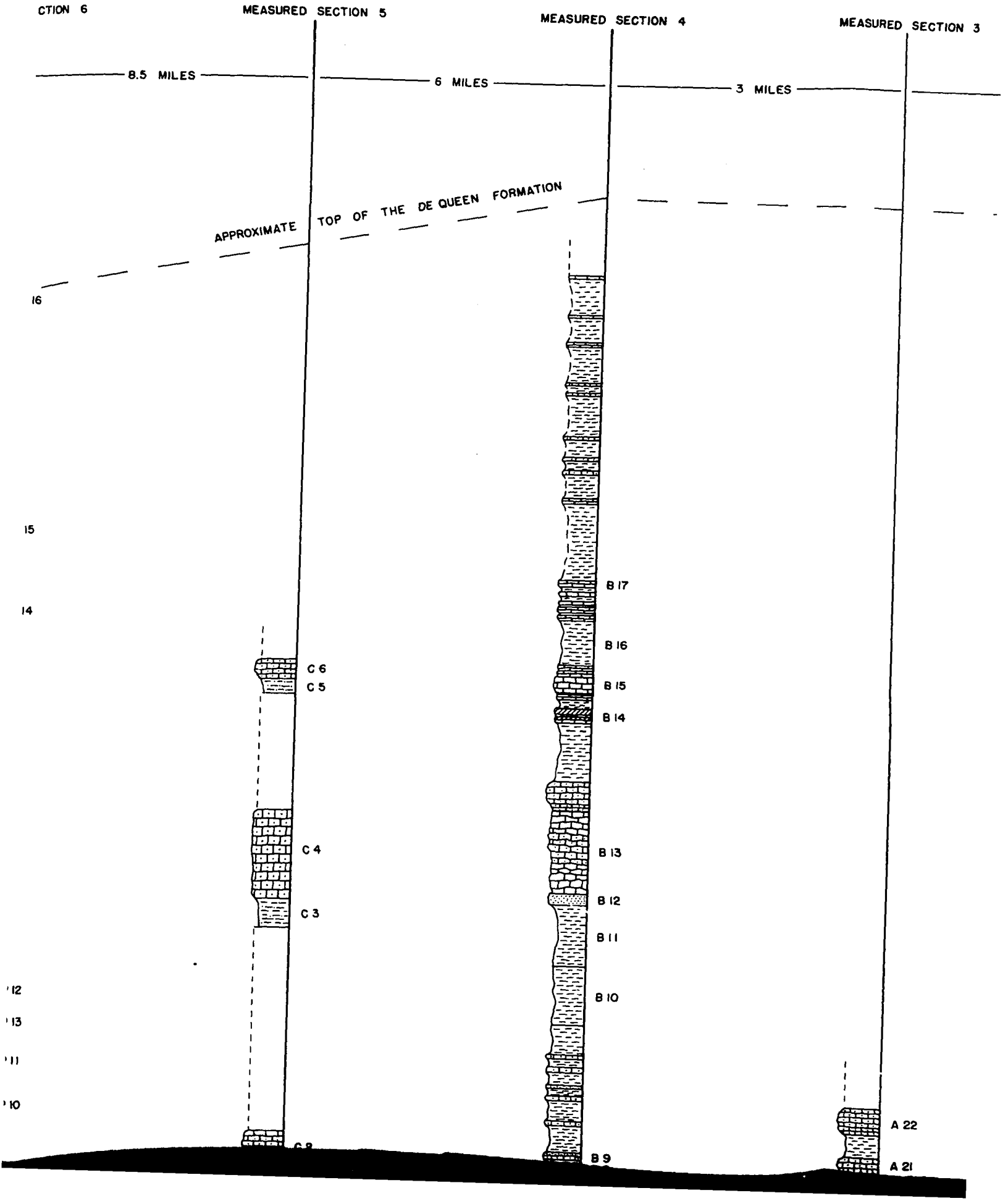
E. HAMRIC PH. D. 1965

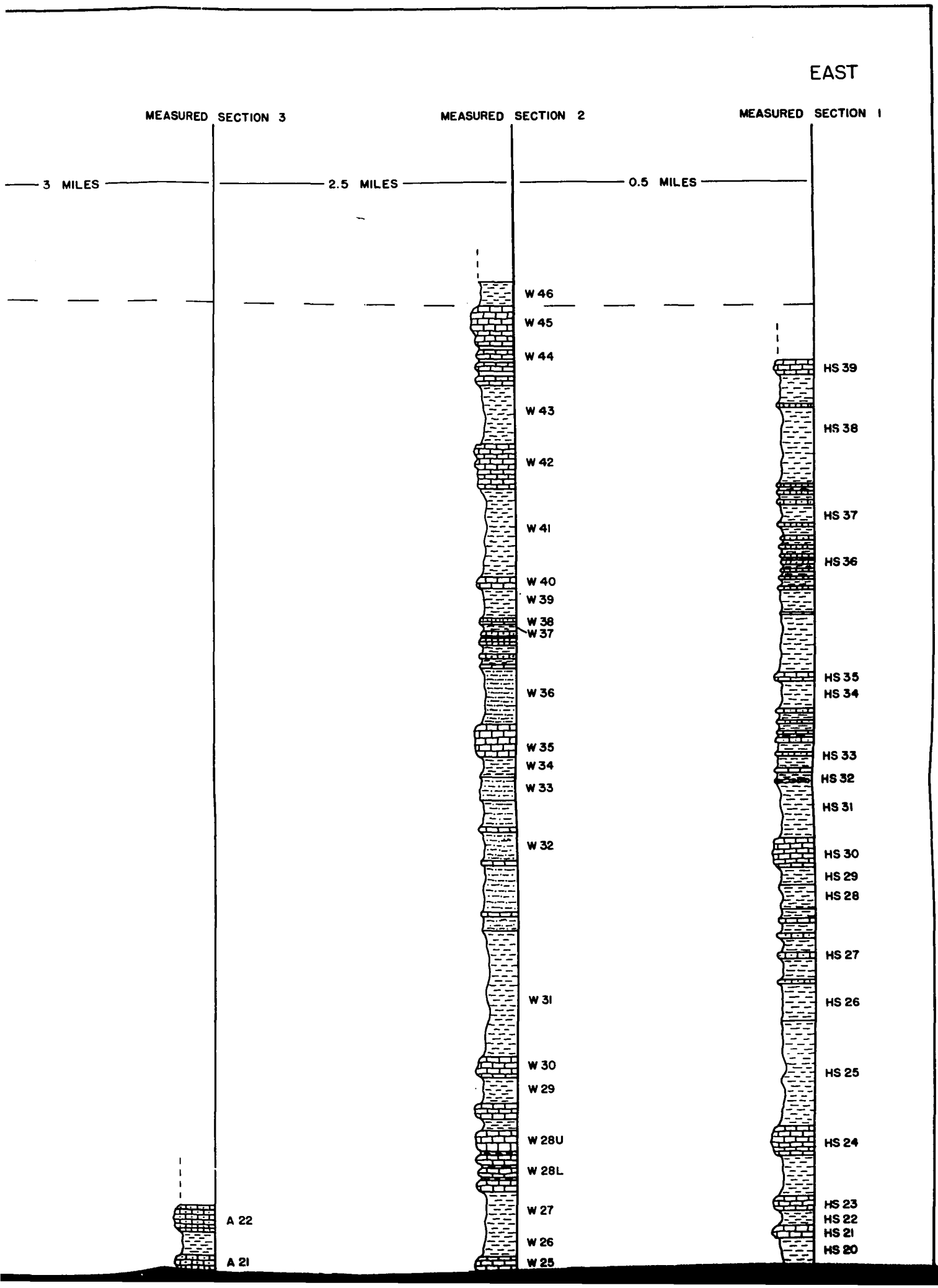
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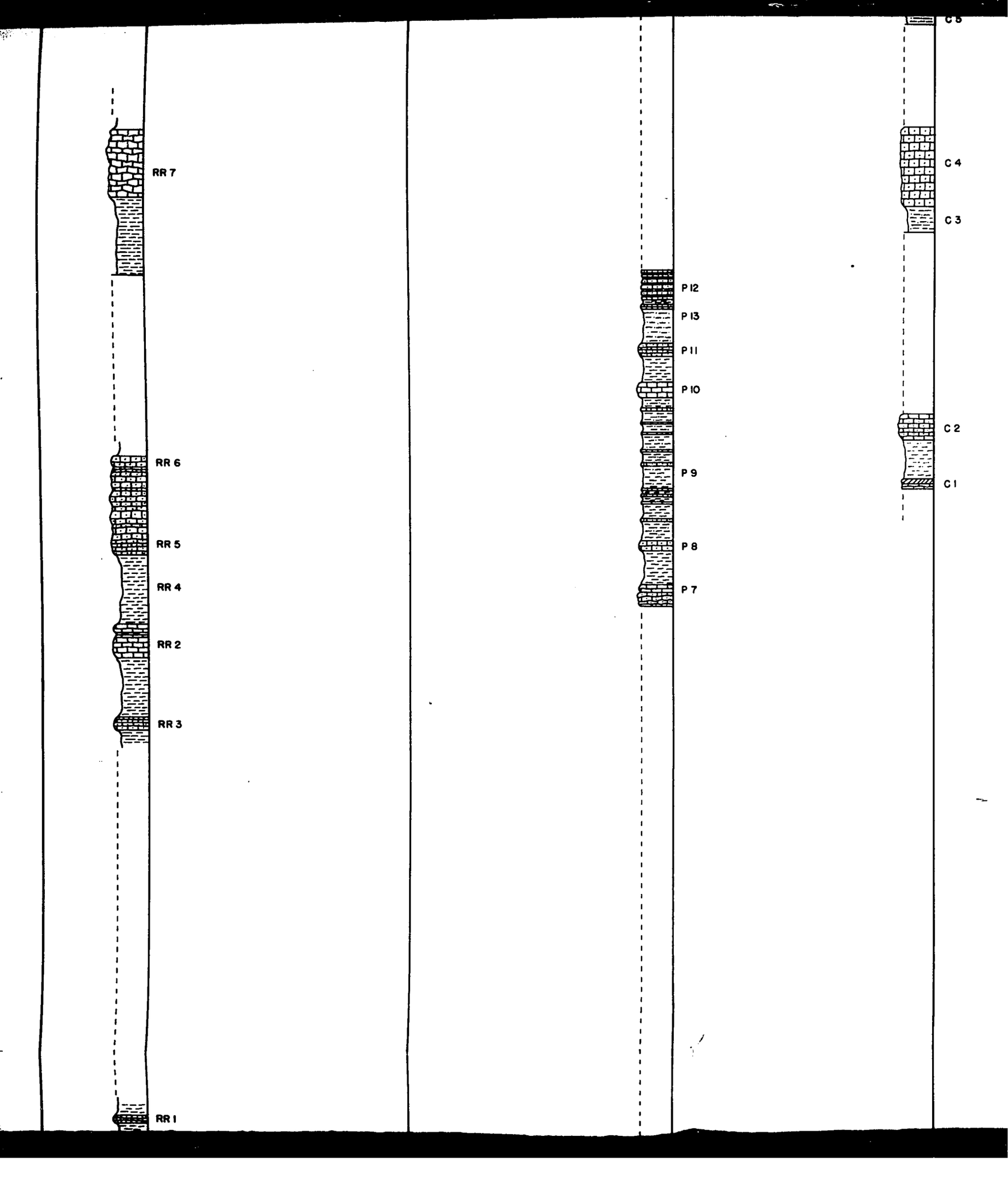
MILES

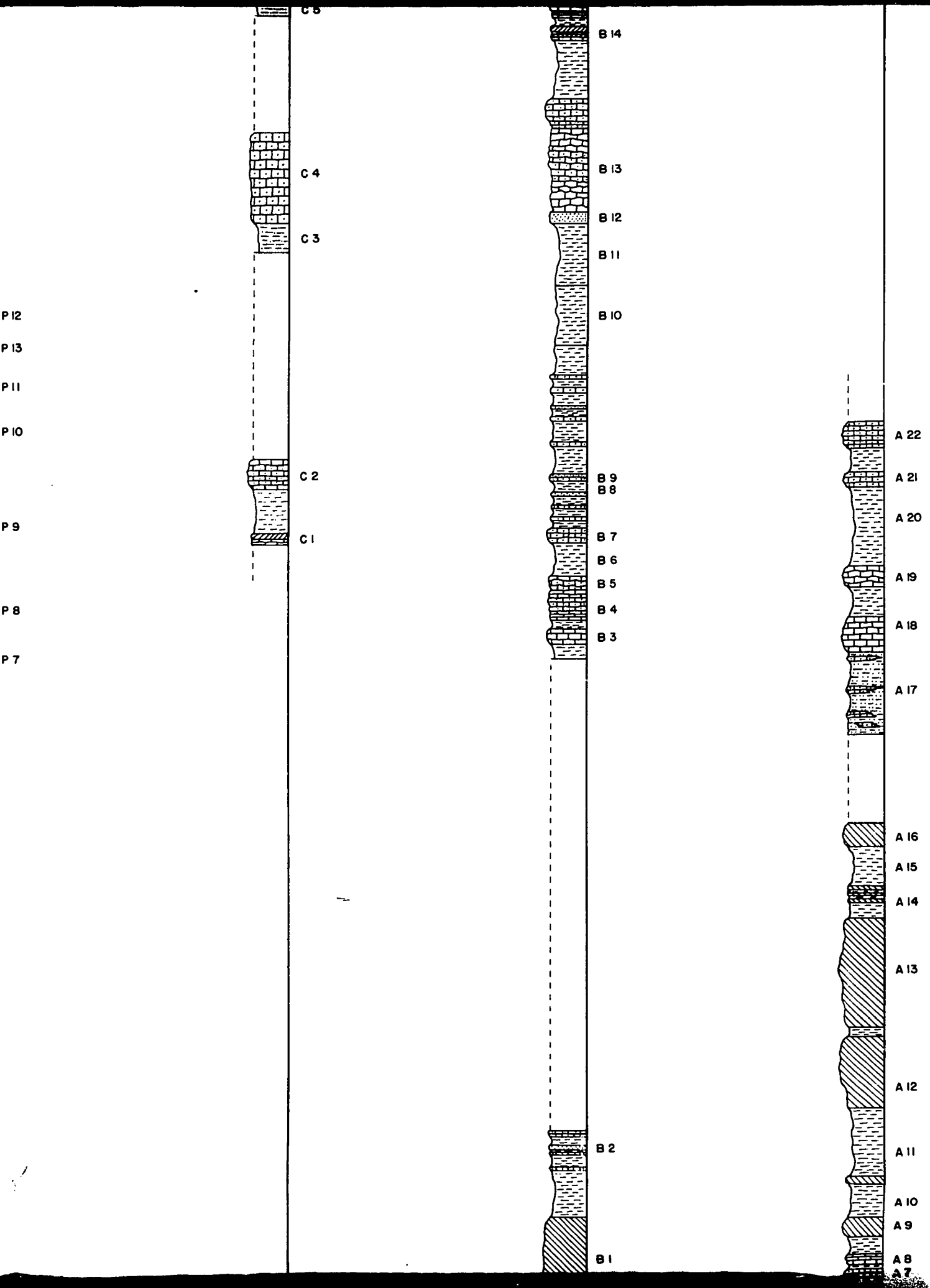

R 26 W
R 25 W
3
2
1
MURFREESBORO
HIGHLAND
T
8
S
9
MEASURED SECTION

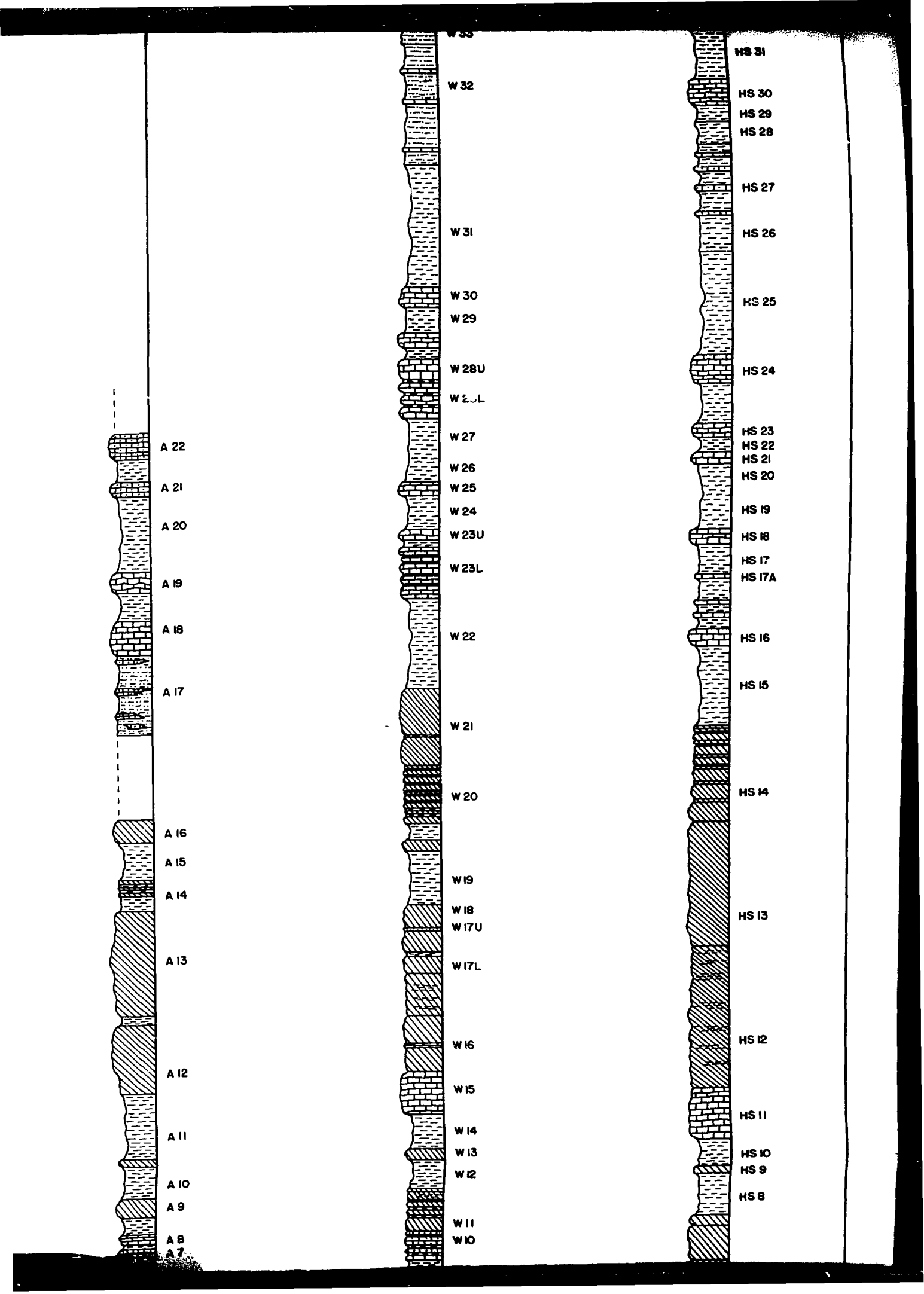

WEST
MEASURED SECTION 8
MEASURED SECTION 7
MEASURED SECTION 6
MEASURED SEC
0.5 MILES
12.5 MILES
8.5 MILES
APPROXIMATE
TC
D 2A
D 2
P 16
P 15
P 14
RR 7
P 12
P 13
P 11
P 10
C
C
C
C

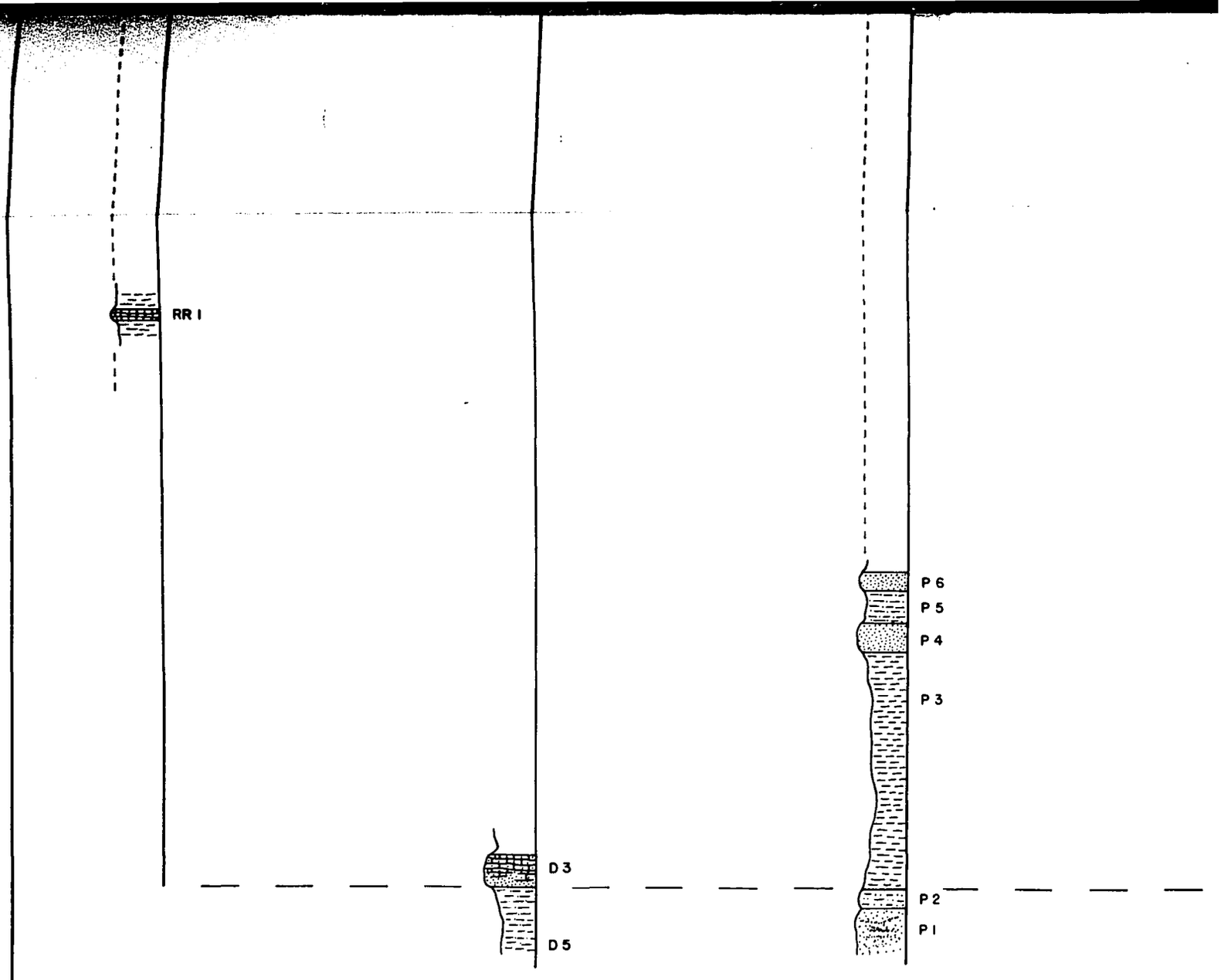

CTION 6
MEASURED SECTION 5
MEASURED SECTION 4
MEASURED SECTION 3
8.5 MILES
6 MILES
3 MILES
APPROXIMATE TOP OF THE DE QUEEN FORMATION
16
15
14
12
13
11
10
C 6
C 5
C 4
C 3
C 2
B 17
B 16
B 15
B 14
B 13
B 12
B 11
B 10
B 9
A 22
A 21


EAST
MEASURED SECTION 3
MEASURED SECTION 2
MEASURED SECTION 1
3 MILES
2.5 MILES
0.5 MILES
W 46
W 45
W 44
W 43
W 42
W 41
W 40
W 39
W 38
W 37
W 36
W 35
W 34
W 33
W 32
W 31
W 30
W 29
W 28U
W 28L
W 27
W 26
W 25
A 22
A 21
HS 39
HS 38
HS 37
HS 36
HS 35
HS 34
HS 33
HS 32
HS 31
HS 30
HS 29
HS 28
HS 27
HS 26
HS 25
HS 24
HS 23
HS 22
HS 21
HS 20


RR 7
RR 6
RR 5
RR 4
RR 2
RR 3
RR 1
P12
P13
P11
P10
P9
P8
P7
C5
C4
C3
C2
C1


C 5
C 4
C 3
C 2
C 1
P 12
P 13
P 11
P 10
P 9
P 8
P 7
B 14
B 13
B 12
B 11
B 10
B 9
B 8
B 7
B 6
B 5
B 4
B 3
B 2
B 1
A 22
A 21
A 20
A 19
A 18
A 17
A 16
A 15
A 14
A 13
A 12
A 11
A 10
A 9
A 8
A 7

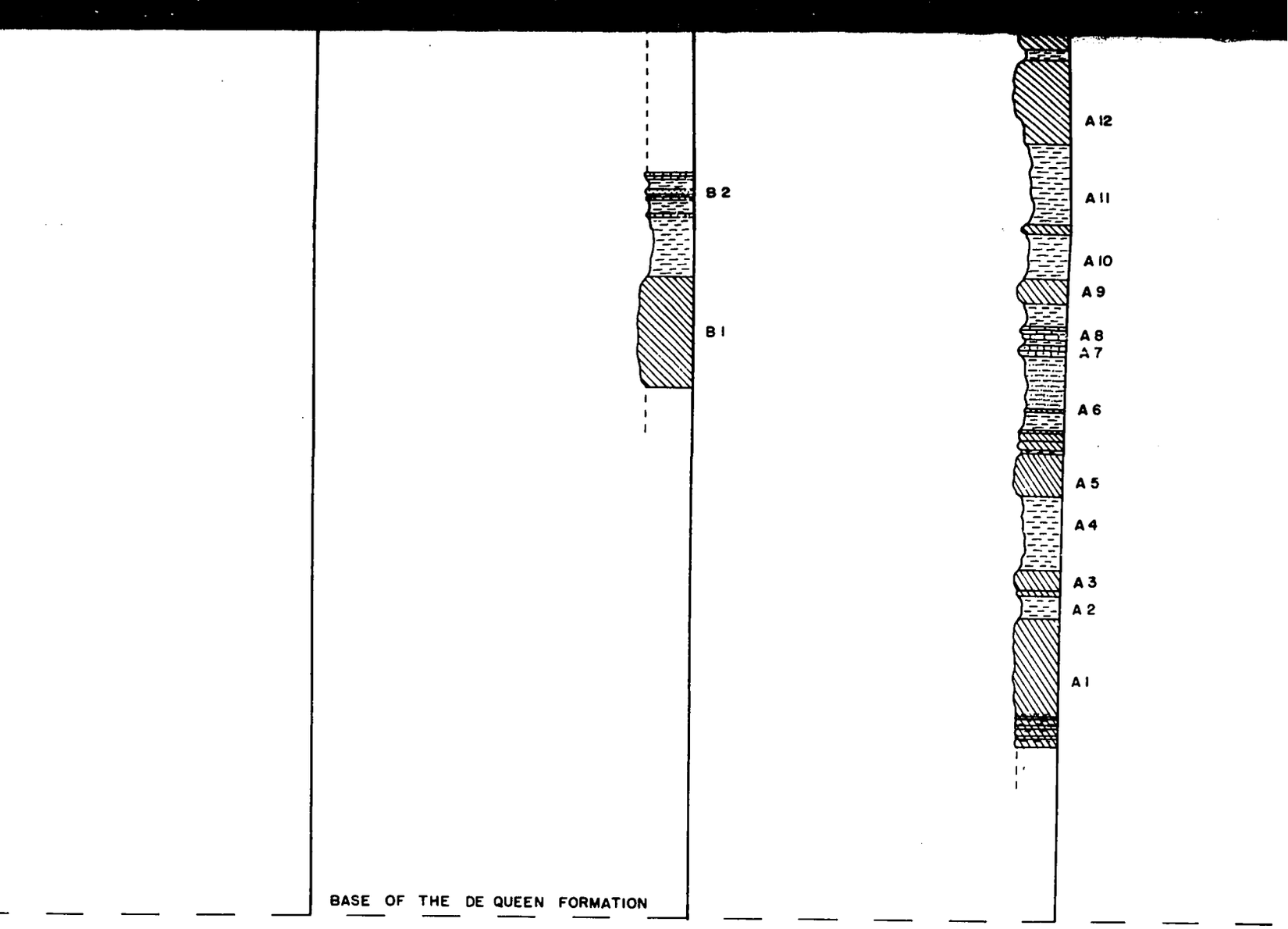

A 22
A 21
A 20
A 19
A 18
A 17
A 16
A 15
A 14
A 13
A 12
A 11
A 10
A 9
A 8
A 7
W 32
W 31
W 30
W 29
W 28U
W 27
W 26
W 25
W 24
W 23U
W 23L
W 22
W 21
W 20
W 19
W 18
W 17U
W 17L
W 16
W 15
W 14
W 13
W 12
W 11
W 10
HS 30
HS 29
HS 28
HS 27
HS 26
HS 25
HS 24
HS 23
HS 22
HS 21
HS 20
HS 19
HS 18
HS 17
HS 17A
HS 16
HS 15
HS 14
HS 13
HS 12
HS 11
HS 10
HS 9
HS 8



EXPLANATION

- LIMESTONE
- SANDY OR SILTY LIMESTONE
- DOLOMITE
- CLAYSTONE OR CLAY SHALE
- MUDSTONE
- SILTSTONE
- SANDSTONE
- GYPSUM
- CELESTITE
- COVERED
- P 3 : SAMPLE NUMBER AND LOCATION

10
8
6
FEET
4
2
0





PLATE

COLUMNAR SECTIONS OF TH

IN SOUTHWESTER

BY

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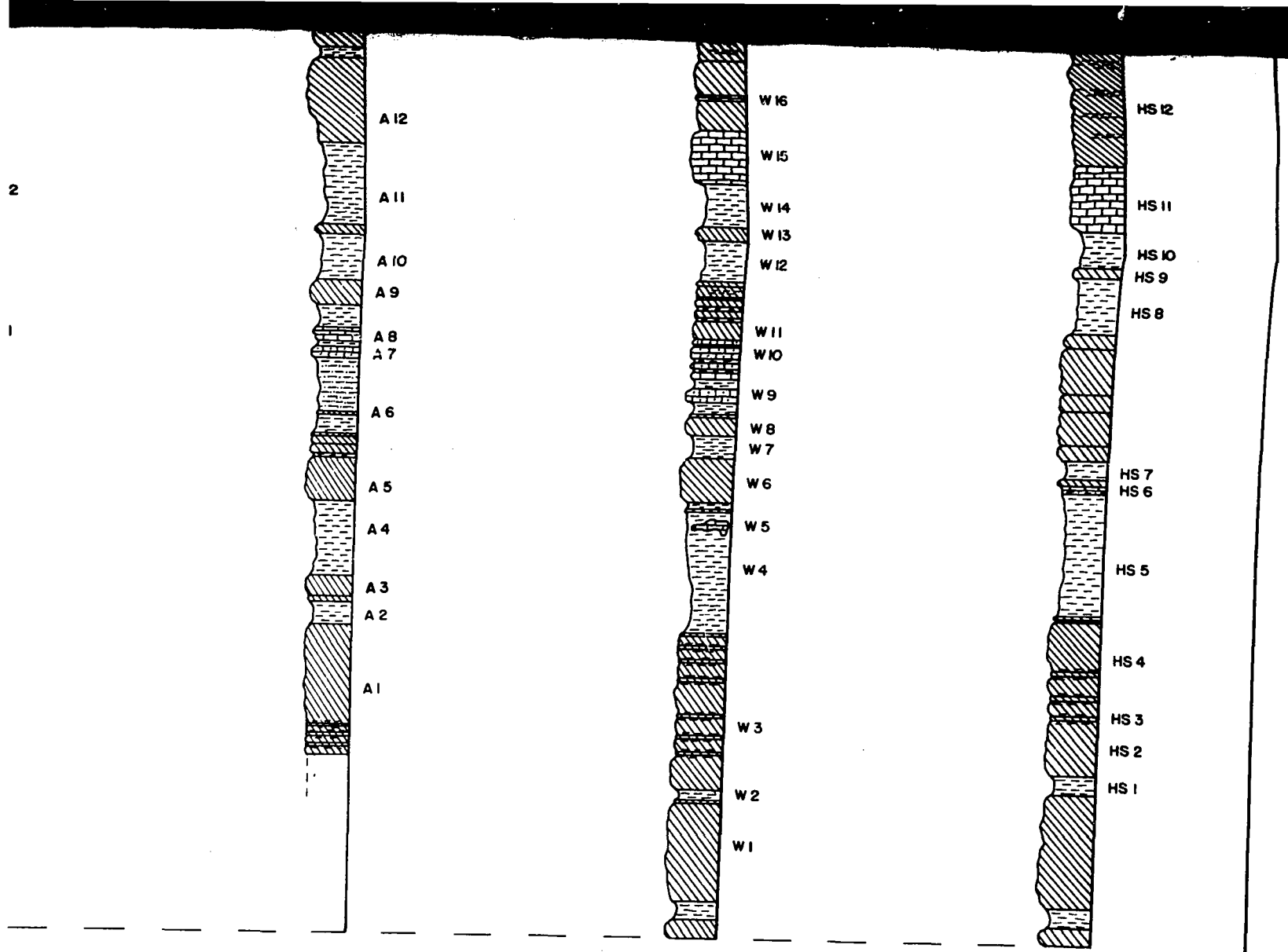


PLATE 2

COLUMNAR SECTIONS OF THE DE QUEEN FORMATION IN SOUTHWESTERN ARKANSAS

BY

BURT E. HAMRIC PH. D. 1965