PHYSICAL STRATIGRAPHY OF THE AVANT LIMESTONE MEMBER OF THE IOLA FORMATION, SOUTHERN OSAGE COUNTY AND PARTS OF NEARBY COUNTIES, OKLAHOMA

By

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STONE MEMBER OF THE IOLA FORMATION,
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PREFACE

This study deals primarily with the mound facies and the depositional trends of the Avant Limestone Member of the Iola Formation in southern Osage County, Oklahoma. Determination of depositional trend and the proposed explanations of development along this trend were accomplished through preparation of a log map, a structural contour map, isopach maps, and correlation sections. Lithology was studied utilizing thin-section microscopy, X-ray diffraction techniques, ordinary inspection of outcrops, and examination of bit cuttings.

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Thanks are given particularly to fellow graduate students who gave aid and advice, to Mr. Lynn Perkins, who offered assistance in field work on his land, and to Mrs. Mildred Lee, who typed the manuscript.

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CHAPTER I

ABSTRACT

The Missourian Avant Limestone Member of the Iola Formation is a phylloid-algal mound at some places in southern Osage County and nearby counties. It is also an "upper" or "regressive" limestone member representing a phase of cyclic deposition within a cyclothem.

The locally-thickened nature, the variety of types of porosity and permeability, and the presence of an overlying shale suggest that the Avant might serve as a petroleum reservoir locally in the subsurface within the study area.

The mound facies of the Avant trends southwestward from R. 12 E. to R. 3 E. along T. 23 N. through T. 20 N. Local thickening of the Avant-Hogshooter interval along the eastern and southern portions of the area of primary mapping generally corresponds well with the thickening of the overlying Avant mound facies. This suggests that submarine paleotopography may have influenced development of a mound facies along this trend.

The Avant can be correlated southward and westward in the subsurface, along R. 8 E. from T. 23 N. through T. 18 N. and from T. 23 N., R. 12 E., to T. 20 N., R. 2 E., respectively.

The name Avant, as used in the subsurface geology of Noble County, is often misapplied to the Wildhorse Dolomite Lentil of the type locality. The stratigraphic position of the Perry Gas Sand is between that of the Wildhorse Dolomite above and the Avant Member below.

CHAPTER II

INTRODUCTION

Location of the Study Area

The area of primary mapping covers approximately 288 sq. mi. in Osage County, Oklahoma, including T. 22 N. and T. 23 N., R. 8 E. through R. 11 E. (Fig. 1). In addition, three lines of cross section were constructed extending outside the primary study area (Fig. 2). One line extends westward in T. 21 N. from R. 8 E. in Osage and Pawnee Counties, to R. 2 W. in Noble County. A second line extends westward along T. 20 N. from R. 8 E. in Pawnee County to R. 2 W. in Noble County. The third cross section extends southward through R. 8 E. from T. 22 N. in Osage County to T. 18 N. in Creek County.

Statement of the Problem

The Avant Limestone Member of the Iola Formation clearly shows evidence of an algal-mound facies similar to that described by Heckel and Cocke (1969), Toomey and others (1977), and other authors. In addition, the Avant displays certain characteristics that resemble those developed in the "upper" limestone member of Moore's "ideal

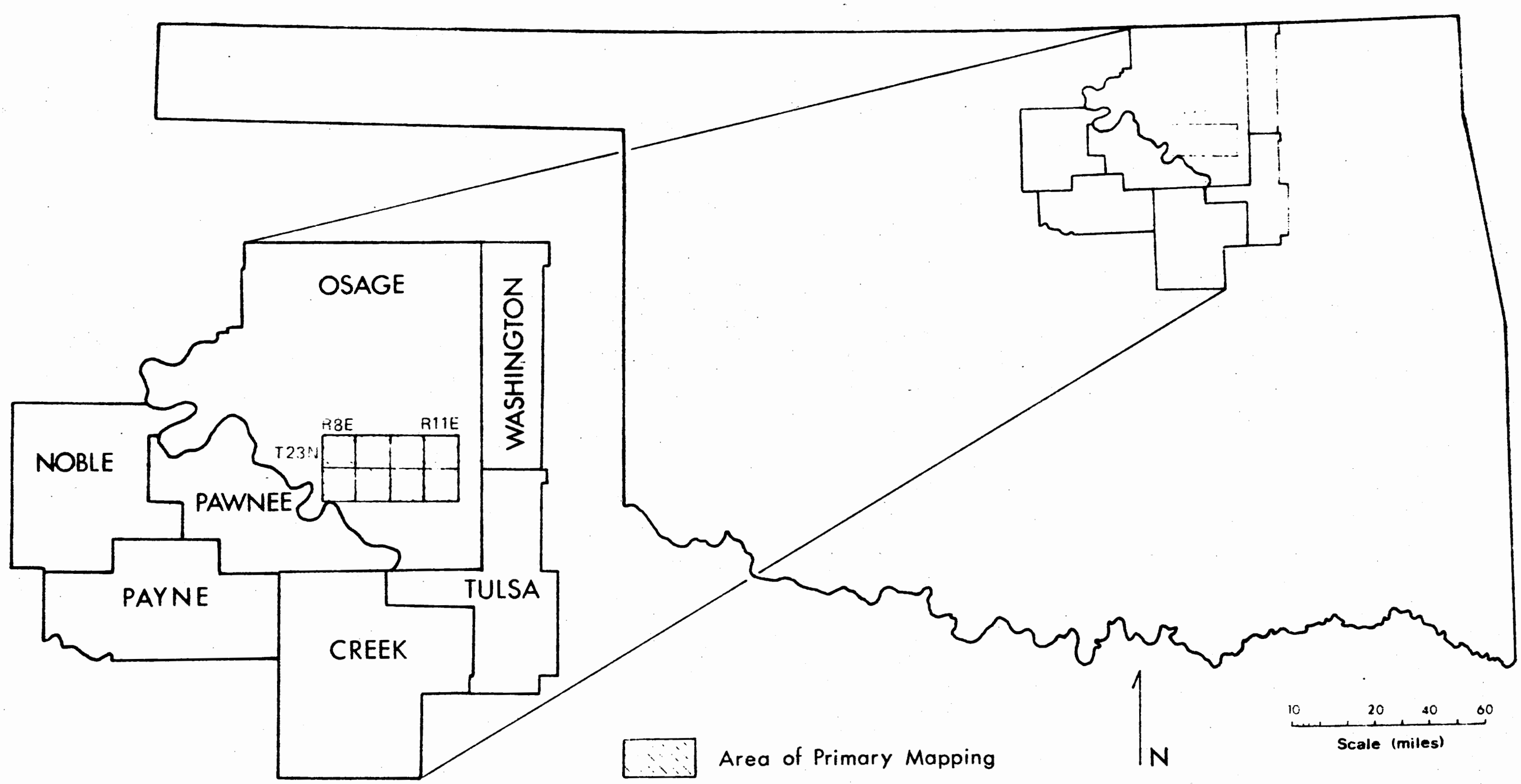

Fig. 1.-Location of area of primary mapping.

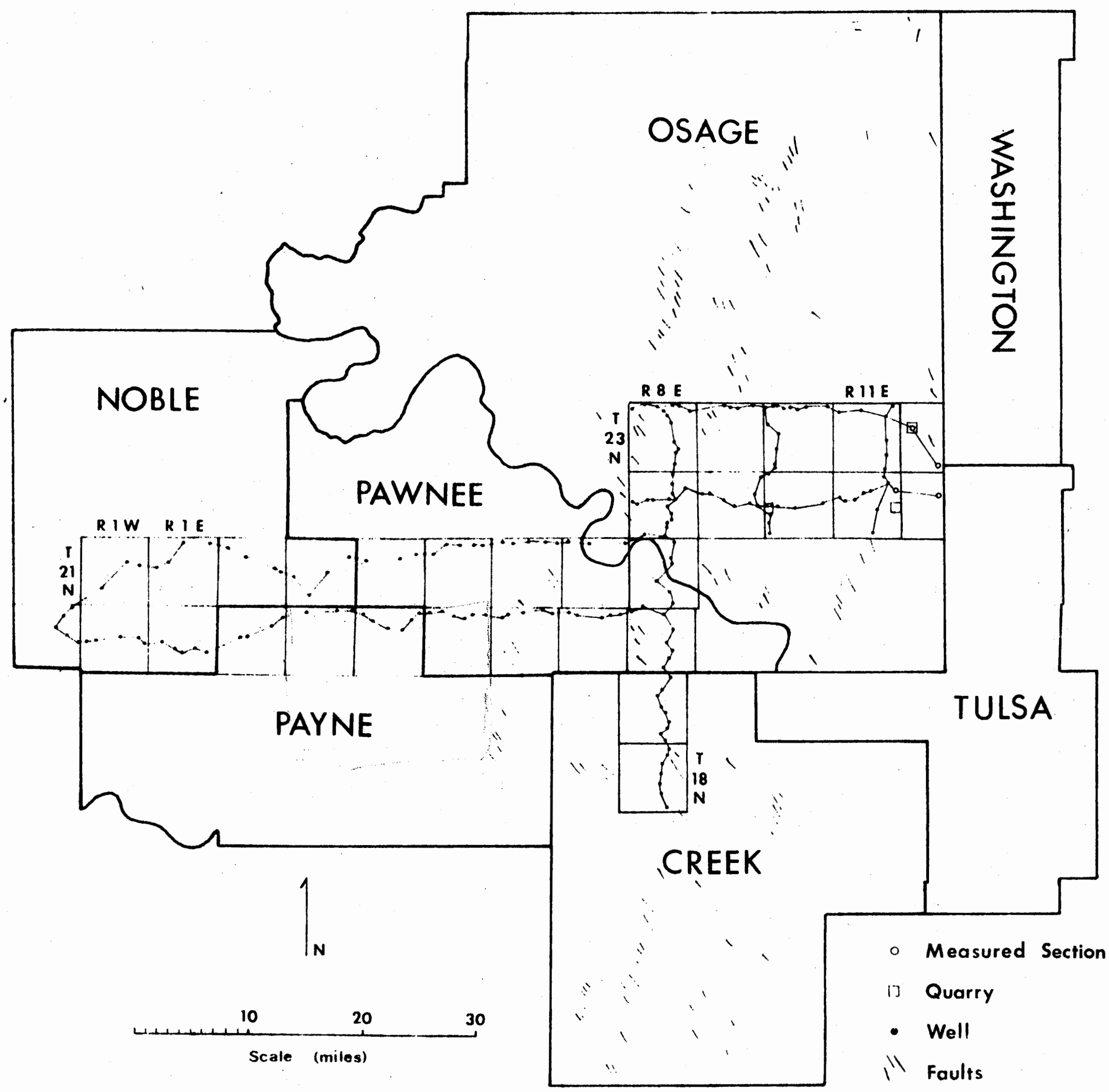

Fig. 2.-Locations of correlation sections and measured sections.

cyclothem" (1935). The objective of this investigation was to determine the mound-facies depositional trend of the Avant in southern Osage County, Oklahoma, and to attempt to establish the factors that were responsible for development of the thick limestone along this trend. During the course of the investigation, several critical subproblems were defined, for example:

1) Specifically, what properties define an algal mound?

2) What properties characterize the members of a typical Midcontinent cyclothem?

3) What contribution do algae make in the precipitation and accumulation of lime mud?

4) What kinds of porosity develop in limestone like the Avant?

5) Can one estimate the location of a shelf edge or shoreline that might have existed during deposition of the Avant Member and if so, what are their trends?[1]

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[1] Some of the stratigraphic names contained in this report are used commonly in subsurface petroleum geology but are regarded by the U. S. Geological Survey and (or) the Oklahoma Geological Survey as being informal terms. Traditionally, the lithologic portions of such names are not capitalized; however, by consensus of the thesis-advisory committee, all stratigraphic names are capitalized herein, if the names are established in the normal vocabulary of operating exploration geologists in Oklahoma. The committee believes that this practice is less confusing than the alternative; but in view of rules of the American Commission on Stratigraphic Nomenclature, the advisory committee would not have made these recommendations for a formal publication.

6) Was mound development in the Avant influenced by pre-existing topography?

7) Was mound development in the Avant influenced by tectonic movement prior to or contemporaneous with mound development?

8) Is the southernmost identifiable limit of the Avant within the subsurface of the study area?

9) Is the westernmost identifiable limit of the Avant within the subsurface of the study area?

10) Is the Avant of the type locality correlative with the Avant of the subsurface in Noble County?

Previous Investigations

The Avant Member was named by Ohern (1910, p. 31) for "semi-crystalline limestone of bluish color, often thin bedded, but near Avant, Oklahoma, forming precipitous cliffs."

The first field study dealing with rock equivalent to the Avant was reported by Haworth and Kirk (1894). They referred to a series of limestones exposed in quarries near the town of Iola, Kansas (Fig. 3) and named this 30- to 40-ft.-thick unit the Iola Limestone. On tracing the Iola northward, Newell (Jewett and Newell, 1935) found that the principal upper portion of the formation was correlative with the Raytown Limestone Member of the Iola Formation in Missouri named by Hinds and Greene (1915). This was confirmed by further field work of Moore (1935).

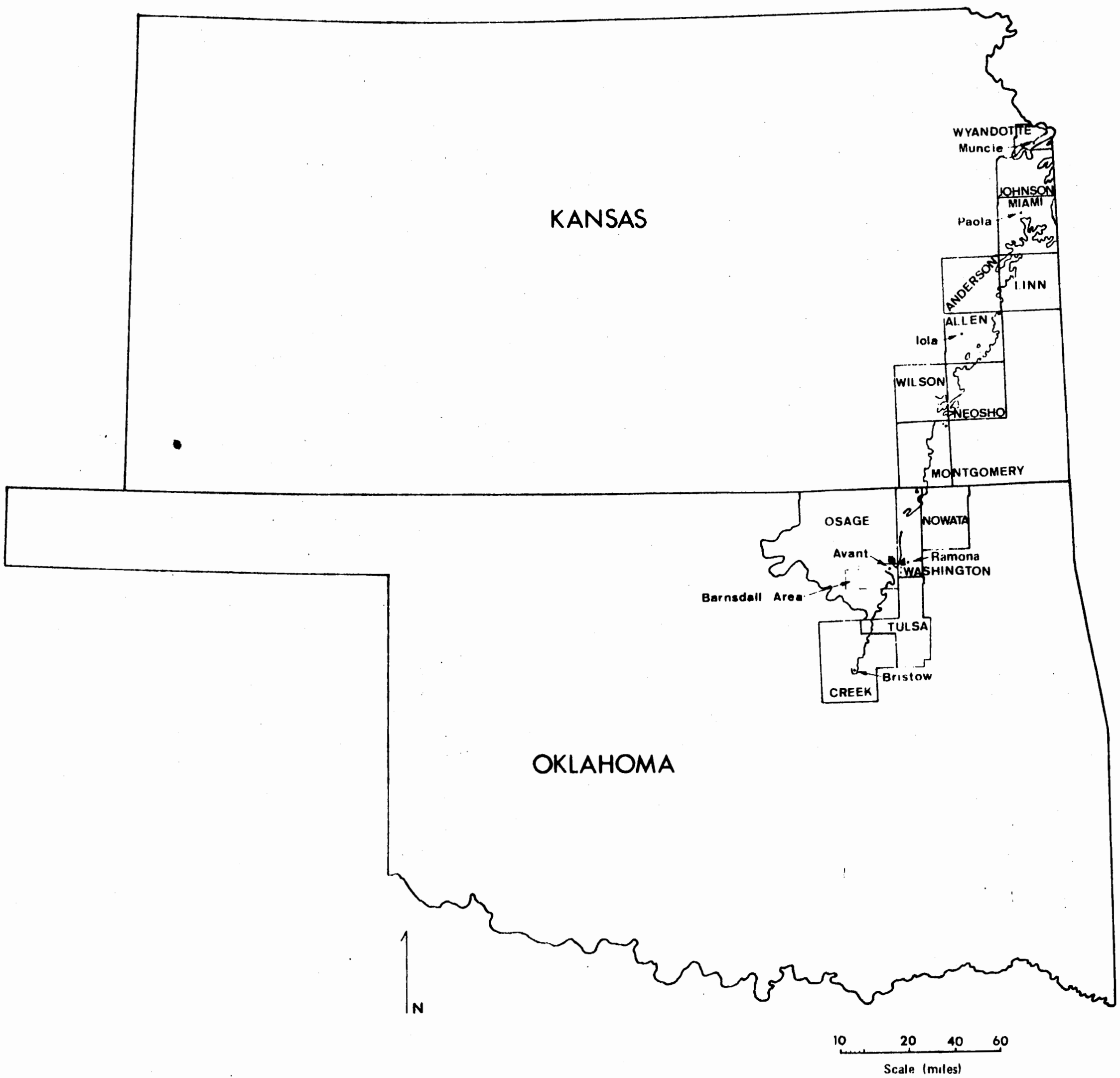

Fig. 3.-Location of the outcrop of the Iola Formation across Kansas and Oklahoma.

Newell (Jewett and Newell, 1935) was the first to report algae occurring locally in the upper portion of the Raytown Member, citing an example from near Iola, Kansas. He found that the Iola Limestone of the type locality consisted of a massive bed of dark gray and buff limestone separated from an underlying darker, denser 1.5- to 2-ft.-thick limestone by a few inches of black carbonaceous shale that contained spheroidal phosphatic nodules. Upon discovering that this three-fold division was widespread in Kansas, he proposed the name Paola Limestone Member for the basal bed from the town Paola in Miami County, and the middle shale the Muncie Creek Shale Member, for exposures near a stream in southern Wyandotte County east of the town Muncie (Fig. 3). Newell traced the formation southward to the Kansas-Oklahoma boundary by following the zone of phosphatic concretions, which was stated to be the most nearly constant feature of the entire formation in Kansas.

Due mainly to the field work by Newell, Moore (Moore and others, 1937) introduced the term Iola Formation into nomenclature of Oklahoma and identified the Avant of northeastern Oklahoma as being equivalent to the upper member of the Iola Formation of Kansas. All three divisions of the Iola Formation were recognized west of Ramona, Oklahoma in the vicinity of Avant (Fig. 3), and elsewhere in this region. Additional field work established this correlation and continuity of strata southward beyond the limits of the previous investigation across Washington County by Oakes

(1940), through southern Osage, western Tulsa and northeastern Creek Counties by Mohler (1942), and again through southern Osage and most of Tulsa County by Oakes (1952). Oakes observed that the persistent upper part of the Avant Limestone Member is calcareous sandstone south of the Arkansas River and the lower portion is sandy limestone. These layers have been referred to as the "upper" and "lower" Avant limestones.

Gardner (1957) mapped the surface geology and described the lithology and stratigraphic relations of units, including the Avant Member, within the Barnsdall area, southeastern Osage County (Fig. 3). In addition, fossils within this unit were collected and identified. These included two species of bryozoa, two species of coelenterates, six species of brachiopods, two species of gastropods, one species of pelecypods, and crinoid columnals.

The Avant was among 23 Missourian and Virgilian limestone units of the Midcontinent described at some localities as phylloid algal-mound complexes by Heckel and Cocke (1969). They stated that in portions of southern Osage and Washington Counties, the Avant consists of sparry algal calcilutite with ferroan dolomite, and that it thins and changes to sparsely algal, brachiopod-rich calcilutite farther south.

Bellis and Rowland (1976) evaluated the economic potential of the Avant in Osage County for use as building material. They reported that the Avant should be suitable for use as road-base material, roofing gravel, concrete aggregate and similar industrial applications, but that the chemical analyses indicate it to be of a grade unsuitable for chemical use, because of the low content of total CaO and high content of impurities.

Methods and Procedures

The Avant was traced from the outcrop along the eastern portion of the study area, westward into the subsurface of Payne and Noble Counties where it is exceedingly difficult to identify on electric logs.

Approximately 350 electric logs were correlated within the primary study area with one or two logs utilized per quarter-section where density of wells allowed. Eleven stratigraphic correlation sections were constructed from the electric logs, and these sections were used as a framework of dissection showing the variation of thickness and facies of the Avant and various overlying and underlying units. In most instances, spacing between wells of 1 mi. or less was maintained, to maximize the probability of accurate correlations. Five of the sections within the area of primary mapping are presented with this manuscript (Pls. 1 through 5).

Four maps of the study area were constructed at a scale of 1 in.:1 mi. These maps are (1) a log map of the Avant Member using the short-normal and spontaneous-potential curves, and where thickness is less than 10 ft., the lateral curve, in order to show variation in thickness and facies (Pl. 6); (2) an isopach map of the Avant that shows depositional trend of the mound facies (Pl. 7); (3) a structural contour map of the base of the Avant to estimate structural configuration (Pl. 8); and (4) an isopach map of the interval between the base of the Hogshooter Limestone and base of the Avant, to estimate the influence of variation in thickness of this interval on thickness of the Avant (Pl. 9).

Three correlation sections that extend outside the primary study area were constructed from electric logs, to attempt to determine the western and southern identifiable extents of the Avant in the subsurface and to determine its stratigraphic relation to the Perry Gas Sand of Noble County (Pls. 10, 11, and 12).

From rock samples collected at the location of Measured Section No. 1 (Appendix A), 12 thin sections were prepared and studied under a petrographic microscope. The thin sections were stained with a solution of Alizarine Red S and potassium ferricyanide to estimate the ratios of calcite to dolomite and the amounts of iron in the carbonate cements (techniques after Evamy, 1963). Samples also were analyzed by X-ray diffraction to determine the presence of quartz, dolomite and calcite.

CHAPTER III

STRATIGRAPHIC FRAMEWORK

Missourian Series

The Missourian is the upper-middle series of the major divisions comprising the Pennsylvanian System in Oklahoma. The Missourian Series of Oklahoma is separated from the overlying Virgilian Series by a faunal change and by truncation of beds, which mark an unconformity; likewise, a faunal change and unconformity separate the Missourian from the underlying Desmoinesian Series (Oakes, 1940). On the suggesions by Moore and others (1937), rock of the Missourian Series of northeastern Oklahoma was divided into two groups, the Skiatook and Ochelata, and an unconformity at the base of the Chanute Shale is the boundary between them. Evidence for the unconformity that divides the two groups was reported by Oakes (1940, 1952, 1959) in Washington, Tulsa, and Creek Counties.

The stratigraphic positions of the formations and members comprising the Skiatook and Ochelata Groups in southern Osage and nearby counties are shown on the chart (Table I) and the lithologic character and relative thicknesses of a portion of these, as they occur at the surface within the

TABLE I

DIVISIONS OF THE MISSOURIAN SERIES IN SOUTHERN OSAGE COUNTY AND NEARBY COUNTIES (MODIFIED FROM OAKES (1940, 1952) AND CRONOBLE AND MANKIN (1965).)

- Virgilian Series

- Missourian Series
  - Ochelata Group
    - Tallant Formation
      - Revard Sandstone Member
      - Bigheart Sandstone Member
    - Barnsdall Formation
      - unnamed shale member
        - Wildhorse Dolomite Lentil
      - Okesa Sandstone Member
      - Birch Creek Limestone Member
    - Wann Formation
      - Torpedo Sandstone Member
      - Clem Creek Sandstone Member (Perry Gas Sand)
      - Washington Irving Sandstone Member
    - Iola Formation
      - Avant Limestone Member
      - Muncie Creek Shale Member
      - Paola Limestone Member
    - Chanute Formations
      - carbonaceous shale member
      - Cottage Grove Sandstone Member
      - Thayer Coal Member
      - unnamed shale member
      - Noxie Sandstone Member
      - basal conglomerate member
  - Skiatook Group
    - Dewey Limestone
    - Nellie Bly Formation
    - Hogshooter Limestone
      - Winterset Limestone Member
    - Coffeyville Formation
      - Lost City Limestone Member
      - Stark Shale Member
      - Canville Limestone Member
      - Dodds Creek Sandstone Member
    - Checkerboard Limestone
    - Seminole Formation

- Desmoinesian Series
  - Marmaton Group

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primary study area, are shown on the stratigraphic column (Fig. 4).

Skiatook Group

The Skiatook Group constitutes the lower Missourian strata of northern Oklahoma. Its lower limit is defined as the top of the Marmaton Group (Table I) and its upper limit is at the top of the Dewey Limestone, or, where the Dewey is absent, at the base of the Chanute Formation. This group is composed of six formations in north-central and northeastern Oklahoma; in descending order these are the Dewey Limestone, Nellie Bly Formation, Hogshooter Limestone, Coffeyville Formation, Checkerboard Limestone, and Seminole Formation.

Ochelata Group

Ohern (1910) introduced the name Ochelata as a stratigraphic term for beds between the Avant and the Dewey Limestone, but its usage has been expanded to include all strata from the top of the Tallant Formation, down to the top of the Dewey Limestone (Oakes, 1951). The upper stratigraphic position corresponds with the Missourian-Virgilian boundary. Primary units composing the Ochelata Group of north-central and northeastern Oklahoma, in descending order, are the Tallant Formation, Barnsdall Formation, Wann Formation, Iola Formation, and Chanute Shale (Oakes, 1952).

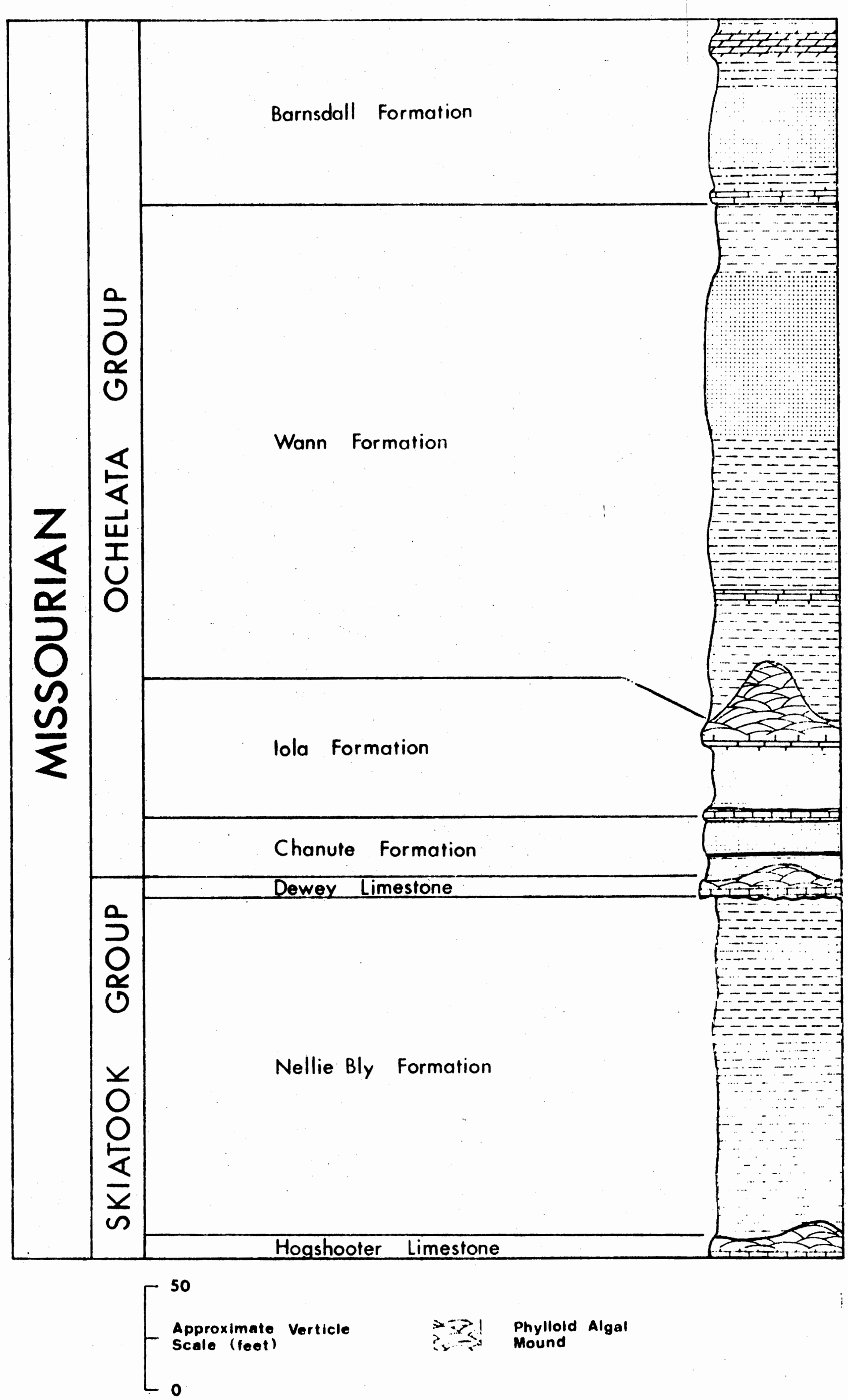

Fig. 4.-Stratigraphic column of some of the formations in the Skiatook and Ochelata Groups in southern Osage County and nearby counties.

Iola Formation

In northern Oklahoma, the Iola Formation is conformable upon the underlying Chanute Formation and beneath the Wann Formation. It consists of three members, in descending order, the Avant Limestone Member, Muncie Creek Shale Member, and Paola Limestone Member.

Thickness of the Iola is highly irregular throughout northern Oklahoma, most of which variation is within the Muncie Creek and Avant. All members vary greatly in lithologic character, and in some locations differentiation is difficult.

Avant Limestone Member. The Avant forms an escarpment in most places along the line of outcrop. It is the most persistent member of the Iola Formation, extending southward from Iowa into central Oklahoma. Emery (White and others, 1922) reported that the Avant is unconformable on the underlying Muncie Creek, but according to Oakes (1952), the lower parts of the Avant grade into calcareous shale in Tulsa County, so that only the upper part of the unit is traceable as limestone.

Maximal known development at the surface is at an abandoned quarry in Sec. 17, T. 23 N., R. 12 E. (Figs. 2 and 5; Measured Section 1, Appendix A). Here, 44 ft. of massive limestone is overlain by 9 ft. of interbedded limestone and shale.

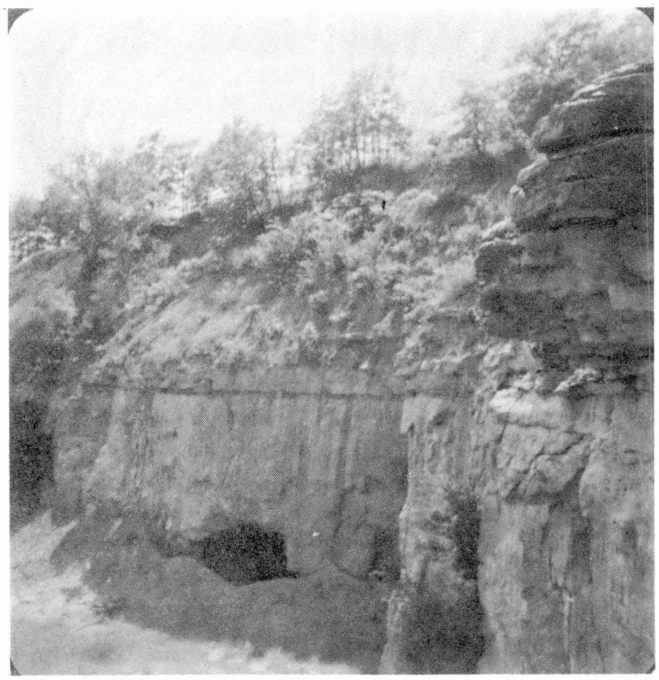

Fig. 5.-Avant Member and overlying Wann Formation in abandoned quarry, sec. 17, T. 23 N., R. 12 E.

The massive limestone is organish gray to steel-gray, mottled, finely to coarsely crystalline, algal, skeletal calcilutite and calcarenite with dolomite and ferroan calcite, indicated by staining techniques. Abundant veinlets of crystalline carbonate are present, which can be leached on weathered surfaces, leaving vuggy secondary porosity, giving rise to a pseudobrecciated appearance (Fig. 6).

The upper thin, wavy-bedded limestone is gray to brown, platy, crystalline, algal, skeletal calcarenite interbedded with gray to dark gray fossiliferous, calcareous shale.

The Avant is noted by Oakes (1940, 1952, 1959) and others for its great variation in thickness. Oakes reported that across Wyandotte and Johnson Counties, Kansas, it is about 5 ft. thick, increasing to 28 ft. in the vicinity of Iola, Kansas, and is locally thin or absent in southern Kansas and across most of Nowata and Washington Counties, Oklahoma (Fig. 3). The unit is 53 ft. thick in the vicinity of Avant, Osage County, Oklahoma and 5 to 15 ft. thick along the southern border of Osage County (Fig. 3).

In southern Osage County, Lloyd and Kirtley (White and others, 1922) reported that a portion of the Avant limestone is sandy, weathering dark brown or rusty, and is conspicuously crossbedded (Fig. 7; Measured Section 3, Appendix A). In western Tulsa County, only the upper few feet of the thick phase exists as limestone (Oakes, 1952). Sandy limestone occupies the same stratigraphic position as the lower Avant of the type locality and is separated from the upper

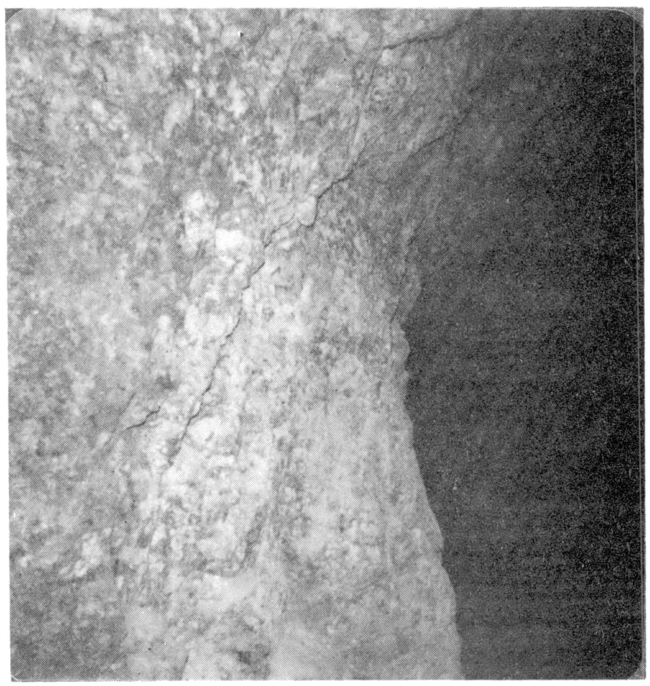

Fig. 6.-Pseudobrecciated appearance of limestone in the Avant Member. Approximate scale: 1 in. = 2 ft.

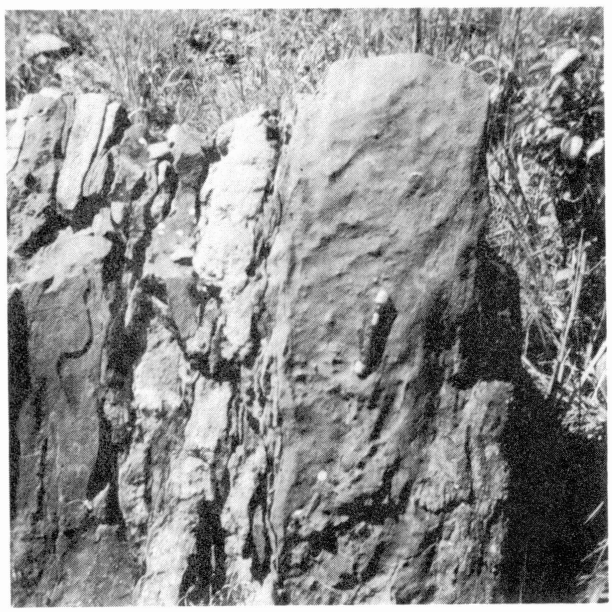

Fig. 7.-Medium-scale crossbedding in limestone of the Avant. Block is located along a fault and top of bed is to the left. Knife is parallel to orientation of cross beds.

calcareous bed by a few feet of shale. According to Oakes, these two calcareous beds have been referred to informally as the "upper" and "lower" Avant limestones. They are believed to denote the upper and lower limits that mark the southern extent of the member as chiefly limestone (but in fact containing less limestone than shale) as they cross the southern part of western Tulsa County. Limy, sandy siltstone, containing molds of fusulinids, represents the Avant east and southeast of Bristow, Creek County (Fig. 3), and here it is of light weight and is porous, owing to leaching (Oakes, 1959). Within this county Oakes reported the upper limit of the Avant cannot be discerned well enough to be mapped, and south of Creek County it is thought to have been removed completely by erosion before deposition of the Barnsdall Formation.

Muncie Creek Shale Member. The Muncie Creek is the exceedingly widespread middle member of the Iola Formation. It is present in south-central Iowa, and extends across Kansas and into north-central Oklahoma. In Kansas thickness ranges from less than 1 ft. to 5 ft. In Oklahoma, thickness is much more variable with a range from 1 to 30 ft. in Nowata, Washington, and Osage Counties, less than 1 ft. to slightly more than 5 ft. in Tulsa County (Oakes, 1952, 1959), and is as thick as 115 ft. in southeastern Pawnee County (Clare, 1963).

The Muncie Creek is dark gray to black, fissile to platy, bituminous shale, weathering light gray to gray-green. Near the base is a bed of gray, spheroidal to elliptical phosphatic nodules ¼ in. to 3 in. in diameter. Many of the nodules contain calcite-filled fractures and some enclose conularids or shark teeth (Jewett and Newell, 1935). Oakes (1952) mapped the outcrop of the Iola and identified exposures across Washington and Nowata Counties, Oklahoma, in part, by tracing the beds from which the nodules weathered.

Oakes (1952) reported that locally in Tulsa County, the upper part of the Muncie Creek grades into limestone of the basal Avant, so that the contact is difficult to define, but near the type locality, I found that the Avant-Muncie Creek boundary is sharp and well defined (Fig. 8).

Paola Limestone Member. The Paola Limestone Member is the basal member of the Iola Formation. Throughout Kansas, thickness ranges from 1 to 2 ft. Near the type locality, the Paola is dark to bluish gray, fine-grained to dense, and weathers light gray. It is a massive layer that breaks along joints into nearly uniform blocks. It is characterized by structures that probably are fossils of algae. The upper surface is pitted and highly irregular, or "hummocky," containing abundant borings which are generally hollow, iron-stained tubes extending a short way into the rock (Jewett and Newell, 1935).

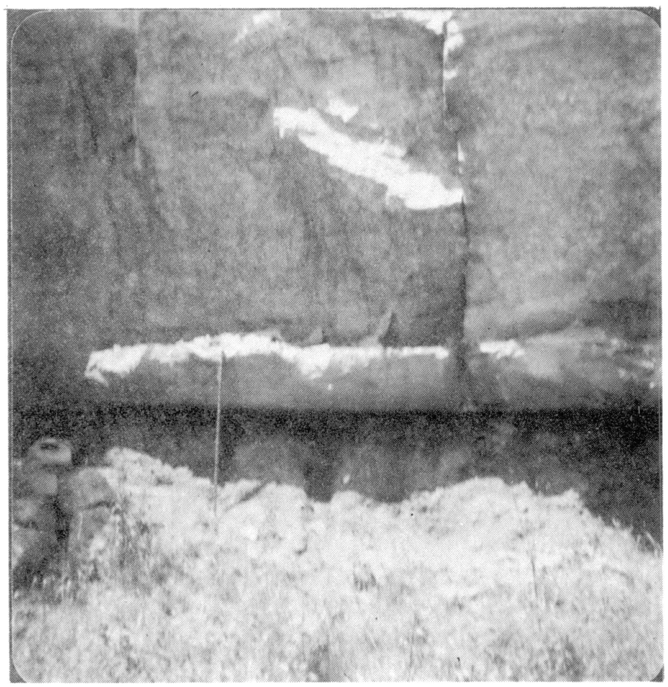

Fig. 8.-Sharp contact between the Avant and Muncie Creek Members. Approximate scale: 1 in. = 5 ft.

In northern Oklahoma, the Paola comprises three lenticular phases that grade into each other laterally and vertically. Thickness ranges from 1 to 5 ft. Lithology varies from relatively pure, bluish gray, fine-grained limestone in northern Nowata and Washington Counties, to a marly limestone or calcareous sandstone in southern Osage and western Tulsa Counties. In Creek County, the Paola is believed to be fine-grained, calcareous sandstone that contains casts and molds of fusilinids (Oakes, 1940, 1952, 1959) (but this unit actually could be the equivalent of the Avant).

Wann Formation

The Wann Formation was defined by Oakes (1949) as comprising all strata between the top of the Iola Formation, below, and the base of the Torpedo Sandstone, above, or the base of the Birch Creek Limestone Member of the Barnsdall Formation in the area where the Torpedo Sandstone was removed by pre-Birch Creek erosion. The Wann was redefined by Tanner (1956) and included the Torpedo Sandstone as the uppermost bed. The original description by Ohern (1910) included all strata between the base of the Hogshooter Limestone and the top of the Birch Creek Limestone Member.

The Wann Formation can be recognized in exposures from the Kansas-Oklahoma border southward into Creek County, where it has been removed completely by pre-Barnsdall erosion (Oakes, 1952). Thickness elsewhere ranges from 95 ft. in Washington County (due to pre-Birch Creek erosion, Oakes,

1940) to 565 ft. in northern Pawnee County (Clare, 1963).

The Wann dominantly is shale and sandstone with limestone and limy sandstone included at some places. Oakes (1940) divided the Wann into four zones that intergrade. Locally, sandstone bodies are thick, are traceable, and therefore are named, such as the Washington Irving Sandstone Member and the Clem Creek Sandstone Member of Pawnee and nearby counties.

Clare (1963) placed the Wildhorse Dolomite Lentil in the upper part of the Wann Formation, but Oakes (1952) and others placed it in the upper portion of the overlying Barnsdall Formation.

Barnsdall Formation

Oakes (1951) defined the Barnsdall Formation as including rocks between the base of the Birch Creek Limestone Member, below, and the base of the Bigheart Sandstone Member of the Tallant Formation, above. Thickness of exposures is relatively uniform, ranging from 100 to 120 ft. from the Kansas-Oklahoma border southward through Washington, Osage, Tulsa, and Creek Counties (Oakes, 1952).

The Barnsdall contains shale, sandstone, dolomitic limestone, and dolomite. It includes three lenticular members; in ascending order they are the Birch Creek Limstone Member, Okesa Sandstone Member, and an unnamed shale member that locally encloses the Wildhorse Dolomite Lentil.

CHAPTER IV

STRUCTURAL FRAMEWORK

Structural Geology and Geologic History

The study area is in the east-central portion of the Northeast Oklahoma Platform (Fig. 9) which was a depositional shelf during Early and Middle Pennsylvanian time. The area is also a part of a post-Permian regional structure referred to by Fath (1920) as the Prairie Plains monocline, which extends from Nebraska to south-central Oklahoma. It is characterized by low-dipping beds that strike approximately northward.

According to the Tectonic Province Map of Oklahoma by Arbenz (1956), the major structures surrounding the study area include the Ozark Dome to the east; the Nemaha Uplift to the northwest; the Anadarko Basin to the southwest; and the Arkoma Basin to the south.

The general westerly dip of strata in northeastern Oklahoma averages about 30 ft. to the mile (White and others, 1922). Most folds were termed "plains type folds" by Powers (1931). Drilling has revealed that many of the folds are slightly offset above pre-Pennsylvanian topographic highs or "buried hills," some of them consisting of Precambrian rock. Well-log correlations have shown that these

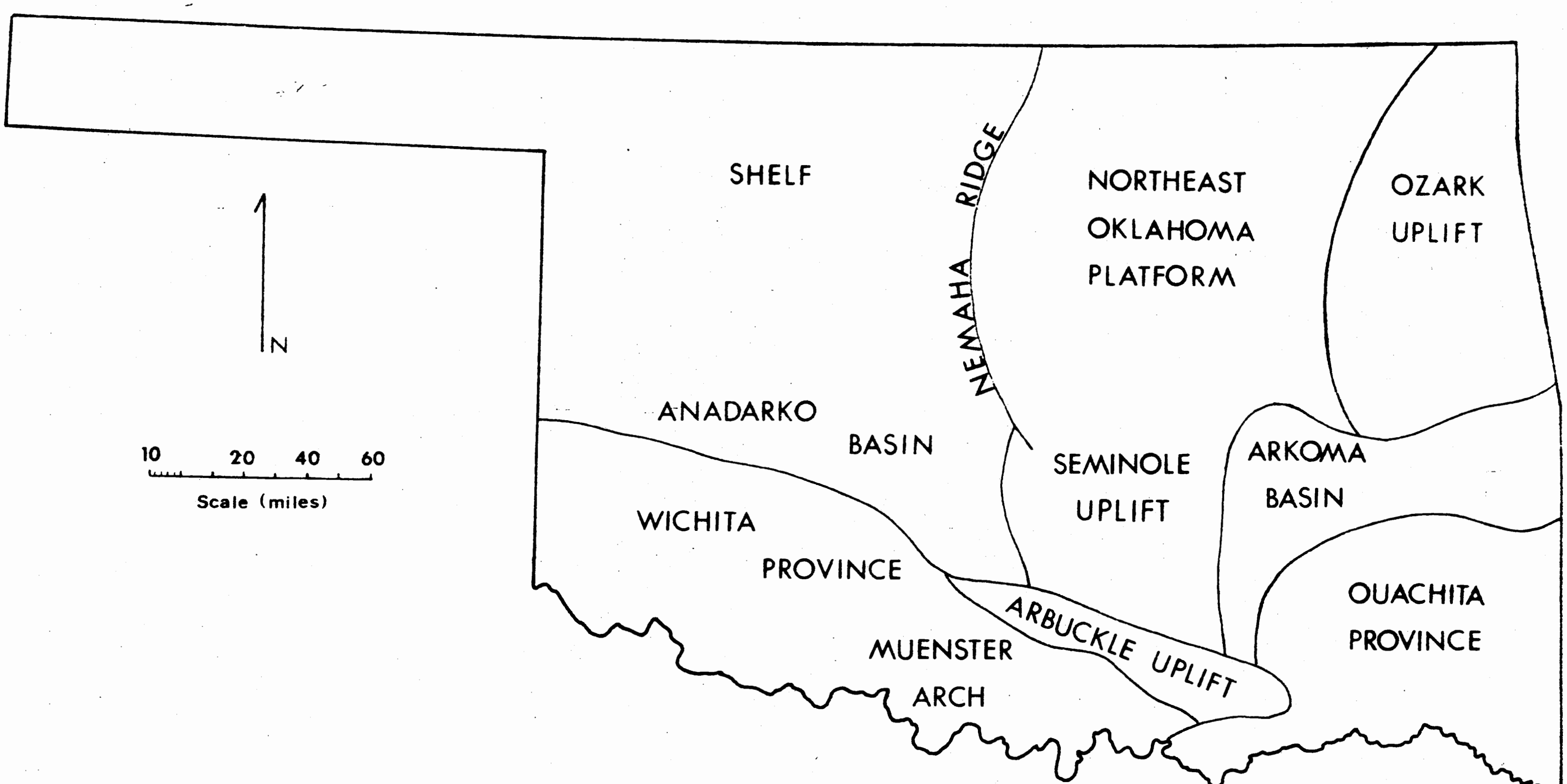

Fig. 9.-Major geologic provinces of Oklahoma (Modified from Arbenz, 1956).

surface structures differ, in varying degree, from corresponding subsurface structures. Powers (1931, p. 131-132) contended that:

> . . . the position of practically all of the anticlines in Oklahoma was determined early in Pennsylvanian time and the position of most of them was influenced by pre-Ordovician topography or grain. . . . Once the location and shape of an anticline was determined, all subsequent structural movement in the geosynclinal prism of sediments tended to accentuate the anticlinal relief in the older rocks. . . . Folding which terminated Paleozoic sedimentation in Oklahoma refolded the pre-existing anticlines.

Numerous northwesterly trending, subparallel, generally aligned normal faults trend northward to northeastward across central Osage County (Fig. 2). These en-echelon fault belts were mapped by Russell (1955), Shannon (1954), Bryant (1957), and others. Structural geologists have proposed several theories concerning the origin of these fault belts.

Fath (1920) postulated that horizontal movement along lines of weakness in deep-seated basement rock, with consequent drag in the overlying incompetent sediments, produced tension resulting in short fractures trending at an angle of about 45 degrees to the direction of deep-seated movement. He also suggested that vertical displacement along these same lines of weakness produced the irregular folds in the overlying sediments.

Foley (1926) indicated that horizontal movement due to rotational stress in strata lying between the westward thrust that produced the Ozark Uplift, and the opposing

Nemaha Uplift of Kansas, produced shear and tensional stresses that in turn produced en-echelon faults.

Sherrill (1929) stated that the present attitudes of Pennsylvanian strata in the area, which are subparallel to the fault zones, clearly demonstrate that forces causing the gentle regional tilting of the strata exerted a torsional stress on the formations and this stress, augmented by a slight uplift, would have produced en-echelon faults.

Melton (1930) related the formation of the fault belts to the Ouachita orogeny. He stated that the fan-like pattern of the faults has a point in the western Ouachita Mountains as the center and that the so-called en-echelon arrangement is "largely fallacious and unreal." He believed that this pattern was plotted as a result of negligent and incomplete field mapping.

Kramer (1934) postulated that the en-echelon faults are the products of tension and are located above major north-northeast trending shear planes produced in basement rock by a shearing couple. A westward thrust from the Ouachita Mountains was proposed as the force that created the couple, causing elongation of the area from northeast to southwest and thus developing the faults.

Link (1929) and others believed that the faults resulted from compaction over buried ridges or hills. The advocates of this theory cite the absence of the faults below the Pennsylvanian strata as evidence supporting their argument.

Structural geology within the study area is shown by a structural contour map constructed on the base of the Avant Limestone Member (Pl. 8). Local structural geology is discussed in pages 80 to 81 of this manuscript.

CHAPTER V

DEPOSITIONAL FRAMEWORK

Cyclic Deposition

Middle and Upper Pennsylvanian sandy shales containing thin local sandstones and persistent limestones characterize the bedrock geology of eastern Kansas and northeastern Oklahoma. The standard stratigraphic section is made of about 2500 ft. of rock that comprises 49 formations, divided into 129 formally named members. Because of the extent of a large number of these units, most were recorded in the 1930's and 1940's by Moore (1935, 1949) and others while mapping in Kansas and surrounding states. Moore noted curious vertical repetitions of particular distinctive units of shale and limestone, including those comprising the Iola Formation, through much of this sequence. This type of repetition in sedimentation has had an important bearing on classification of strata within the Midcontinent.

During Late Pennsylvanian time, deposition seemingly was essentially continuous in extensive portions of the Midcontinent, although unconformities within the stratigraphic column indicate that periods of erosion and nondeposition did occur intermittently. Northern Oklahoma was situated between an eroding landmass to the south and a marine basin to the north (Clare, 1963).

Weller (Wanless and Weller, 1932) observed cyclic repetitions of beds in Illinois that were bounded above and below by disconformities. He proposed that each "cycle" be referred to as a formation. Moore (1935) contended that a formation should be composed of a compact group of beds, similar in lithologic nature and faunal content, and should be classified on the basis of characteristics that can be observed readily in the field. He realized the definite genetic relationship of the elements composing individual cycles, but elected to reject the nomenclatural equivalence of formation and individual cycle, because numerous cyclic units of the Midcontinent contained some or all of the members of various successive formations.

Weller (Wanless and Weller, 1932) proposed the term "cyclothem" for the deposits that constitute a single sedimentary cycle. The AGI Glossary defines the term as

> a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period, typically associated with unstable shelf or interior basin conditions in which alternate marine transgressions and regressions occur (Gary and others, 1974, p. 177).

This fundamental transgressive-regressive nature of deposition responsible for simple cyclothems was recognized by Moore (1935) in the Wabaunsee and Cherokee Groups in Kansas and Oklahoma. He devised a scheme of classification for ten members representing an ideal Pennsylvanian or

Permian cyclothem of the Midcontinent (Table II). Members are represented by lithologic or paleontologic divisions of formations that have stratigraphic significance and reasonable persistence. Index numbers of the decimal system were employed to distinguish individual units.

Moore (1935) observed a cyclic repetition of elements within the shale units as well as within the limestones. Four genetically different limestone types, typically appearing with the same relative position, were designated as "lower," "middle," "upper," and "super." Shales, separating limestones, differ in character from one another while their order of succession is relatively constant. Upper and lower shales were thick, sandy, and predominantly marine, whereas center shales, positioned between "middle" and "upper" limestones, were black and fissile, and occurred nowhere else in the cyclothem.

Moore (1935) developed the term "megacyclothem" to account for a more complex repetitive sequence entailing various limestone and shale units such as those represented in the Shawnee Group (Fig. 10). Thus, a megacyclothem is a complex but distinctive succession of different but related shale-limestone couplets that are repeated several times upward in the sequence (Heckel, 1978). Moore used beds of the Shawnee Group in Kansas as the type section for megacyclothems because it was in these strata that he first recognized clearly cyclic repetition of Midcontinent composite cyclothems. Moore's megacyclothem was composed of

TABLE II

MEMBERS OF AN IDEAL CYCLOTHEM
(MOORE, 1936)

.9. Shale (and coal).

.8. Shale, typically with molluscoid fauna.

.7. Limestone, algal, molluscan, or with mixed molluscoid fauna ("super" limestone).

.6. Shale, molluscoids dominant.

.5. Limestone, contains fusulinids, associated commonly with molluscoids ("upper" limestone).

.4. Shale, molluscoids dominant.

.3. Limestone, molluscan, or with mixed molluscoid fauna ("middle" or "lower" limestone).

.2. Shale, typically with molluscoid fauna.

.1. c. Coal.

.1. b. Underclay.

.1. a. Shale, may contain land plant fossils.

.0. Sandstone.

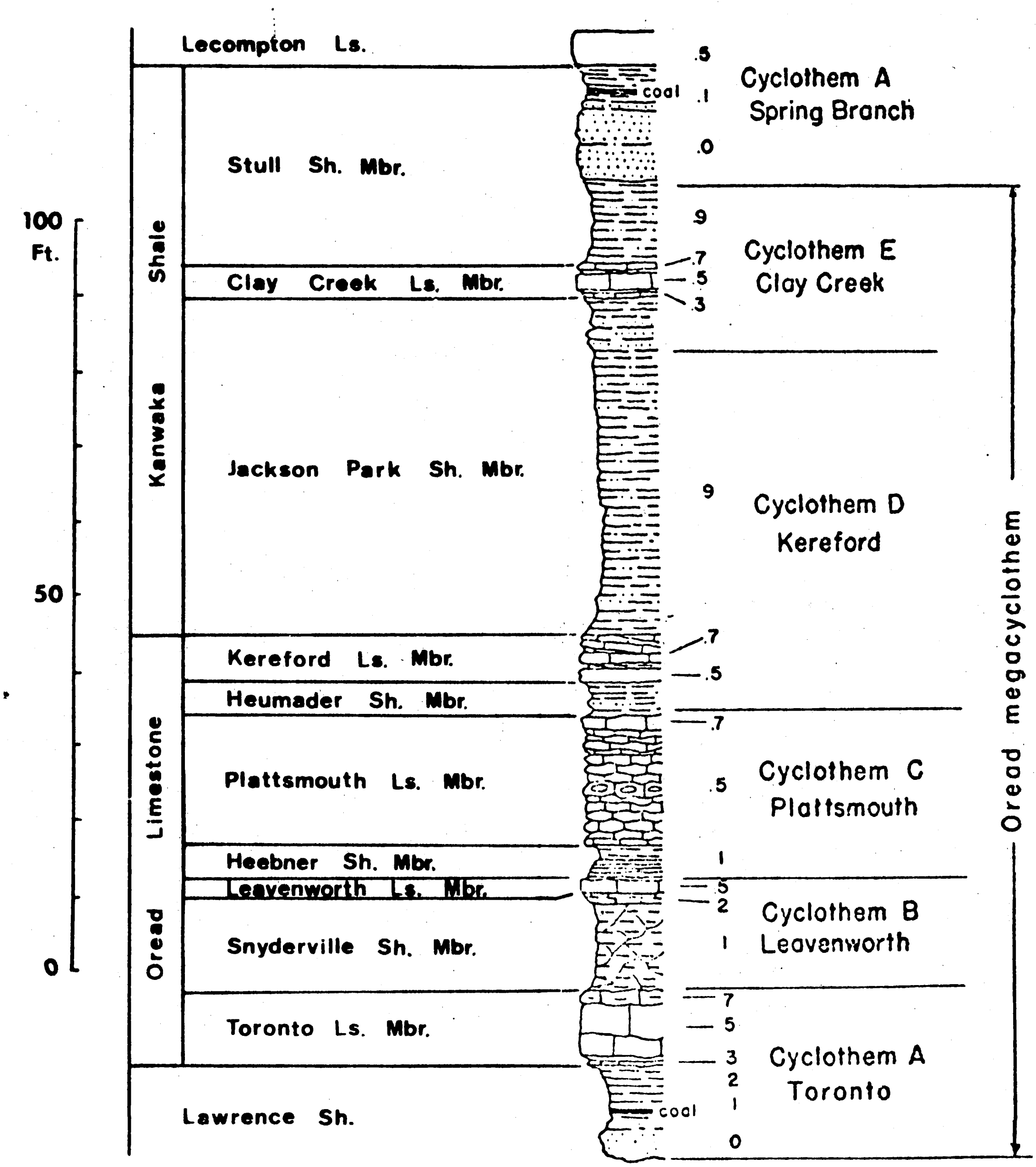

Fig. 10.-Typical megacyclothem of the Shawnee Group.

a succession of five associated and related unit cyclothems of significantly different character (A-E), with certain members that are developed only locally.

Westoll (Murchison and Westoll, 1968) contended that the "simple cyclothem" components of Moore's Kansas-type megacyclothem are not sufficiently similar to be regarded as individual cyclothems and that the megacyclothem is the true rhythmic unit.

Moore (1935) also employed this concept of megacyclothemic classification to the sequences developed in the Lansing Groups and Kansas City of Kansas, which are equivalent to portions of the Ochelata and Skiatook Groups of Oklahoma, respectively. He stated that cyclothems of the Missourian Series are less regular and less complete than those of the Shawnee Group, but that general similarities do exist.

Heckel (1978) simplified Moore's 10-fold ideal cyclothem model by grouping various sequential members into a five-part depositional unit, to which he referred as a "Kansas cyclothem." He stated that individual depositional cycles recording single transgressive-regressive marine sequences consist of the following components, in ascending order: (1) thick, nearshore sandy shale; (2) thin, transgressive limestone; (3) thin offshore shale, commonly with phosphatic black facies; (4) thick, regressive limestone; (5) repeat of thick, nearshore sandy shale. Heckel asserted that limestone units, containing thin shales, form the nuclei of the cyclothems in these divisions and intervening sandy shales form their boundaries.

Harbaugh (1964) proposed that alternating Pennsylvanian shale-limestone sequences in southeastern Kansas were deposited during only moderate oscillations of the sea and that general shorelines were relatively constant during the latter part of the Paleozoic. He suggested that transitional marine to nonmarine sediments are due to (1) ecologic succession of organism communities, and (2) differences in types and volumes of sedimentary material supplied to the sites of deposition. Harbaugh cited evidence in the stacking of algal-mound complexes and stated that mounds would be unlikely to form generally in the same places several times in succession if large-scale migration of the shoreline took place during or between episodes of deposition of mounds.

Moore (1950) interpreted black shales, located between "middle" and "upper" limestones, to be products of deposition in marine swamp environments with thick growths of seaweed, which allowed relatively calm bottom conditions to prevail. He noted the greater lateral extent of black shales than of most related limestones and concluded that these dark shales are relatively uniform in thickness between the limestones. The "upper" and "lower" shales were observed to thicken as megacyclothems were traced southward toward the detrital source of Missourian time, in Oklahoma.

Heckel (1977) disagreed and regarded interpretation of certain characteristics possessed by these black, middle shales as being extremely significant in defining their depositional environments. He interpreted lateral continuity and other properties as evidence of offshore sediment-starved deposition in deep water, rather than evidence of nearshore conditions with an increase in detrital influx as was previously implied.

Heckel (1977, 1978) described the members of a typical "Kansas cyclothem" (Fig. 11) as follows.

(1) Nearshore (Outside) Shales

Nearshore shales generally are gray, silty to sandy, and sparsely fossiliferous, but have concentrations of fossils near the tops, which represent early marine transgressions. They thin northward into Iowa and Nebraska, indicating less detrital influx from the north, thin over phylloid algal mound complexes in Kansas and northern Oklahoma, and thicken farther southward as underlying limestones thin. Thickening in Oklahoma occurred due to increase in terrigenous influx as they neared a major deltaic detrital source of the time period.

Shaly sections normally include locally fossiliferous silty to sandy shales, thick crossbedded sandstone, thin-bedded siltstones, and coals with underclays. These beds represent a wide range of environments from offshore to deltaic including shallow marine, shallow subtidal, shoreline, alluvial, and fluvial.

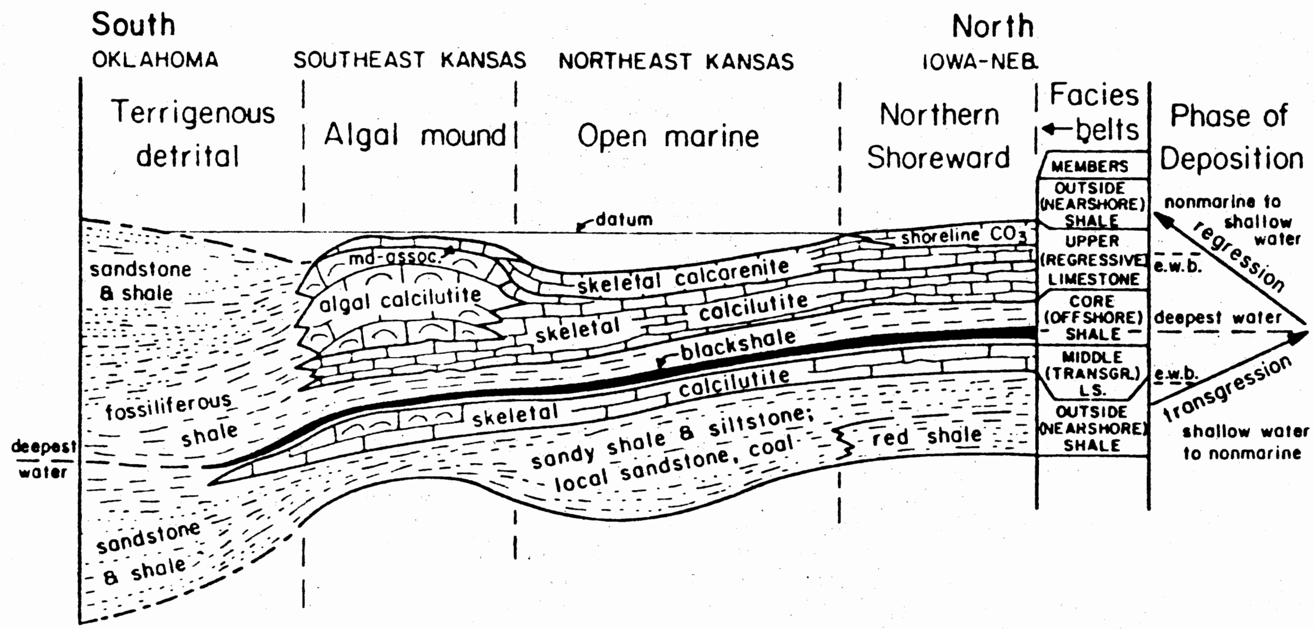

Fig. 11.-Basic pattern of lateral facies change in members of "Kansas cyclothem" along outcrop of Pennsylvanian rocks across the Midcontinent (Heckel, 1977, Fig. 4).

(2) Transgressive (Middle) Limestones

"Middle" limestones commonly are almost uniform in thickness and character, extending laterally along outcrop for hundreds of miles. Some have been reported to thicken southward as content of algae increases. They typically are thin, dark, dense ledges of skeletal calcilutite. Diverse biota and a fine-grained nature indicate open-marine deposition far enough offshore to be below effective wave base, thereby recording widespread marine inundation of the Midcontinent.

(3) Offshore (Core) Shales

These shales usually consist of dark-gray, thin, laterally-persistent marine shales, containing fish remains, brachiopods, and certain deep-marine conodonts, among other fossils. Commonly included is a black fissile facies, organically rich, and typically enclosing a zone of phosphatic nodules and relatively high heavy-mineral concentration. In some, the black facies dies out laterally but the nodules generally are present. These characteristics suggest slow, deep-water deposition, with anoxic bottom conditions, away from detrital influx. Sedimentation occurred below the effective limit of algal carbonate-mud production where the nature of deposition was affected little by the minor differences in bottom topography. These units were termed "core shales" by Heckel and Baesemann

(1975) because of their central position between the transgressive and regressive limestone units of a typical cyclothem.

(4) Regressive (Upper) Limestones

The upper limestones normally are thicker and contain a more diverse facies than do transgressive limestones. They are massive, finely to coarsely crystalline, and most grade laterally into phylloid algal-mound complexes. The lower parts are believed to have been deposited above the lower limit of carbonate production by algae, but below effective wave base, in an offshore environment. This is indicated by their lateral extent, variety of marine biota, and fine-grained lithology. The most obvious facies changes occur in the upper parts of these limestones. This portion records increased water agitation and shallowing conditions with time, presumably as the southern shoreline encroached northward toward the open sea. They may be capped by cross-bedded, abraided-grain, skeletal to algal calcarenite and oolite representing the mound-associated or "super-limestone" facies.

(5) Nearshore (Outside) Shales

Following deposition of the shallow-water, mound-associated facies, the influx of terrigenous material overwhelmed carbonate production, producing another stage of nearshore shales in the subtidal environment that flanked and overlay the regressive limestone. This is represented by the gradation of limestone upward into shales and sandstones. The cycle then repeated with another change of sea level. (All the above discussion was drawn from Heckel, 1977, 1978.)

Many people have studied the Iola Formation in eastern Kansas. Their examination has led several of them to believe that the three members of the Iola Formation represent a portion of the transgressive-regressive phase within a typical unit cyclothem and that in southern Kansas and northern Oklahoma, the upper Avant Limestone Member is a phylloid algal-mound complex (Heckel and Cocke, 1969).

I observed evidence that lends support to these ideas, particularly as regards the character and depositional environment of the Avant Member in southern Osage County.

Missourian rock units within the Wann, Iola, and Chanute Formations of Oklahoma are compared to members of Moore's "ideal cyclothem" and to Heckel's simplified "Kansas cyclothem." This is shown in Table III.

Mound Development

The AGI Glossary defines an algal mound as "a local thickening of limestone attributed chiefly to the presence of a distinctive suite of rock types (such as massive calcilutite) containing algae" (Gary and others, 1974, p. 15).

TABLE III

COMPARISON OF BEDS WITHIN THE WANN, IOLA, AND CHANUTE FORMATIONS OF NORTHEASTERN OKLAHOMA TO THE "IDEAL CYCLOTHEM" OF MOORE (1936) AND TO THE "KANSAS CYCLOTHEM" OF HECKEL (1977)

Wann Formation	.9. Shale (coal)	(5) Thick, nearshore sandy shale
Iola Formation Avant Limestone Member	.8. Shale, typically with mollusc fauna	
	.7. Limestone, algal, with mixed molluscoid fauna ("super" lm.)	(4) Thick, regressive limestone
Muncie Creek Shale Member	.6. Shale, molluscoids dominant	
Paola Limestone Member	.5. Limestone, contains fusulinids, molluscoids common ("upper" lm.)	
	.4. Shale, molluscoids dominant	(3) Thin offshore shale, commonly with phosphatic black facies
Chanute Formation carbonaceous shale member	.3. Limestone, with mixed molluscoid fauna ("middle" or "lower" lm.)	
Cottage Grove Sandstone Member	.2. Shale, typically with mollusc fauna	(2) Thin, transgressive limestone
Thayer Coal Member	.1. c. Coal	
	.1. b. Underclay	(1) Thick, nearshore sandy shale
unnamed shale member	.1. a. Shale, may contain plant fossils	
Noxie Sandstone Member	.0. Sandstone	

Precipitation of Calcium Carbonate

Sea water is approximately saturated with calcium carbonate (Krauskopf, 1967) which is observed to be precipitating in some parts of the sea. Regulation of its solubility can be governed by slight shifts in the marine environment. Temperature and pressure greatly affect the solubility of carbon dioxide, which directly influences the solubility of calcium carbonate. As is commonly known, carbon dioxide is less soluble under low pressure and in warm water than under high pressure and in cold water. Therefore, in shallow, warm water, carbon dioxide and thus calcium carbonate are less soluble. Processes that further decrease the carbon-dioxide content in sea water can lead to precipitation of calcium carbonate.

The precipitation or dissolution of calcium carbonate in water, as it is related to the evasion or invasion of carbon dioxide, was summarized by Krauskopf (1967) in the following equation:

$$\begin{array}{c} H_2O + CO_2 \\ \upharpoonleft\downharpoonright \\ CaCO_3 + H_2CO_3 \rightleftharpoons Ca^{++} + 2HCO_3^- \end{array}$$

Carbon dioxide and calcium carbonate are dissolved if these equilibria move to the right. If carbon dioxide is removed, the equilibria move to the left and calcium carbonate is precipitated.

Green plants, including algae, are known to synthesize carbohydrates with the aid of sunlight. Carbon dioxide is used in this process. When CO_2 is extracted from sea water in which the plants grow, this can lead to the precipitation of calcium carbonate in the immediate vicinity.

Dalrymple (1965) suggested that decomposition of abundant organic material in algal mats by bacterial action could result in the production of ammonia and the precipitation of calcium carbonate. He conceded that this anaerobic bacterial action would take place only in reducing environments, but contended that the black, odoriferous character of the lower layers of some algal mats indicates that reducing conditions do prevail. He observed such conditions in algal mats found in Baffin Bay, Texas.

According to Lowenstam (1955), common marine calcareous algae from near equatorial West Atlantic waters are subject to post-mortem disaggregation. The calcareous hard parts of a variety of these algae are composed partially or completely of aragonite needles. Upon digestion of algal material with 5.3 percent sodium hypochlorite, the residual was found to consist of fragments including single aragonite crystals. The algally derived needles were identical in habit and dimension with those found in sediment being deposited currently. Lowenstam concluded that calcilutites attributed to physiochemical precipitation or mechanically reduced skeletal carbonates may have been created partially or largely from algally-derived aragonite needles.

Stockman and others (1967) reported on the contribution of similar algally derived aragonite needles to the accumulation of lime mud in Florida Bay. By comparing rates of production with rates of accumulation, they postulated that Penicillus, a lightly calcified green and red algae, could account for all the fine aragonite mud in the inner Florida reef track and one third of the same material in northeastern Florida Bay.

Phylloid Algae

Phylloid is a term applied to a type of calcareous algae recognized in abundance in many late Paleozoic limestones of the Midcontinent. The term was proposed by Pray and Wray (1963, p. 209):

> Phylloid--meaning literally leaflike or resembling a leaf. This is the dominant character of the algal fragments so prevalent in shallow water carbonate rocks of Pennsylvanian and Permian age. . . . The term applies only to the shape of the algal remains as we now see them. It can be applied without regard to biological classification and can be applied to forms with different growth habits. Thus, the term 'phylloid' has no implication as to whether these algae existed as encrusting 'mats' or upright 'leaves'.

Ginsburg and Lowenstam (1958) proposed that certain marine grasses, such as Thallasia, are capable of influencing the environment in a way that is similar to that of terrestrial plants. They reported on the local concentrations of sediment by marine grasses that produce elongate mud banks standing 4 to 8 ft. above the sea floor.

Recent forms such as calcareous green algae and coralline red algae have been used by analogy to speculate about environmental tolerations and growth habits of phylloid algae (Pollard, 1970).

Initiation of Growth of Mounds

Harbaugh (1964) compared the marine-bank limestones of the Kansas City Group in Kansas to offshore bars. He suggested that an accumulation of unconsolidated argillaceous and calcareous material was piled into heaps above the level of the surrounding sea floor. He contended that this was accomplished partially by current and wave action and partially by biological processes.

Toomey and others (1977) postulated that hard foundational surfaces, forming low-relief banks above the surrounding sea floor, are developed when shell debris and invertebrate remains accumulate in shallow-water shelf environments where proliferation and abundance of calcium-secreting organisms is great.

Heckel and Cocke (1969) proposed that mounds began on topographic highs situated favorably between the open seas and regions of great clastic influx. They contended that underlying mounds, surrounded by shales that had undergone greater compaction, may have generated positive topographic influence, thus producing stacking of mounds. The mounds would have shifted position in response to fluctuations in clastic influx.

Harbaugh (1964) postulated that algal communities began along banks on the sea floor. He suggested that banks may have also served as barriers that inhibited movement of sediment and thus helped to provide clear, sunlit water, whereas clay and silt were being deposited on the adjacent sea floor. Once initiated, the mound became carpeted with phylloid algae which thrived in the relatively shallow water. Toomey and others (1977) stated that the optimal depth range was probably a few tens of feet. They proposed that quiet water over the mounds decreased replenishment of nutrients and made it very difficult for other shallow-water organisms to compete successfully for living space on the sea floor, and thus dominance of plants could explain a reduction in the diversity and number of other marine organisms.

Heckel and Cocke (1969) suggested that phylloid algae created a baffle-like effect, which caused the settling of lime mud from suspension, and in addition stabilized the sediment with the root system. Pollard (1970) and other authors related phylloid algae to carpets of marine grasses described by Ginsburg and Lowenstam (1958). These marine grasses were believed to be capable of producing semimotionless water over the bottom, in which fine sediment could settle out that would normally be bypassed. Once the fine sediment had drifted into the root mat, tidal currents or wave action could no longer cause its resuspension. Toomey and others (1977) inferred that phylloid-algal buildups accumulated and kept pace with sedimentation and subsidence through the mud-trapping process. Algae thrived in the optimal sunlight conditions while shallow depths and warm temperatures of water over the banks stimulated production by lime-secreting organisms, contributing more material to the bank.

An isopach map of the interval between the base of the Hogshooter Limestone and the base of the Avant Member (Pl. 9) shows thicking southeastward. This corresponds in general trend with thickening of the overlying mound facies, shown by a log map and an isopach map of the Avant (Pls. 6, 7). This relationship indicates existence of an optimal zone on the southward paleoslope, where mound development was initiated. Figure 12 indicates absence of an overall clear-cut relationship between development of the Avant mound and thickening of the underlying interval, although portions of the graph do show strong lineation (see also Appendix B and Pl. 13). These facts suggest that a belt of optimal water-depth may have been the major factor in development of the Avant mound.

Tectonic subsidence of underlying strata may have had significant influence on the positions of shorelines and thus the locations of developing mounds. Distribution of stacked algal mounds in southeastern New Mexico has been shown to be related to tectonic activity in the area (Toomey and others, 1977). These mounds are positioned along the La Luz anticline, which presumably was active during the time of mound-facies deposition. Toomey suggested that this movement brought about shallow-water environments favorable

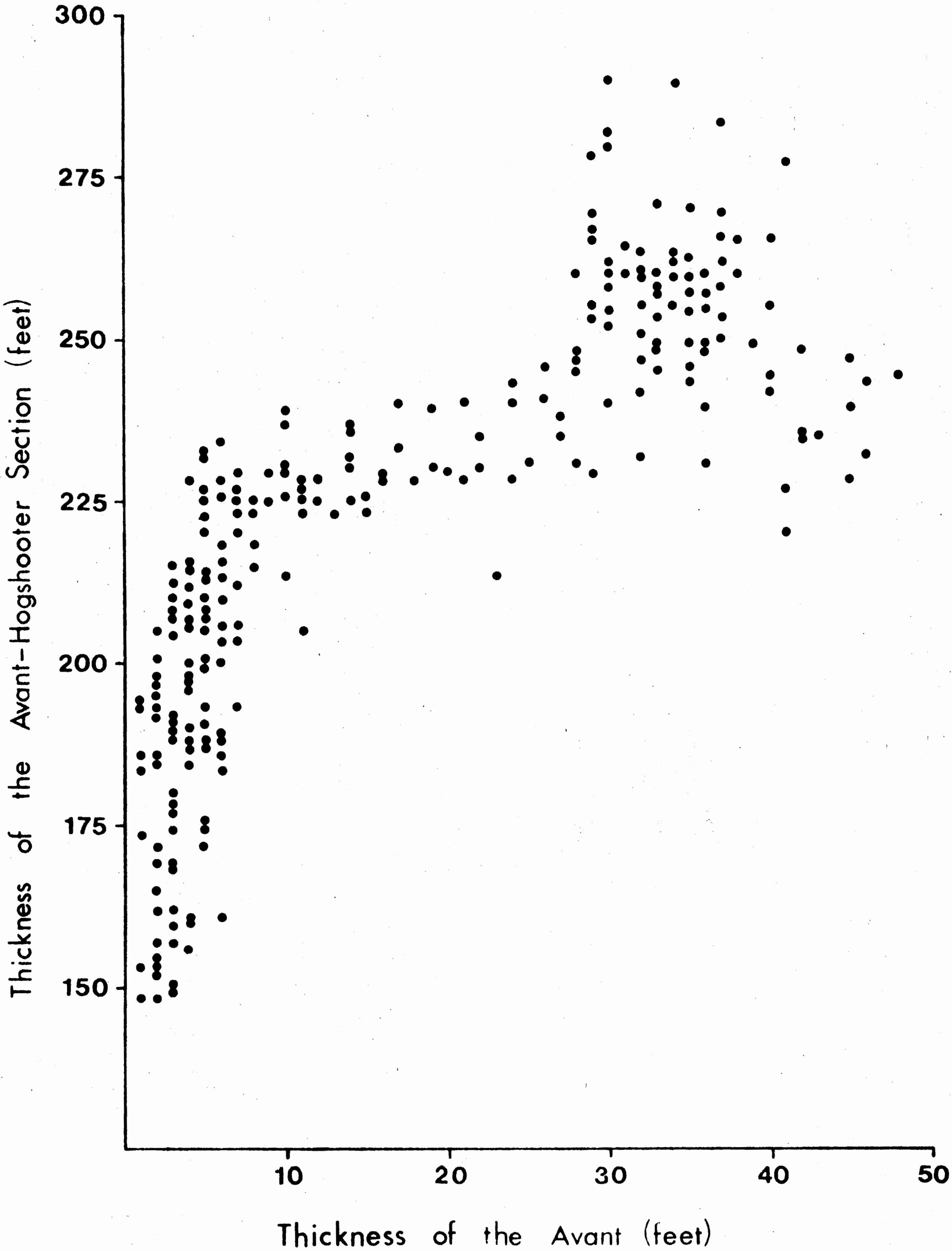

Fig. 12.-Relation of thickness of the Avant Member (abscissa) and thickness of the base-of-Avant to top-of-Hogshooter section (ordinate).

for algal proliferation. However, mound complexes of the Midcontinent differ from small, localized mounds such as the one reported by Toomey which was positioned over a small, distinctly-bounded tectonic high. Mounds in the Midcontinent are much wider and formed on a broad marine shelf subject to little tectonism. However, aligned edges of mound terminations in southern Kansas and northern Oklahoma do suggest possible tectonic control (Heckel and Cocke, 1969).

Stacking of mound complexes in northeastern Oklahoma consists of local thickening of sequential limestones, partially or wholly composing the Hogshooter, Dewey, Avant, and Wann rock units (Fig. 13). Northern terminations of the Hogshooter, Dewey and Wann mounds occur at the southern side of a well-defined area of thin, nonmound, Missourian limestone beds and thick clastic rocks. This area is located between the regions of mound development in Kansas and in Oklahoma (Heckel and Cocke, 1969).

From studies of the subsurface, several intervals between certain Pennsylvanian limestones were shown to thicken southward from my thesis area, in R. 8 E., through R. 11 E. I found that thickness between the Avant and Hogshooter limestones increased from T. 23 N. to T. 21 N. Mohler (1942) observed that thickness of the section between the Dewey and Checkerboard Limestones increased from T. 20 N. to T. 19 N. and that thickness of section between the Checkerboard and Oswego Limestones increased from T. 22 N. to T. 19 N. Thickening of the interval below the Avant

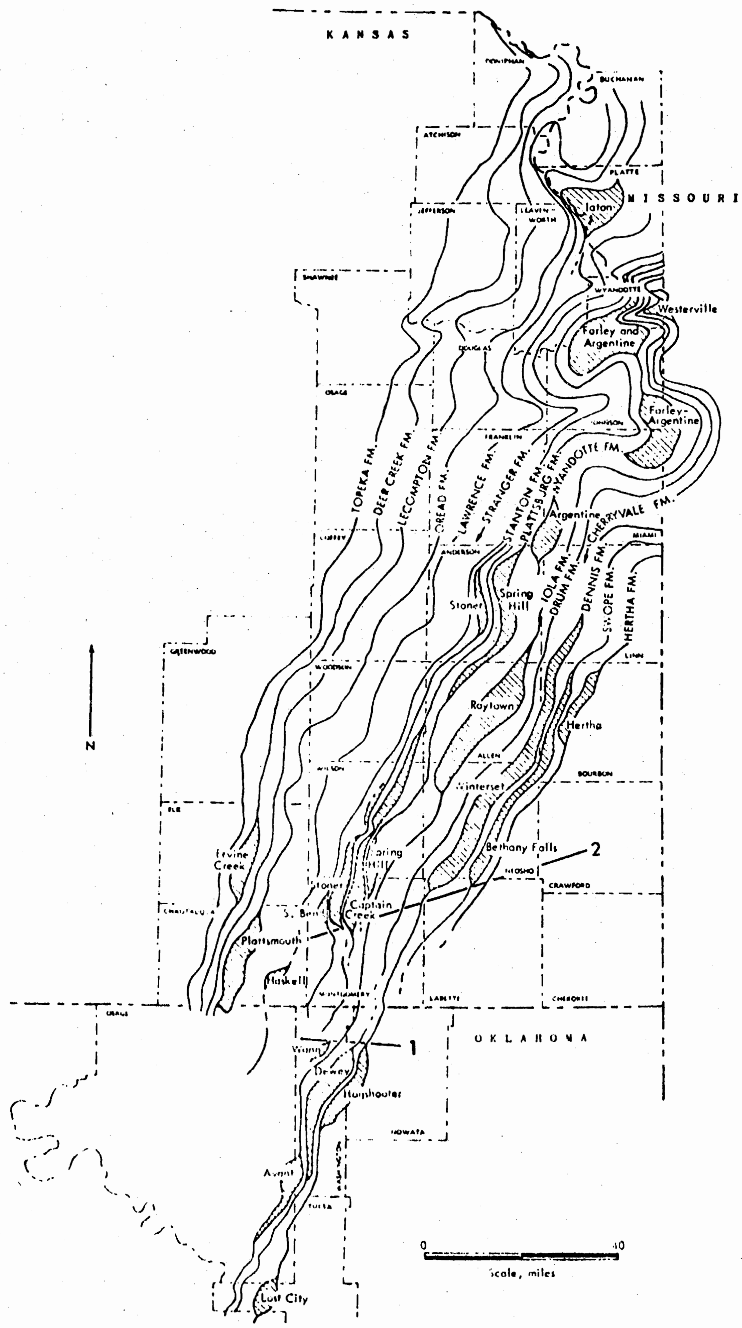

Fig. 13.-Outcrop distribution of Missourian and lower Virgilian phylloid algal-mound complexes in eastern Kansas and northeastern Oklahoma (modified from Heckel and Cocke, 1969, Fig. 2). Areas with oblique lining represent outcrops of mound complexes; narrow lines represent non-mound facies; lines 1 and 2 mark alignment of Missourian mound terminations.

Limestone Member corresponds well (in part) to mound development (Fig. 12; Appendix B). Exposures of the Hogshooter show that thickness increases from T. 20 N. to T. 19 N. and Heckel and Cocke (1969) indicated that this corresponded to mound development. Mohler (1942) showed that the interval between the Dewey and Checkerboard Limestones, which includes the Hogshooter Limestone, increases in the subsurface through these two townships, down-dip and west of the Hogshooter outcrop.

Mound Facies

Southward from the open-marine facies belt, most regressive limestones increase in thickness, changing into phylloid algal-mound complexes. Most mound complexes are located in the upper portions of the limestone units and comprise the "upper limestone" of Moore's ideal cyclothem. Flanking shale deposits could have been deposited synchronously. Overlying shales commonly thin and some pinch out over the tops of mounds.

Mounds are thick-bedded to massive. Thickness ranges from about 10 to about 80 ft. and normally the mounds are two to four times as thick as lateral nonmound limestone equivalents. Some mounds extend as little as 2 or 3 mi., but others may be 25 mi. long, or longer (Heckel and Cocke, 1969). Mounds show little evidence indicating the presence of frame-building organisms or that they formed masses sufficiently wave-resistant to be classed as organic reefs

(Toomey and others, 1977).

The Avant mound, like most mounds of the Midcontinent, is composed primarily of four distinctive rock types grading laterally and vertically into one another. These are sparry algal calcilutite, algal microsparite, skeletal algal calcarenite, and nonalgal calcilutite, all with varying proportions of calcite and dolomite. The presence of quartz, calcite, and dolomite, and the relative proportions of each in samples of limestone in the Avant, was determined using X-ray diffraction (Appendix C). Carbonate material consists principally of lithified lime mud, fragmented algal blades and invertebrate grains, and finely to coarsely crystalline spar. Some spar or microspar represents recrystallization or replacement of the original sediment by diagenetic processes that formed grain-growth crystalline carbonate (Fig. 14). Nonalgal calcilutite may represent original lime mud derived from total post-mortem disaggregation of algal blades, like that described in modern carbonates by Lowenstam (1955).

Algal blades generally are fragmented. Thin outlines or "ghost" structures resembling algal blades commonly are present. They probably represent incomplete destruction of the algae (Heckel and Cocke, 1969). Most blades appear as ribbon-like strips or stringers of sparry carbonate devoid of recognizable organic structure, owing to diagenetic changes that generally prohibit specific identification. Figure 15 shows a cluster of phylloid-algal blades from the Avant.

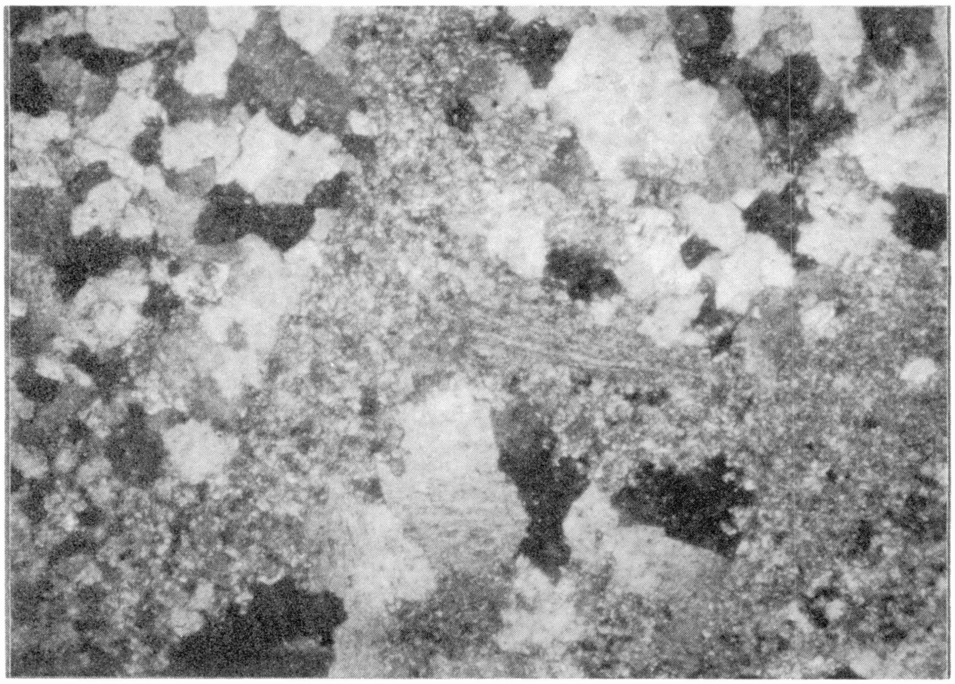

Fig. 14.-Diagenetic microspar and embayed crystals of dolomite. Crossed nicols, X25, approximate scale: 1 in. = .02 in.

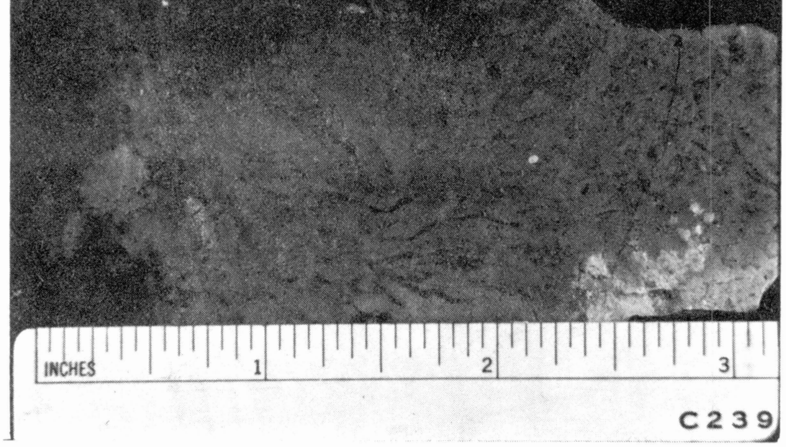

Fig. 15.-Cluster of phylloid algal blades in limestone of the Avant. Length of blades approximately ½ in.

Some well-preserved specimens have been reported in various algal limestones. Wray (1964) identified the corolline red algae Archaeolithophyllum in the Plattsburg Formation (Missourian) of Kansas. He also identified codiacean green Anchicodium and Eugonophyllum from the Captain Creek and Stoner Members of the Stanton Limestone (Missourian), respectively. Thick, laminated, partly foraminiferal encrustations of the blue-green genus Sphaerocodium, coating poorly preserved phylloid algae, have been identified tentatively by Wray in the Avant mound (Heckel and Cocke, 1969). Figure 16 is a photomicrograph of a fairly well preserved, recrystallized blade fragment from the Avant mound. It has not been identified as to genus.

Leaf-like phylloid algae commonly exerted an "umbrella effect" when they settled and accumulated on the sea floor. Lime mud collected on the upper surfaces of individual algal blades creating sheltered "voids" beneath, in which macrocrystalline calcite and ferroan dolomite precipitated (Harbaugh, 1964). Hollow interiors of invertebrate shells created voids which were also subject to filling by spar. Figure 17 shows a spar-filled ostracod from the Avant mound.

Troughs developed locally, perhaps due to movement of water across parts of the mound, and became minor channels forming a drainage system through parts of the mound area. Channels were filled with skeletal sand formed from fragmented algal blades and grains of invertebrates (Fig. 18).

Fig. 16.-Well-preserved recrystallized fragment of algal blade within skeletal sparite. Parallel nicols, X25, approximate scale: 1 in. = .02 in.

Fig. 17.-Ostracod filled with sparry crystalline carbonate rock. Parallel nicols, X25, approximate scale: 1 in. = .02 in.

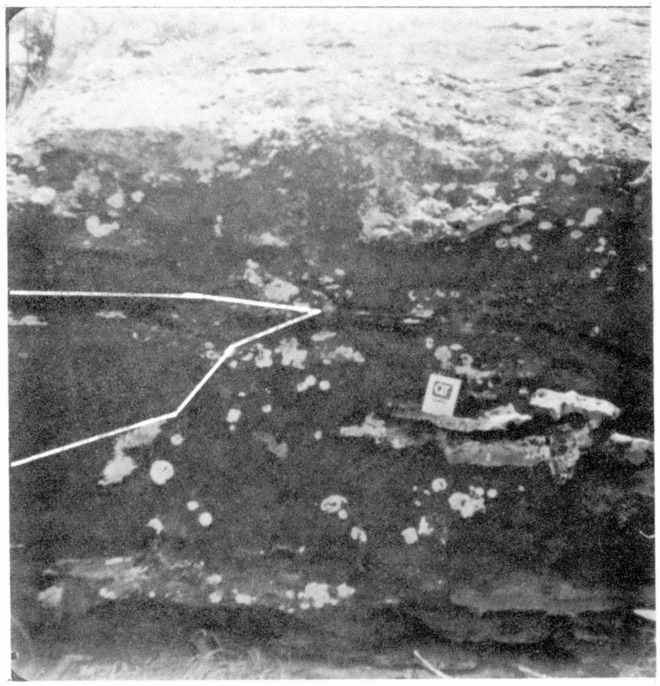

Fig. 18.-Minor channel filled with skeletal debris.

Crossbedded accumulations of skeletal debris developed due to wave and current action around prominent mounds.

Oolites can form similar accumulations under certain conditions of carbonate supersaturations. Heckel (1975) stated that oomoldic porosity can develop when aragonite ooliths are removed during diagenesis, producing spheroidal voids. Brecciation of carbonate mud and silt can occur when slightly consolidated aggregates are broken up by wave and current action or during exposure as tidal flats after mud cracks were formed. This produces pore spaces that are later partially or completely filled with crystalline carbonates (Toomey and others, 1977). Reopening of pore spaces can occur by circulation of slightly acidic solutions through permeable fractures and incompletely filled voids.

Figure 19 shows the result of partial void-filling by crystalline carbonate. Figure 20 is a photomicrograph of a thin section taken from the same specimen. It shows evidence of three episodes of carbonate precipitation. The first episode produced a large crystal at least 17 mm long which was precipitated either directly as dolomite or as calcite that underwent an early stage of dolomitization. Figure 21 shows dolomite rhombohedra developed along fractures or cleavage planes of this large dolomite crystal, suggesting that the latter hypothesis for its formation is more likely to be correct. Two episodes of precipitation of ferroan calcite occurred, as is indicated by two zones of different-sized crystals. The first produced crystals

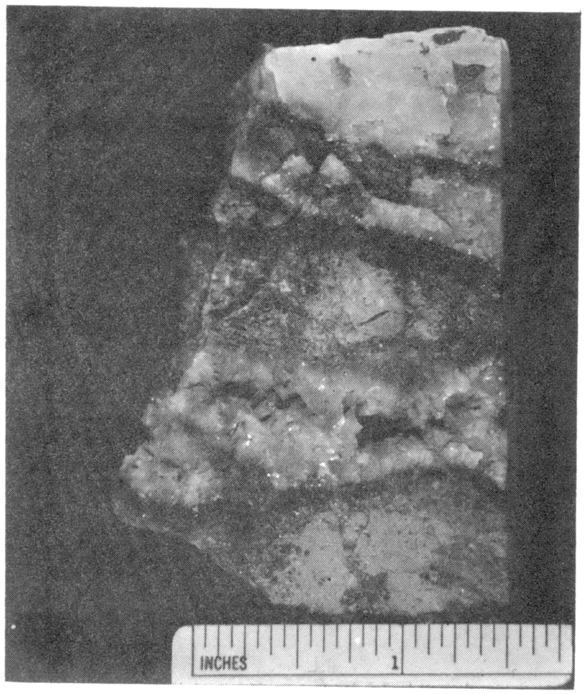

Fig. 19.-"Void space" partly filled with crystalline carbonate rock.

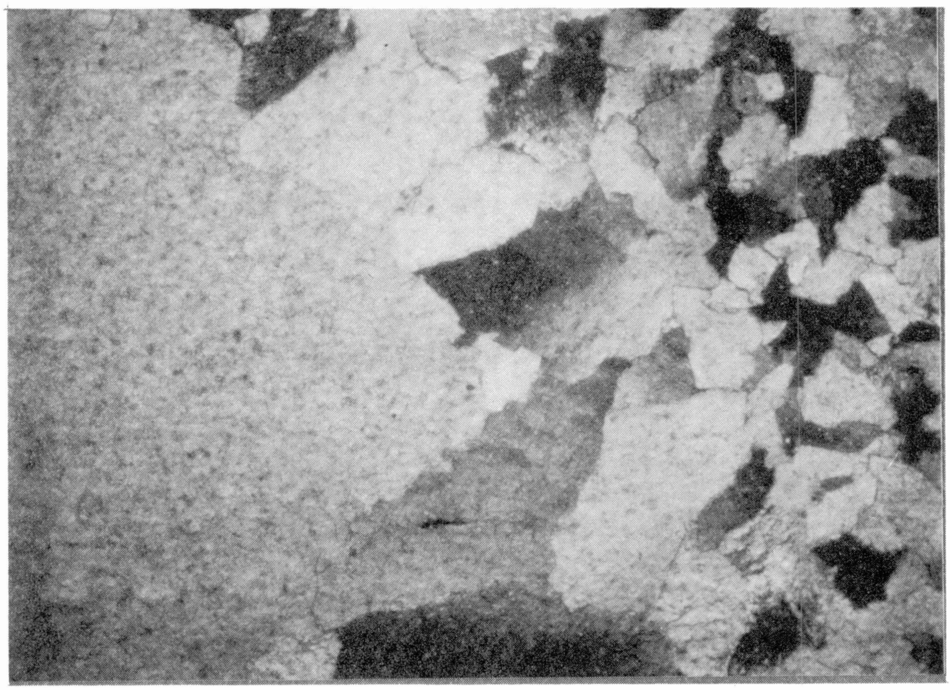

Fig. 20.-Calcium carbonate with three sizes of crystals indicating three episodes of precipitation. Crossed nicols, X25, approximate scale: 1 in. = .02 in.

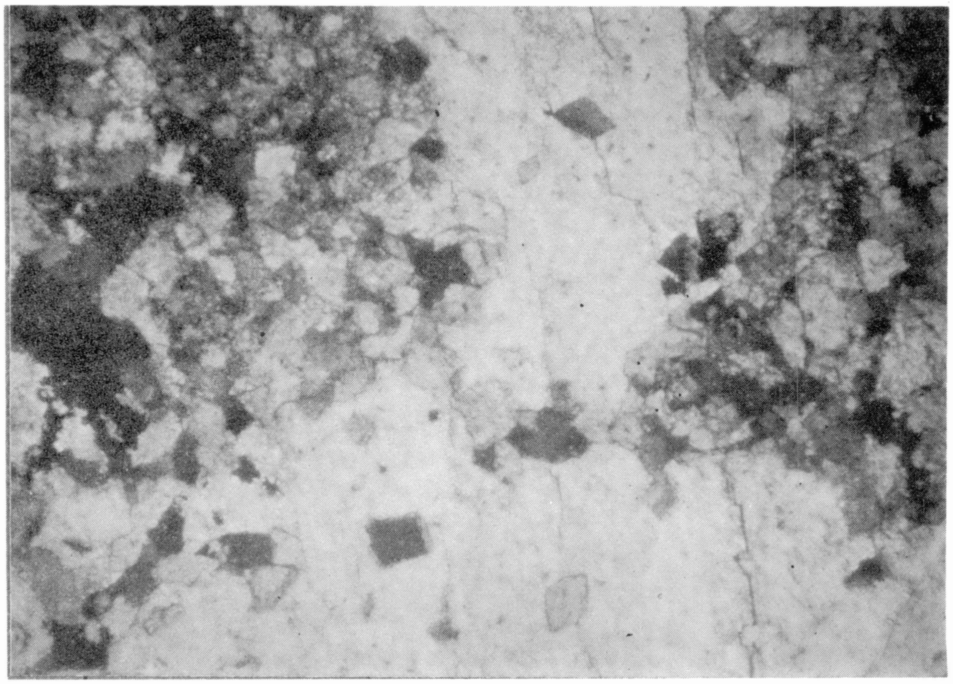

Fig. 21.-Rhombohedral crystals of dolomite. Crossed nicols, X25, approximate scale: 1 in. = .02 in.

ranging in length from 1.14 to 3.04 mm. The second produced crystals that range from 0.5 to 0.05 mm long, the smaller size due probably to the decrease in available space.

According to Heckel (1977), during early regression, open-marine deposition in the Midcontinent accounted for mound facies commonly containing bedded skeletal calcilutite with essentially the same biotic assemblage extending laterally in all directions. As water shallowed, skeletal calcarenites were deposited below effective wave base and probably below the limit of much algal activity as well. They consisted almost entirely of grains of invertebrates that bear no evidence of abrasion, crossbedding or definite algal structure. As water shallowed to limits above wave base, it was agitated and skeletal calcarenites were formed that show various amounts of abraded grains, channeling, and crossbedding. Detrital influx that formed overlying and flanking shales often overwhelmed carbonate production within the subtidal environment. This is indicated by the absence of capping, shoalwater to shoreline carbonate facies (Heckel, 1977).

Mound-associated Facies

Some mound facies are overlain and flanked by a mound-associated facies. The mound-associated facies is the "super limestone" member of some unit cyclothems within

Moore's megacyclothem. The facies grades locally into overlying and surrounding shales.

Mound-associated facies include the most abundant and diverse assemblage of rock and fossil types, but they are less important volumetrically than the mound facies (Heckel and Cocke, 1969). Dominant rock types in the Avant, as within most mound-associated facies with algal mounds in the Midcontinent, include algal to skeletal calcarenite, calcilutite and microsparite. They commonly contain some combination of the following features: abraded algal segments and invertebrate fragments, oolites, "micrite envelopes" resulting from boring, thin wavy bedding with shale laminae, crossbedding, and mudcracks. Figure 22 shows an example of wavy bedding in the upper, thin-bedded, mound-associated facies of the Avant.

Tanner (1956) proposed a lagoonal environment of deposition for intervals containing facies composed primarily of grayish-green shales interbedded with thin beds of limestone, calcareous siltstone, and limonitic siltstone. He asserted that these strata generally are characterized by marine invertebrate fossils, limonite concretions, trails, burrows, ripple marks, and wavy-bedded limestone. Scouring and winnowing by currents and waves are the processes to which the formation of wavy bedding is attributed.

Toomey and others (1977) attributed deposition of the upper mound facies and flanking beds of the Yucca mound complex, in southern New Mexico, to the concentration of

Fig. 22.-Wavy bedding in mound-
associated facies of
the Avant Member.

skeletal and detrital debris. This was done, he stated, by wave-winnowing, shallow-water processes following a sequence of intermittent sedimentation of red silt and mud that accounted for the thin interbedded shales.

CHAPTER VI

SUBSURFACE STUDY

The Avant Member crops out in the southeastern quarter of T. 22 N., R. 11 E. within the area of primary mapping. Measured sections were taken at three locations in this and surrounding areas (Appendix A). From these measured sections, and others by Gardner (1957), the Avant was correlated by electric logs into the subsurface in Noble and Creek Counties.[1] Cross sections within the primary mapping area include correlation, in descending order, of the lower portion of the Wann Formation, the Avant Limestone Member, Muncie Creek Shale Member, Paola Limestone Member, Dewey Limestone, and Hogshooter Limestone. From these correlations, four maps of subsurface intervals were constructed. The cross section extending southward from the primary mapping area includes correlation of the Avant. Cross sections extending westward from the primary mapping area include correlations of the Perry Gas Sand, the Avant Limestone Member, below, and a locally thick carbonate interval, above, referred to by Lukert (1949) as the "Wildhorse Limestone."

[1]Names and locations of wells and measured sections used in the correlation sections are in Appendix D.

Oakes (1952) reported that the Wildhorse Dolomite Lentil is near the top of the Barnsdall Formation, exposed in southern Osage County within an unnamed shale member (Table I, p. 14). According to Bellis and Rowland (1976), maximal known thickness of the Wildhorse in outcrop is 26 ft. at an abandoned quarry in sec. 19, T. 22 N., R. 10 E. (Fig. 2, p. 5). Oakes (1952) reported that the Wildhorse has not been recorded south of the Arkansas River.

The Wildhorse is white to gray, fine- to medium-grained dolomite with abundant veins and vugs filled with crystalline carbonate. It is mostly thin- to medium-bedded, but contains some thick beds. Abundant thin reddish brown stringers of iron oxide are present along with minor amounts of pyrite and clay (Bellis and Rowland, 1976).

According to Lukert (1949), the Wildhorse is traceable in the subsurface from sec. 5, T. 22 N., R. 10 E., to sec. 13, T. 22 N., R. 1 E., where it makes up the upper part of a well-developed limestone. Lukert attributed the increased thickness in some areas to development of calcareous beds within strata down to and including the Wann Formation. Lukert reported that the name Avant, as used in the subsurface, is often misapplied to this limestone zone.

"Perry Gas Sand" is a subsurface-stratigraphic term that Lukert (1949) applied to a zone consisting of any sandstone between the Wildhorse Dolomite above, and the Avant Limestone Member below (Fig. 23). It includes the Washington Irving and Clem Creek Members of the Wann Formation

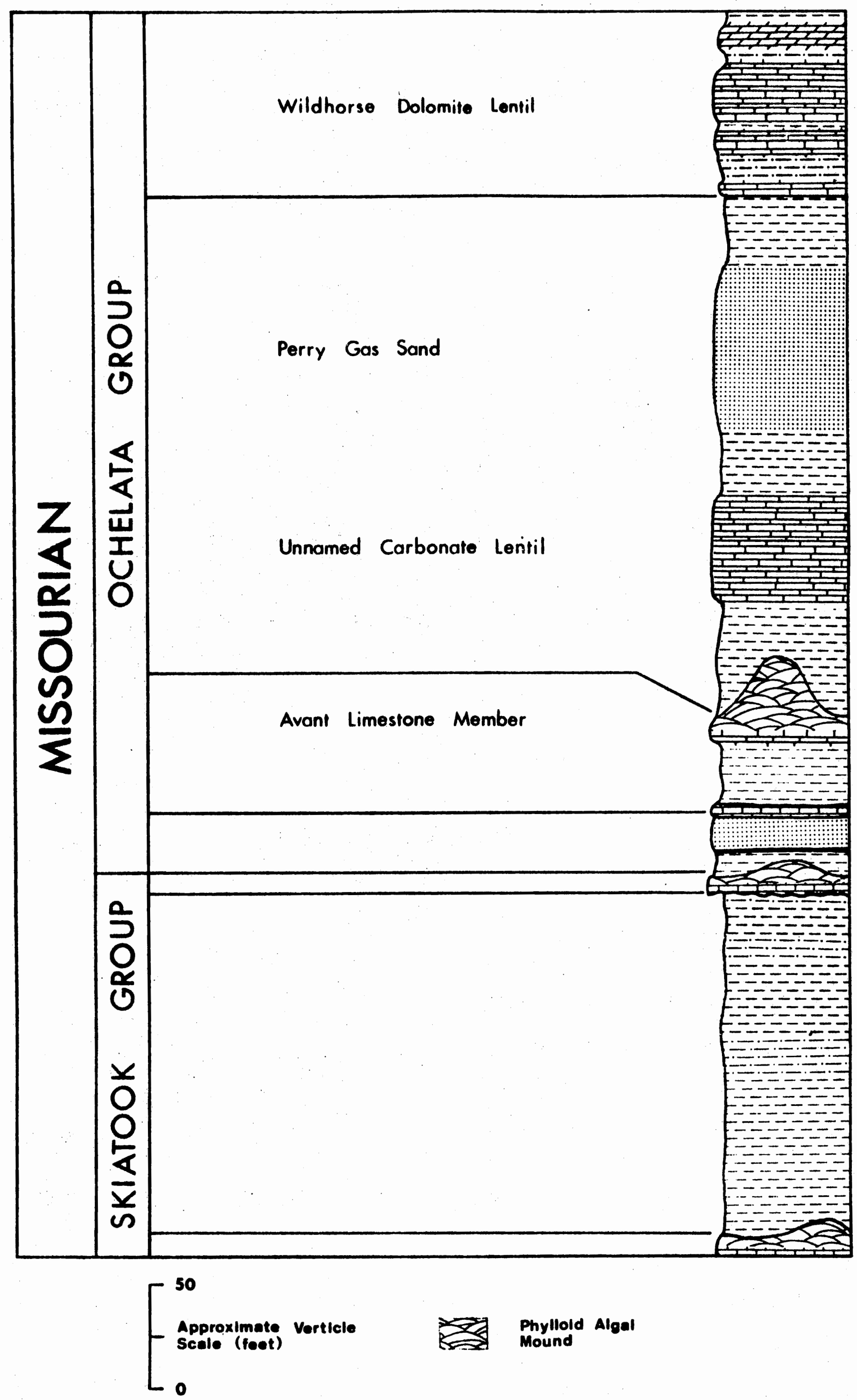

Fig. 23.-Generalized column of beds correlated outside the primary area of mapping.

(Table I, this report; and Clare, 1963). It normally is 50 to 200 ft. thick and contains numerous shale partings that compose as much as one-quarter of the zone. Clare reported that the Perry Gas Sand is white to tan, locally slightly argillaceous and calcareous, very fine- to coarse-grained, tight to porous, and generally friable.

Correlation Sections and Maps

Correlation Section A-A'

Gardner (1957) measured a section located in sec. 33, T. 23 N., R. 12 E. (Fig. 2). He reported 22.5 ft. of Avant overlain by 67 ft. of shale of the lower Wann and underlain by 40 ft. of shale of the Muncie Creek. Downward in the section the interval consisted of 2 ft. of limestone of the Paola, 47.6 ft. of sandstone and shale composing the Chanute Formation, and 20.6 ft. of limestone and shale of the Dewey Limestone. His measured section marks the easternmost point (Loc. 23) on the cross section A-A' (Pl. 1).

Location 22 is a section measured at an abandoned quarry in sec. 17, T. 23 N., R. 12 E. (Appendix A, Measured Section 1). Here, 53 ft. of the Avant is underlain by at least 40 ft. of the Muncie Creek. The Paola was not observed. The Avant is overlain by at least 70 ft. of the Wann, which is shale interbedded with thin beds of sandstone and siltstone.

The nearest well down-dip with an available electric log shallow enough to include the Avant is 2.6 miles away in sec. 11, T. 23 N., R. 11 E. (Loc. 21, Correlation Section A-A'). Here 43 ft. of the Avant is underlain by 38 ft. of the Muncie Creek and 3 ft. of the Paola. The section between the Avant and Hogshooter is 235 ft.

In sec. 1, T. 23 N., R. 10 E. (Pl. 1), the Avant is only 2 ft. thick, the Muncie Creek is 18 ft. thick, and the Paola is 5 ft. thick. From this point westward to sec. 4, T. 23 N., R. 8 E., all three members vary little in thickness. In sec. 1, T. 23 N., R. 8 E., a 33-ft. sandstone underlies the Paola. It probably is equivalent to the Cottage Grove Sandstone Member of the Chanute Formation. It thickens slightly and extends westward to the limit of the cross section. In secs. 4, 5, and 6, T. 23 N., R. 8 E., the Avant apparently has been cut out by a channel-fill sand believed to have developed in the lower portion of the overlying Wann Formation.

Thickness of the Dewey Limestone increases from 8 ft. in sec. 6, T. 23 N., R. 11 E., to 19 ft. in sec. 4, T. 23 N., R. 9 E. This might indicate a trend toward development of a mound facies, but additional thickening westward cannot be determined along the cross section because the Dewey has been removed by channeling of the overlying Cottage Grove.

Overall, east to west along cross section A-A', thickness of the Avant, Muncie Creek, and Avant-Hogshooter interval decreases significantly. Thickness of the Paola is relatively uniform.

Correlation Section B-B'

Gardner (1957) also measured a section located in sec. 16, T. 22 N., R. 12 E. (Fig. 2). He reported 18 ft. of Avant underlain by 39 ft. of Muncie Creek, 2 ft. of Paola, 40 ft. of sandstone and shale making up the Chanute Formation, and 14.5 ft. of limestone and shale that compose the Dewey Formation. His measured section marks the easternmost point (Loc. 23) on the cross section B-B' (Pl. 2).

Locality 22 is a section measured in sec. 13, T. 22 N., R. 11 E. (Appendix A, Measured Section 2). Here, 18.5 ft. of Avant is overlain by Wann shale and underlain by shale of the Muncie Creek.

The nearest well westward with an available electric log including the Avant is located in sec. 11, T. 22 N., R. 11 E. (Fig. 2). Here, the Avant is 41 ft., indicating that the sections to the east were measured in a portion of the thinner mound flanks. The Muncie Creek is 45 ft. thick, the Paola 4 ft., and the Avant-Hogshooter interval is 277 ft. thick.

Westward, the Avant thins to 10 ft. in sec. 13, T. 22 N., R. 9 W. where the Muncie Creek and Paola are 18 ft. and 3 ft. thick, respectively. Thickness of the Avant increases slightly to about 15 ft. in the last few wells of the cross section. This may be due to a change in facies to what appears from log characteristics to be marl.

Thickness of the Dewey increases from 3 ft. in sec. 16,

T. 22 N., R. 9 E. to 18 ft. in sec. 16, T. 22 N., R. 8 E. This might indicate a tendency toward development of a mound facies.

Overall, thicknesses of the Avant, Muncie Creek, and the Avant-Hogshooter interval decrease westward along cross section B-B', but not as much as along cross section A-A'. Thickness of the Paola is relatively uniform.

Correlation Section C-C'

Correlation section C-C' traverses R. 11 E., north to south along the eastern portion of the primary area of mapping diagonally through a northeast-southwest-trending portion of the thicker mound facies (Pl. 3). Locality 1 is a well in sec. 1, T. 23 N., R. 11 E. It contains 28 ft. of Avant underlain by 35 ft. of Muncie Creek, and 4 ft. of Paola, with an Avant-Hogshooter interval of 231 ft. Thickness of the Avant increases to 43 ft. slightly more than 1 mi. to the south-southwest at Location 2. Thicknesses of the Muncie Creek, Paola, and Avant-Hogshooter interval remain relatively uniform.

Thickness of the Avant is relatively constant, on available logs, southward to the limit of the cross section. Thickness of the Muncie Creek increases to 50 ft. and of the Avant-Hogshooter interval to 282 ft. Thickness of the Paola remains relatively uniform. The southernmost well, Locality 9, is within a quarter-mile updip from an outcrop of the Avant in sec. 34, T. 22 N., R. 11 E., so the Iola Formation is not included on the log.

The thickest section of Avant recorded on available logs within the area of primary mapping is located in sec. 21, T. 23 N., R. 11 E., 1.6 mi. west of well 3 of this cross section (Pl. 4). Here the Avant is 48 ft. thick and is underlain by 40 ft. of Muncie Creek, 5 ft. of Paola, and 244 ft. of the Avant-Hogshooter interval.

Correlation Section D-D'

Correlation section D-D' extends north-to-south along the boundary between R. 9 E. and R. 10 E. (Pl. 4). Locality 1 is a well in sec. 6, T. 23 N., R. 10 E. Here, the Avant is 2 ft. thick and is underlain by 14 ft. of Muncie Creek, 3 ft. of Paola and an Avant-Hogshooter interval of 159 ft. This cross section shows gradual thickening of the Avant from the nonmound facies, across flanks of the mound, into the mound facies, with a maximal thickness of 33 ft. in the southernmost well, located in sec. 32, T. 22 N., R. 10 E. (Pl. 4). Along this cross section, the Muncie Creek thickens to 25 ft., the Paola to 8 ft. and the Avant-Hogshooter interval to 260 ft.

Logs of wells in secs. 17 and 29, T. 23 N., R. 10 E., show development of a channel-fill sandstone below the Paola, believed to be the Cottage Grove. Maximal thickness is 52 ft. in sec. 29.

Correlation Section E-E'

Correlation section E-E' extends north-to-south through the middle portion of R. 8 E. (Pl. 5). It is the westernmost cross section of the primary mapping area. It shows the widest north-to-south range of thicknesses and facies.

Locations 1 and 2 are wells in sec. 4, T. 23 N., R. 8 E. In these wells, the Avant and a portion of the Muncie Creek have been cut out by channeling in the lower portion of the overlying Wann Formation. The Paola is about 3 ft. thick and the Avant-Hogshooter interval averages about 155 ft. The Dewey also is cut out, by channeling of the overlying Cottage Grove sandstone.

The Avant is 2 ft. thick in sec. 10, T. 23 N., R. 8 E. and the Avant-Hogshooter interval is 153 ft. thick. Log characteristics of the Avant suggest presence of a marly facies in sec. 22, T. 23 N., R. 8 W. This pattern extends southward to where significant thickening indicates development of a possible mound facies in sec. 15, T. 22 N., R. 8 E. Here, the Avant is 15 ft. thick and it includes a thin shale parting near the top. The Dewey is about 20 ft. thick, which is evidence of possible mound buildup.

Maximal thickness of the Avant in cross section E-E' is 33 ft. in sec. 27, T. 22 N., R. 8 E. (Loc. 17). The Avant is underlain by 13 ft. of Muncie Creek, 4 ft. of Paola, and an Avant-Hogshooter interval of 149 ft. Thickness of the Avant decreases southward along cross section F-F' that extends outside the primary mapping area. The southward decrease in thickness of the Avant suggests that logs in cross section F-F' record an interval within the southern flank of the mound.

Log Map, Avant Limestone Member

Approximately 300 electric logs were used to construct the log map shown as Plate 6.[2] The short-normal and spontaneous-potential curves were used for all logs and the lateral curve was included on logs where correlation of the Avant was difficult otherwise. Contour lines have been used to distinguish between the thicker mound facies (for purposes of general definition, more than 20 ft.) and the flanking beds or mound-associated facies. A dotted contour line was used to estimate limits of the area where the Avant has been removed due to channeling in the overlying Wann Formation. Arrows extending from the borehole lines of some wells indicate stratigraphic positions on logs where the Avant is thin, or "phantom" positions on logs where the Avant is absent. The map shows the trend of the thick mound facies.

Isopach Map, Avant Limestone Member

A contour interval of 10 ft. was used in constructing

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[2]Lithologic descriptions representing characteristic log shapes of four facies shown on the log map are in Appendix E.

the isopach map (Pl. 7) with one 5-ft. contour along the northern flank of the mound. In addition, a dotted contour was used to estimate limits of the area where the Avant was cut out by channeling in the overlying Wann Formation. Removal of the Avant occurred mostly in the western one-half of T. 23 N., R. 8 E.

Subparallel contours indicating thickness between 10 and 30 ft., on the northern mound flank, trend diagonally northeast to southwest across T. 23 N., R. 11 E. and T. 22 N., R. 10 E. Direction changes at the eastern boundary of T. 22 N., R. 9 E., and the trend is northwestward to the western limits of the map. The thickest portion of the mound (more than 40 ft.) trends parallel to these contours in T. 23 N., R. 11 E., but the unit thins to less than 40 ft. in the central part of T. 22 N., R. 10 E.

No lateral extensions of the thick mound facies seem to exist within the study area, though one mushroom-shaped extension of the thin (5 to 10 ft.) mound flank or mound-associated facies does spread through the western portion of T. 23 N., R. 9 E.

Structural Contour Map, Base of Avant Limestone Member

A structural contour map was constructed of the base of the Avant Member, using a contour interval of 50 ft. (Pl. 8). Domes and anticlines, most with an areal extent of less than 4 sq. mi., are the most conspicuous local structural features within the study area, and the majority show structural closure of less than 100 ft. Poorly defined belts of the folded areas appear to follow the regional strike of the beds, although no systematic arrangement of the individual structures is readily apparent.

As mentioned previously, rocks at the surface are cut by numerous short normal faults that show a general trend subparallel to that of the regional en-echelon fault belts. Locally faults are centralized in the vicinity of structures, but few can be observed in the field except where prominent beds are affected. One of the few observable faults within the study area having a displacement of more than 50 ft. is located near the center, N½ sec. 13, T. 22 N., R. 11 E. (Fig. 2, Measured Section 2). At this location, the Avant is displaced 57 ft. by a northwest-trending fault (Gardner, 1957).

Isopach Map, Avant-Hogshooter Interval

A contour interval of 20 ft. was used in constructing the Avant-Hogshooter interval isopach map (Pl. 9). Contour lines are irregular, but trend southwestward through T. 23 N., R. 11 E., and T. 22 N., R. 10 E. Near the western boundary of T. 22 N., R. 10 E., contour lines trend westward. Although the lines do show many sinuosities, their general trend does follow that of the isopach map of the Avant Member, with thickness increasing from northwest to southeast.

Correlation Section F-F'

Cross section F-F' extends southward from cross section E-E' in the area of primary mapping, through the middle portion of R. 8 E., to sec. 34, T. 18 N., R. 8 E. (Pl. 10).

Thickness of the Avant is 14 ft. in sec. 21, T. 21 N., R. 8 E. From this point southward to sec. 22, T. 20 N., R. 8 E., thickness is less than 10 ft. and probably represents the southern flank of the mound. Log characteristics change to indicate transition to sandy limestone in sec. 22, T. 20 N., R. 8 E. Southward, the interval representing the Avant shows gradation into a sequence of calcareous sandstone and shales that probably correspond to the basal portion of the Tiger Creek sandstone of Fath (1925). Oakes (1959) and other authors reported a similar transition in rock exposed at the surface in western Tulsa County and nearby counties. The Avant consists of 5 ft. of sandy limestone at the measured section in sec. 20, T. 20 N., R. 11 E. (Appendix A).

Correlation Sections G-G' and H-H'

Correlation sections G-G' (Pl. 11) and H-H' (Pl. 12) extend westward from the primary study area through T. 21 N. and T. 20 N., respectively, into T. 20 N., R. 2 W., Noble County.

The Avant can be correlated quite easily from the cross section extending south of the primary study area through R. 8 E. (section F-F'), to the west side of R. 3 E. Along cross section G-G', thickness of the Avant varies between 25 and 50 ft. westward from sec. 34, T. 22 N., R. 8 E. to a well in sec. 19, T. 21 N., R. 3 E. This portion of the cross section, with a relatively thick section of Avant, suggests that each well log has recorded an interval within the mound facies. The corresponding thick interval is recorded along cross section H-H' in wells between sec. 1, T. 20 N., R. 5 E. and sec. 2, T. 20 N., R. 3 E. (Pl. 12). The Avant is not recognizable in sec. 16, T. 21 N., R. 2 E. or in sec. 23, T. 20 N., R. 1 E. The right-lateral offset of wells along this portion of the two cross sections recording the presence of the Avant indicates that mound trend is west-southwest in this area. However, termination of recognizable Avant in wells along these lines, and the difficulty of correlating the Avant farther west, north, or south in the vicinity, suggest that this might be an area where mound development never took place.

The Perry Gas Sand was correlated along these cross sections from west to east starting in sec. 15, T. 20 N., R. 2 W. Here, the Perry is a sandy zone 130 ft. thick with numerous shale partings, and is overlain by a section of carbonate rock 180 ft. thick. Lukert (1949) believed that this carbonate rock corresponded to the Wildhorse Dolomite of the type locality.

Eastward, thickness of the Perry zone is extremely variable with a range of 10 to 150 ft. As much as one-quarter of the zone may consist of shale beds. The zone can be correlated along G-G' and H-H' into the primary study area.

Gearhart (1958) reported a maximal thickness of the carbonate-rock section overlying the Perry Gas Sand of 120 ft. in Pawnee County. It can be divided into three zones, distinguishable on the basis of interbedded shales. Thickness of the interval decreases from west to east along cross sections G-G' and H-H'. Marked lateral facies changes make subsurface correlation difficult in places. The upper and lower zones are absent in sec. 1, T. 21 N., R. 1 E., and sec. 23, T. 20 N., R. 1 E., but the middle zone is correlative to sec. 32, T. 21 N., R. 3 E., and sec. 2, T. 20 N., R. 3 E. Lukert showed the position of the Wildhorse on an electric log in sec. 30, T. 22 N., R. 8 E. (1949, p. 148), where it is 25 ft. thick. A correlative unit, 20 ft. thick, is present in sec. 1, T. 21 N., R. 7 E. (well 34 of cross section G-G'). In well 33, cross section G-G', sec. 4, T. 21 N., R. 7 E., it is not recognizable. The lenticular nature of both units suggests that the thick carbonate section in the western part of cross sections G-G' and H-H' may not be correlative with the Wildhorse of the type locality. Because of its lenticular, locally-thickened nature, I suspect that this interval could be a phylloid algal mound at some places.

Another section of carbonate rock is in the interval between the Avant and Perry in sec. 2, T. 20 N., R. 3 E. and sec. 18, T. 21 N., R. 4 E. Westward, it develops a maximal observed thickness on correlation section H-H' of 105 ft. in sec. 22, T. 20 N., R. 1 E., and is absent in sec. 24, T. 20 N., R. 1 W., and sec. 6, T. 21 N., R. 2 E. The lenticularity of this interval and the right-lateral offset of wells recording its presence along the two lines of cross section suggest presence of a marine bank that trends northeast-southwest, similar to that of the Avant.

CHAPTER VII

PETROLEUM GEOLOGY

In an effort to evaluate the structure and petroleum potential of the Osage Reservation, Osage County, Oklahoma, White and others (1922) mapped the surface geology through most of this area. The folded beds were observed to be particularly irregular in the eastern and southern parts of the county. This portion of the reservation was judged to be the best "oil territory" because of numerous folds, and shallow depths of some sandstone units that were potential petroleum reservoirs.

All known major folds and numerous other smaller structures in the primary area of mapping have produced oil or gas from one or more of 17 beds ranging from the uppermost part of the Arbuckle Group of Ordovician age upward to the Cochahee Sandstone Member of the Nelagoney Formation of Pennsylvanian age (Fig. 24). All these beds are at depths of less than 3000 ft. within the area (Dillard and others, 1952).

The G. I. Joe field, in secs. 13 and 24, T. 22 N., R. 11 E. (Fig. 2, p. 5) produces oil from the Burgess Sandstone of Pennsylvanian age, and from the Burgen Sandstone of Ordovician age (Wagner, 1967). Production is along two

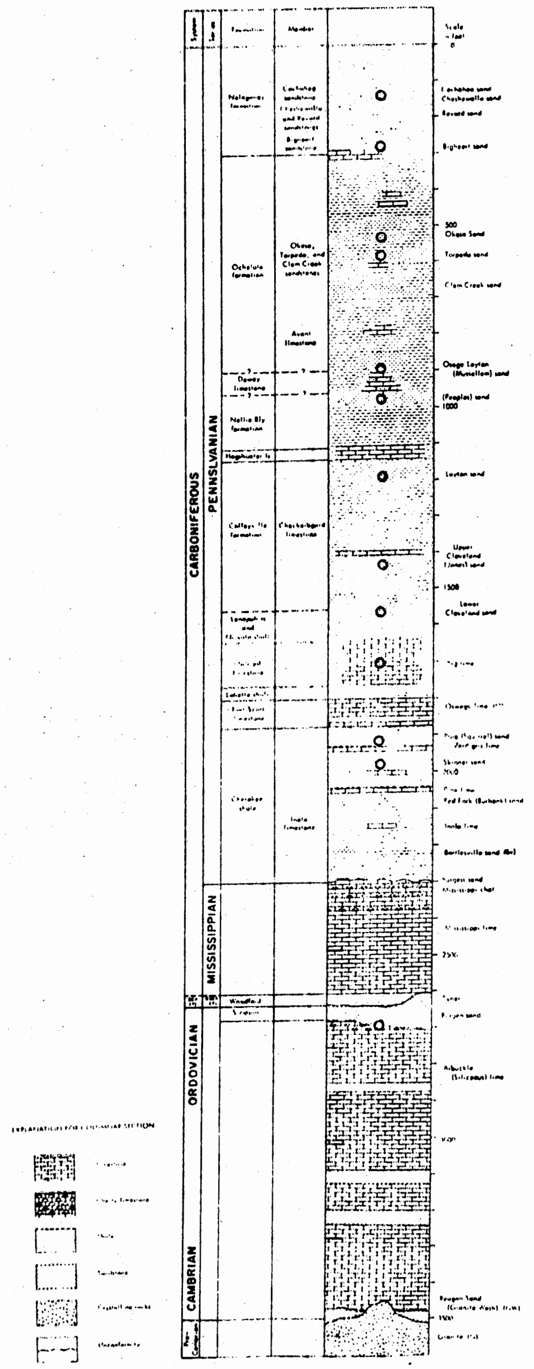


Fig. 24.-Stratigraphic column showing positions of strata that produce hydrocarbons within the primary area of mapping.

faults trending north-northwestward through the area. These faults parallel the general trend of numerous en-echelon faults in the area (Fig. 2). When the local structural geology was mapped by Ross (White and others, 1922), an upthrown block was shown between the two faults. Initial production of some wells in the field was near 1000 barrels per day (Lynn Perkins, personal communication, 1978). Gardner (1957) reported that the eastern fault displaced the Avant Member 57 ft. in the N½ of sec. 13 (Figs. 25 and 26).

Lithologic characteristics, as discussed in the section on mound development, suggest that the Avant might be a productive petroleum reservoir in the subsurface of the study area and elsewhere. This is due chiefly to the variety of porosity and permeability types than can be developed.

The Avant of the type locality is equivalent to the Oil City Lime of the subsurface, named by Green (1918). This limestone yields oil in minor amounts in southeastern Pawnee County in the Lauderdale, Southeast Osage City, and Northeast Terlton Fields (Clare, 1963). The name Avant is being applied to a gas-producing zone in Lucien Field, sec. 31, T. 20 N., R. 3 W., Garfield County. Jordan (1957) reported that production is probably actually from the Perry Gas Sand because the pay zone is not at the horizon equivalent of the true Avant.

The Oklahoma Gas Report (Petroleum Information, 1977) cites the Avant as a reservoir producing in southern Noble

Fig. 25.-Drainage along fault and truncated blocks of Avant Limestone.

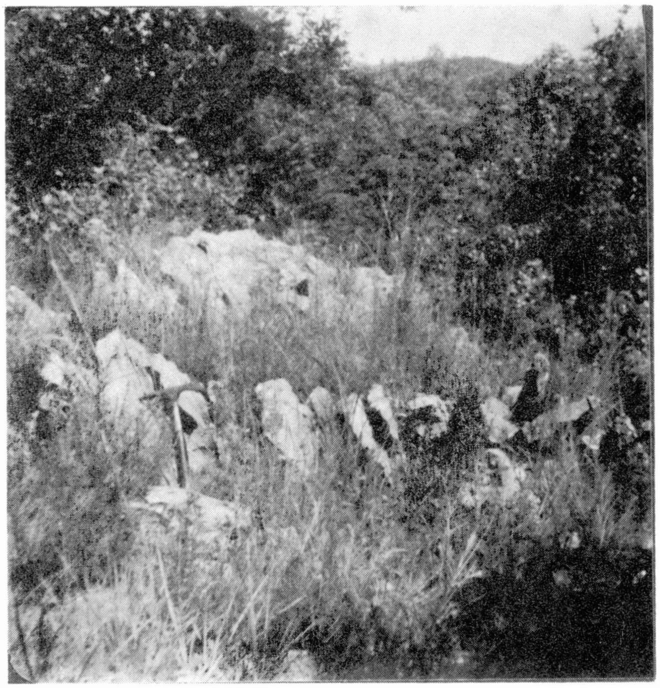


Fig. 26.-Irregular blocks of limestone of the Avant along fault.

County, but my correlations show that this horizon corresponds to the interval referred to by Lukert (1949) as the "Wildhorse Limestone" (Pls. 11 and 12). Nevertheless, I judge that the probability is good of discovering oil or gas fields in the Avant.

CHAPTER VIII

SUMMARY

1. A literature survey and my own research have shown that typical Late Pennsylvanian phylloid-algal mounds of the Midcontinent, such as the Avant, are characterized by:

    a. local to subregional thickening of limestone;

    b. presence of distinctive rock types (such as massive calcilutite and microsparite) containing phylloid algae;

    c. overlying mound-associated facies containing some or all of the following features: abraded algal segments and fragments of invertebrates, thin wavy bedding with shale laminae, minor channels, crossbedding, and mudcracks.

2. Typical late Paleozoic cyclothems of the Midcontinent commonly consist of the following members, in ascending order (Heckel, 1977):

    a. thick, nearshore sandy shale;

    b. thin, transgressive limestone;

    c. thin, offshore shale, commonly with phosphatic black facies;

d. thick, regressive limestones, many of which grade into phylloid algal-mound complexes; and

e. thick, nearshore sandy shale.

3. Algae are involved in the following three processes that have pronounced influence on the occurrence of calcium carbonate in sea water:

a. removal of carbon dioxide from sea water through photosynthesis, causing calcium-carbonate precipitation in the immediate vicinity;

b. evolution of ammonia due to bacterial action in decaying algal mats, which may react with calcium-carbonate-saturated solutions and initiate carbonate precipitation; and

c. post-mortem disaggregation of calcareous algae, producing fragments including single aragonite crystals.

Phylloid algae aid in the accumulation of calcium-carbonate particles after they are produced. They create a baffle-like effect that causes the settling of lime mud from suspension and they stabilize the sediment with their root systems.

4. Porosity can occur in a phylloid algal-mound limestone in at least three ways:

a. incomplete spar filling of algal-blade-sheltered voids and hollow interiors of invertebrate shells;

b. differential leaching of carbonate veinlets and spar-filled voids, producing vugs; and

c. removal of aragonite ooliths during diagenesis, creating spheroidal voids.

5. The mound facies of the Avant Member trends southwestward from R. 12 E. to R. 3 E. along T. 23 N. through T. 20 N. This indicates a similar-trending paleoshoreline or paleo-shelf edge, assuming that these features were parallel to mound development during deposition of the Avant.

6. Local thickening of the Avant-Hogshooter section through the eastern and southern parts of the area of primary mapping corresponds well with thickening of the overlying Avant mound facies. This suggests that development of the mound facies began in a "belt" of optimal water depth, which may have been determined by the submarine paleoslope.

7. A structural geologic map on the base of the Avant indicates no single prominent structure or anomalous trend of small structures corresponding to the mound trend in the area.

8. The Avant can be correlated southward in the subsurface along R. 8 E. from T. 23 N. through T. 18 N. Southward from this locality, the Avant is incorporated in a sequence of calcareous sandstones and shales.

9. The Avant can be traced from exposures at the surface in T. 22 N. and T. 23 N., R. 12 E., westward in the

subsurface to the western half of T. 21 N. and T. 20 N., R. 2 E. From this point westward, along the lines of cross section, the Avant is not directly identifiable.

10. The name Avant, as used in the subsurface geology of Noble County, is often misapplied to the carbonate interval referred to as the "Wildhorse Dolomite Lentil." The stratigraphic position of the Perry Gas Sand is between that of this carbonate interval above and the Avant Limestone Member below.

SELECTED BIBLIOGRAPHY

Arbenz, J. K., 1956, Map of tectonic provinces of Oklahoma: Okla. Geol. Survey, Map GM-3.

Bathurst, R. G. C., 1975, Carbonate sediments and their diagenesis: New York, Elsevier, 658 p.

Bellis, W. H., and Rowland, T. L., 1976, Shale and carbonate-rock resources of Osage County, Oklahoma: Okla. Geol. Survey Circular 76, 50 p.

Bryant, D. G., 1957, Geology of the Gray Horse area, Osage County, Oklahoma: Unpub. M. S. thesis, Univ. Okla., 119 p.

Clare, P. H., 1963, Petroleum geology of Pawnee County, Oklahoma: Okla. Geol. Survey Circular 62, 62 p.

Cronoble, W. R., and Mankin, C. J., 1965, Petrology of the Hogshooter Formation: Okla. Geol. Survey Bull. 107, 148 p.

Dalrymple, D. W., 1965, Calcium carbonate deposition associated with blue-green algal mats, Baffin Bay, Texas: Contrib. in Marine Sci., v. 10, p. 187-200.

Dillard, W. R., Bass, N. W., Kennedy, L. E., Hengst, J. H., Jenkins, H. D., Kirk, C. T., and Leatherock, Otto, 1952, Subsurface geology and oil and gas resources Osage County, Oklahoma: U. S. Geol. Survey Bull. 900, p. 1-88.

Evamy, B. D., 1963, The application of a chemical staining technique to a study of dedolomitization: Sedimentology, v. 2, p. 164-170.

Fath, A. E., 1920, The origin of the faults, anticlines and buried "Granite Ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey Prof. Paper 128-C, p. 75-84.

________ 1925, Geology of Bristow quadrangle, Creek County, Oklahoma, with reference to petroleum and gas: U. S. Geol. Survey, Bull. 759, 63 p.

Foley, L. L., 1926, The origin of the faults in Creek and Osage Counties, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 10, p. 293-303.

Folk, R. L., 1959, Practical petrographic classification of limestones: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1-38.

Gardner, W. E., 1957, Geology of the Barnsdall area, Osage County, Oklahoma: Unpub. M. S. thesis, Univ. Okla., 102 p.

Gary, M., McAfee, R. Jr., and Wolf, C. L. (eds.), 1974, Glossary of geology: Amer. Geol. Inst., Wash., 805 p.

Gearhart, H. L., 1958, Subsurface geology of northwestern Pawnee County, Oklahoma: Unpub. M. S. thesis, Univ. Okla.

Ginsburg, R. N., and Lowenstam, H. A., 1958, The influence of marine bottom communities on the depositional environment of sediments: Jour. Geol., v. 66, p. 310-318.

Greene, F. C., 1918, A contribution to the geology of eastern Osage County, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 2, p. 118-123.

Harbaugh, J. W., 1964, Significance of marine banks in southeastern Kansas in interpreting cyclic Pennsylvanian sediments: Kansas Geol. Survey Bull. 169, p. 199-203.

Haworth, E., and Kirk, M. Z., 1894, A geologic section along the Neosho River from the Mississippian Formation of the Indian Territory to White City, Kansas, and along the Cottonwood River from Wyckoff to Peabody: Kansas Univ. Quarterly, v. 2, no. 3, p. 104-115.

Heckel, P. H., 1975, Stratigraphic and depositional framework of the Stanton Formation in southeastern Kansas: Kansas Geol. Survey Bull. 210, 45 p.

________ 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Midcontinent North America: Am. Assoc. Petroleum Geologists Bull., v. 61, p. 1045-1068.

________ 1978, Upper Pennsylvanian cyclothemic limestone facies in eastern Kansas: Kansas Geol. Survey Guidebook, series 2, 79 p.

Heckel, P. H., and Baesemann, J. F., 1975, Environmental interpretation of conodont distribution in Upper Pennsylvanian (Missourian) megacyclothems in eastern Kansas: Am. Assoc. Petroleum Geologists Bull., v. 59, p. 486-509.

________ and Cocke, 1969, Phylloid algal-mound complexes in outcropping Upper Pennsylvanian rocks of Mid-Continent: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 1058-1074.

Hinds, H., and Greene, F. C., 1915, The stratigraphy of the Pennsylvanian Series in Missouri: Missouri Bur. of Geol. and Mines (2), v. 13, 407 p.

Jewett, J. M., and Newell, N. D., 1935, The geology of Johnson, Miami, and Wyandotte Counties, Kansas: Kansas Geol. Survey Bull. 21, 205 p.

Jordan, L., 1957, Subsurface stratigraphic names of Oklahoma: Okla. Geol. Survey, Guidebook 6, 220 p.

Kramer, W., 1934, En echelon faults in Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 18, p. 243-250.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill, 721 p.

Link, T. A., 1929, En echelon tension fissures and faults: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 627-643.

Lowenstam, H. A., 1955, Aragonite needles secreted by algae and some sedimentary implications: Jour. Sediment. Petrol., v. 25, p. 270-272.

Lukert, L. H., 1949, Subsurface cross sections from Marion County, Kansas, to Osage County, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 131-155.

Melton, F. A., 1930, Age of the Ouachita orogeny and its tectonic effects: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 57-72.

Mohler, C. E., 1942, A field study of the Iola Formation of Osage and Tulsa Counties, Oklahoma: Unpub. M. S. thesis, Univ. Okla., 96 p.

Moore, R. C., 1935, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geol. Survey Bull. 22, 256 p.

________ 1949, Divisions of the Pennsylvanian System in Kansas: Kansas Geol. Survey Bull. 83, 203 p.

Moore, R. C., 1950, Late Paleozoic cyclic sedimentation in central United States: 18th Internat. Geol. Cong., Great Britain, 1948, Rept., pt. 4, p. 5-16.

Moore, R. C., Newell, N. D., Dott, R. H., and Borden, J. L., 1937, Definition and classification of the Missouri Subseries of the Pennsylvanian Series in northeastern Oklahoma: Kansas Geol. Soc. Guidebook, 11th Annual Field Conference, p. 39-43.

Murchison, D., and Westoll, T. S. (eds.), 1968, Coal and coal-bearing strata: New York, Elsevier, 418 p.

Oakes, M. C., 1940, Geology and mineral resources of Washington County, Oklahoma: Okla. Geol. Survey Bull. 62, 208 p.

________ 1951, The proposed Barnsdall and Tallant Formations in Oklahoma: Tulsa Geol. Soc. Digest, v. 19, p. 119-122.

________ 1952, Geology and mineral resources of Tulsa County, Oklahoma: Okla. Geol. Survey Bull. 69, 234 p.

________ 1959, Geology and mineral resources of Creek County, Oklahoma: Okla. Geol. Survey Bull. 81, 134 p.

Ohern, D. W., 1910, The stratigraphy of the older Pennsylvanian rocks of northeastern Oklahoma: The State Univ. of Okla. Research Bull. 4, p. 31.

Petroleum Information, 1977, Extra detail cumulative gas data, Noble County, Oklahoma: Petrol. Information Corp., p. 462-465.

Pettijohn, F. J., 1975, Sedimentary rocks: Third edition, New York, Harper and Row, 628 p.

Pollard, W. D., 1970, Stratigraphy and origin of Winchell Limestone in Possum Kingdom area, north-central Texas, and role of phylloid algae in carbonate sedimentation: Unpub. M. S. thesis, Univ. Kansas, 108 p.

Powers, S., 1931, Structural geology of northeastern Oklahoma: Jour. Geol., v. 39, p. 117-132.

Pray, L. C., and Wray, J. L., 1963, Porous algal facies (Pennsylvanian) Honaker Trail, San Juan Canyon, Utah, <u>in</u> R. O. Bass and S. L. Sharps (eds.), Shelf carbonates of the Paradox Basin: Four Corners Geol. Soc., 4th Field Conference, p. 204-234.

Purdy, E. G., 1963, Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentary facies: Jour. Geol., v. 71, p. 472-497.

Russell, O. R., 1955, Geology of the Hominy area, Osage County, Oklahoma: Unpub. M. S. thesis, Univ. Okla., 84 p.

Shannon, P. J., 1954, The geology of the Pawhuska area, Osage County, Oklahoma: Unpub. M. S. thesis, Univ. Okla., 98 p.

Sherrill, R. E., 1929, Origin of the en echelon faults in north-central Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 31-37.

Stockman, K. W., Ginsburg, R. N., and Shinn, E. A., 1967, The production of lime mud by algae in south Florida: Jour. Sed. Petrol., v. 37, p. 633-648.

Tanner, W. F., 1956, Geology of northeastern Osage County, Oklahoma: Okla. Geol. Survey Circular 40, 76 p.

Toomey, D. F., Wilson, J. L., and Rezak, R., 1977, Evolution of Yucca Mound complex, Late Pennsylvanian phylloid-algal buildup, Sacramento Mountains, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 61, p. 2115-2133.

Wagner, O. E. Jr., 1967, Subsurface geologic structure of the top of the Oswego Limestone, T. 22 N. and T. 23 N., R. 8 E. through R. 12 E., Osage County, Oklahoma: U. S. Geol. Survey and Bureau of Indian Affairs, Maps 14 and 15.

Wanless, H. R., and Weller, J. H., 1932, Correlation and extent of Pennsylvanian cyclothems: Geol. Soc. Am. Bull., v. 43, p. 1003.

White, D., Emery, W. B., Mather, K. F., Lloyd, E. R., Ross, C. S., and Goldman, M. I., 1922, Structure and oil and gas resources of the Osage Reservation, Oklahoma: U. S. Geol. Survey Bull. 686, 427 p.

Wilson, J. L., 1975, Carbonate facies in geologic history: New York-Heidelberg-Berlin, Springer-Verlag, 471 p.

Wray, J. L., 1964, _Archaeolithophyllum_, an abundant calcareous algae in limestones of the Lansing Group (Pennsylvanian), southeastern Kansas: Kansas Geol. Survey Bull. 170, p. 1-13.

APPENDIX A

MEASURED SECTIONS

Measured section 1
Abandoned quarry in the Avant Limestone Member, SW NW sec. 17, T. 23 N., R. 12 E.

Description of Unit (descending order)	Thickness in ft.
Wann Formation	
Shale, siltstone, and sandstone: maroon and gray, fissile, calcareous shale; interbedded with beds of tan to rusty-brown calcareous siltstone and sandstone.	72.0
Avant Limestone Member, Iola Formation	
Limestone: gray, weathering light brown, coarse-grained crinoidal calcarenite; contains sparry crystalline carbonate.	0.8
Shale and shaly limestone: dark gray, fissile, calcareous; interbedded with gray, thin, platy beds of skeletal limestone.	2.8
Limestone: gray to brown, thick-bedded, crystalline, algal, skeletal calcarenite; contains ferroan calcite.	6.2
Limestone: orangish gray to stell-gray, mottled, massive, finely to coarsely crystalline, algal, skeletal calcilutite and calcrenite; contains dolomite and ferroan calcite; pseudobrecciated appearance due to leaching of veinlets of crystalline carbonate.	44.0
Muncie Creek Shale Member, Iola Formation	
Shale: dark gray to black, weathers light gray to gray-breen, fissile to platy; near the base the shale contains a 1 ft. nodular bed of gray elliptical phosphatic concretions, ¼ in. to 3 in. in diameter. Base covered.	40.0

Measured section 2
NE NW sec. 13, T. 22 N., R. 11 E.

Wann Formation

Shale: gray, fissile; not measured.

Description of Unit (descending order)	Thickness in ft.
Avant Limestone Member, Iola Formation	
Limestone: light gray to brown, mottled, weathers light brown; massive, finely to medium crystalline, fossiliferous calcilutite; contains small veinlets filled with sparry crystalline carbonate.	7.5
Limestone: light gray to tan, mottled; weathers blue-gray, medium to thickly bedded, algal, fossiliferous, calcilutite; wavy bedded; large solution cavities.	11.0
Muncie Creek Shale Member, Iola Formation	
Shale: dark gray, fissile; not measured.	

Measured section 3
NW NW sec. 20, T. 20 N., R. 11 E.

Wann Formation	
Shale: gray, fissile; not measured.	
Avant Limestone Member, Iola Formation	
Limestone: light brown to gray, weathers rusty brown; medium to thickly bedded, crystalline, skeletal calcilutite; small channel filled with skeletal calcrenite; lowermost 8-in. bed is sandy and includes medium-scale cross-bedding.	5.0
Muncie Creek Shale Member, Iola Formation	
Shale: dark gray, fissile; not measured.	

APPENDIX B

GRAPH SHOWING RELATIONSHIP BETWEEN DEVELOPMENT OF THE AVANT MOUND AND THICKNESS OF THE UNDERLYING INTERVAL

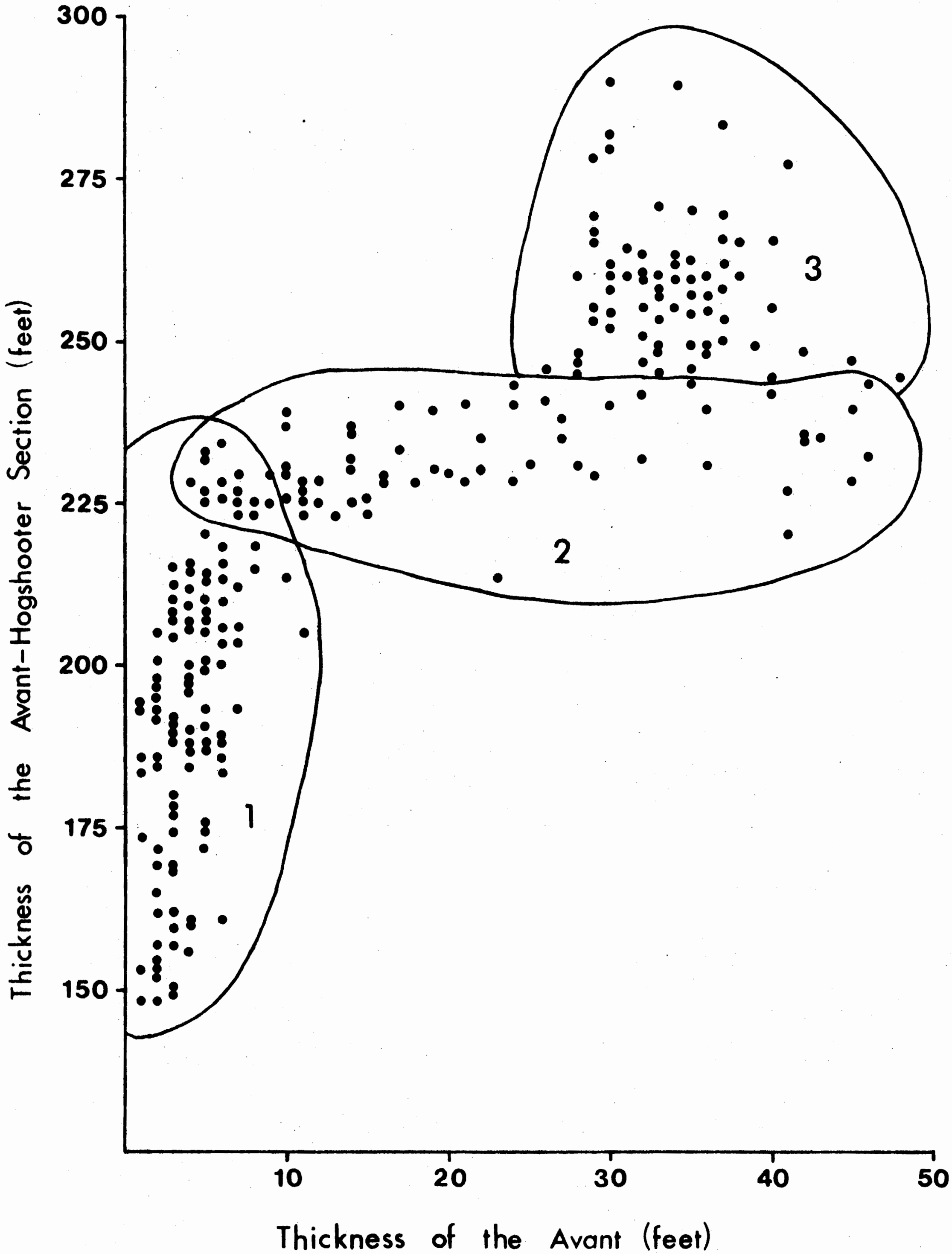


Fig. 27.-Graph showing relationship between thickness of the Avant and thickness of the base-of-Avant to top-of-Hogshooter section with circumscribed point-groups 1, 2 and 3.

First review of the correlation diagram shown in Figure 12 (page 51) obviously shows no overall close, straight-line relationship between thickness of the Avant Member and thickness of the underlying base-of-Avant to top-of-Hogshooter interval. However, the distribution of points does show three apparent groups, circumscribed in Figure 27 strictly on a qualitative basis, by inspection, as Groups 1, 2, and 3 (and a mixed minor group, 1 and 2).

The hypothesis was drawn that the three main groups are representative of tracts of distinct facies. The hypothesis was tested by posting of group-numbers beside each data point, as shown on a log map of the Avant (Pl. 13). In the opinion of the author, distributions of numbers and log-types shown on Plate 13 correspond in general trend and position to the mound and non-mound tracts. The three major groups shown in Figure 27 are taken as indirect evidence of rather discrete paleodepositional tracts that spanned the time of deposition of the Avant to top-of-Hogshooter interval. Figure 12 seems actually to show absence of "straight-line" correlation because three major geologic populations of data points are mixed.

APPENDIX C

X-RAY DIFFRACTION ANALYSIS DATA

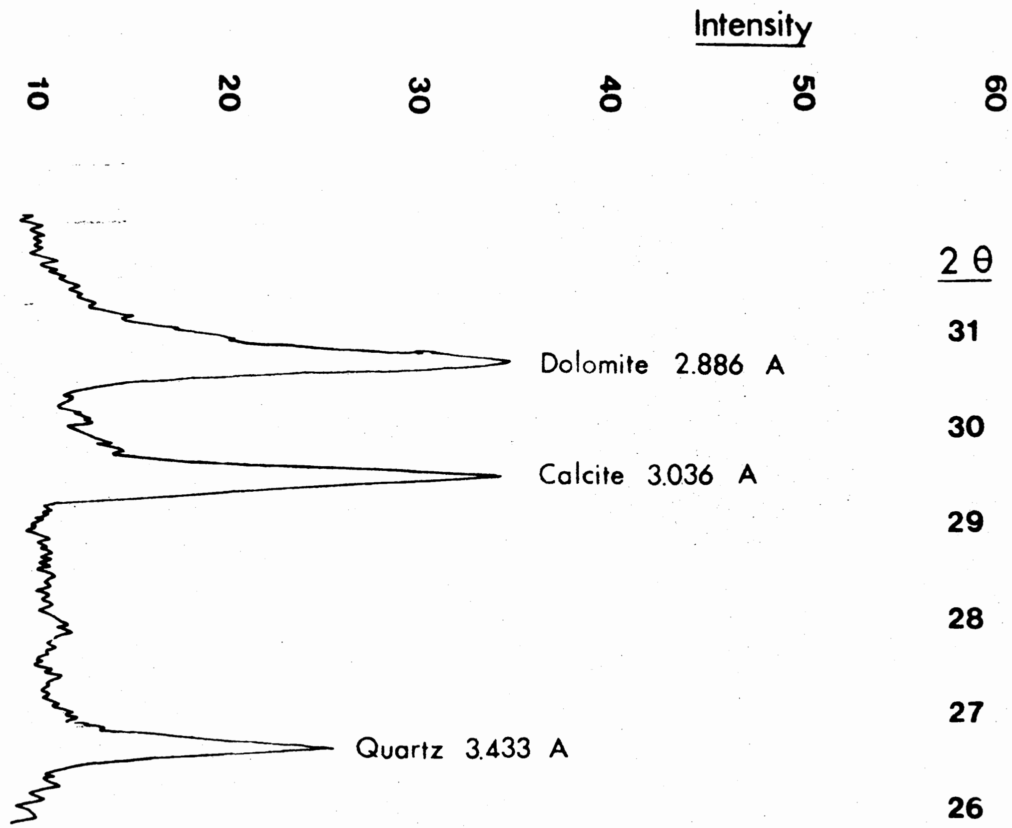


Fig. 28.-X-ray diffractometer record of skeletal sparry calcilutite, from base of Avant Member, SW NW Sec. 17, T. 23 N., R. 12 E.

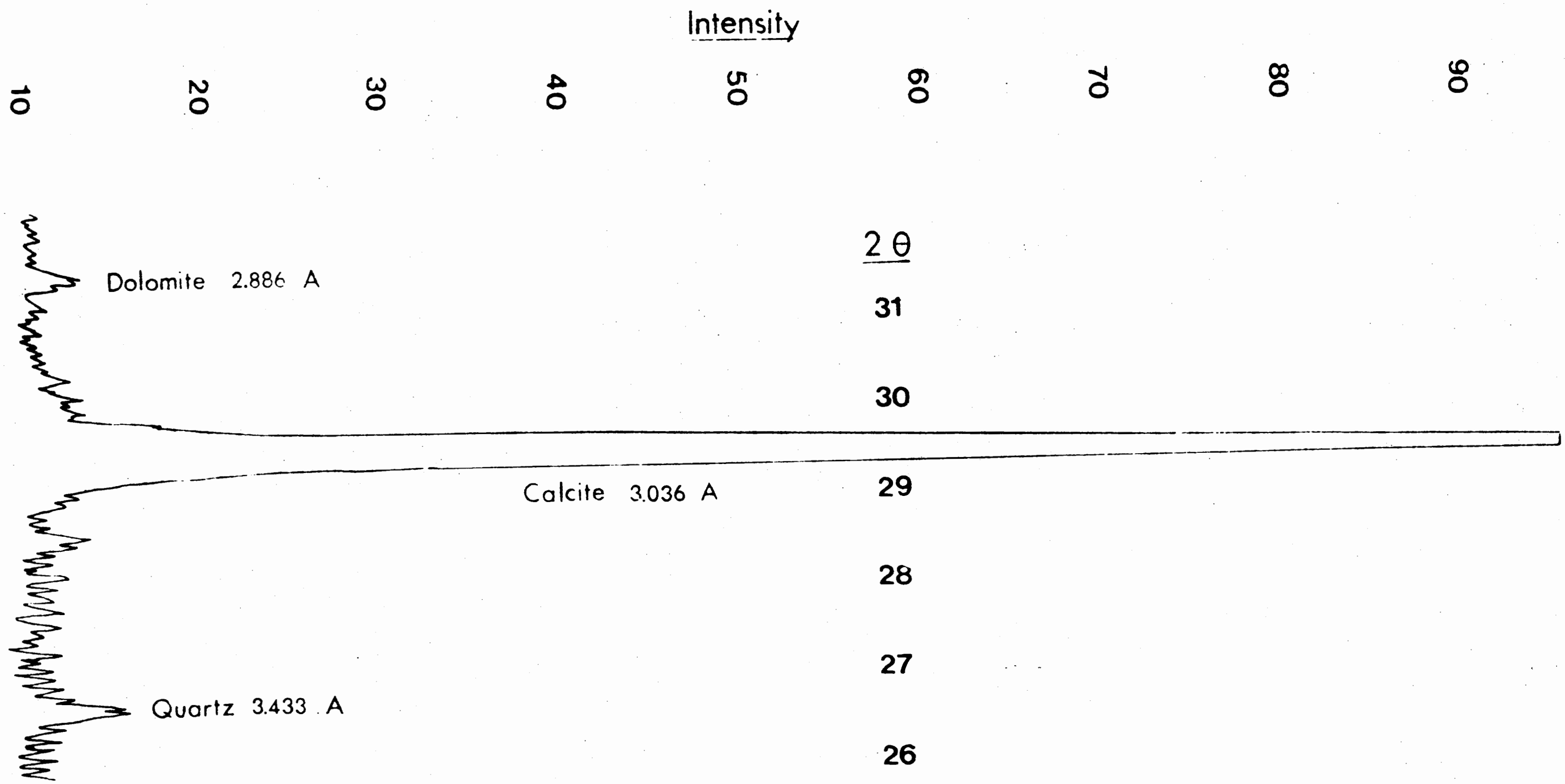


Fig. 29.-X-ray diffractometer record of skeletal algal sparry calcilutite, from 3 ft. above base of Avant Member, SW NW Sec. 17, T. 23 N., R. 12 E.

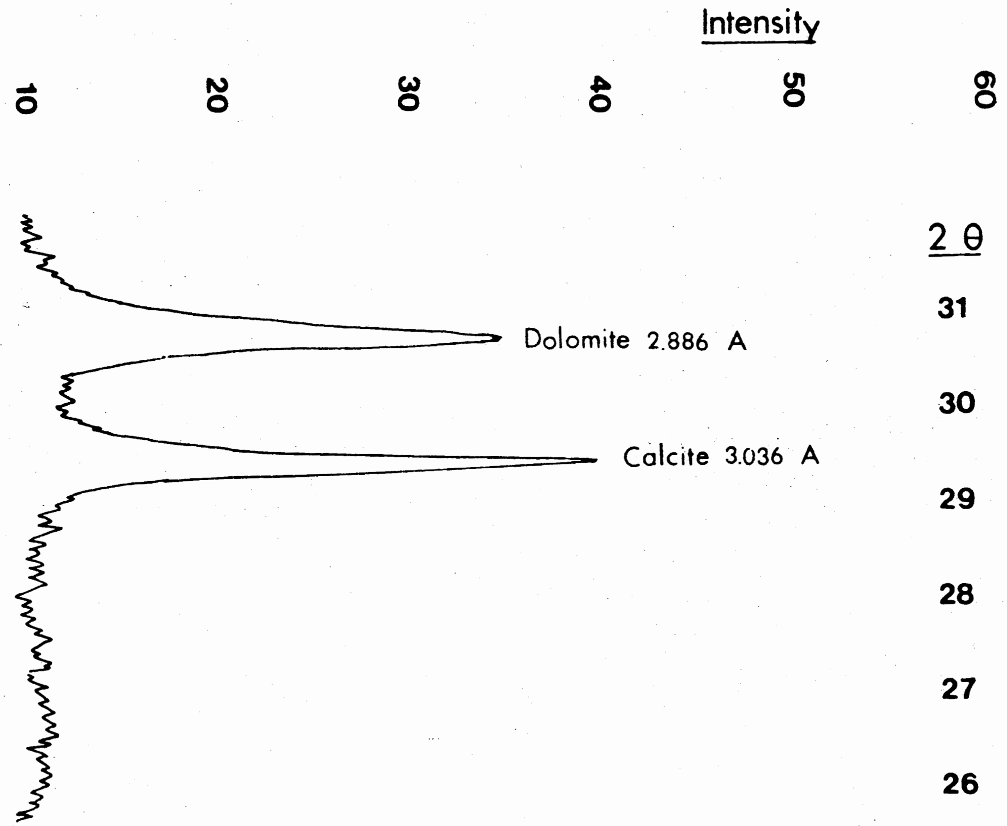


Fig. 30.-X-ray diffractometer record of sparry calcilutite, from 8.4 ft. above base of Avant Member, SW NW Sec. 17, T. 23 N., R. 12 E.

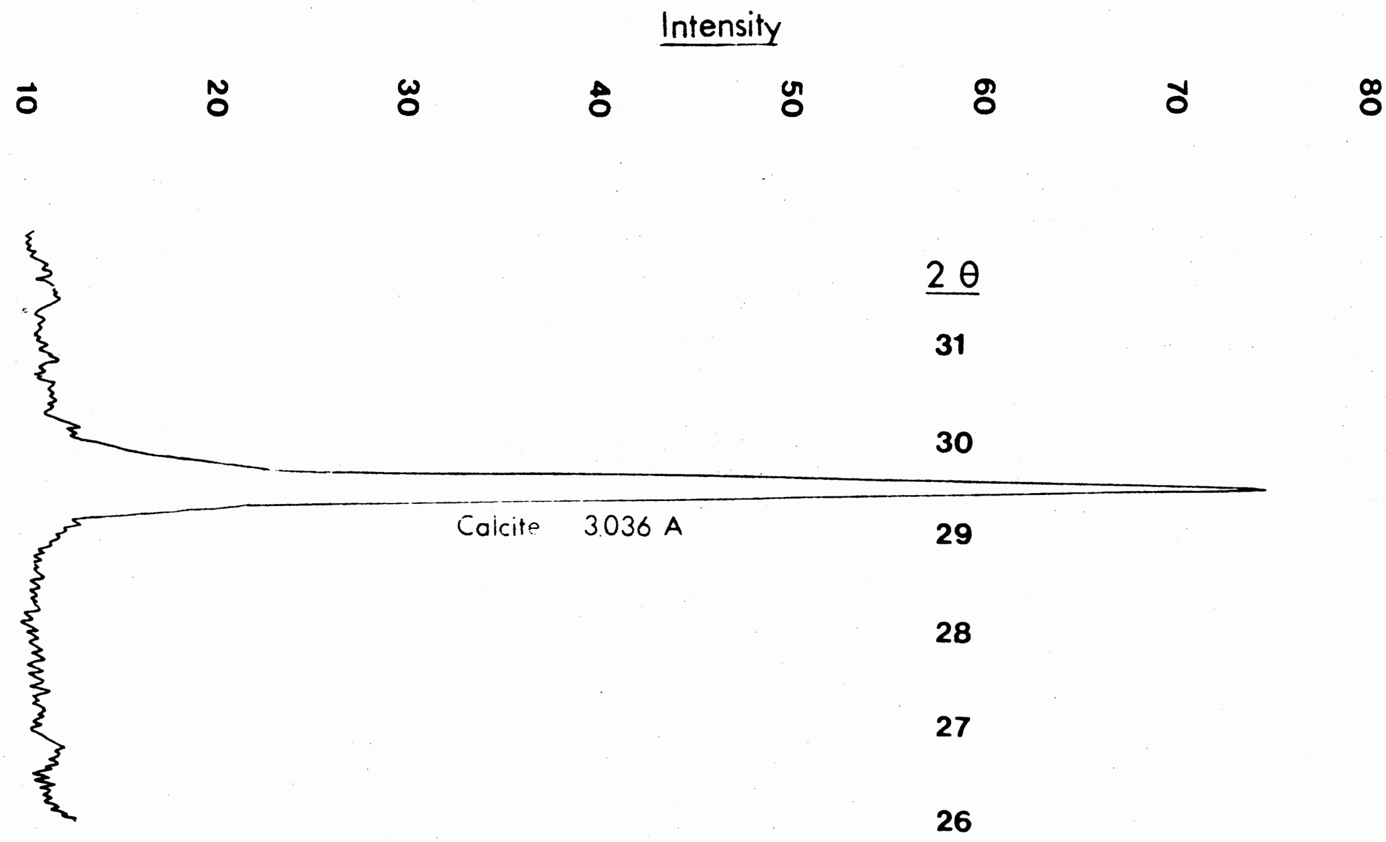


Fig. 31.-X-ray diffractometer record of skeletal sparry calcilutite, from 20.1 ft. above base of Avant Member, SW NW Sec. 17, T. 23 N., R. 12 E.

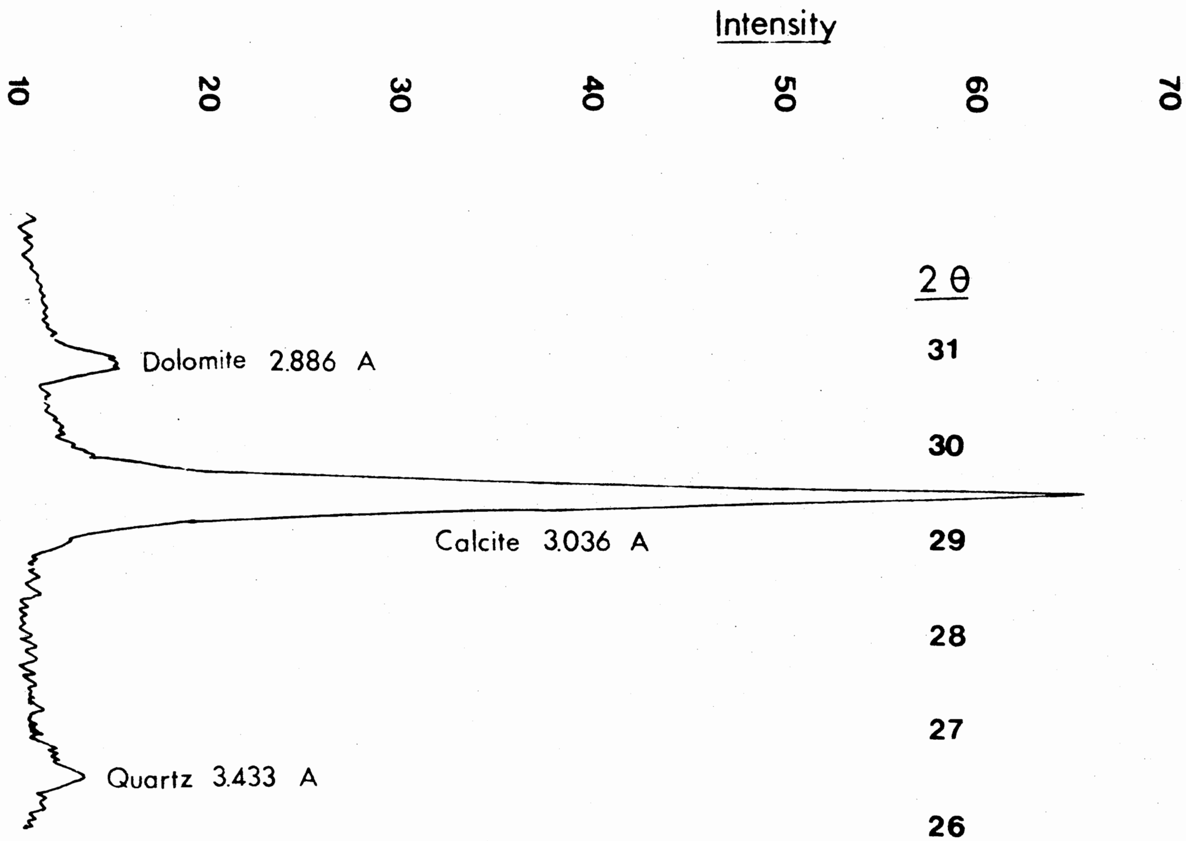


Fig. 32.-X-ray diffractometer record of skeletal sparry calcarenite, from 48.1 ft. above base of Avant Member, SW NW Sec. 17, T. 23 N., R. 12 E.

APPENDIX D

NAMES AND LOCATIONS OF WELLS AND MEASURED SECTIONS USED IN CORRELATION SECTIONS

No.	Operator and Well Number	Location
	West-East Correlation Section A-A'	
1.	Prue, Osage-Hominy #184	NW NW SW Sec. 6-23N- 8E
2.	Prue, Osage-Hominy #186	SE NE NW Sec. 5-23N- 8E
3.	Prue, Osage-Hominy #185	ne ne sw Sec. 4-23N- 8E
4.	Josaline, Keahsompah #3	SW NW NE Sec. 3-23N- 8E
5.	Parsage, Osage 2 #3A	SW NW NW Sec. 2-23N- 8E
6.	A. G. Wadsworth, Barker #1	SE SE SW Sec. 1-23N- 8E
7.	Sunray, Osage #5	NW SW NW Sec. 4-23N- 9E
8.	A. D. Griffith, Bangs #2	SW SW NE Sec. 4-23N- 9E
9.	Plunkett & Duffield, Winters #1	SE SE NW Sec. 3-23N- 9E
10.	J. M. Graves, Pitts #2A	E½ NW NW Sec. 1-23N- 9E
11.	J. A. Huitt, McKenzie #2	NW SW NW Sec. 6-23N-10E
12.	National Assoc., Osage Nation #3	SE NE NE Sec. 6-23N-10E
13.	National Assoc., South Four Mi. #7	SW NW NW Sec. 5-23N-10E
14.	National Assoc., South Four Mi. #11	SE SE NW Sec. 5-23N-10E
15.	A. G. Oliphant, McKenzie #5	NE SE NE Sec. 5-23N-10E
16.	Atlas, McKenzie #B1	NW NE SW Sec. 4-23N-10E
17.	A.P.A. & Apache, Osage #1A	NW SE NW Sec. 3-23N-10E
18.	Texas, Carlton #1A	NW NE NE Sec. 1-23N-10E
19.	S. Lebow, Keener #1	NW SW SE Sec. 6-23N-11E
20.	DYCO, Avant #6	NE SW Sec. 4-23N-11E
21.	Gulf, Avant Unit #1-13W	NE NE Sec. 11-23N-11E
22.	Measured Section	SW NW Sec. 17-23N-12E
23.	Measured Section	N½ Sec. 33-23N-12E
	West-East Correlation Section B-B'	
1.	Tesoro, Hargrove #18-1	N½ SE NW Sec. 18-22N- 8E
2.	Johnson, Gas Well #154	SE SW NE Sec. 18-22N- 8E
3.	Tomar, Josephine Kipp #1-A	SE NW NE Sec. 17-22N- 8E
4.	C. R. Colpitt, West #1	SW NW NW Sec. 16-22N- 8E
5.	Wilcox, Lassley #1	SW NW NE Sec. 15-22N- 8E
6.	Glenwood, Leo Maker #1	SW SW NE Sec. 11-22N- 8E
7.	Gilcrease, Mary Penn #2	SE SW SW Sec. 7-22N- 9E
8.	Thermo Dyne, Red Eagle #1	SE SE SE Sec. 7-22N- 9E
9.	Mesker, Drummond #1-A	NW Sec. 16-22N- 9E
10.	Nodel & Gussman, Hominy #7	SE SW Sec. 15-22N- 9E
11.	BBR, Bone #1	SE Sec. 14-22N- 9E
12.	Ada, La Zelle #1	SE SE SW Sec. 13-22N- 9E
13.	Tesoro, Trumbley #20-1	NW NW NW Sec. 20-22N-10E
14.	Bowman, Perrier #1-A	NE NE NW Sec. 21-22N-10E
15.	L & R, Drummond #2-A	SE SE Sec. 14-22N-10E
16.	ECC, Osage #7	NE SE NW Sec. 18-22N-11E
17.	ECC, Osage #13-112	NW NW SW Sec. 17-22N-11E
18.	ECC, Osage #5	SE SW NE Sec. 17-22N-11E
19.	DYCO, Osage #4	SW SW SW Sec. 9-22N-11E
20.	Service, White #3	NW SE SE Sec. 9-22N-11E
21.	L. B. Smith, Selby #1	SE SE NW Sec. 11-22N-11E
22.	Measured Section	SE NE NW Sec. 13-22N-11E
23.	Measured Section	SW NE Sec. 16-22N-12E

No.	Operator and Well Number	Location
	North-South Correlation Section C-C'	
1.	Shell, Avant #1-C	NE NW Sec. 1-23N-11E
2.	Gulf, Avant Unit #1-13W	NE NE Sec. 11-23N-11E
3.	Lafayette, West #1	SW SE NW Sec. 23-23N-11E
4.	BBR, Stuart #1-B	NE SW Sec. 26-23N-11E
5.	C. R. Rittenberry, Stuart #2	SE NW SW Sec. 35-23N-11E
6.	Murphy, Osage #1	NE NE SE Sec. 3-22N-11E
7.	L. B. Smith, Selby #1	SE SE NW Sec. 11-22N-11E
8.	Oil Devel., Burton #1A	NW NE SW Sec. 22-22N-11E
9.	S. F. Duggan, V. O. Norwood #1	W½ NW SW Sec. 34-22N-11E
	North-South Correlation Section D-D'	
1.	J. A. Huitt, McKenzie #2	NW SW NW Sec. 6-23N-10E
2.	Benson & Montin, Osage #1A	SW SW SE Sec. 7-23N-10E
3.	F. Buttram, Drummond #1A	SE Sec. 17-23N-10E
4.	BBR, Osage-White #1A	SE NE NW Sec. 29-23N-10E
5.	F. Buttram, Cecil #1A	SW SE NW Sec. 32-23N-10E
6.	Saxon, Moore #3	SW NE SW Sec. 32-23N-10E
7.	S. G. Pappas, Moore #1	NW NW NE Sec. 6-22N-10E
8.	L. B. Smith, Moore #1	SE SE NE Sec. 1-22N- 9E
9.	White Star, Trumbly #1A	SW SW SW Sec. 12-22N- 9E
10.	Ada, La Zelle #1	SE SE SW Sec. 13-22N- 9E
11.	BBR, Osage-Millsap #1	NW SW SE Sec. 19-22N-10E
12.	Jackson, Millsap #1A	NE NE SW Sec. 30-22N-10E
13.	M. Meyer, Maher #1	NE NE SW Sec. 31-22N-10E
	North-South Correlation Section E-E'	
1.	Pure, Osage-Hominy #185	NE NE SW Sec. 4-23N- 8E
2.	Pure, Osage-Hominy #195	E½ SE Sec. 4-23N- 8E
3.	Nadel & Gussman, Kirby #4C	NW NW Sec. 10-23N- 8E
4.	Nadel & Gussman, Kirby #13-A	SE SW Sec. 10-23N- 8E
5.	Jet, Townsend #1	SW SW NE Sec. 22-23N- 8E
6.	H. G. Kramer, Duncan #1	SE SE SE Sec. 22-23N- 8E
7.	H. G. Kramer, Singer #1A	NE NW NE Sec. 27-23N- 8E
8.	Demier, Harding #5	NW SW NE Sec. 34-23N- 8E
9.	Jet, Thornton #1	SE SE NW Sec. 3-22N- 8E
10.	Tennessee, Osage Tribe #C1	NE SE NW Sec. 10-22N- 8E
11.	Jernigan & Morgan, Dagen #1	NE SE SW Sec. 10-22N- 8E
12.	Wilcox, Lassley #1	SW NW NE Sec. 15-22N- 8E
13.	Wilcox, Beason #2	NE NW SW Sec. 15-22N- 8E
14.	Butler & Webco, Lookout #1	NE NE NW Sec. 22-22N- 8E
15.	Tesoro, Escue #22-1	SW SW NE Sec. 22-22N- 8E
16.	L. Evans, Lookout #1	SW SW SE Sec. 22-22N- 8E
17.	Oakleaf, Pitts #6	NW Sec. 27-22N- 8E
18.	T. F. Dunham, Lookout #1	SW Sec. 27-22N- 8E
19.	A. N. Edwards, Mullins #1	SW SW SW Sec. 34-22N- 8E

No.	Operator and Well Number	Location
	North-South Correlation Section F-F'	
1.	A. N. Edwards, Mullins #1	SW SW SW Sec. 34-22N- 8E
2.	P. Hanson, Mullins #1	SE NE Sec. 3-21N- 8E
3.	T. M. Anderson, Whipkey #14	SE NE SW Sec. 10-21N- 8E
4.	T. M. Anderson, Nellie Osage #4	NW NW NE Sec. 15-21N- 8E
5.	Redman, Sheppard #4A	W½ Sec. 21-21N- 8E
6.	R. L. Glazner, Vermillion #1A	SW SE Sec. 27-21N- 8E
7.	Gulf, Widener #20	SE NE SE Sec. 34-21N- 8E
8.	Redman, Peoples #1A	SE SE NW Sec. 3-20N- 8E
9.	H. Rockett, Short #1	SW NE SW Sec. 11-20N- 8E
10.	R. C. Jones, Shepherd #1	SW NW NW Sec. 22-20N- 8E
11.	R. Cobb Jr., Edgar #1	NW SE SE Sec. 22-20N- 8E
12.	Woods, Klintworth #1	NW NW SE Sec. 27-20N- 8E
13.	P. Briscoe, State #1	SE NE SE Sec. 33-20N- 8E
14.	JHJ, Waffle #1	NE NE NE Sec. 3-19N- 8E
15.	Mercury, Klintworth #B1	SW SE NW Sec. 10-19N- 8E
16.	W. E. Anderson, Klintworth #1	SW SW SW Sec. 10-19N- 8E
17.	B. B. Blair, Brian #1	NE SE SW Sec. 15-19N- 8E
18.	Stiles-Godsey, Miller #3	NE NW NE Sec. 22-19N- 8E
19.	Dirickson & Lewis, Hinton #1	SE SE SE Sec. 22-19N- 8E
20.	Graybol, Bray #1	NW NE SE Sec. 27-19N- 8E
21.	Fain-Porter, Briggs #1	NE SW NW Sec. 34-19N- 8E
22.	Big Four, Marshall #5	NW SW SE Sec. 34-19N- 8E
23.	Texkan, Texkan-Cantrall #1	NE NE SE Sec. 3-18N- 8E
24.	H. H. Diamond, Garrett #1	NE NE NE Sec. 10-18N- 8E
25.	Simon & Bassett, Marlin #2	SW SW SE Sec. 10-18N- 8E
26.	C. C. Nye, Reynolds #1	NW NE SW Sec. 15-18N- 8E
27.	K. D. Emrick, Lacy #3	SE SE NW Sec. 22-18N- 8E
28.	Springer, Williams #11	SW NW NE Sec. 27-18N- 8E
29.	Power, Wilson #4	NE NE SE Sec. 34-18N- 8E
	West-East Correlation Section G-G'	
1.	T. E. Berry, Brier #2	NE SE NE Sec. 15-20N- 2W
2.	T. E. Berry, Bolay #1	SE SE NW Sec. 11-20N- 2W
3.	Frankfort, Turner #2	SE NE NW Sec. 1-20N- 2W
4.	Summit, Gillaspy #1	NE NE SE Sec. 29-21N- 1W
5.	Dirickson & Lewis, Elliott #1	NE SW NW Sec. 14-21N- 1W
6.	Herndon, State #1	NE NE SW Sec. 13-21N- 1W
7.	Pipeline, Detwieler #1	NE NE SW Sec. 18-21N- 1E
8.	Redlands, Fox #1	SE NE NW Sec. 17-21N- 1E
9.	Lynn, Cress #1	NE NE SE Sec. 4-21N- 1E
10.	Hanlon-Boyle, Allen #1	SW SW NE Sec. 1-21N- 1E
11.	Harper, Reiman #1	SE SE SE Sec. 6-21N- 2E
12.	Big Four, State-Chessmore #1	NE NE NW Sec. 16-21N- 2E
13.	Mohawk, Schmaltz #1	SE NE NW Sec. 24-21N- 2E
14.	T. E. Berry, Dolezal #1	SW SE NE Sec. 24-21N- 2E
15.	Eason, Testerman #1	SW SE SW Sec. 19-21N- 3E
16.	H. S. Chancey, Vaclay Pour #1	NE NE NE Sec. 32-21N- 3E
17.	R. L. Kinkaid, Emick #1	SE SE NW Sec. 22-21N- 3E

No.	Operator and Well Number	Location
18.	Nadel & Gussman, State #1	NW NW SW Sec. 13-21N- 3E
19.	Smalley, Marlow #1	SE SW SE Sec. 18-21N- 4E
20.	E. Sadler, Dairs #1	NE NE SW Sec. 14-21N- 4E
21.	D. Wegener, Tate #1	SW SW SW Sec. 12-21N- 4E
22.	P. Morris, Baker #1	sw sw se Sec. 7-21N- 5E
23.	Carter & Mandel, Waters #1	SE NW SW Sec. 4-21N- 5E
24.	Gulf Coast Western, Griesel #1	SW NE SW Sec. 3-21N- 5E
25.	Barton & Rich, Rogers #1	SE NE SW Sec. 2-21N- 5E
26.	C. Brown, Hill #B3	SW NW SW Sec. 1-21N- 5E
27.	Mid Continent, J. Dallas #1	SW SW NE Sec. 6-21N- 6E
28.	Bilinda & Magness, McCaslin #1	NW NW SE Sec. 5-21N- 6E
29.	R. G. Woods, Brewington #1	NW SW NE Sec. 3-21N- 6E
30.	Massey & Moore, Muck #1	SW SW NE Sec. 2-21N- 6E
31.	L. J. Horwitz, Hammer #1	NE NW SE Sec. 1-21N- 6E
32.	Western, Brown #1	NW SW NE Sec. 6-21N- 7E
33.	Big Four, J. Byrd #1	SE SE NW Sec. 4-21N- 7E
34.	Gulf, F. Boston #70	NW SE NE Sec. 1-21N- 7E
35.	Comail, McCarthy #12	SE SW Sec. 32-22N- 8E
36.	A. N. Edwards, Mullins #1	SW SW SW Sec. 34-22N- 8E

West-East Correlation Section H-H'

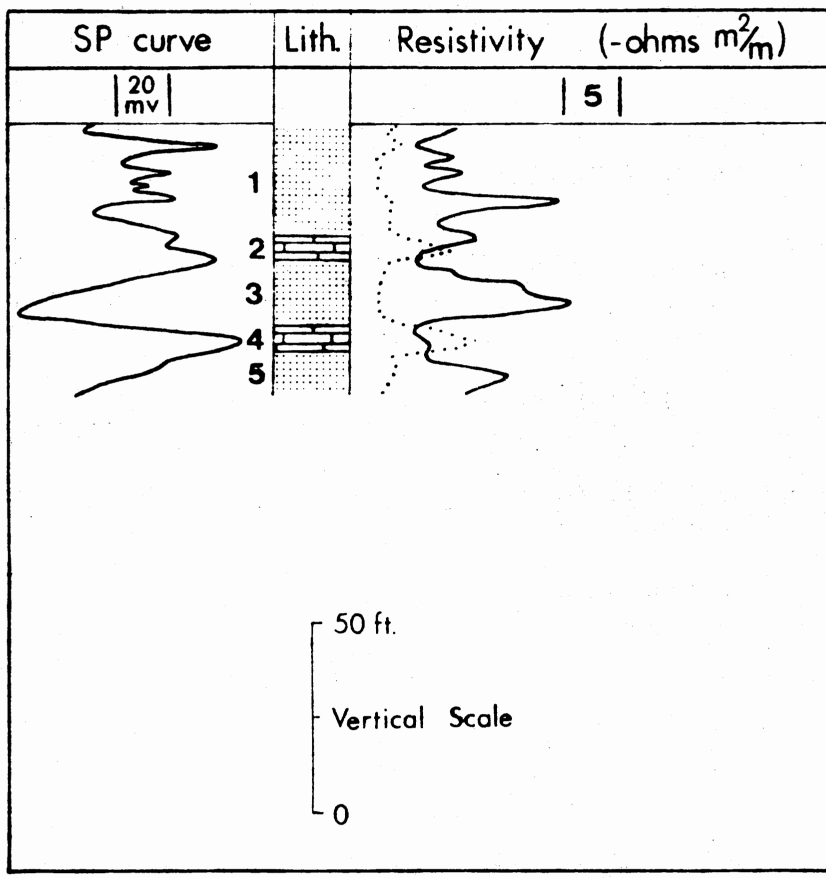
1.	T. E. Berry, Brier #2	NE SE NE Sec. 15-20N- 2W
2.	G. E. Phelps, Pierce #1	NW NW NE Sec. 23-20N- 2W
3.	B. Kidd, McCoy #1	SE SE SE Sec. 24-20N- 2W
4.	N. Barrett, Lively #1	NE SE SW Sec. 19-20N- 1W
5.	D. Wegener, Kauffman #1	SE NW SW Sec. 20-20N- 1W
6.	Magnolia, F. J. Dvorak #1	NW NE NW Sec. 22-20N- 1W
7.	Tennessee, G. Shelton #1	NE SE NE Sec. 23-20N- 1W
8.	Tennessee, G. Bechtold #B1	NE NE SW Sec. 24-20N- 1W
9.	Tennessee, L. Seids #A4	SW SW NW Sec. 20-20N- 1E
10.	Creslenn, Spillman #1	SW SE SE Sec. 20-20N- 1E
11.	Creslenn, Busse #1	NE NW NW Sec. 28-20N- 1E
12.	Publishers, Meagher #1	NW SE Sec. 22-20N- 1E
13.	Sparton, C. Smith #1	SW SE Sec. 23-20N- 1E
14.	Falcon Seaboard, Downey #1	NE NE SW Sec. 17-20N- 2E
15.	T. W. & J. M. Loffland Jr., State #1	SE SW NW Sec. 16-20N- 2E
16.	Jones & Pellow, Thomason #1	SE SE Sec. 11-20N- 2E
17.	Sullivan & Leroux, Kerr #1	NE NE Sec. 12-20N- 2E
18.	Howell & Howell, Human #1	NE NW SE Sec. 5-20N- 3E
19.	L. A. Gorce, Newson #1	SE NW NW Sec. 2-20N- 3E
20.	Tidewater, R. Adams #1	SW NE NE Sec. 1-20N- 3E
21.	Arrow, Holland #1	SE SE NW Sec. 6-20N- 4E
22.	Dudley & Heath, Price #1	NW NW NW Sec. 8-20N- 4E
23.	Sohio, K. Price #1	NE SE SW Sec. 9-20N- 4E
24.	Jones & Shelburne, Groom #1	SE SE SE Sec. 10-20N- 4E
25.	Carter & Mandel, Raper #1	NE NE NE Sec. 11-20N- 4E
26.	Et. Al., Davis #1	SW SE NE Sec. 1-20N- 4E
27.	Massey & Moore, Clark #2	SE SW NW Sec. 6-20N- 5E
28.	Indian High Eagle #1	NW SW NE Sec. 5-20N- 5E
29.	A. A. Borton, David #1	NE NE SW Sec. 4-20N- 5E

No.	Operator and Well Number	Location
30.	Harper & Turner, Blue Hawk #1	SW NE SE Sec. 3-20N- 5E
31.	Gulf, Knox #1	NE NE SW Sec. 2-20N- 5E
32.	Massey & Moore, Mellis #2	SE SW NE Sec. 1-20N- 5E
33.	Goldsmith & Perkins, Goodwin #1	NW SE SE Sec. 6-20N- 6E
34.	S. C. Yingling, Shedeck #1	SW NW SW Sec. 5-20N- 6E
35.	B. S. Pace, Adler #1	NE NE SW Sec. 4-20N- 6E
36.	L. Portman, Cave #1	NE NW NW Sec. 2-20N- 6E
37.	Mid Continent, A. Privett #1	NE NE SW Sec. 1-20N- 6E
38.	Western, Tisdal #1	NE SW NE Sec. 6-20N- 7E
39.	Mid Continent, H. Thomas #1	NW NE SW Sec. 5-20N- 7E
40.	Jones & Morris, Tisdal #1A	SW NE SW Sec. 3-20N- 7E
41.	C. Watkins, Ramsey-Ward #1	NW NE SW Sec. 2-20N- 7E
42.	G. C. Wallace, Byers #6A	SE SW NW Sec. 1-20N- 7E
43.	Johnson & Clark, Wagner #2A	NW NW Sec. 6-20N- 8E
44.	Deloris, Young #1	NW SW SW Sec. 32-21N- 8E
45.	Redman, Peoples #1A	SE SE NW Sec. 3-20N- 8E

APPENDIX E

LITHOLOGIC DESCRIPTIONS CORRESPONDING

TO CHARACTERISTIC LOG SHAPES



Sample Description

1. Wann Formation - Subangular, friable, fine-grained sandstone with gray and maroon shale.

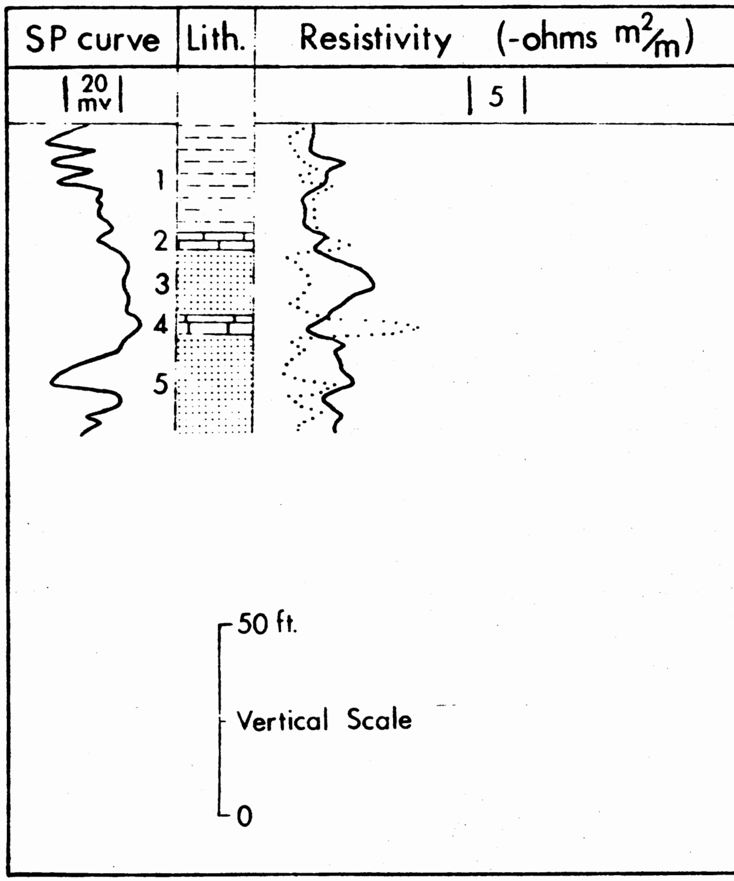
2. Avant Limestone Member - Gray micrite with sparry crystalline carbonate.

3. Muncie Creek Shale Member - Not distinguishable in cuttings.

4. Paola Limestone Member - Not distinguishable in cuttings.

5. Chanute Formation - Not distinguishable in cuttings.

Fig. 33.-Electric log and well-cuttings description, Pure Oil Co. No. 184 Osage Hominy, NW NW SW Sec. 6, T. 23 N., R. 8 E. (see Correlation Section A-A', Pl. 1, Loc. 1).



Sample Description

1. Wann Formation - Gray, noncalcareous fissile shale.

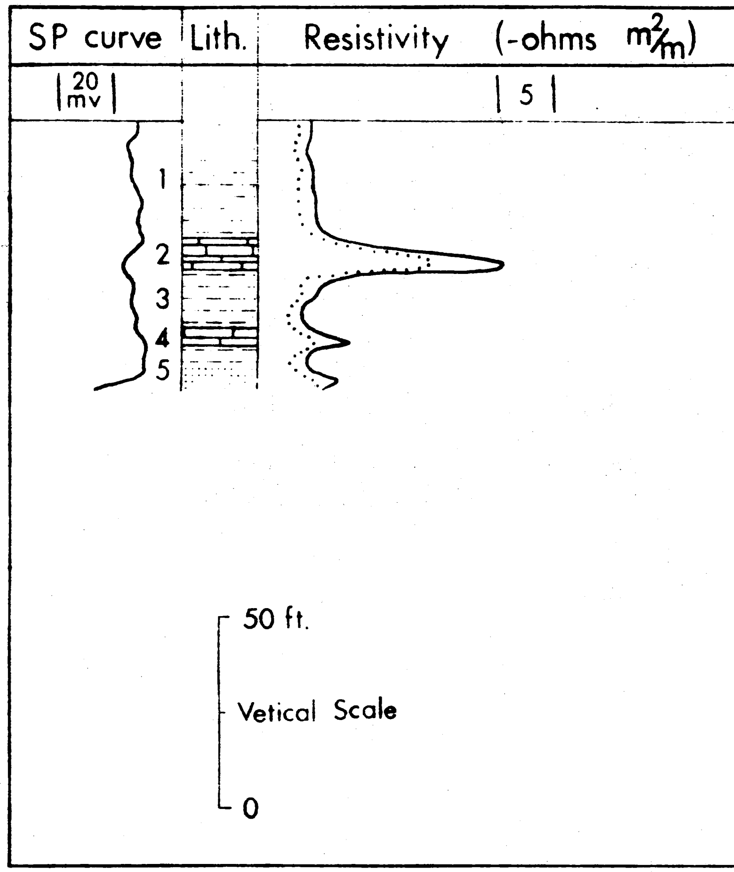
2. Avant Limestone Member - Gray, crinoidal micrite, with sparry crystalline carbonate.

3. Muncie Creek Shale Member - Not distinguishable in cuttings.

4. Paola Limestone Member - Not distinguishable in cuttings.

5. Chanute Formation - Subangular, micaceous, calcareous, very fine-grained sandstone.

Fig. 34.-Electric log and well-cuttings description, Jet Petroleum Corp. No. 1 Thornton, SE SE NW Sec. 3, T. 22 N., R. 8 E. (see Correlation Section E-E', Pl. 5, Loc. 8).



Sample Description

1. Wann Formation - Dark gray, micaceous, noncalcareous fissile shale.

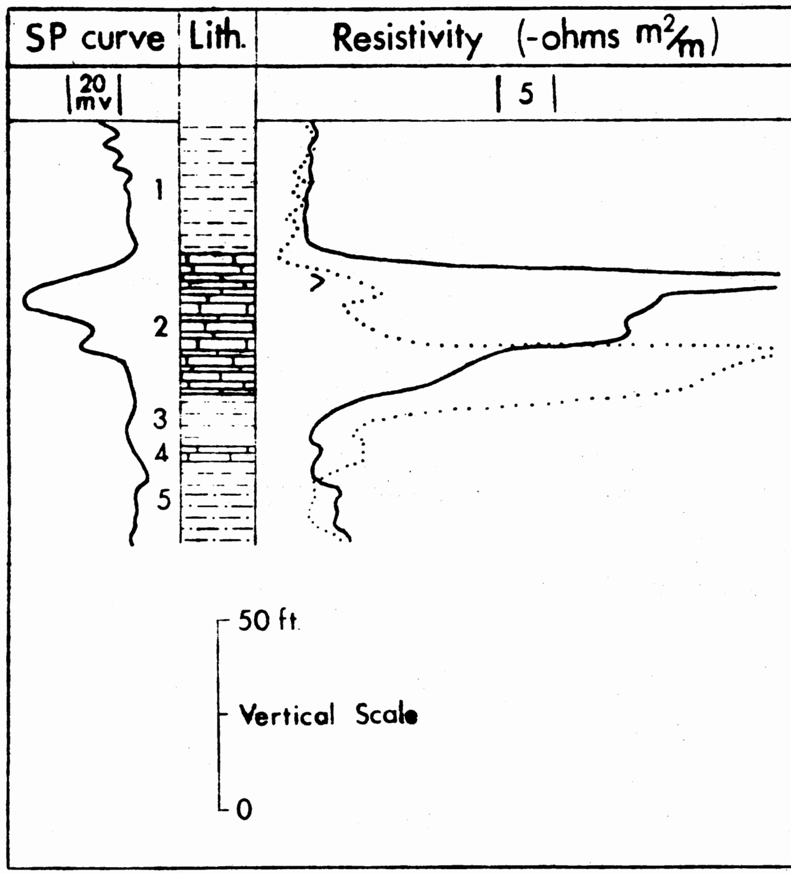
2. Avant Limestone Member - Gray and brown crinoidal micrite with sparry crystalline carbonate.

3. Muncie Creek Shale Member - Dark gray, noncalcareous fissile shale.

4. Paola Limestone Member - Not distinguishable in cuttings.

5. Chanute Formation - Not distinguishable in cuttings.

Fig. 35.-Electric log and well-cuttings description, White Star Oil Co. No. 1A Trumbly, SW SW SW Sec. 12, T. 22 N., R. 9 E. (see Correlation Section D-D', Pl. 4, Loc. 9).



Sample Description

1. Wann Formation - Dark gray and maroon noncalcareous fissile shale.

2. Avant Limestone Member - Gray crinoidal micrite with sparry crystalline carbonate.

3. Muncie Creek Shale Member - Gray and maroon fissile shale.

4. Paola Limestone Member - Not distinguishable in bit cuttings.

5. Chanute Formation - Not distinguishable in cuttings.

Fig. 36.-Electric log and well-cuttings description, A. N. Edwards Co. No. 1 Mullins, SW SW SW Sec. 34, T. 22 N., R. 8 E. (see Correlation Sections E-E', Pl. 5, Loc. 19, and F-F', Pl. 10, Loc. 1).

VITA

Joe Dwain Davidson

Candidate for the Degree of

Master of Science

Thesis: PHYSICAL STRATIGRAPHY OF THE AVANT LIMESTONE MEMBER OF THE IOLA FORMATION, SOUTHERN OSAGE COUNTY AND PARTS OF NEARBY COUNTIES, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Mangum, Oklahoma, April 24, 1953, the son of Mr. and Mrs. C. Dwain Davidson.

Education: Graduated from Putnam City West High School, Oklahoma City, Oklahoma, in May, 1971; received Bachelor of Science degree in Geology from Oklahoma State University at Stillwater, in May, 1976; completed requirements for Master of Science degree at Oklahoma State University in December, 1978, with a major in geology.

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