RELATIONSHIP OF THE CARBONATE SHELF AND BASINAL CLASTIC DEPOSITS OF THE MISSOURIAN AND VIRGILIAN SERIES OF THE PENNSYLVANIAN SYSTEM IN CENTRAL BEAVER COUNTY, OKLAHOMA

By

STEVEN DALE LANE

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
1974

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1976

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Thesis Approved:

Gary F. Stewart
Thesis Adviser

George E. Moore

R. N. Donovan

Norman N. Durham
Dean of the Graduate College

PREFACE

Sincere appreciation and gratitude is extended to several individuals who contributed to this study. Mr. George Moore of Union Oil of California, Midland Regional Office, Midland, Texas, suggested the problem and provided assistance in the preparation and writing of the text. Dr. Gary F. Stewart gave much time, effort and advice, not only for this thesis, but throughout the author's educational career.

Special thanks is expressed to Dr. R. Nowell Donovan, who served on the writer's thesis committee and gave valuable help in interpreting the acetate peels. Mr. Paul Dinkmeyer of Union Oil of California, Oklahoma City District Office, Oklahoma City, Oklahoma, aided in the preparation as well as the interpretation of the acetate peels. Mr. Garner L. Wilde, Exxon Company, Midland, Texas, gave valuable help through examination of the core for fusulinids.

Thanks are also expressed to Mr. Troy Brooks, Mr. Max Walker, and Mr. Tom Joe for drafting of the plates contained in this thesis and to Mr. John Fritts, graduate student at Oklahoma State University, for photographs of the core.

Finally, I am sincerely indebted to my wife, Suzanne, and to my father and mother, Frank and Maggie, for their constant support and encouragement.

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CHAPTER I

ABSTRACT

In the area of investigation, T. 1-6 N., R. 23-25 ECM, the Lansing and Kansas City Groups consist primarily of limestones with minor amounts of shale. The submarine paleotopography of the upper Lansing Group can be determined by an isopachous map of the overlying clastic wedge. Delineated on the isopachous map are areal extent of major carbonate depositional environments; shelf, shelf-margin, and basin. "Time-markers" within the Lansing-Kansas City section were judged mostly to be correlative shale "breaks." Relative thicknesses between shale "breaks" can be used to infer major carbonate depositional environments and log maps show trends as well as the areal extent of the environments.

The Tonkawa sandstone is contained in the foreset-slope sediments deposited with the Virgilian, Douglas Group and therefore not equivalent to the Missourian, Lansing Group. Buildups of the Tonkawa clastics show no signs of downcutting; therefore, they probably were spilled into the basin and redistributed by current and storm waves. They formed sand buildups that are subparallel to the shelf margin.

Trapping of hydrocarbons in the sandstone reservoirs primarily is due to stratigraphic changes that are coincident structural trends. Present discovered limestone reservoirs have developed upon anticlinal structures.

CHAPTER II

INTRODUCTION

Location of the Study Area

The study area is in the central one-third of Beaver County, in the Oklahoma Panhandle. The region is approximately 620 square miles, including T. 1 N. through T. 6 N., and R. 23 ECM through R. 25 ECM (Fig. 1).

Statement of the Problem

The purpose of the study is to examine in detail the relationship of the carbonate shelf and basinal clastic deposits of the Missourian and Virgilian Series of the Pennsylvanian System. The objectives necessary to solve such a problem were to:

1. Establish the relationship of the Tonkawa sandstone to the Lansing and Kansas City Groups.
2. Determine possible "time-markers" in the Lansing-Kansas City section.
3. Determine areal distribution of the clastic wedge that is bounded above by the Heebner Shale and below by the uppermost limestone of the Lansing Group.
4. Establish limits of the Upper and Lower Tonkawa sandstones and the Endicott (Douglas) sandstone.

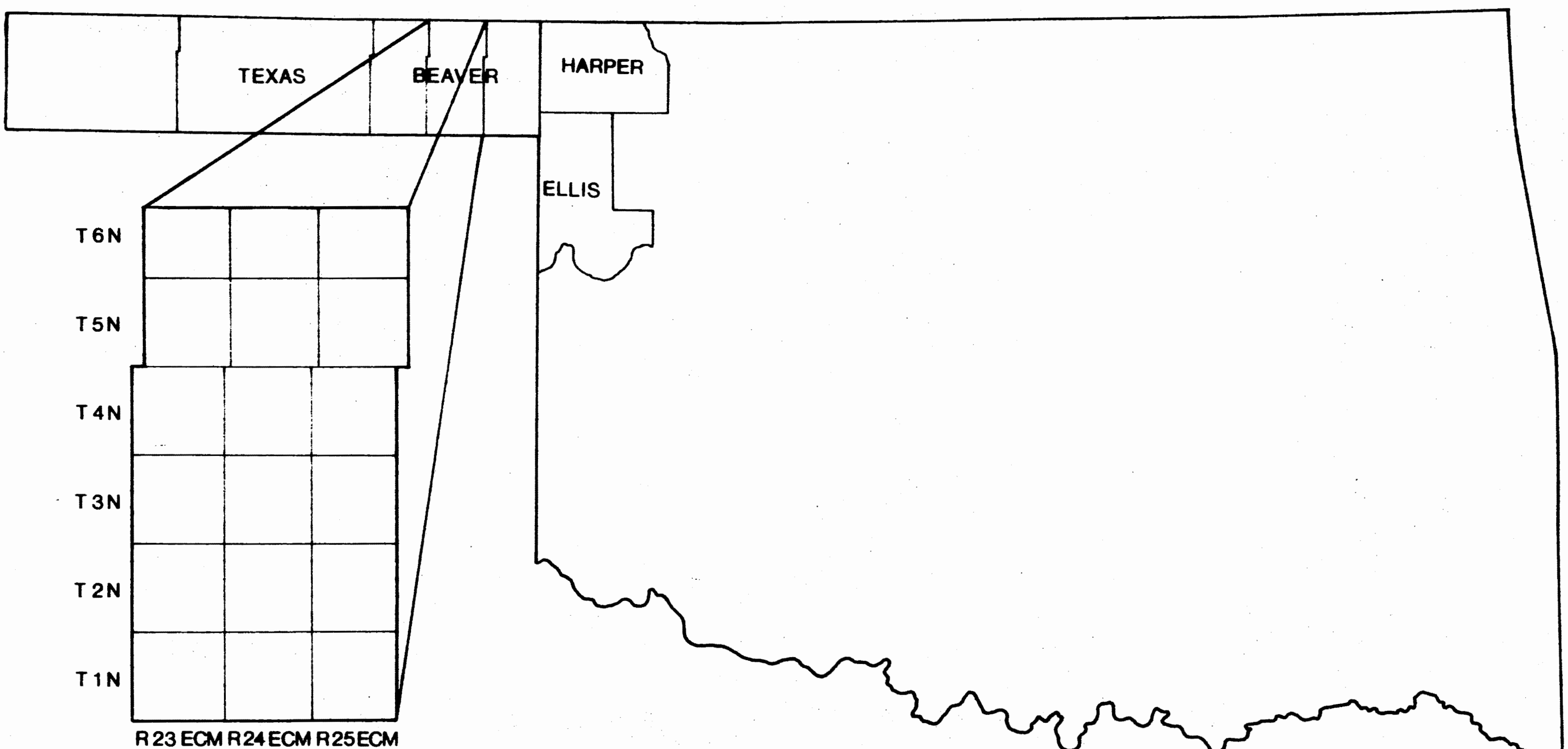


Fig. 1.-Location of the study area.

5. Determine the Pennsylvanian Missourian-Virgilian boundary and extend it basinward.
6. Illustrate the facies distribution of the upper part of the Lansing-Kansas City section.
7. Discuss the role of structural geology and (or) stratigraphy as determinants in the accumulation of hydrocarbons.

Previous Investigations

The Virgilian and Missourian Series of the Pennsylvanian System in the study area have been included in or bounded by several regional studies. These studies primarily have been concerned with correlations across the Anadarko Basin and with isopachous maps illustrating the paleodrainage patterns (Capps, 1959; Gibbons, 1960). Detailed cross-sections to determine shelf-basin relationships of the Missourian series have not been published. The section of strata under investigation is bounded above by the Heebner Shale Member of the Oread Limestone, Shawnee Group, in the Virgilian Series, and below by the Pleasanton Group of the Missourian Series (Fig. 2). In ascending order, this interval comprises the undifferentiated Lansing and Kansas City Groups of the Missourian Series, the Douglas Group of the Virgilian Series, and a small part of the overlying Virgilian Shawnee Group (Fig. 2).

Several regional studies have been made in areas adjacent to or including the present study area. A

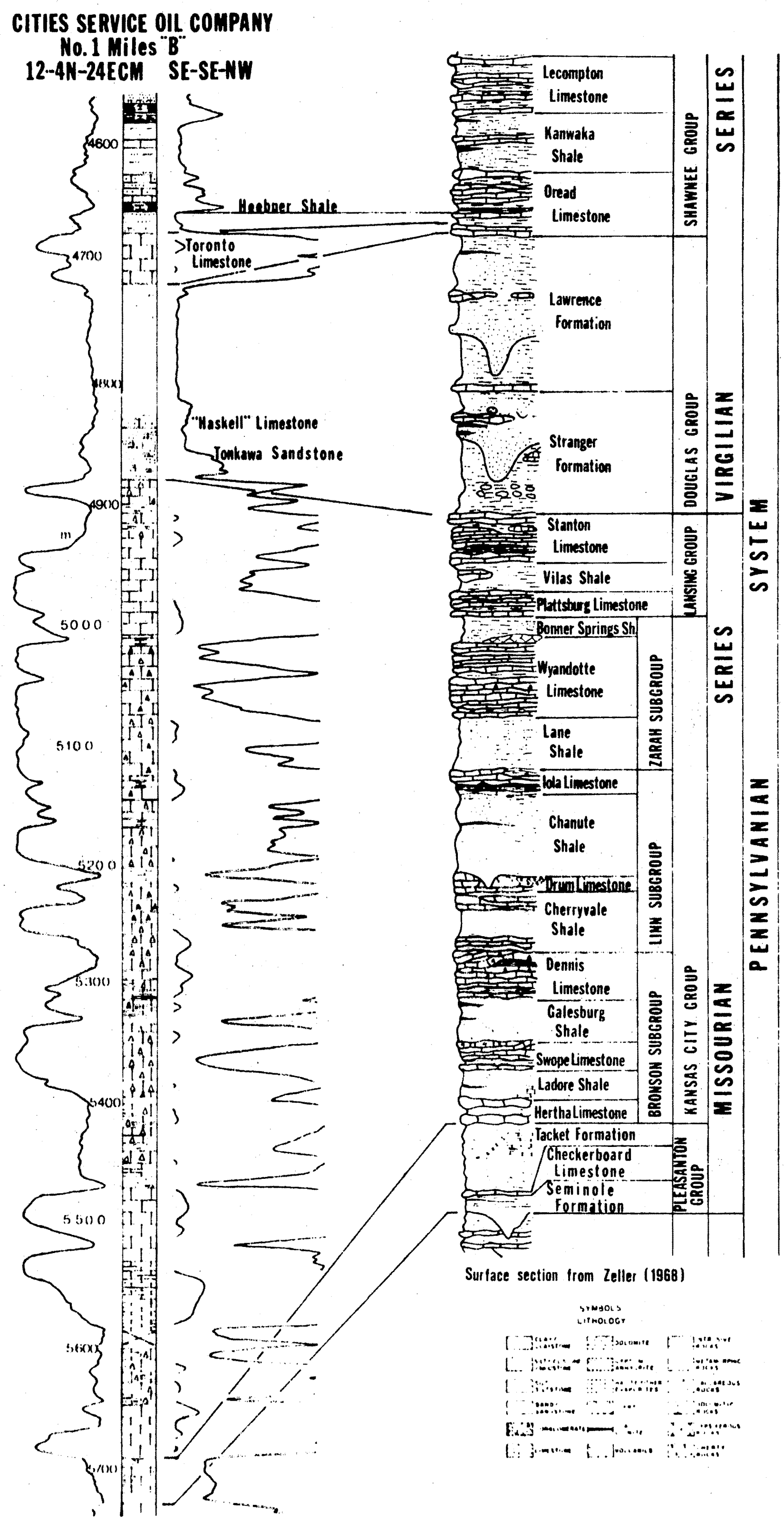


Fig. 2.-Section of strata under investigation.

stratigraphic analysis of the strata cited above was made in an adjacent area to the east by Capps (1959). A comprehensive regional evaluation of the geometries, distribution patterns, and depositional environments of four Pennsylvanian sandstone bodies was made approximately in the same locality by Khaiwka (1968); it included the Upper Tonkawa and Endicott (Douglas) sandstones. The section was correlated and configuration of the basin through Pennsylvanian time was mapped by Gibbons (1960) according to thicknesses of strata.

Stratigraphic traps along the northern shelf of the Anadarko Basin, which included hydrocarbon traps ranging in age from Silurian through Permian (Wolfcampian), were described by Pate (1959). The studies by Pate (1959) and Khaiwka (1968) overlapped on the topic of Pennsylvanian sandstone bodies. The main conflict of these two studies is that Pate interpreted as bars all the sandstone bodies and Khaiwka was not so liberal in interpreting the depositional environments.

Generalized stratigraphic relationships between the shelf and basinal deposits of the post-Springer Pennsylvanian and pre-Leonard Permian were illustrated and discussed in a larger regional study by Rascoe (1962) which included parts of Colorado, Texas, Oklahoma, and Kansas. This study contained isopachous maps, as well as lithofacies maps. Superimposed on the lithofacies maps were the areal limits of the economically important reservoir sandstones (Tonkawa and others).

Paleotectonics of the study area were discussed by Frezon and Dixon (1975).

Sedimentary cycles in the Virgilian Series of the Anadarko Basin were described in a recent paper by Rascoe (1978). He used the model of foreset-slope deposits as the "key" to deciphering these cycles.

Methods and Procedures

Materials involved in interpretation and solution of the specific problem in this study are a structural contour map of the base of the Heebner Shale Member, Oread Limestone (Pl. 1), an isopachous map of strata between the Heebner and the uppermost limestone bed in the Lansing Group (Pl. 2), a set of cross-sections (Pls. 3-8), a sand-distribution map (Pl. 9), and log maps of the upper portion of the combined Lansing and Kansas City Groups (Pls. 10-12).

No type log was available in the study area. Major correlations were based upon evidence gained by personal communication with Mr. George Moore of Union Oil of California, Midland Regional Office, Midland Texas, Pate's (1959) "Stratigraphic Traps Along North Shelf of Anadarko Basin, Oklahoma," and the Clark County type log of "Kansas Type Logs" (Kansas Geological Society, 1967). Identifications of named units are consistent with Jordan's (1957) "Subsurface Stratigraphic Names of Oklahoma."

Due to the lack of cores and the thick section included in this study, correlations were based chiefly on electric-log characters and on commercial sample logs. Some bit cuttings were inspected, primarily for use in interpretation of the log maps (Pls. 10-12). The abrupt changes that occur "horizontally" within the Lansing-Kansas City section required use of "time-markers," which are judged mostly to be correlative shale "breaks." These lateral variations include both thinning and facies changes of the limestones to shale, from shelf to basin. Along with the available electric logs from the Oklahoma City Geological Society's log library, all accessible radioactivity logs were used in constructing the structural contour and isopachous maps.

An isopachous map (Pl. 2) generally is made to illustrate the thickness of strata between two time-markers; such a map was not constructed in solution of the problem dealt with here. Due to facies changes within the uppermost limestone units of the Lansing Group, the bottom time-marker used in construction of Plate 2 was lowered to the limestone stratus next below when correlation became impractical (Fig. 3). The primary purpose of making this isopachous map was to show the areal distribution of the clastic wedge, and from these data a rough estimate of the paleotopography atop the Lansing Group can be ascertained. The isopachous map also was used to estimate relationship of stratigraphy to formation of hydrocarbon traps.

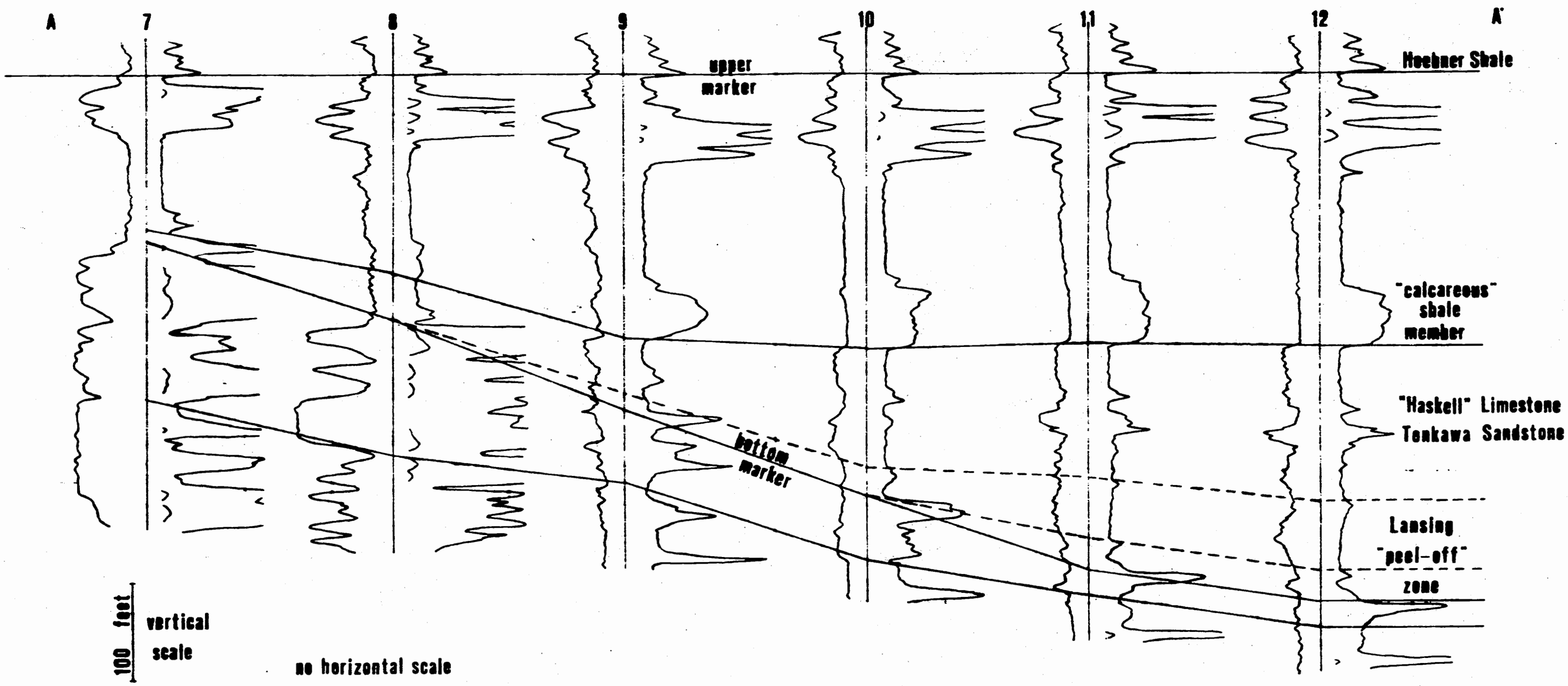


Fig. 3.-Method used in determining the bottom time-marker of the isopachous map (Pl. 2) along AA' (Pl. 3).

A structural contour map (Pl. 1) on the base of the Heebner Member was used to estimate the general structural configuration. This map was also the basis for judging probable relationships of geologic structure and hydrocarbon accumulation.

Only electrical logs were used in the construction of the log maps (Pls. 10-12). The primary reason for this was to maintain visual consistency in the log characters so that the signals could be grouped according to shape. Boundary markers for the vertical sections were established in the basinal region and were correlated onto the shelf. For practical purposes, these limits can be considered to be "time-markers." The upper marker is a very resistive shale that grades shelfward into a compact limestone. The lower marker is a shale that underlies the uppermost limestone marker within the Lansing Group in the basinal part of the study area (Fig. 3). This interval of strata was divided into three sections, as delineated in the cross-sections (Pls. 3-8), by shale "breaks." Clusters of visually common log characters were then isolated for the upper, middle, and lower sections, in Plates 10, 11, and 12, respectively.

The Virgilian-Missourian boundary was established on the basis of detailed cross-sections (Pls. 3-8). Evidence in support of this boundary was discovered through examination of fusulinids. The examination was made by Mr. Garner L. Wilde, Exxon Company, Midland, Texas.

Only one core was available in the study area. A detailed description of the core was made, photographs were taken, and fusulinids from part of it were examined, as described above. Various samples within the core were stained with Alizarin Red-S and acetate peels made of them were studied with a binocular microscope and photographed. Photographs of the core and acetate peels are included in Appendix A.

CHAPTER III

STRATIGRAPHY

The section of strata under investigation comprises the Lansing and Kansas City Groups of the Missourian Series, the Douglas Group of the Virgilian Series, and a small part of the overlying Virgilian Shawnee Group (Fig. 2). Regionally, this interval of strata is represented as an overall transgression marked by extensive regressions that are recorded by prodelta shales and siltstones and deltaic sandstones (Khaiwka, 1968) in the Douglas section. No widespread erosional surfaces have been determined to exist within the interval or to bound the section; however, local, channeled erosional contacts have been postulated (Khaiwka, 1968).

Correlations

To determine rock-stratigraphic and, possibly, time-stratigraphic boundaries, was a fundamental activity in this study. Commercial sample logs were used primarily for judgments about lithology. Study of bit cuttings of the "Lansing" Group and of the available core assisted in estimation of rock types.

Six cross-sections were prepared to establish grid correlation and thereafter to illustrate the stratigraphicsedimentologic relationships. The base of the Heebner was chosen as a datum for each section because of its consistent appearance on electrical logs and its position at the top of the interval of study. Geological reasons that contribute to the logic of using the Heebner as a datum are the lack of unconformities above and below the unit and its basinal origin (Evans, 1966). These considerations imply smooth boundaries and a very low paleodepositional slope. Thus, originally the Heebner should have been about tabular and should have been almost horizontal. Locations of the three northwest-southeast and three southwest-northeast sections are shown by the index map of cross-sections (Fig. 4).

Missourian Series

Lansing and Kansas City Groups

The Lansing and Kansas City Groups (Fig. 2) are undifferentiated in the study area. The older Kansas City Group is bounded below by a set of strata consisting mainly of dark gray to black, laminated, micaceous shales, gray to dull gray, tight, gritty marls, and buff, finely crystalline and arenaceous, "tight" limestones. These rock types are characteristic of the Pleasanton Group, Missourian Series. According to Rascoe (1962), the Pleasanton Group is overlain by a shelf-carbonate facies of the Kansas City Group. Therefore, the inherent differences in the characteristic lithologies of the Pleasanton and Kansas City Groups

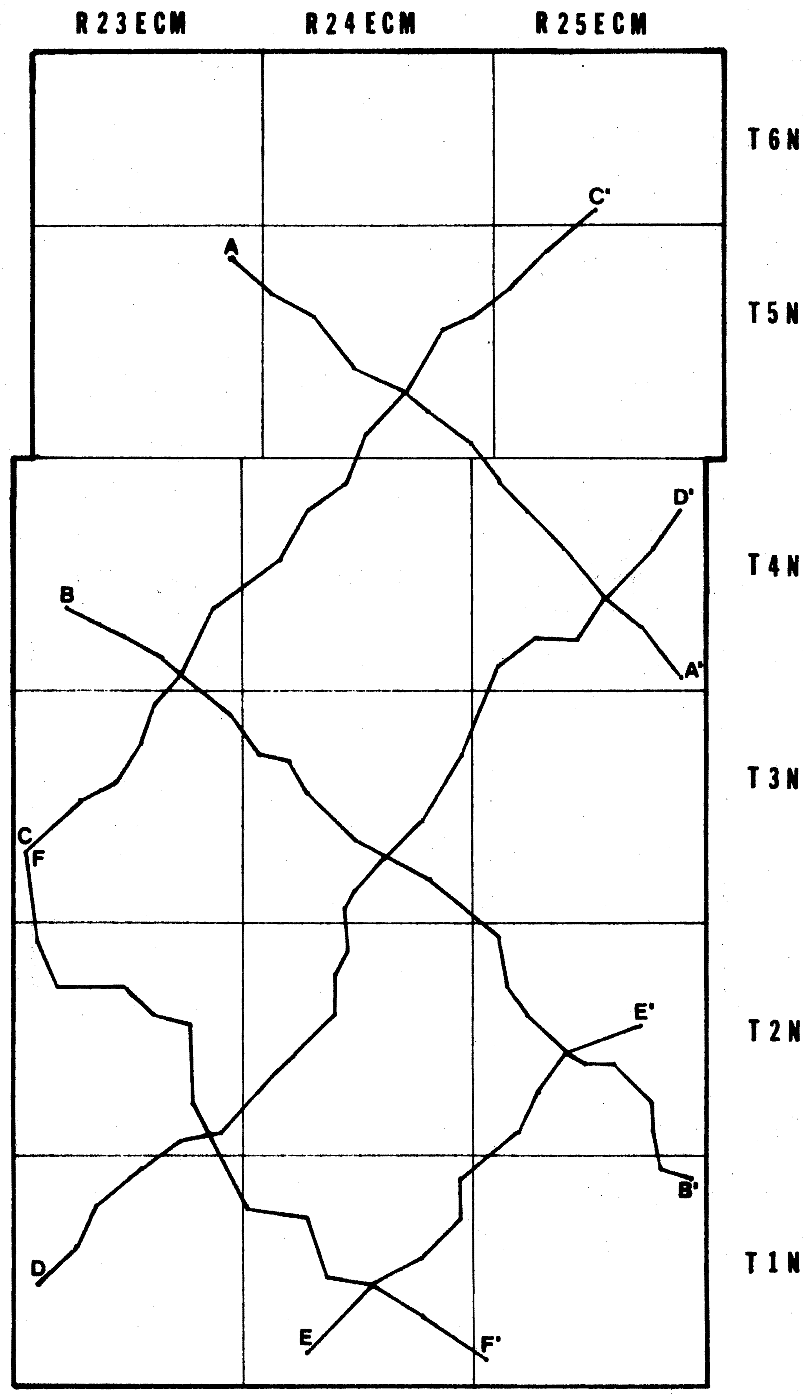


Fig. 4.-Index map of cross-sections.

produce a distinctive lithologic "break" across the study area, which was correlated by electrical logs and checked by sample logs.

Limestones and shales primarily make up the Lansing-Kansas City section; however, basinward and outside the study area sandstones do occur (Cottage Grove Sandstone). The Tonkawa Sandstone has been ranked as Virgilian. Evidence justifying this conclusion is discussed later.

Within the section are several shale breaks. Some of these have been correlated in the cross-sections as a double line if spontaneous potential (SP) and resistivity curves among wells agree (for example, see Pl. 4). A dashed line appears if only the SP shows a deflection. The shales are commonly about 5 ft. thick and are dark gray, thinly laminated, and generally calcareous.

A great variety of limestones is recorded in the Lansing and Kansas City Groups. In this area a general relationship concerning thicknesses and lithologies of limestone units has been observed. (In the following discussion, "large" implies the maximal value and "thin" means the minimal value of a specific interval. Numerical values were not used because a maximal value of one interval may also be a minimal value of a generally thicker interval.) Where the thickness of a given unit is relatively large, the limestones that compose it commonly are buff to buff-brown, finely crystalline, and slightly fossiliferous to oolitic, with slight to fair porosity. In areas where the unit is thin, the limestones generally are brown to dark gray, finely crystalline, compact marls or dense, slightly impure limestones.

Accessory minerals in the Lansing and Kansas City limestones include mainly chert, which is in nodules and generally is described as being buff to bluish gray, vitreous, and opaline. Pyrite also is common. Minor amounts of dolomite have been recorded in sample logs and observed in core samples. Dolomite generally is confined to small patches within micrite, to fossil casts, and is localized along stylolites.

Several types of porosity occur within the Lansing and Kansas City Groups. The most common of these is oomoldic porosity. This has been observed in core and by samples where it is usually termed "pin-point" or "oolicast." In core samples, intraparticle and vuggy porosities were also recorded, but these are considered to be minor in function, as compared to the effects of oomoldic porosity, according to evidence gained through inspection of core and of sample logs.

The only available core was from the Cities Service No. 1-B Girk located in Sec. 35, T. 5 N., R. 24 ECM., in Beaver County. Description and photographs of this core are in Appendix A. Core samples were examined for fusulinids by Mr. Garner L. Wilde, Exxon Co., Midland, Texas. He found no genera other than _Triticites_. In samples from 4755 ft. to 4760 ft., species similar to _Triticites moorei_ (Dunbar and Condra, 1927) and Triticites beedi (Dunbar and Condra, 1927) were observed, along with a questionable specimen of Triticites jacksboreonsis (Kauffman and Roth, 1966). No fusulinids were found in samples from 4765 ft. to 4800 ft. In the 4806 ft. sample, two species of Missourian affinity were found. Numerous nonfusulinid foraminifera, bryozoans, platy algae, brachiopods, and crinoids also were present in the core.

As supported by the information above and the lithologic sequence of the core, the Missourian-Virgilian contact was placed at 4802 ft. in the Cities Service No. 1-B Girk. Upon correlating this marker to the southeast, the Tonkawa Sandstone was determined to be Virgilian in age. Figure 5 shows correlation of the Missourian-Virgilian contact to the number 3 well in Plate 3, so that the contact can be followed within the grid system of cross-sections.

Virgilian Series

Douglas Group

The Douglas Group consists (Fig. 2) primarily of clastic rocks; it underlies the Shawnee Group conformably except where the Endicott ("Douglas") sandstone has cut through the Toronto Limestone Member of the Shawnee Group (Khaiwka, 1968).

Most evidence points to the Tonkawa sandstone as having been deposited along the foreset slope of the Lansing

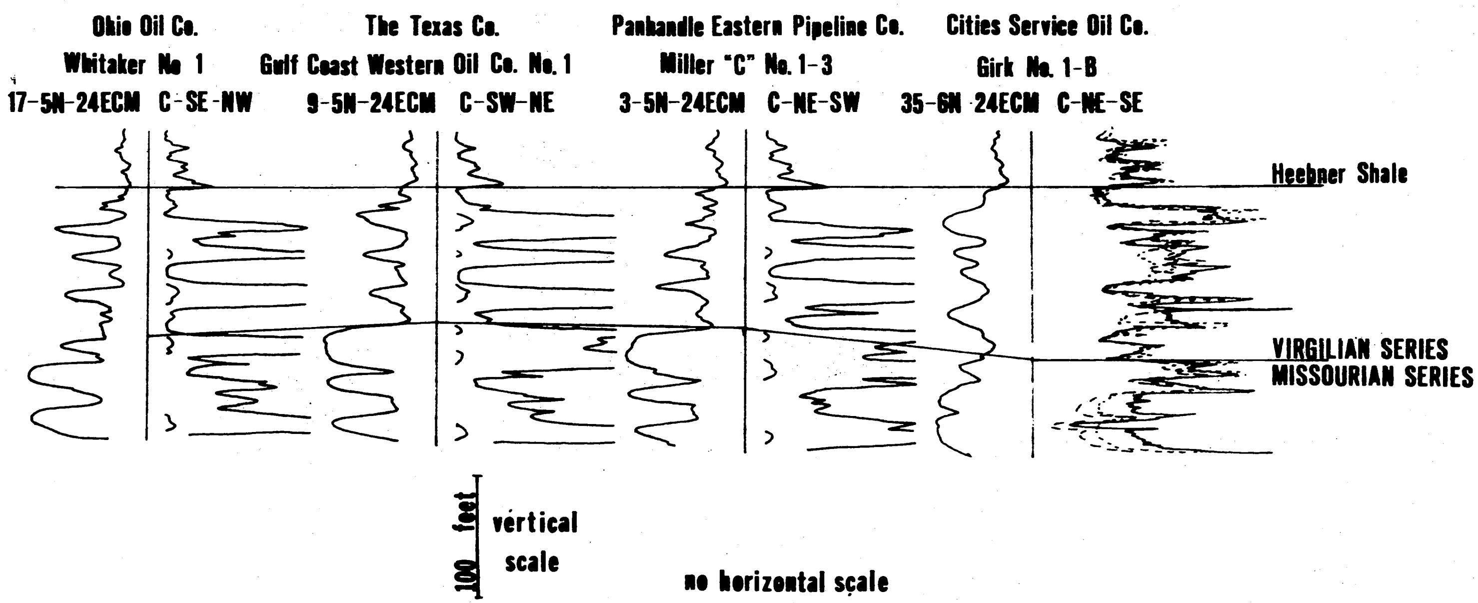


Fig. 5.-Correlation of the Missourian-Virgilian contact to well 3 in AA' (Pl. 3).

shelf-margin carbonate band (Pls. 3-8). In the study area this sandstone has two distinct members. The lower member used in this study probably consists of the middle and lower Tonkawa sandstones, that according to Khaiwka (1968), apparently merge vertically along the northern shelf into a single multistoried sandstone body. Therefore, the top of the middle Tonkawa sandstone of Khaiwka would be the top of the lower Tonkawa sandstone of this study. By Khaiwka's definition, the lower Tonkawa member would be 35 to 50 ft. below the "Haskell" so as not to be confused with the upper Tonkawa sandstone which lies directly below the "Haskell." Well 22, Pl. 4, and Fig. 16 illustrate the relationships of the Lower and Upper Tonkawa sandstone members to the "Haskell." The Lower Tonkawa Sandstone generally is described by commercial sample loggers as being white to gray, subangular to angular, fine-grained, slightly calcareous, micaceous, and slightly porous. The upper Tonkawa, according to Khaiwka, is separated from the lower sandstone member by shale. The upper Tonkawa sandstone generally is white to gray, subangular to angular, fine-grained, calcareous, micaceous, and slightly porous. Shelfward, the Tonkawa zone grades into a sandy shale.

The "Haskell" limestone according to Pate (1959) is not equivalent to the Haskell Limestone Member, Stranger Formation (Virgilian), at the surface. Pate (1959) considered the Tonkawa to be Missourian. The "Haskell" changes facies locally to calcareous shale in the southeastern part of the study area; however, to the northwest and in the Cities Service No. 1-B Girk, it is an oolitic packstone capped by platy algal wackestone.

The subsurface marker bed that lies next above the "Haskell" is an unnamed calcareous shale member (Fig. 3) that grades shelfward into buff to white, finely to medium-crystalline, slightly porous, and slightly dolomitic limestone containing buff, subvitreous opaline chert according to sample logs. Above this marker and extending to the base of the Toronto Limestone of the Oread Formation (Shawnee Group), is sandy shale that thickens basinward (Pls. 3, 4, 8).

Shawnee Group

The basal Toronto Limestone Member of the Shawnee Group (Fig. 2) marks a major transgression. This limestone is continuous throughout the study area and is commonly described in sample logs as being white to buff, finely crystalline, chalky, slightly porous, and oolitic.

The Endicott sandstone, which is locally called "Douglas" sandstone, is disconformable upon the Toronto (Khaiwka, 1968). The Endicott generally is described in sample logs as gray, fine- to medium-grained, angular to subangular, slightly argillaceous, calcareous sandstone containing fine to coarse flakes of mica.

The Heebner Shale Member, Oread Formation (Fig. 2) is the upper boundary of the study section. This marker bed is throughout the study area and is described as a black, laminated, calcareous shale in sample logs. Evans (1966) described the Heebner as containing phosphatic laminae of varying purity and high uranium content. This characteristic produces a very distinctive "kick" on radioactivity logs.

CHAPTER IV

GENERAL GEOLOGY

Regional Tectonics

The following discussion is based on the work of Frezon and Dixon (1975), and Stewart (1975). Surrounding the Anadarko Basin are eight significant positive tectonic features. These include the Nemaha Anticline, Central Kansas Uplift, Cimarron Uplift-Keyes Dome, Amarillo Uplift, Wichita Uplift, Arbuckle Uplift, Ouachita Uplift, and Ozark Uplift (Fig. 6).

The northward-trending Nemaha Anticline (Fig. 6) was a positive tectonic feature during Morrowan and Atokan time, although numerous periods of subsidence are recorded by the Desmoinesian strata that overstep the tilted and eroded Mississippian and older rocks. Slow subsidence continued through the Missourian and Virgilian and the Nemaha Anticline appears to have acted as a partial barrier to sediment entering the Anadarko Basin from southeastern sources (Krumme, 1973).

During Desmoinesian time, the Ozark Dome (Fig. 6) was rejuvenated (Huffman, 1958). Its climax of tectonic activity occurred early in Pennsylvanian time (Branson, 1962).

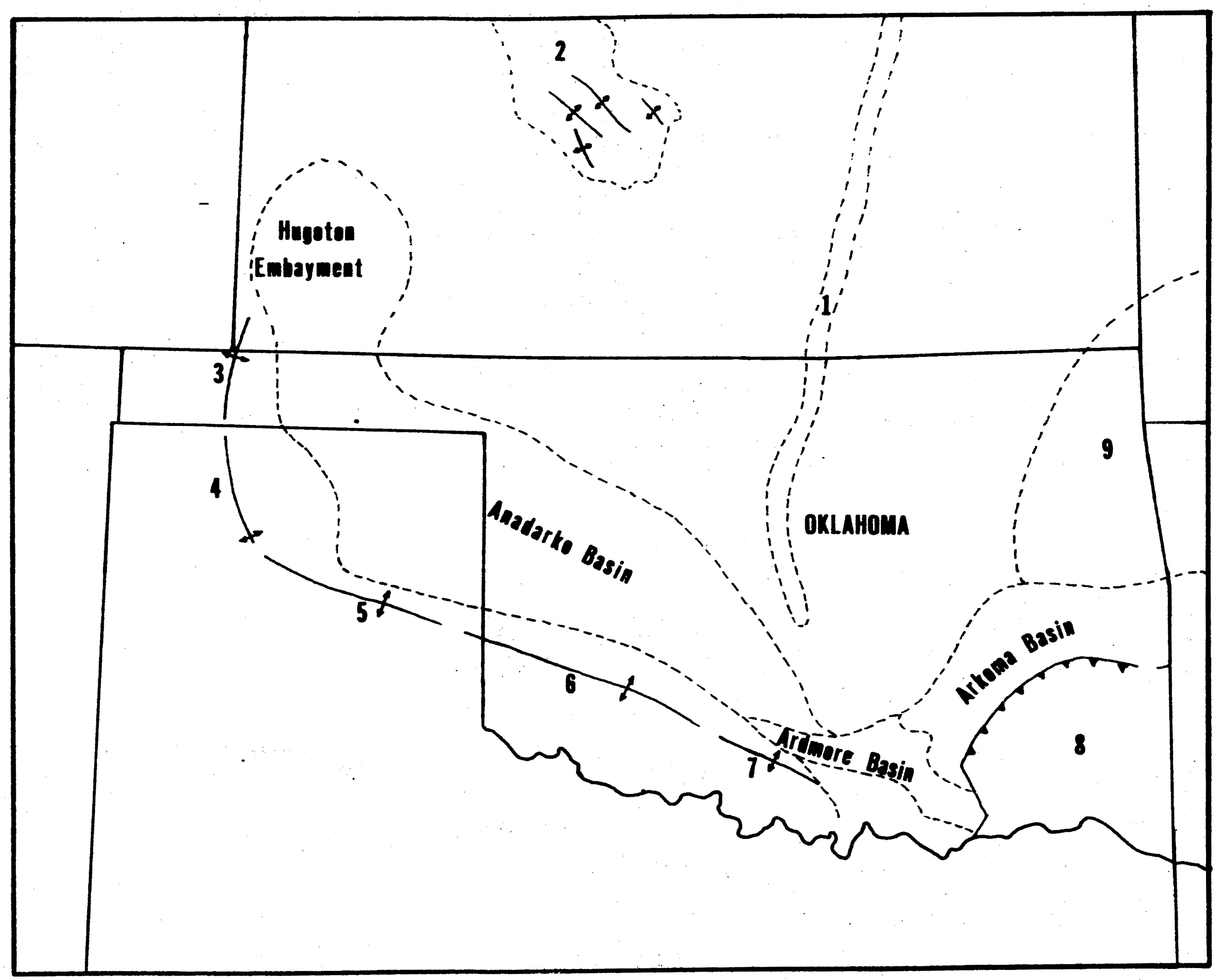


Fig. 6.-Regional tectonic map.

In the Missourian and Virgilian, the Ozark Dome was probably a broad low-lying land area which may have supplied minor amounts of detrital material to the adjacent basin (Huffman, 1958).

The Ouachita Uplift (Fig. 6), which began during Desmoinesian time, continued to shed clastics during the Missourian and Virgilian (Krumme, 1973; Rascoe, 1978). According to Krumme, the first incursion of coarse Pennsylvanian clastics from southeastern sources onto the shelf was marked by the lower Missourian Cleveland sandstone. Rascoe concluded that the Missourian and Virgilian coarse clastics were also derived from the Ouachita Mountains. In Rascoe's study, the Tonkawa sandstone was considered to be Missourian in age.

The already-established Central Kansas Uplift was rejuvenated during Missourian time, and it formed a large shelf platform in Kansas. The oldest Pennsylvanian beds that extend across this feature are Missourian.

To the west and south of the study area are the Cimarron Uplift-Keyes Dome, the Amarillo Uplift, Wichita Uplift, and Arbuckle Uplift (Fig. 5). The Cimarron Uplift-Keyes Dome began rising near the close of the Mississippian. A strong period of uplift of these features occurred near the close of Desmoinesian time, recorded by the appreciable amounts of sediments that were spread from it (Roth, 1949). The Cimarron Uplift-Keyes Dome continued to be positive throughout Missourian and Virgilian. The Amarillo, Wichita, and Arbuckle Uplifts were actively rising during Late Pennsylvanian time. Each was a major source area of Missourian and Virgilian clastics deposited along the southern limits of the Anadarko Basin.

Virgilian time marked the beginning of a dying phase in uplift and basin development. Tectonic features were less active.

Structural Geology

Structural configuration of the study area is illustrated by the structural contour map (Pl. 1). As mentioned above, the datum used in construction of the map was the base of the extensive Heebner Shale Member. This marker bed is identifiable in the subsurface by its characteristic calcareous and radioactive nature, as well as by its stratigraphic position.

Within the limits of the study area, the general structural strike of the Heebner Shale is about N. 45° E., and the datum shows a general tilted monoclinal character. Structural slope varies from approximately 30 ft. per mi. in the northwest to 80 ft. per mi. along the central belt to 45 ft. per mi. in the southeast. The reason for the variable slope probably is differential compaction of the underlying clastic wedge of post-Missourian rocks of the study stratigraphic column. Similarities displayed in the structural contour map (Pl. 1) and isopachous map (Pl. 2) support this hypothesis. In some respects, southeastern tilt of the monocline mainly represents subsidence of the Anadarko Basin after deposition of the Heebner.

The southeastward regional dip is interrupted locally by minor anticlines and synclines. The directions of these minor anticlinal and synclinal trends are shown in Figure 6. Their overall discontinuous and sinuous patterns suggest an origin of differential compaction. The major evidence toward this conclusion is illustrated in Figure 6 by the location and trend direction of S1 and S2, which correspond in position to a nose-like thickening feature on the isopachous map (Pl. 2). Since the isopachous map was constructed to delineate the areal distribution of a clastic wedge, the nose-like feature represents an increase in a clastic interval. Cross-section CC' (Pl. 6) shows that the increase of clastics was at the expense of the underlying carbonates. Because clastics generally compact more per unit volume than carbonates, it was concluded that S1 and S2, which are primary contributors to a major synclinal affect illustrated on the structural contour map (Pl. 1), probably are results of differential compaction.

Three prominent anticlinal trends have been noted as A1, A2, and A3 on Figure 7. The distinctive character of these trends suggests a tectonic origin, although only A1 and A3 have been considered to be so. A3 is a domal fold with approximately 50 ft. of closure. Surrounding this structure is a series of anticlines and synclines which have a semi-radial "draping" pattern off its flanks. Well

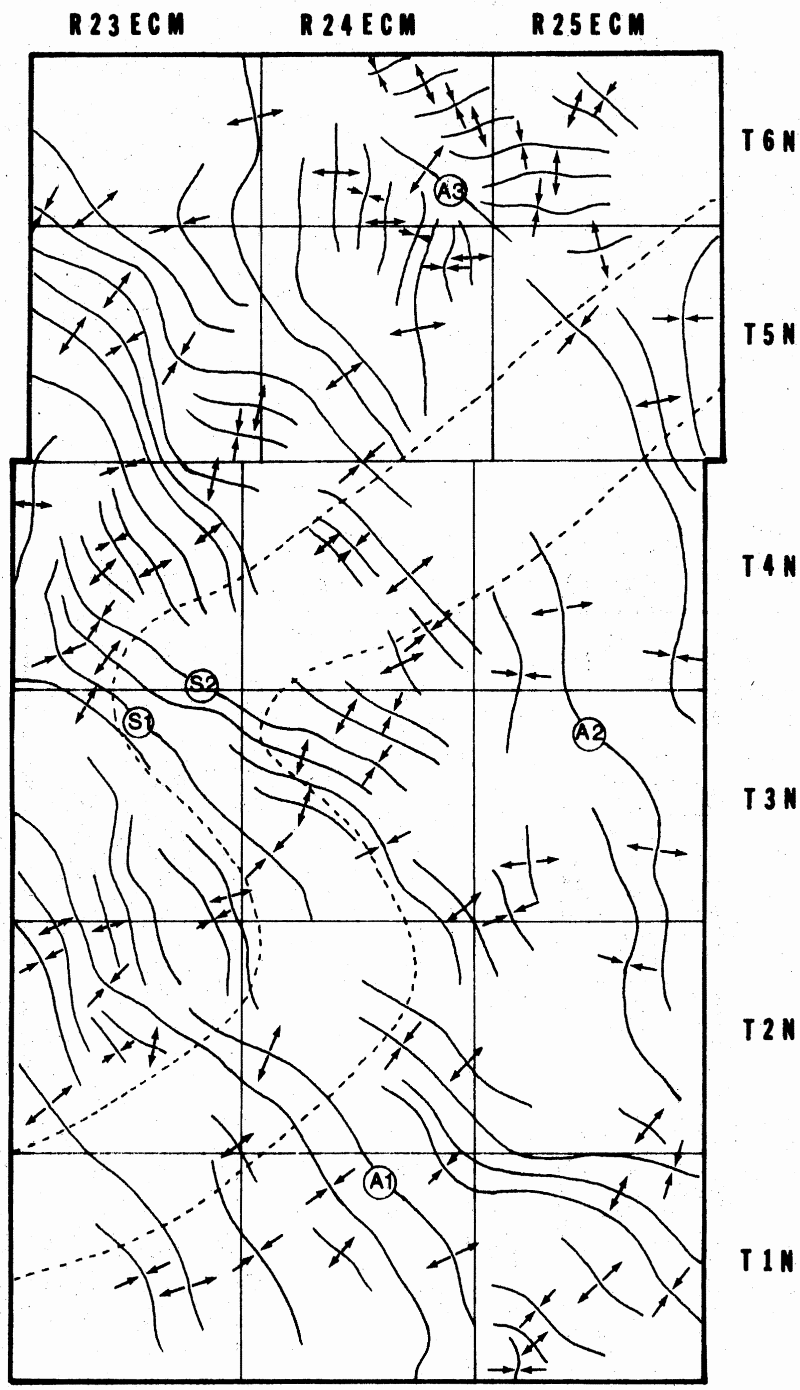


Fig. 7.-Minor anticlinal and synclinal trends and the three populations determined by visual density differences of the trends.

number 16 in cross-section CC' shows an elevated section of lower Missourian rocks which is evidence that this structure was active before the deposition of the Heebner Shale and therefore is almost certainly tectonic. The structural contour map (Pl. 1) indicates that the structure was also active in post-Heebner time. A3, as well as A1, correspond to anticlinal trends interpreted by Khaiwka (1968) in structural contour maps drawn of the Mississippian unconformity and the Morrowan Series. These similarities in mapped structures support the hypothesis that A1 and A3 are of a tectonic origin.

Three populations can be determined, according to visual density differences of these minor structural trends (Fig. 7). The areal extents of these populations correspond to the three belts of structural slope mentioned above (Fig. 5). The structurally high belt has a relatively large number of structural trends. The central structural belt has relatively few structural trends within it. The structurally low belt has a density appearance which is intermediate to that of the central and structurally high belts.

Several factors seem to be responsible for these density differences, and most of those are probably related to the clastic wedge defined by the isopachous map (Pl. 2). In any effect, these factors most likely have caused local differences in compaction of the clastic wedge. One factor may be lenticular Douglas sandstone bodies which have a shingled arrangement that can be determined by the cross-sections (Pls. 3-8). Because of their lenticularity, no attempt was made to correlate these minor sandstone bodies; however, it would seem reasonable to expect that where these sandstones have built-up or have overlapped, they might create differences in compaction with relation to the surrounding shales. Other factors probably are the thickness and rate of thickening of the clastic wedge. The exact functions of these factors was not determined in this study; however, their effects probably are the major reason in formation of populations determined by density differences of structural trends as illustrated in Figure 7.

CHAPTER V

CARBONATE DEPOSITIONAL ENVIRONMENT

Regional Paleoclimate

According to Wilson (1975), climatic differences along with tectonics have left strong imprints in the Pennsylvanian rocks. The seas were generally warm, tropical, and of normal salinity, as indicated by the fauna.

Clastic Wedge and Paleotopography

As mentioned previously, in order to delineate areal distribution of the clastic wedge between the Heebner Shale Member and the top limestone of the Lansing Group, an isopachous map was constructed (Pl. 2). In the study area this wedge strikes approximately N. 45° E. The rate of thickening perpendicular to strike clearly is not uniform. General configuration of the wedge, in the dip direction, is one of little change in thickness in the north (Pl. 2), bordered by a trend of marked increase in thickness, grading into a belt of gentle thickening in the south. An exception to this statement is a nose-like feature located between Beaver City and Elmwood that trends northwestward (Pl. 2). Along this line a less variable rate in thickening is shown. The clastic wedge shows a maximal thickness of 745 ft. in the southeasternmost part of the mapped area, and thins northwestward to a minimum of approximately 100 ft. (Pl. 2).

As explained earlier, facies changes in the Lansing Group required that the bottom marker of the Heebner-Lansing section be lowered from place to place, across apparent time boundaries (Fig. 3). The part of the study area in which these adjustments were made is shown on the isopachous map (Pl. 2).

Paleotopography on the Lansing Group can be described as a mold, distinguishable by the clastic-wedge cast. Accordingly, areas of thickness can be classified as submarine paleotopographic "lows" and areas of thinness are taken as evidence of submarine paleotopographic "highs." Disregarding the zone in which the bottom marker was lowered, this line of reasoning is operationally reliable. Figure 3 illustrates that within the transitional zone and southeastward, if the bottom marker had not been lowered, more gentle southeastward dip would have been detectable. The three "bands" delineated in the clastic wedge are interpreted as showing environments of the shelf, shelf margin, and basin, respectively (Fig. 8).

The nose-like feature cited in reference to the isopachous map (Pl. 2) and located approximately midway between Beaver and Elmwood may have been an embayment in the shelf. Cross-section CC' (Pl. 5) and DD' (Pl. 6) show that since approximately medial Missourian time, the presumed embayment has existed. This judgment is illustrated by the increase

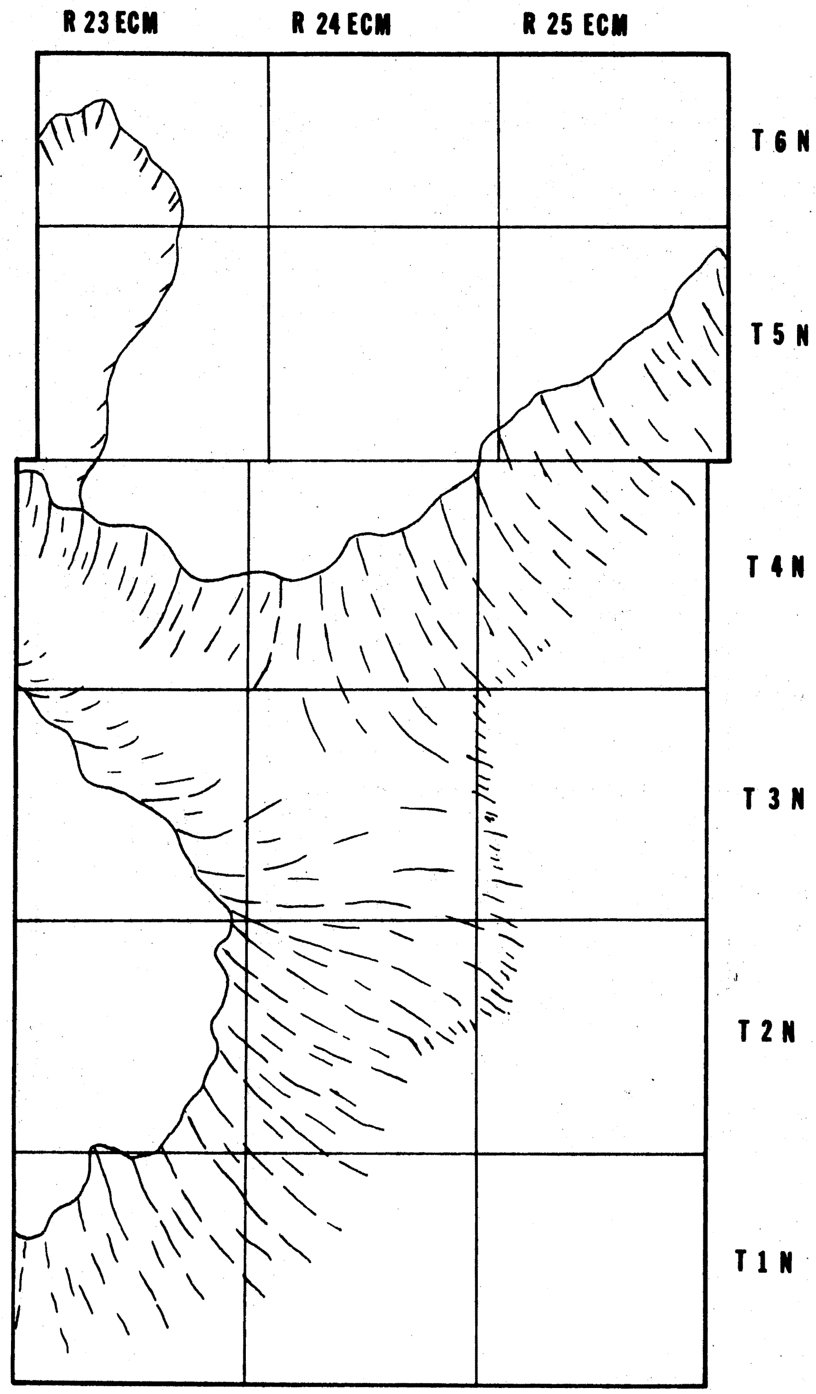


Fig. 8.-Exaggerated and idealized
Lansing paleotopography.

in thickness of shale and decrease in carbonate rock. Hypotheses to explain its beginning include differential subsidence or faulting, but no evidence of faulting was observed in the study area during the course of this study. In my opinion the probable "cause" was differential subsidence. Subsidence could have resulted in deeper water, which would have hampered carbonate growth and should have been accompanied by influx of mud. Enhancement of the embayment was probably made by differential advancement of the shelf, primarily to the west. This is illustrated in cross-section D-D' (Pl. 6) by the addition of a thick massive limestone unit in the area of wells 1 to 10 and between shale "breaks" x and y. The end result is an orientation of the postulated embayment approximately perpendicular to N. 45^{o} E., the depositional strike.

Environments of Deposition

The boundary markers for the construction of the log maps (Pls. 10-12) were chosen primarily for their reliability in correlation and for the Missourian strata contained within it. On the shelf, the top of the uppermost limestone marks the Virgilian-Missourian contact as correlated from the Cities Service No. 1 Girk (Fig. 5), and the lower marker has been correlated to a questioned Lansing-Kansas City contact reported on the Clark County, Kansas, type log (Type Logs of Kansas, 1967). Therefore, primarily according to these correlations the Missourian strata will be referred to as "Lansing" and the upper, middle, and lower sections as upper, middle, and lower "Lansing."

Seven distinct type logs were used in clustering the log characters for each "Lansing" section (Fig. 9). The numbering system was devised for the type logs so that comparisons could be made among the "Lansing" sections. Overall log characteristics were matched in each section and a corresponding number was assigned. The areal distributions of general upper "Lansing" depositional environments as interpreted from the isopachous map (Pl. 2) were used in assigning type logs of the upper "Lansing" to environments of deposition. The upper "Lansing" type logs were then used as guides in designating depositional environment to type logs of the middle and lower "Lansing" sections.

The log traces associated with the major environments have a general typical pattern. In describing these patterns, several electrical log properties were used. Because most of the determinations of lithology and the physical characteristics obtained through electrical logs are estimates, all available corresponding commercial sample logs and some of the bit cuttings from the study area were used in checking the descriptions.

The shelf traces type log 1 illustrates a general thinning and breaking up of the massive shelf-margin carbonates to form interbedded limestones and shales. The shelf-margin traces, type logs 2, 3, 4, and 6, show basically a relative thickening of the section that is judged to be associated

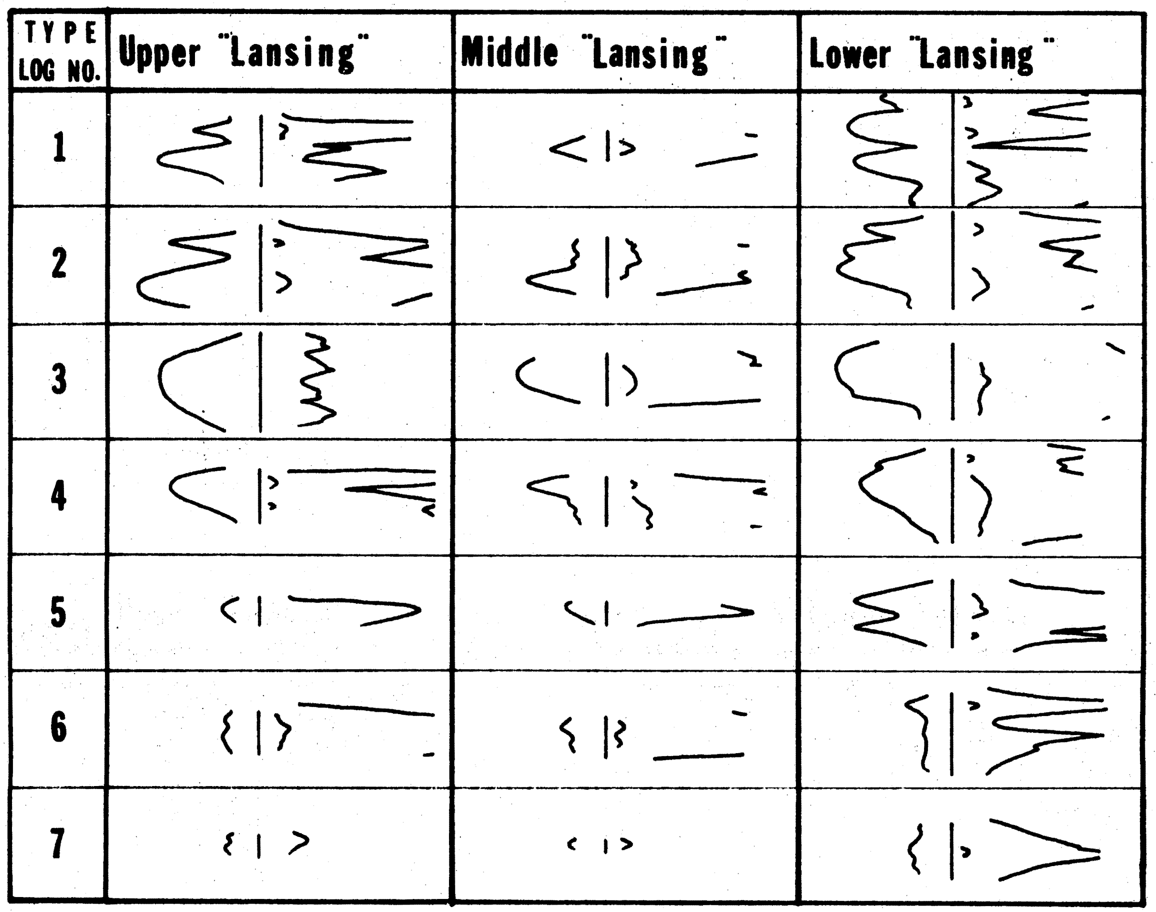


Fig. 9.-Type logs used in clustering log characters on the log maps (Pls. 10-12).

with massive carbonate buildups that are progressively denser, more shaly, and thinner basinward. Trends of the clustered log characters in the shelf-margin environment paralleled "bands" previously delineated by the structural contour (Pl. 1) and isopachous (Pl. 2) maps. The environment of type log 5 will be discussed later in the study. Type log 7 shows primarily dense limestones that grade basinward into calcareous shales and shales.

Observations made of the "Lansing" sections from the cross-sections (Pls. 3-8) and log maps (Pls. 10-12) indicates that maximal interval thickness might indicate shelf or shelf-marginal environments and minimal interval thickness might imply shelf-marginal or basinal environments. Therefore, interval thickness between shale "breaks" may be useful as a general environmental indicator.

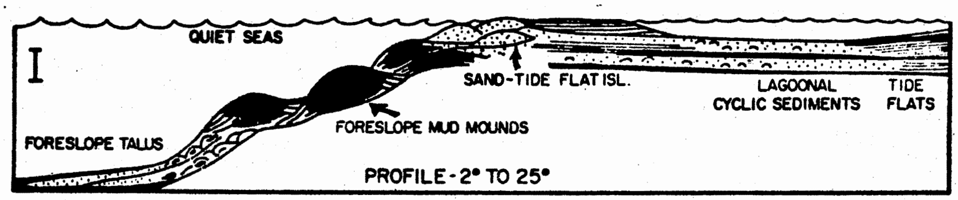
Wilson (1975) illustrated three major shelf-margin profiles. The presence of platy algal wackestone in core samples suggests that the shelf margin environment in the study area (Fig. 10) generally matches Wilson's type I model of "downslope mud accumulations." According to Wilson, this profile comprises linear trends of bioclastic lime mud or belts of mounds located on the foreslope of the shelf margin with upslope sand beaches and islands. The "specialized" sessile organisms that baffle the downslope sediments are most likely phylloid algae. Surrounding the mounds and located downslope are probably channel-fill calcarenites. (Probably such calcarenites were recorded by Heckel (1972), in phylloid algae mounds associated with the Lansing Group in Kansas.) In the study area, conclusive evidence of sand beaches and islands upslope has not been found, although platy algal wackestone that caps an oolitic packstone in rocks of the lowermost Douglas Group suggests that carbonate bars may have formed in shallow marine water. Paleodepositional slope was calculated to be about 1^{o} southeastward, as determined from the isopachous map (Pl. 2). The diverse lithology in the shelf-margin environment is evident by the wide variability in electric log traces.

Generally, limestones of the shelf environment were oolitic and fossiliferous, containing fusulinids, bryozoans, brachiopods, crinoids, and platy algae, according to observations of the above-cited core and of sample logs. These characteristics indicate that depths of water probably were less than 100 feet. Also observed in the core were oolitic packstones with algal micrite intraclasts. This implies that either some of the algal mounds were above wave base or that algal-mound debris mixed downslope with oolitic muds due to gravity slumps or slides.

The shelf environment extended over most of Kansas (Rascoe, 1962). According to the fauna, seas were generally warm and of normal salinity. Conditions were such that the shelf was the most likely source of the carbonates. Oolites necessarily were found in the shelf environment (Plumley and others, 1961), and much of the lime mud of which the algal mounds consisted probably originated upslope, but may represent degenerate algal blades.

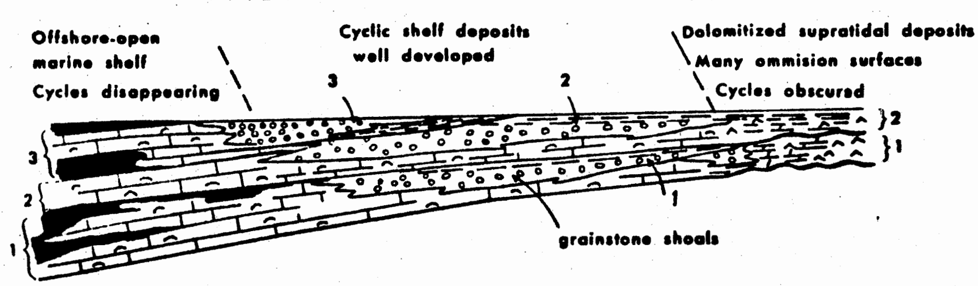
Although water depth was shallow on the shelf, no widespread erosional surface could be detected from the data available to me. Therefore, the relative lowering of sea level implied by cyclic sedimentation (Wanless and Shepard, 1936; Weller, 1930; Wells, 1960) was not determined in the study area. The record of cyclic sedimentation in the Lansing and Kansas City Groups of the study area may be represented by the widespread and correlative shale breaks. The relative lack of variation in the shelf-type electric-log trace (Fig. 9, No. 1) probably is due to the open marine conditions that expressed only subtlely the cyclic sedimentation of nearshore portions of the shelf (Fig. 11).

Primarily, muds and dense, dark limestones were deposited in the basinal environment. The distance of clastic sources permitted only the slow deposition of muds and the deep, cool, nonoxygenated waters of the basin let to deposition only of dense, dark limestones. Also, in the basinal environment, "peel-offs" are identifiable where limestones have thinned to the point of being operationally uncorrelatable, and they are interfingered with shales. This is illustrated in cross-sections (Pls. 3-8). Figure 3 illustrates that this facies change occurred prior to the deposition of the Tonkawa sandstone. This figure illustrates that the Tonkawa sandstone lies above the "peel-off" facies of the basinal Lansing limestones.



From Wilson (1975)

Fig. 10.-Type I model of "Downslope Mud Accumulations".



From Wilson (1975)

Fig. 11.-Shelf open marine conditions masking cyclic deposition.

In late Missourian time the embayment previously noted from the isopachous map (Pl. 2) may have been a tidal pass that funneled carbonate sands into the basin. Evidence toward this conclusion is shown by the isopachous map (Pl. 2), log maps (Pls. 10-12), and sample logs. On the isopachous map, located basinward of the "tidal pass mouth" is a "fan"-shaped outline generally T. 3 N., R. 24 ECM and the northern half of T. 2 N., R. 24 ECM. The limit for the "fan" has been enhanced by the zone in which "time lines" used in mapping were lowered (Pl. 2). Because the limestones end abruptly and shale intervals are thick beneath them, lowering the bottom boundary of the unit of rock shown by the isopachous map (Pl. 2) makes the clastic wedge appear to have a marked increase in thickness around the "fan." The "fan" shape is evidence toward funneling. Further evidence is given by log maps of the upper, middle, and lower "Lansing" sections, of which each shows a "fan"-shaped zone located basinward of the inferred tidal pass, type log 5 (Fig. 9). Some sample-log descriptions of the lithology associated with these zones have reported abundant oolites and assorted fossil fragments. These sample logs are shown in Figure 12, and are listed in Appendix B.

General Observations

As mentioned above, thicknesses of intervals between shale "breaks" may be useful as environmental indicators. According to observations made of the "Lansing" sections,

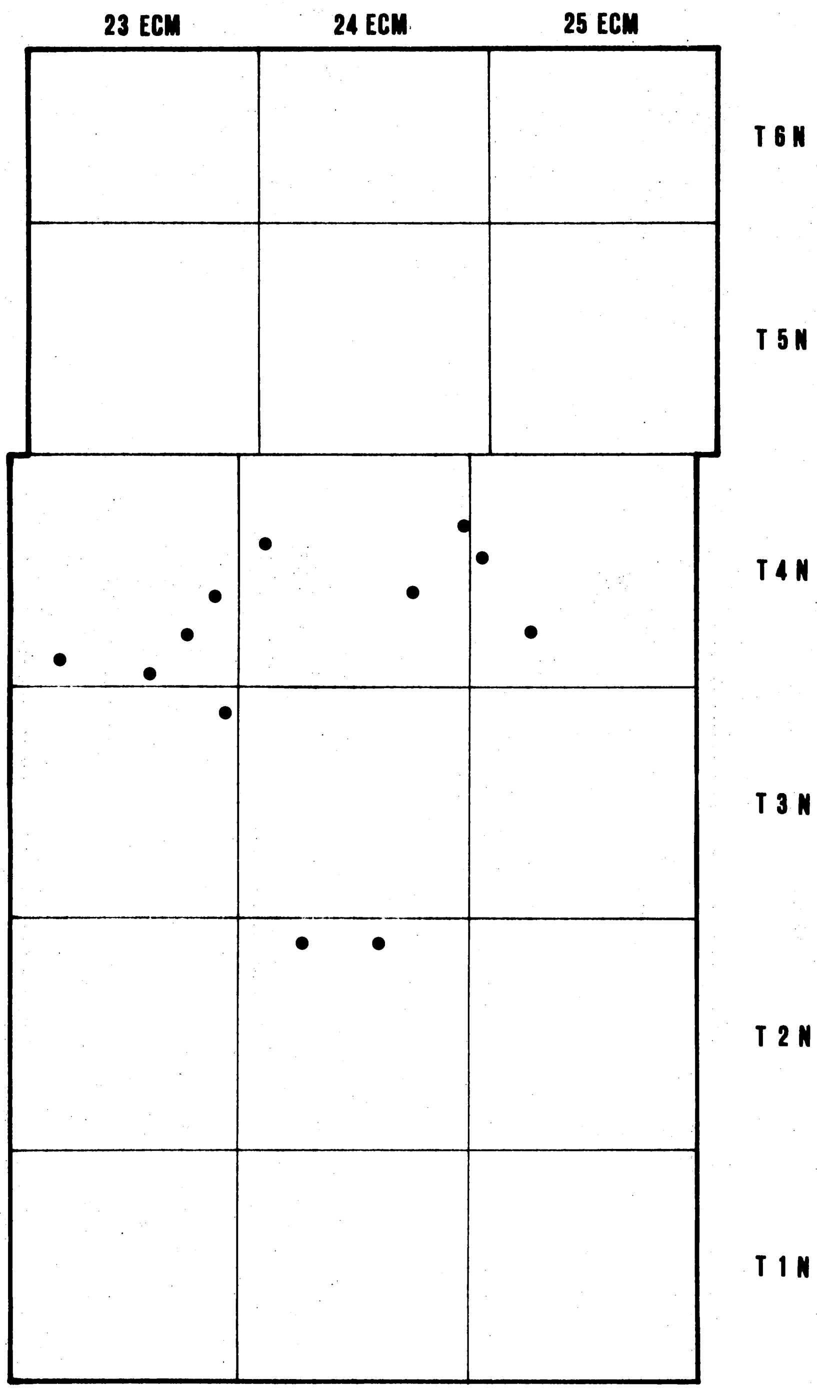


Fig. 12.-Location of wells in the Carbonate "Fan" facies in which sample logs have reported abundant oolites and (or) assorted fossil fragments.

from place to place maximal interval thickness might imply environments of the shelf or shelf-margin, and minimal interval thicknesses could indicate shelf-margin or basinal environments. Primarily, the shelf and basinal environments show laterally persistent and subequal thicknesses among strata in the same interval. Whereas, the shelf-margin environment is represented as a zone of variable thicknesses that range between minimum and maximum values and is located between the shelf and basinal environments. By noting the relative positioning of these major environments among the correlated sections and among the units of the Lansing, stacking patterns can be recognized in the Lansing section.

Two such stacking patterns can be identified in the cross-sections (Pls. 3-8). Figure 13 shows these patterns schematically, associated with cross-sections AA' (Pl. 3) and FF' (Pl. 8). Both patterns basically suggest a gradual rise in sea level, because the stacks have somewhat orderly and similar arrangements. It would seem that rapid sea-level fluctuations would produce markedly different patterns, wherein similar environments would be displaced horizontally in the stacking arrangement with increments of sea-level rise. Variations in the stacking also may be due to other factors, including differential buildups of carbonate and differential influx of clastics.

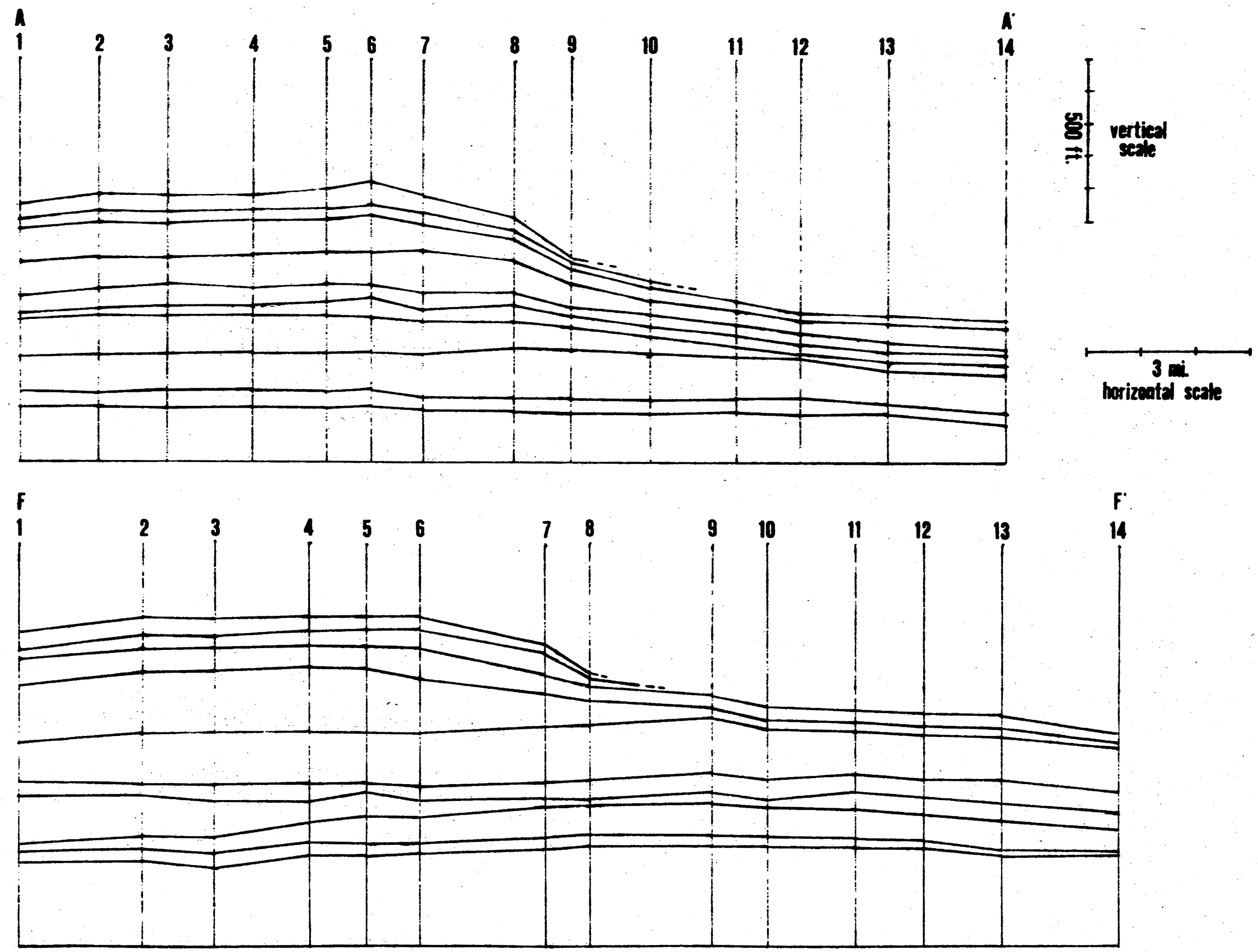


Fig. 13.-Stacking pattern displayed in cross-section AA' (Pl. 3) and FF' (Pl. 8).

CHAPTER VI

TRENDS AND DISTRIBUTIONS OF SANDSTONES

Some significant properties related to genesis of sandstone can be recognized from electrical logs (Goetz and others, 1977). Descriptive terminology for the electrical log characters will be as defined in their paper. "Bell", "funnel", and "cylinder" shape (Fig. 14) imply fining upward, coarsening upward, and uniform grain size, respectively and "smooth" and "serrate" imply massive and interbedded sandstones and shales, respectively.

The major sandstone bodies in the study area are the Lower and Upper Tonkawa sandstones and the Endicott sandstone. The limits of the sandstone bodies are shown on the sand-distribution map (Pl. 9). This map was constructed from data collected through electrical-log correlations and from commercial sample logs. Major geological factors that probably have affected the distributions and trends of the sandstones are the amounts of clastic sediment available, topographic relief, and types and amounts of transportational energy. Detailed examination of the internal sedimentary structures of sandstone bodies was not possible in this study, due to the lack of cores. Therefore, interpretations of depositional environments were made on the basis of

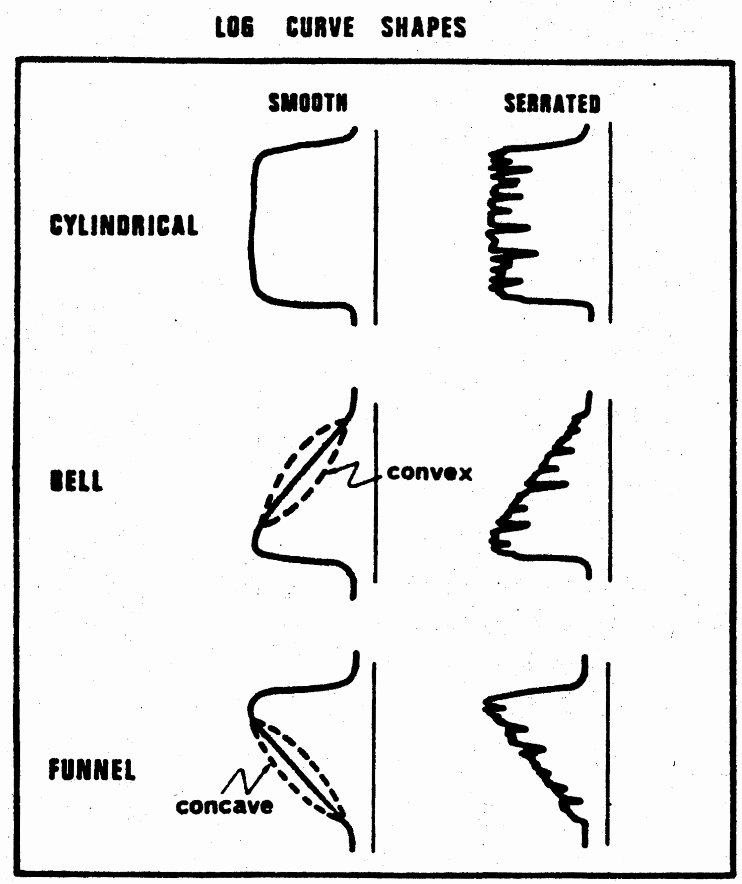


Fig. 14.-Classification of self potential (SP) log curve shapes.

evidence put forth in previous studies by Khaiwka (1968) and Pate (1959), and from distributional patterns of the sandstone bodies.

In judging the depth of water during deposition of the Tonkawa sandstone, the following rationale was used: thickness of the interval between the lower contact of the Tonkawa and the base of the Toronto Limestone Member was measured. The average thickness of the section from the base of the Toronto to the top of the Lansing, in the area interpreted to have been a shelf environment is approximately 70 ft. By subtracting 70 ft. from the previously determined interval thickness, one calculates an approximate difference of elevation from the base of the Tonkawa sandstone to the top of the Lansing shelf carbonates (Fig. 15).

At this point, if one adds an estimated water depth of the shelf environment, the final value would be an approximation of the maximal water depth during deposition of the Tonkawa sandstone (Fig. 15). This would be a maximum value because Tonkawa marks a regressive period, and water depth on the shelf should have been less during deposition of the Tonkawa than during the deposition of the shelf carbonates. However, no evidence was found to suggest that the shelf environment in the study area was exposed to subaerial conditions. Taking into consideration the presence of oolites and the types of fauna contained in the shelf carbonates, water depth was estimated to have been 60 ft. on the shelf.

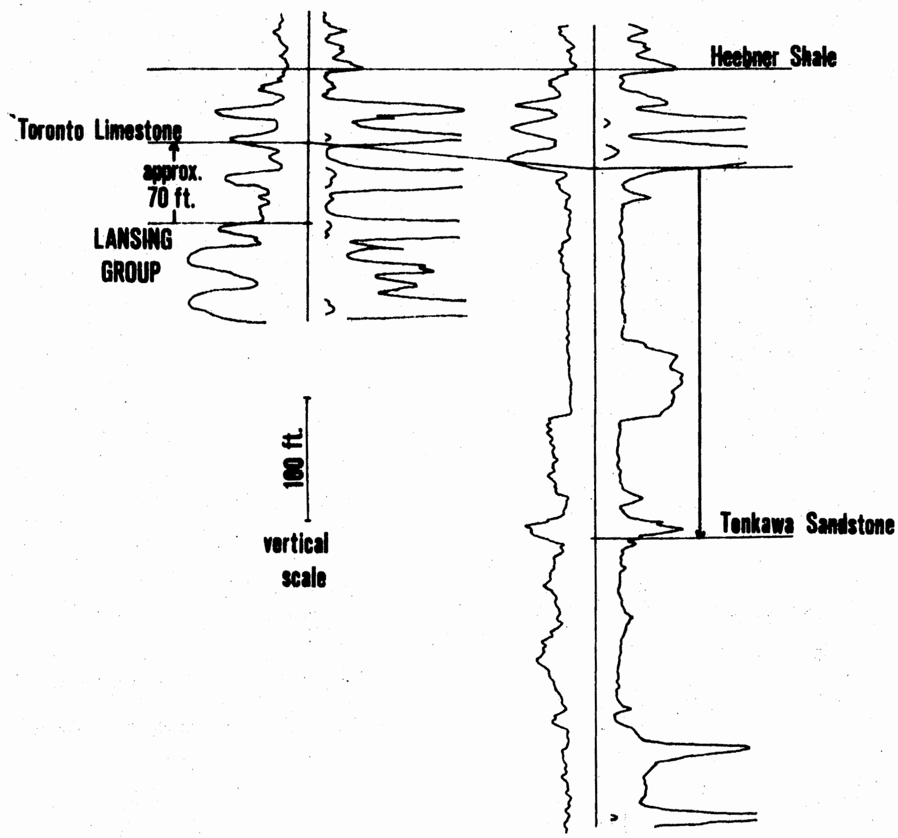


Fig. 15.-Illustration of water depth determinations.

Tonkawa Sandstone

As described above, primarily on the basis of data gathered through the isopachous map (Pl. 1), cross-sections (Pls. 3-8), and commercial sample logs, the upper Lansing section is interpreted as having been deposited on the shelf, shelf-margin, and in the basin. Therefore, it follows that the lower part of the mapped clastic wedge (Douglas Group) is interpreted as foreset-slope strata that were deposited during a regression.

The Lower Tonkawa sandstone was deposited in the basinal environment; it trends generally parallel to the shelf margin. The sandstone body is confined southwestward of a line from Sec. 32, T. 1 N., R. 23 ECM to Sec. 13, T. 3 N., R. 25 ECM (Pl. 9). Within this area are several localities where the Lower Tonkawa sandstone is not present. Probably the Lower Tonkawa sandstone was never deposited at these places. By the rationale described above, depths of water are estimated to have been about 400 ft., which would have put the sands below wave base. Distributional processes probably were primarily currents and storm waves. Locally, these forces developed sand that trended subparallel to the shelf margin. These buildups are located generally along lines Sec. 32, T. 1 N., R. 25 ECM to Sec. 1, T. 1 N., R. 25 ECM and Sec. 11, T. 2 N., R. 24 ECM to Sec. 24, T. 2 N., R. 25 ECM on the sand-distribution map (Pl. 9). Log characteristics within the sand buildups primarily indicate coarsening-upward grain-distribution patterns (Fig. 16).

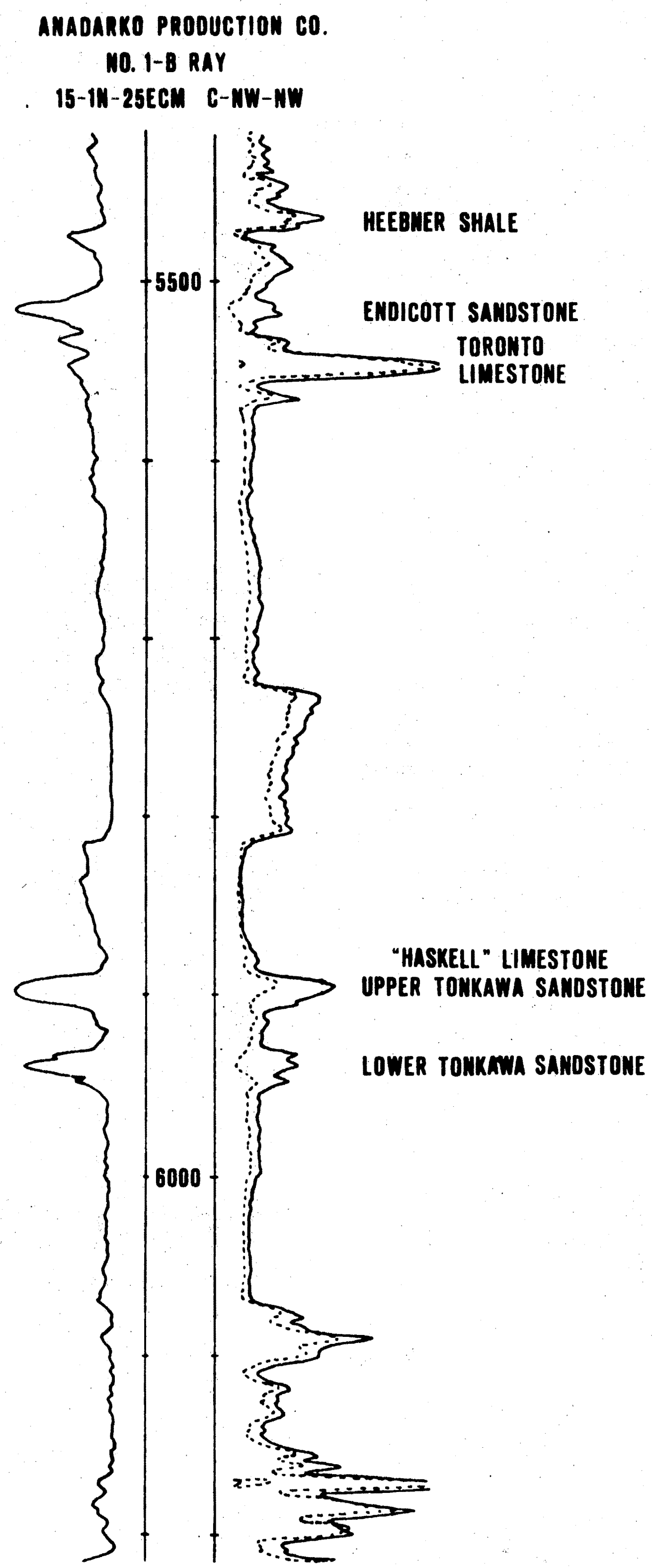


Fig. 16.-"Funnel" shape of lower and upper Tonkawa sandstones.

The Upper Tonkawa sandstone is distributed primarily atop the basinal and proposed carbonate "fan" environments of the upper "Lansing" section. Distribution of this sandstone generally is widespread in these environments, with the exception of a wedge-shaped area that is located approximately within the triangle defined by points in Sec. 2, T. 1 N., R. 23 ECM, Sec. 3, T. 2 N., R. 25 ECM, and Sec. 34, T. 1 N., R. 24 ECM and southwestward on the sand-distribution map (Pl. 9). Within this tract the Upper Tonkawa sandstone probably was not deposited. Water depth during deposition of the sand is estimated to have ranged from about 370 ft. in the basinal environment to about 200 ft. in the presumed tidal pass.

Two explanations are offered for deposition of sand in the tidal pass. The tidal pass may have funneled the clastics into the basinal environment, or sands might have migrated up the pass. Both explanations have serious negative implications. If funneling was the mode of deposition, evidence of channeling has not been observed, and the sandstones have thinned up-dip to the point of being nondetectable on electric logs. If the sands cannot be correlated upon the shelf, then one has no evidence for funneling. On the other hand, migration up the tidal pass would require that the sands move upslope in water that was below wave base. However, according to the isopachous map (Pl. 2), paleotopographic slope should have been less than 0.01° in the tidal pass and storm waves could account for the migration.

Khaiwka (1968, Pl. 7) described the general depositional environment of the Upper Tonkawa sandstone in this part of Oklahoma as having been deltaic. His isopachous pattern illustrated a major bifurcation with a consequent interbranch area that widened basinward. The sands were described as having abrupt lateral and vertical facies changes (Khaiwka, 1968, p. 55).

Within the limits of the present study, abrupt vertical contacts are not a general electrical-log characteristic. In fact, the electric logs indicate primarily a coarsening-upward cycle (Fig. 16). Further evidence to suggest that these sands probably were not deposited by the mapped distributary system by Khaiwka (1968, Pl. 7) within the present study area is the relatively nondefinitive isopachous pattern. The small distributary system that was mapped by Khaiwka and interpreted as a "delta" in the study area was indeed small. Its existence is difficult to establish on the basis of data available to me. However my opinion may not be conclusive, because of the possibility that the clastics in fact may have been related to a delta that extended close to the present study area on the east, and from which the sands may have spilled into the basin as delta-front bodies that show no significant downcutting. Therefore, it is my opinion that the Upper Tonkawa sandstone in the study area could be reworked deltaic sediments that have been funneled through the proposed tidal pass and deposited basically in a sheetlike manner with locally thicker bodies.

Trends of the sand buildups were difficult to establish in this study, although relying on Khaiwka's isopach map (1968, Pl. 7), trends can be described generally as parallel to the shelf margin. Sediment was probably spread by currents from an easterly direction. Evidence for a downstream-westerly current direction is elongation of the carbonate "fan" deposits mapped in Plate 10.

Endicott Sandstone

The Endicott sandstone was also included in the study by Khaiwka (1968). He described its origin as deltaic channel-fill. Its distribution pattern suggests bifurcating channels, and in some places these cut well into the underlying Toronto Limestone Member (Khaiwka, 1968). It was also stated that the Endicott delta probably was deposited adjacent to a coastal plain of relatively high relief. Evidence cited leading toward this conclusion were the amounts of down-cutting and the sizes of sand grains (Khaiwka, 1968, p. 66). The sand distribution map (Pl. 9) shows this kind of distribution and down-cutting is indicated by the cross-sections (Pls. 3-8).

Sources of the Clastics

According to Krumme (1973) and Rascoe (1978), Missourian and Virgilian coarse clastics of the Anadarko Basin were derived from the Ouachita Mountains. Krummes (1973, p. 235) stated that the first incursion from this source was recorded by the Cleveland sandstone (Missourian). Therefore, other incursions could be represented by the Cottage Grove sandstone (Missourian) and Tonkawa sandstone (Virgilian). Deposition of these coarse clastics into the basin primarily was from deltas along the eastern and northeastern flanks of the Anadarko Basin (Rascoe, 1978).

On the other hand, according to Khaiwka (1968, p. 56), the Endicott sandstone implies a northern clastic source. The sand distribution map (Pl. 9) of this study indicates a similar source direction. Possibly the source areas may have been as distant as the ancestral Rocky Mountains. These clastics would have been transported across the Hugoton Embayment, a shallow northern extension of the Anadarko Basin (Fig. 6), but this would seem to be unlikely. However, during periods of low sea level, areas of the Hugoton Embayment in which clastics from the west may have accumulated could have been exposed, and the sediments might have been eroded and transported to deeper parts of the Anadarko Basin. Coarse clastics might also have been transported directly to the Anadarko Basin from western sources across the shelf during stands of relatively low sea level.

CHAPTER VII

PETROLEUM GEOLOGY

Four oil and (or) gas fields in the study area produce from reservoirs in strata between the Heebner Shale Member of the Oread Limestone, Shawnee Group, Virgilian Series and the Pleasanton Group, Missourian Series. Locations and names of these fields are shown in Figure 17.

Como Field

The Como Field (Fig. 17) produces oil and gas from the Tonkawa sandstone. It trends parallel to the structural strike as determined from the structural contour map (Pl. 1). This trend is also parallel to the shelf margin and corresponds in position to the local sand buildups of the Lower and Upper Tonkawa sandstones. Apparently, hydrocarbons in this field were trapped stratigraphically by permeable sandstone buildups that are capped and flanked by shales.

Ridgeway Field

The Ridgeway Field (Fig. 17) shows no clear-cut trends. It produces gas from the Tonkawa sandstone. This field is located primarily above the sheet-like Upper Tonkawa

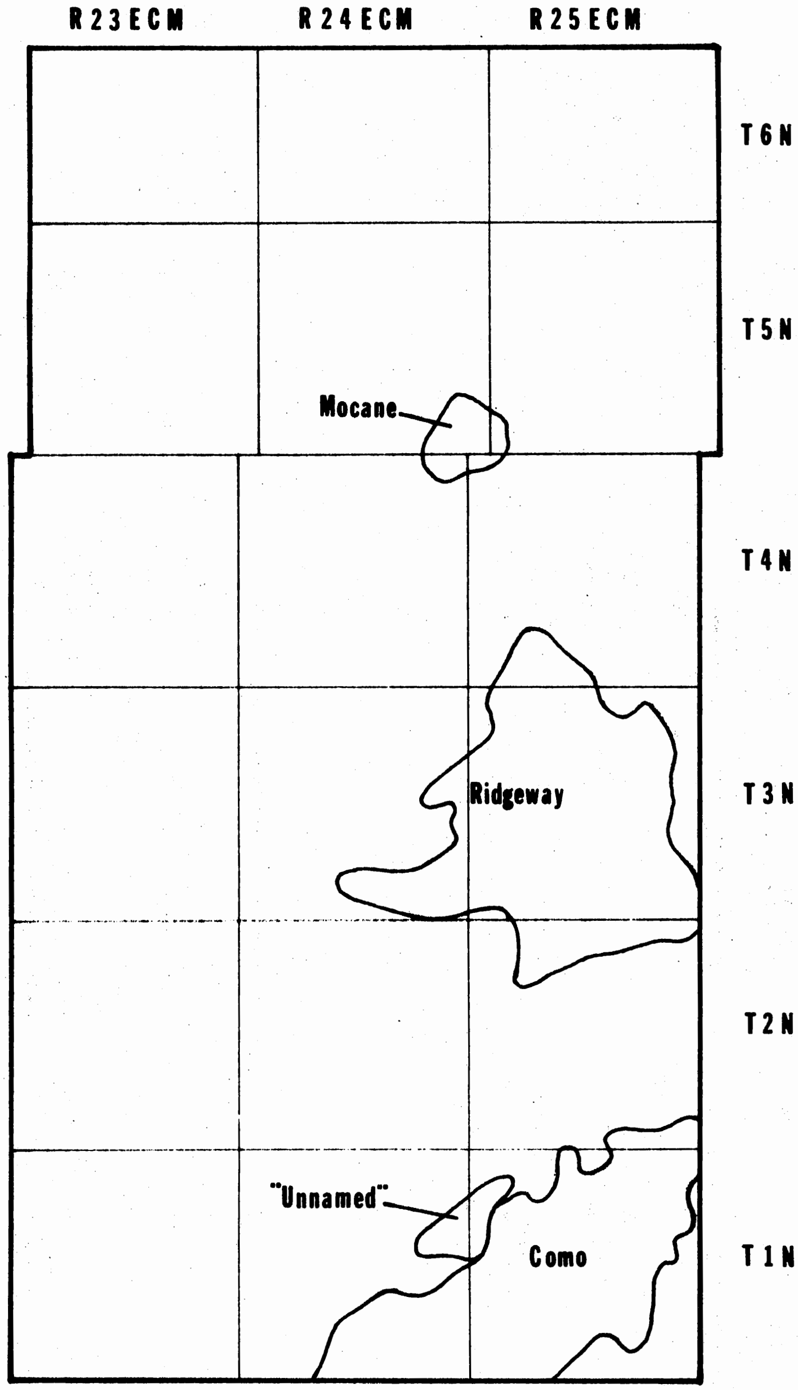


Fig. 17.-Location of oil and gas
fields in the study area.

sandstone that contains local sand buildups which are subparallel to the shelf-margin trend. It is also located on the anticlinal trend noted as A2 in Figure 7. These structural and stratigraphical trends are approximately at right angles, which probably accounts for the field's somewhat circular shape. Trapping is judged to be by folding of the sheet-like facies of the Upper Tonkawa sandstone.

"Unnamed" Field

An unnamed field is located northwestward of Como Field (Fig. 17). Gas is produced from Endicott channel-fill sandstone. Although the unnamed field is on an anticlinal fold, noted as A1 in Figure 7, it trends northeast-southwest along the Endicott channel trend. Therefore, the trapping mechanism is interpreted as being stratigraphic and structural.

Mocane Field

The Mocane Field produces both oil and gas from several reservoirs (Fig. 17). One of the producing formations is within the Lansing-Kansas City Group. Other productive formations are contained in the older Marmaton Group and in Chesteran (Mississippian) rocks. The field is located on an anticlinal trend noted as A3 in Figure 7. The updip anticlinal nose has produced approximately 50 ft. of structural closure and is the only apparent trapping circumstance.

In summary, trapping of hydrocarbons in the sandstone reservoirs primarily is due to stratigraphic changes that are coincident structural trends. Limestone reservoirs discussed so far are developed upon anticlinal structures.

Future Prospects

That location of reservoirs in limestones are difficult to predict is a well-known fact. Some major physical and chemical properties that induce secondary porosities are leaching, dolomitization, and fracturing. Although a working understanding of these properties is achievable, factors controlling their distributions probably are variable for any given situation. With understanding of the depositional environments of limestones, the probability of locating zones of porosity is enhanced; additionally, the likelihood is increased of mapping lithologies that are prone to development of secondary porosity.

The inferred carbonate "fan" environment is the most probable carbonate facies to have developed reservoir properties in the study area. Several factors collected from commercial sample logs support this statement. Some of the limestones have oomoldic porosity and instances are recorded of lost mud circulation during drilling, and of oil stains. Any commercial hydrocarbon traps probably would be in the porous and permeable zones of the "tidal-pass" facies which abut impermeable shales of the Douglas Group.

CHAPTER VIII

CONCLUSIONS

1. Distributions of major carbonate depositional environments (shelf, shelf margin, and basin) can be estimated from an isopachous map of strata included in this study.

2. Approximate time markers can be determined in the Lansing-Kansas City section from correlatable shale "breaks." Relative thicknesses between shale "breaks" can be used to infer major carbonate depositional environments.

3. Log maps show distributions and trends within carbonate depositional environments; these maps would be useful in exploration for facies-belts.

4. The Tonkawa sandstone is Virgilian and is not equivalent to the Missourian, Lansing Group.

5. The Tonkawa sandstone is contained in foreset-slope sediments deposited with the Douglas Group.

6. Buildups of the Tonkawa clastics show no signs of down-cutting; therefore, they probably were spilled into the basin and redistributed by current and storm waves. They formed sand buildups that are subparallel to the shelf margin.

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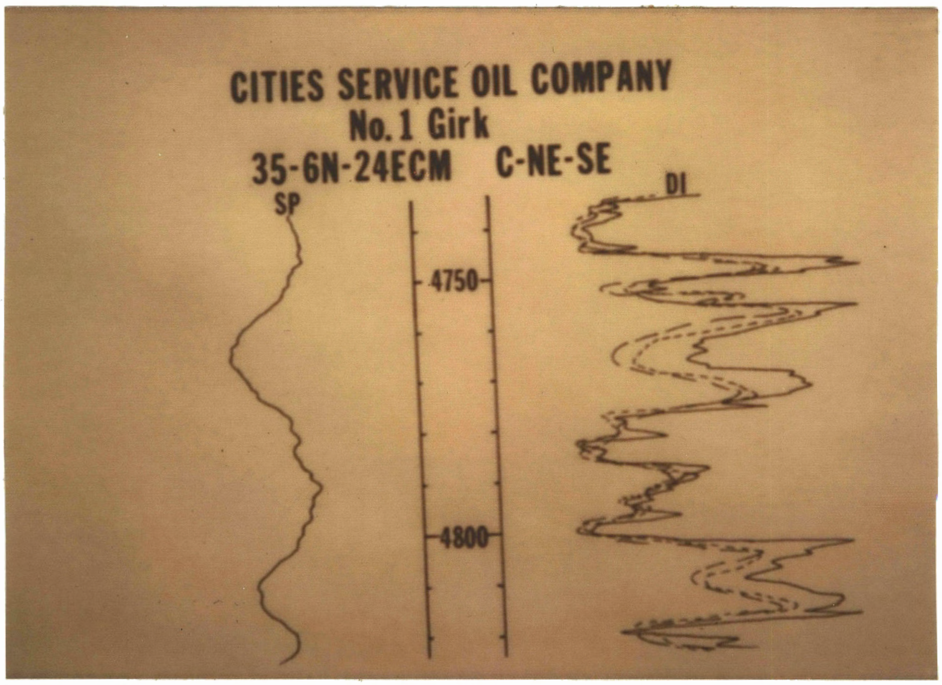
APPENDIX A

PHOTOGRAPHS OF CORE AND ACETATE PEELS



Electrical log of cored interval 4755 to 4805

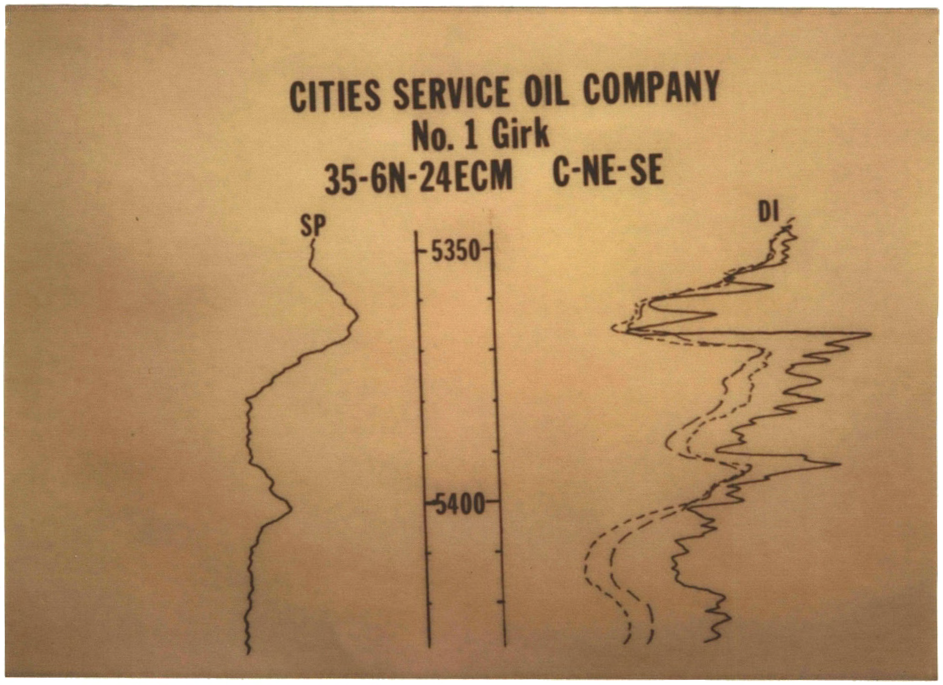
Core 4755 to 4765 (scale 1:8)

Core 4765 to 4774 (scale 1:8)

Core 4774 to 4785 (scale 1:8)

Core 4785 to 4795 (scale 1:8)

Core 4795 to 4805 (scale 1:8)



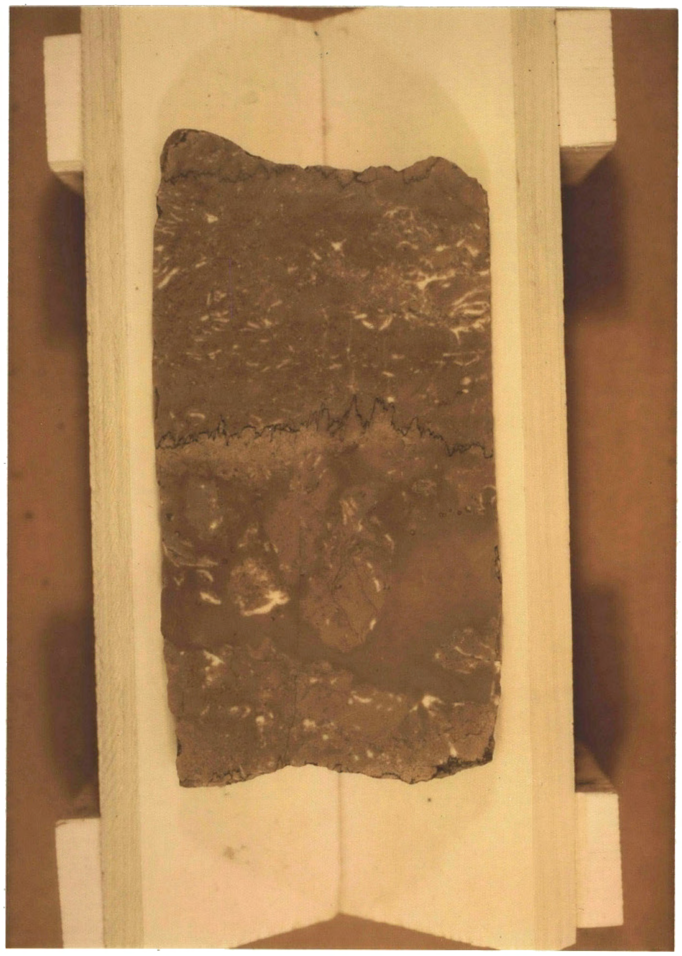
Electrical log of cored interval 5372 to 5402

Core 5372 to 5381 (scale 1:8)

Core 5381 to 5390 (scale 1:8)

Core 5390 to 5402 (scale 1:8)

4761 Chert nodules in the initial stages of formation with simular texture of host rock, but with increased porosity (scale 1:2)

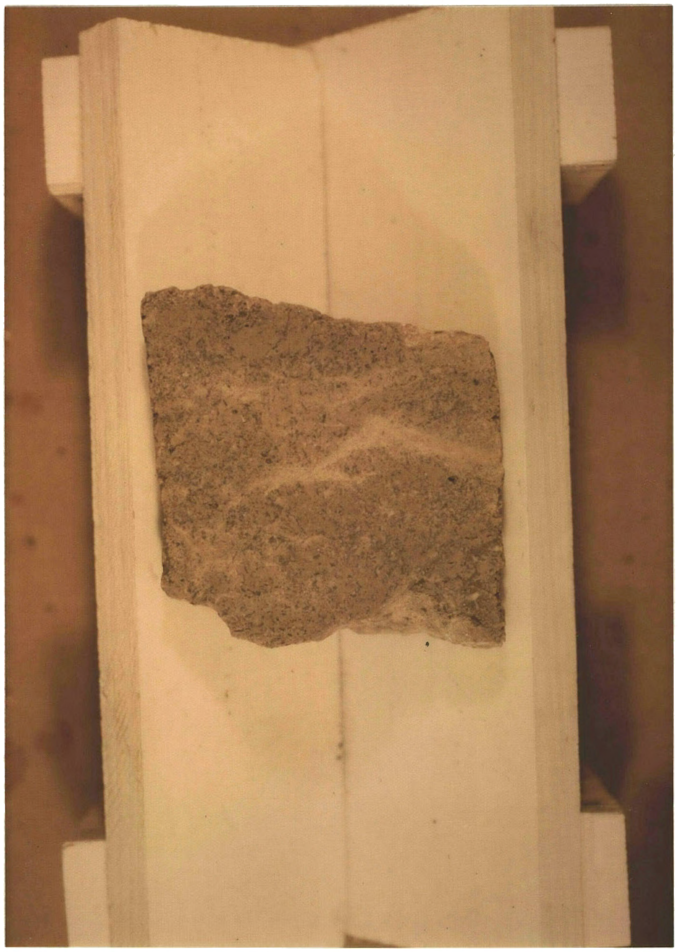


4767 Platy algal wackestone
lithoclasts in micrite
(scale 1:2)

4769 Platy algal wackestone (scale 1:2)

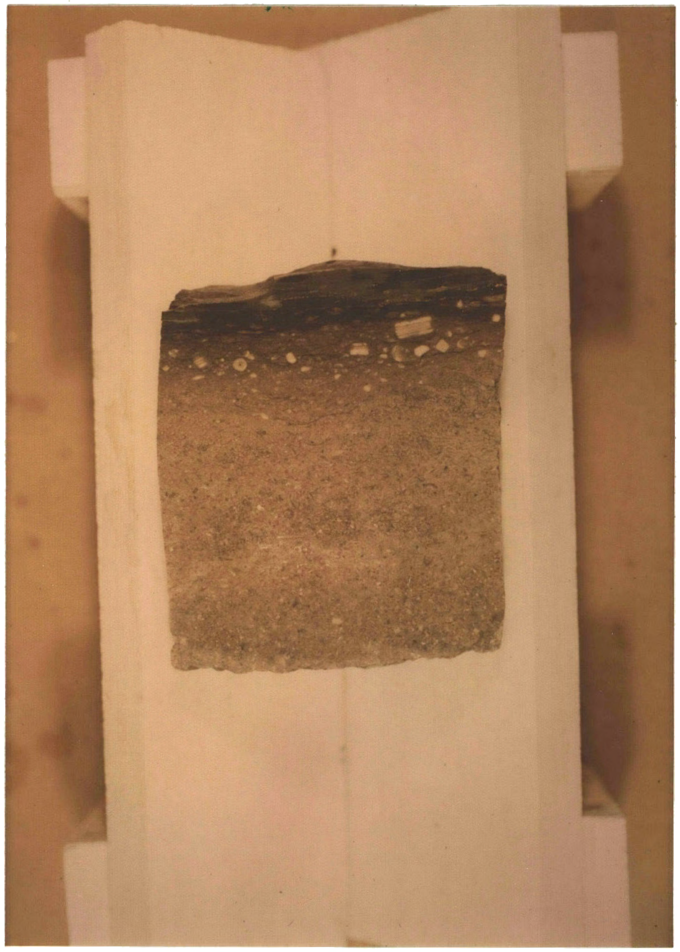
4783 Chert nodule (Note: Styolite following outline of nodule which is an indication that styolization was a late stage in diagenesis and occurred after the formation of the nodules) (scale 1:2)

4792 Oolitic wackestone (scale 1:2)



4794 Platy algal wackestone
lithoclasts in oolitic mud
(scale 1:2)

4801 Assorted fossil fragments. Identifiable fragments include corals, fusulinids, pelecypods, and crinoids. (scale 1:2)

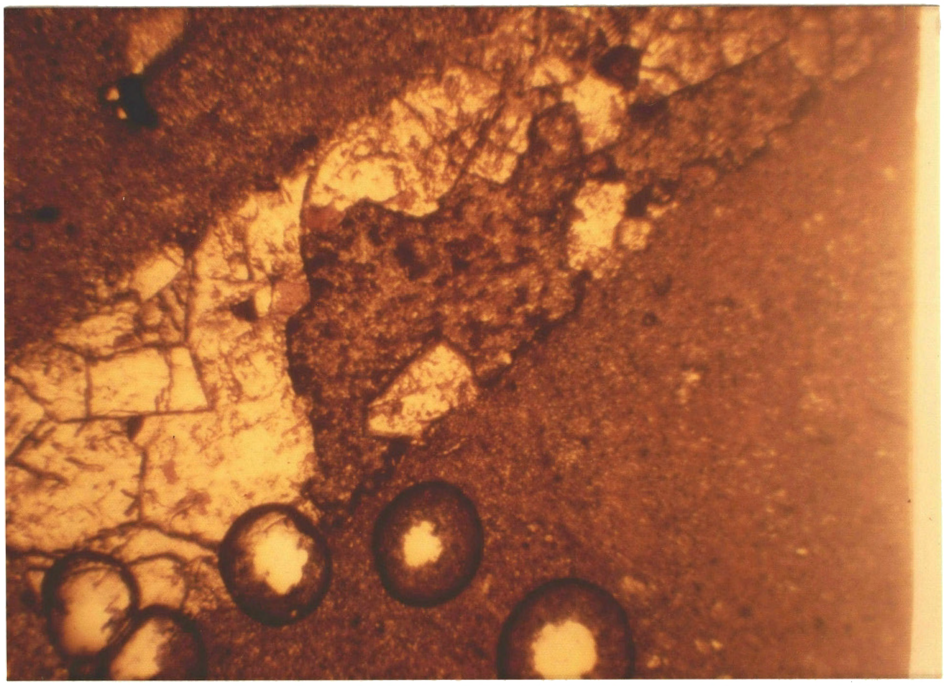


4805 The proposed Virgilian-
Missourian contact (scale 1:2)

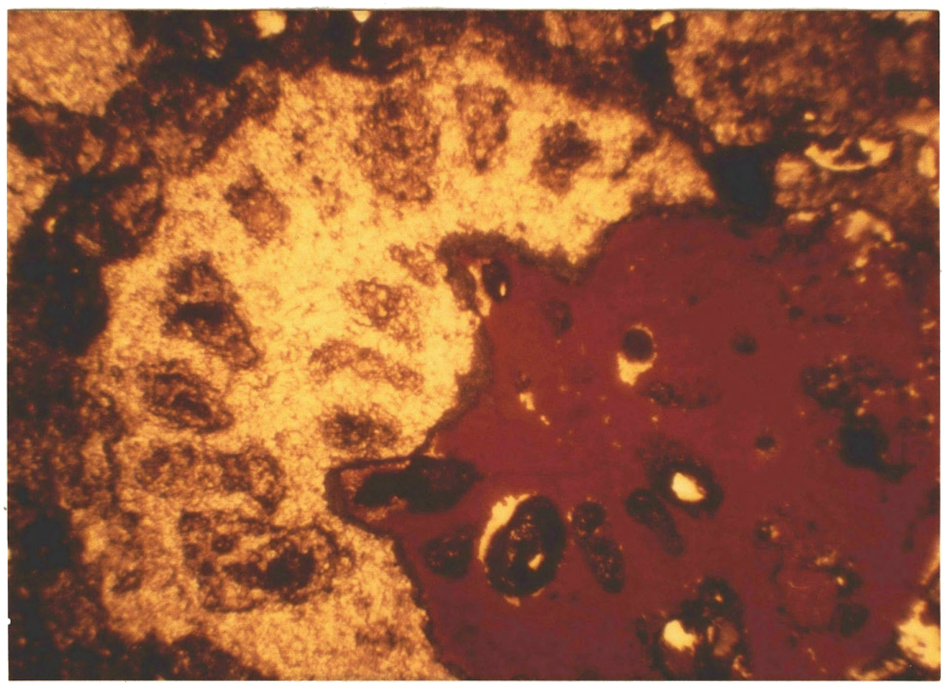
5375 Vuggy porosity (scale 1:2)

5385 Intraparticle porosity (scale 1:2)

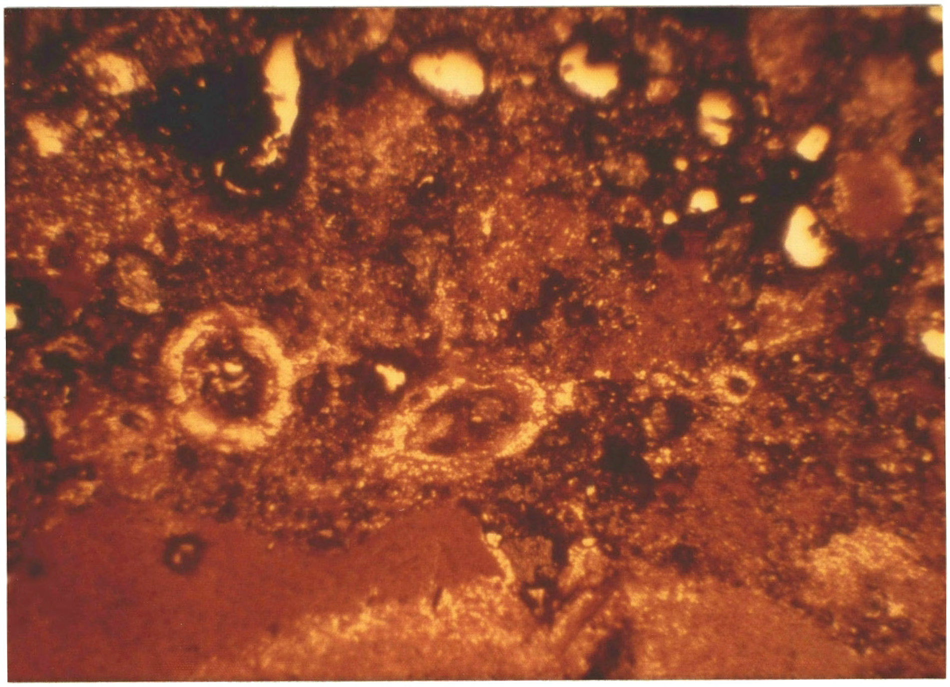
5401 Oomoldic porosity (scale 1:2)



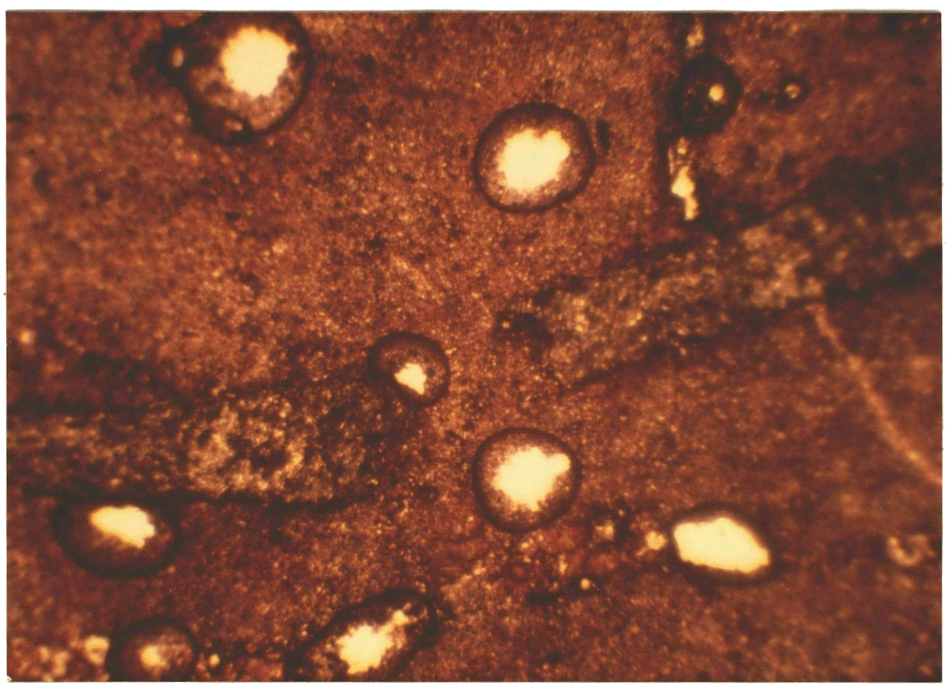
4769 Phyloid algae replaced by coarse-grained sparry calcite (scale 50:1)



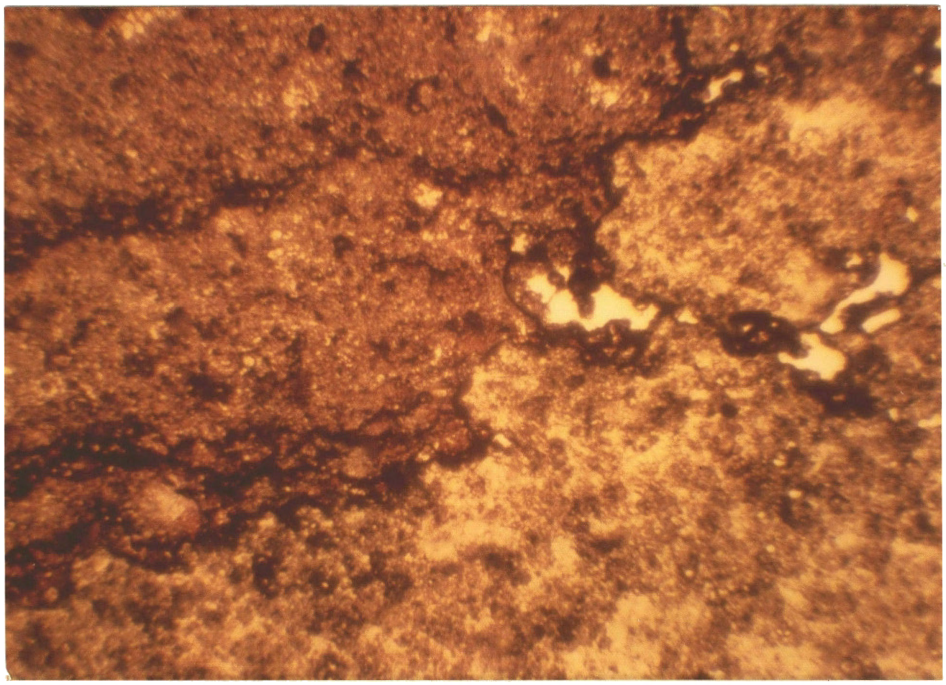
4760 Silica replacement (Note: Silica and calcite of the fusulinid as direct evidence of replacement.) (scale 50:1)



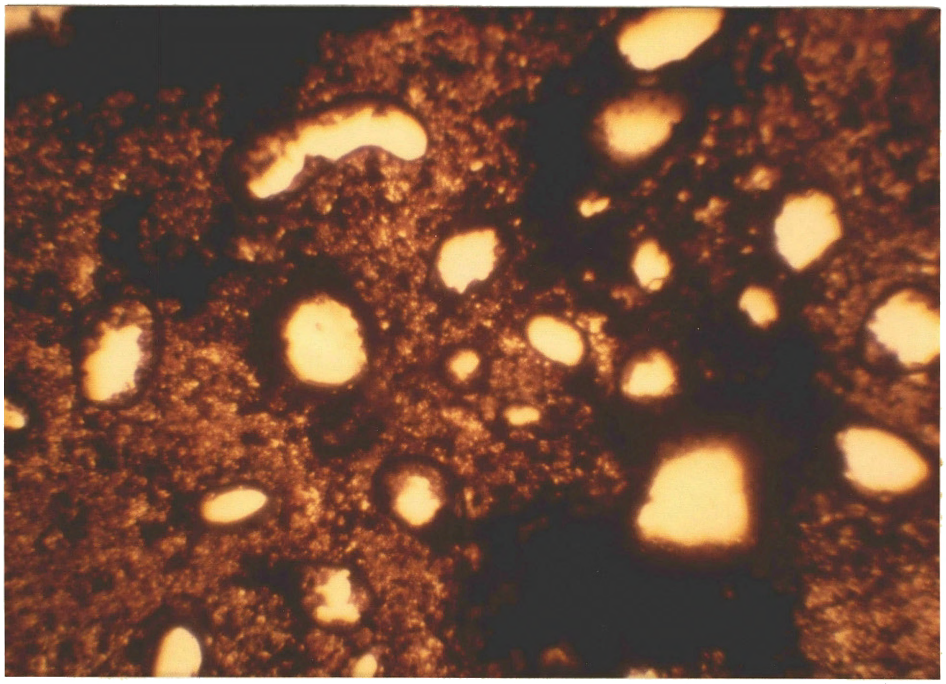
4760 Oolites (scale 50:1)



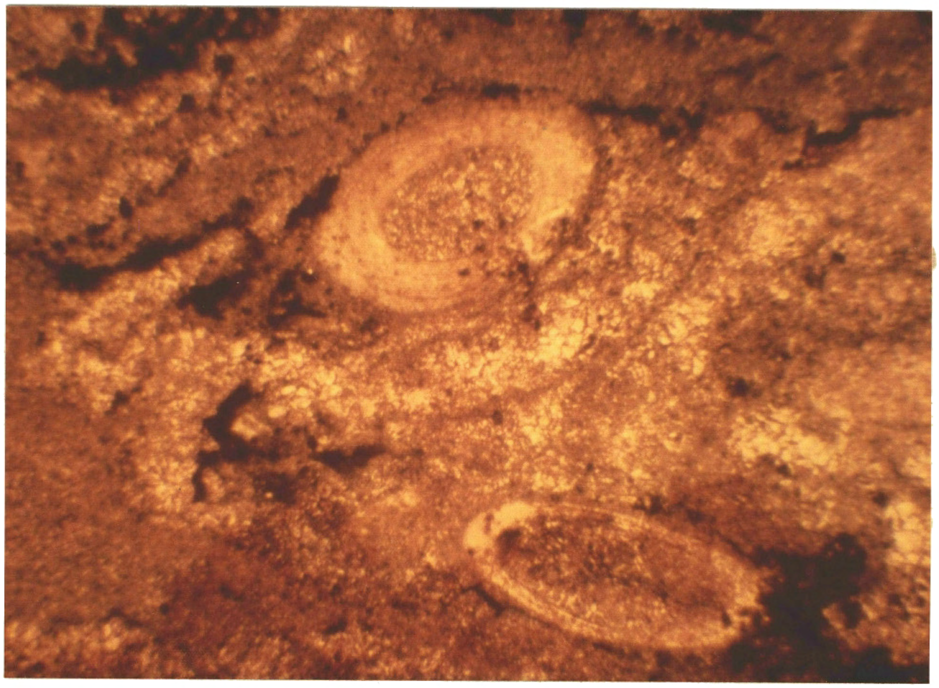
4767 Abraded phyloid algae (Note: Absence of internal structures (scale 50:1)



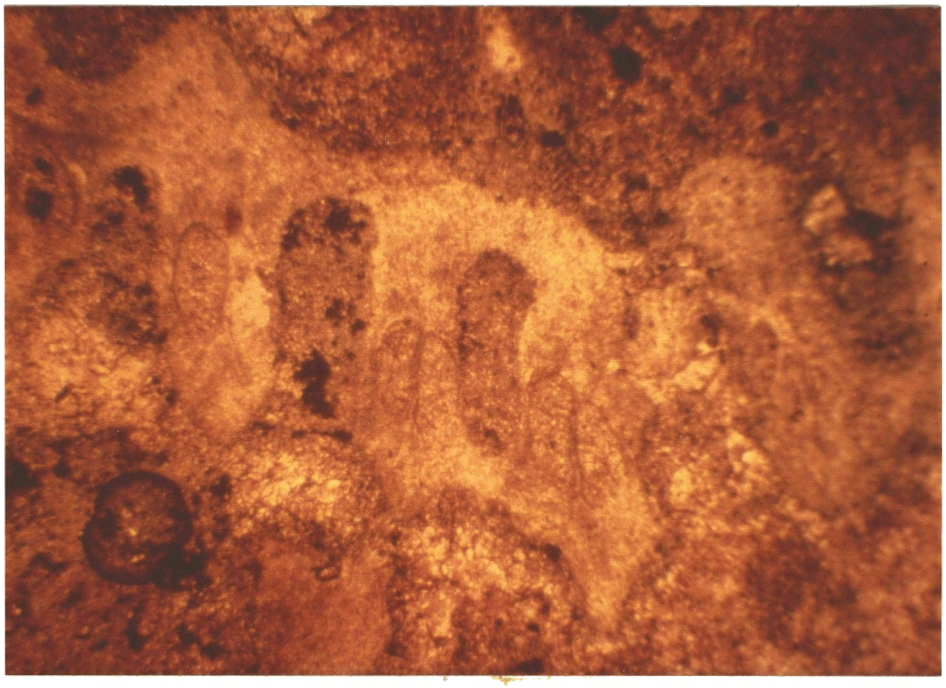
4782 Irregular boundary of a chert nodule
(scale 50:1)



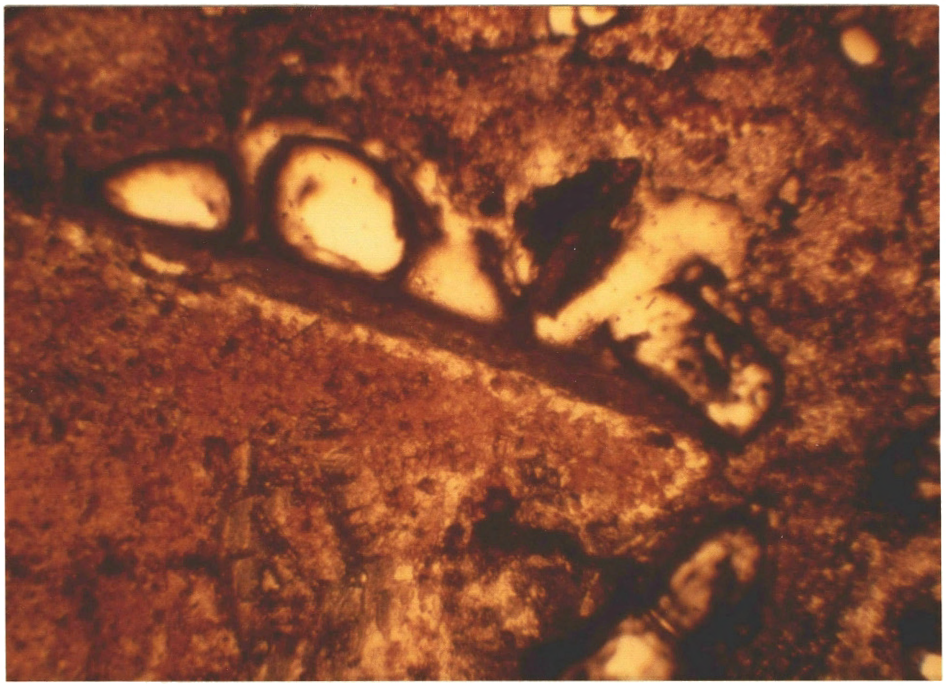
4793 Oomoldic porosity (scale 50:1)



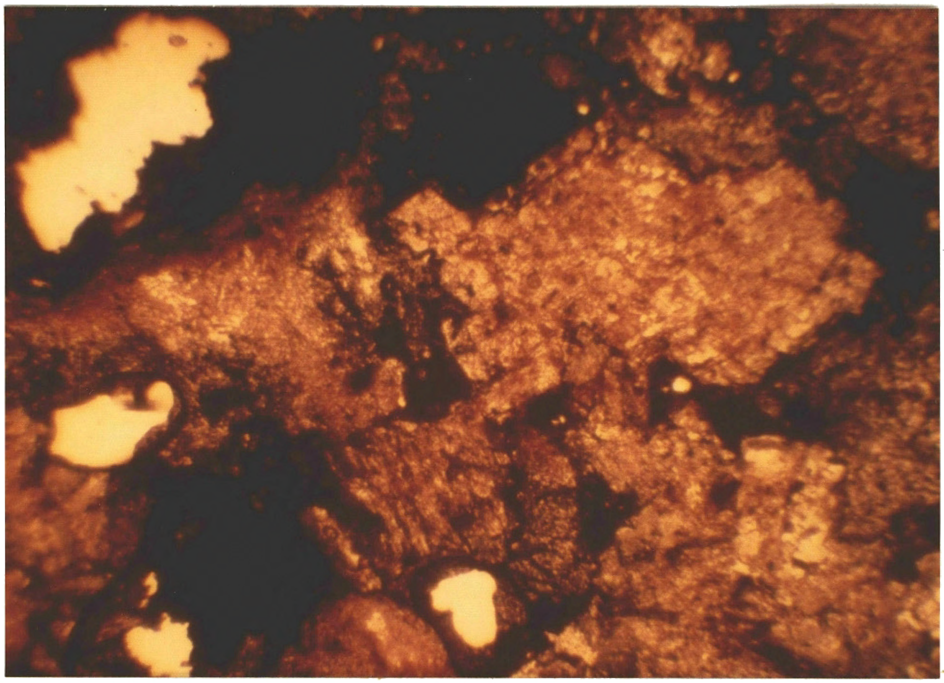
4805 Brachiopod spines (scale 50:1)



4805 Bryozoan (scale 50:1)



5385 Large sparry calcity rhomb contained in a pelecypod (scale 50:1)



5385 Possible dolomite rhombs (scale 50:1)

APPENDIX B

SAMPLE LOG LOCATIONS

No.	Operator and Well Number	Location
1.	Cities Service Oil Co., Baggerly C #1	C NW SE Sec. 2-2N-24ECM
2.	Stanolind O&G Co., Campbell #1	NW NW SE Sec. 5-2N-24ECM
3.	Harper Oil Co., Miller #1	NW NW SE Sec. 1-3N-23ECM
4.	Mid-America Minerals, Inc., Thomas #1	C NE SW Sec. 24-4N-23ECM
5.	Mid-America Minerals, Inc., Gregg #1	C NE SW Sec. 26-4N-23ECM
6.	Atlantic Refining Co., Phelps #1	C SW NE Sec. 32-4N-23ECM
7.	Cities Service Oil Co., Benjegerdes C-1	C NW SE Sec. 34-4N-23ECM
8.	Cities Service Oil Co., Miles B #1	SE SE NW Sec. 12-4N-24ECM
9.	Sohio Petroleum Co., Beaver City #1	NW SE SE Sec. 18-4N-24ECM
10.	Kingwood Oil Co., C. T. McClune #1	C NW SE Sec. 23-4N-24ECM
11.	United Production Co., Nina Mayo #1	C SW NE Sec. 18-4N-25ECM
12.	Carter Oil Co. and Ohio Oil Co., R. P. Savoy #1	NW NW SE Sec. 29-4N-25ECM

APPENDIX C

LOCATIONS OF ELECTRIC LOGS USED IN PREPARATION OF CORRELATION CROSS-SECTIONS

Correlation Section A-A'

No.	Operator and Well Number	Location
1.	Bridger Petroleum Corp., Hodges "B.P." #25	C SW SW Sec. 1-5N-23ECM
2.	Panhandle Eastern Pipeline Co., Miles #1-7	C NE SW Sec. 7-5N-24ECM
3.	Ohio Oil Co., Whitaker #1	C SE NW Sec. 17-5N-24ECM
4.	Texaco Incorporated, J.C. Hodges #1	C NE SW Sec. 21-5N-24ECM
5.	The Texas Co., H.F. & Robert McFarland #1	NW SW NE Sec. 27-5N-24ECM
6.	Headington Oil Co., Maple Ranch #1	C SW Sec. 26-5N-24ECM
7.	Sinclair Oil & Gas Co., Pearl Maple #1	C NE SW Sec. 36-5N-24ECM
8.	United Production Co., Inc., Nina Mayo #3	C NW SE Sec. 6-4N-25ECM
9.	Hamilton Brothers, Inc., Ezra H. Evans #1-8	C SE NW Sec. 8-4N-25ECM
10.	Cabot Corp., Barby Ranch #1-7	C SE NW Sec. 16-4N-25ECM
11.	Cabot Carson Co., L.J.Barby #B-3	C NE SW Sec. 22-4N-25ECM
12.	Cabot Carson Co., L.J. Barby #B-4	C SE NW Sec. 26-4N-25ECM
13.	Tennessee Gas Transmission Co., Otto Carl Barby #1	C NE SW Sec. 36-4N-25ECM
14.	Ambassador Oil Co., Overton #1	C NE SW Sec. 5-3N-26ECM

Correlation Section B-B'

1.	Pan American Petroleum Corp., Jesse T. Brown #1	C SE SW Sec. 20-4N-23ECM
2.	John H. Hill, Noble #1	C SW NW Sec. 28-4N-23ECM
3.	Jennings Petroleum Corp., Helen #1	C NE SE Sec. 28-4N-23ECM
4.	Aikman Brothers Corp., Benjegerdes #1	C NE NE Sec. 34-4N-23ECM
5.	Cities Service Oil Co., Benjegerdes "B" #1	C NE SW Sec. 35-4N-23ECM
6.	Harper Oil Co., Miller #1	NW NW SE Sec. 1-3N-23ECM
7.	Sinclair Oil & Gas Co., Lucy Overton #1	C NE SW Sec. 7-3N-24ECM
8.	Zoller & Daneberg Exploration, Kenneck #B005	C SW/4 Sec. 8-3N-24ECM
9.	Oklahoma Natural Gas Co., Kenneck #1	C NW SE Sec. 17-3N-24ECM
10.	Texas Oil & Gas Corp., Starcher #1	C SE SE Sec. 21-3N-24ECM
11.	Panhandle Eastern Pipeline Co., Shadden #1-27	C SW NE Sec. 27-3N-24ECM
12.	Fryer & Hanson Drilling Co., Shadden #1	C SE SE Sec. 26-3N-24ECM
13.	Pan American Petroleum Corp., Baggerly "B" #1	C SW NE Sec. 6-2N-25ECM
14.	Kennedy & Mitchell, Inc., Overton #3-19	C NE SE Sec. 7-2N-25ECM
15.	Shell Oil Co., Foreman State #1-17	C SW NE Sec. 17-2N-25ECM

No.	Operator and Well Number	Location
16.	Rip C. Underwood, Baggerly #1	C SE NW Sec. 21-2N-25ECM
17.	Kingwood Oil Co., Kingwood Baggerly "A" #1	C NE SE Sec. 21-2N-25ECM
18.	Sohio Petroleum Co., Hendricks #1	C NW SE Sec. 21-2N-25ECM
19.	Phillips Petroleum Co., Burditt "B" #1	C NW SE Sec. 26-2N-25ECM
20.	Phillips Petroleum Co., Tice #1	C SE NW Sec. 35-2N-25ECM
21.	Phillips Petroleum Co., Altmiller "C" #1	C SE NE Sec. 2-1N-25ECM
22.	Cities Service Petroleum Co., Mercer "A" #1	NW NW SE Sec. 1-1N-25ECM

Correlation Section C-C'

1.	Superior Oil Co., Williams #1	C NE NW Sec. 30-3N-23ECM
2.	May Petroleum, Inc., Oral Blackwell #1	C S½ SE Sec. 17-3N-23ECM
3.	Petroleum, Inc., Oklahoma State "F" #1	C SW NE Sec. 16-3N-23ECM
4.	Sinclair Oil & Gas, Hannah Epp #1	C SE NW Sec. 10-3N-23ECM
5.	Cities Service Oil Co., Benjgerdes "D" #1	C SW NE Sec. 3-3N-23ECM
6.	Cities Service Oil Co., Benjgerdes "B" #1	C NE SW Sec. 35-4N-23ECM
7.	Bridger Petroleum Corp., Airport "BP" #27	C SW SW Sec. 24-4N-23ECM
8.	Blaik Oil Co., Beaver City #1	C NE NE Sec. 18-4N-24ECM
9.	Cities Service Oil Co., Miles "D" #1	C SW NE Sec. 8-4N-24ECM
10.	Hamilton Brothers LTD, J.O. Miles "A" #1-4	C NW SE Sec. 4-4N-24ECM
11.	Panhandle Eastern Pipeline Co., Hodges "E" #1-33	C SE NW Sec. 33-5N-24ECM
12.	The Texas Co., H.F. & Robert McFarland #1	NW SW NE Sec. 27-5N-24ECM
13.	Cabot Carbon Co., Black #1	C NW SE Sec. 14-5N-24ECM
14.	United Production Co., Evans #4	C SE NW Sec. 13-5N-24ECM
15.	Carter Oil Co., Baldwin-Evans #1	NE NE SW Sec. 7-5N-25ECM
16.	Pure Oil Co., Judy "B" #1	C NE SW Sec. 5-5N-25ECM
17.	United Production Co., Inc., Adams #7	C NW SE Sec. 33-6N-25ECM

Correlation Section D-D'

1.	Phillips Petroleum Co., Mahoney "A" #1	C SW NE Sec. 19-1N-23ECM
2.	Harper Oil Co., Cates #1	C SW NE Sec. 17-1N-23ECM
3.	Phillips Petroleum Co., Fowler #1	C NW SE Sec. 9-1N-23ECM
4.	Parker Petroleum Co., Inc., Mitchell #1	C SE NW Sec. 3-1N-23ECM
5.	Atlantic Refining Co., Inc., State-Schlehoffer G. U. #1	C NE SW Sec. 35-2N-23ECM
6.	Parker Petroleum Co., Inc., Sleeper "A" #1	C NW SE Sec. 26-2N-23ECM

No.	Operator and Well Number	Location
7.	O. H. Parker, Pruitt #1	C SE NW Sec. 30-2N-24ECM
8.	Texas Pacific Oil Co., Pruett Holder #1	C SE SE Sec. 19-2N-24ECM
9.	Texas Pacific Oil Co., Hezzie Holder #1	C SE NW Sec. 20-2N-24ECM
10.	Cities Service Oil Co., Overton "A" #1	C SE NW Sec. 16-2N-24ECM
11.	Atlantic Refining Co., Inc., Longcor Gas #1	C SE NW Sec. 9-2N-24ECM
12.	Cities Service Oil Co., Baggerly "D" #1	C NW SE Sec. 4-2N-24ECM
13.	Stanolind Oil & Gas Co., Art D. Miller #1	SE SE SE Sec. 33-3N-24ECM
14.	Panhandle Eastern Pipeline Co., Shadden #1-27	C SW NE Sec. 27-3N-24ECM
15.	Shell Oil Co., Shell Bass #1-23	C SW NE Sec. 23-3N-24ECM
16.	Cities Service Oil Co., Fickel #C-2	C NW SE Sec. 12-3N-24ECM
17.	Sinclair Oil & Gas Co., Blanche Cunningham #1	C SW NE Sec. 31-4N-25ECM
18.	The Carter Oil Co., Ray P. Savoy #1	C NW SE Sec. 29-4N-25ECM
19.	Cabot Carbon Co., Hageman-Barby #1	SE NW SE Sec. 28-4N-25ECM
20.	Cabot Carbon Co., L.J. Barby #B-3	C NE SW Sec. 22-4N-25ECM
21.	Caulkins Oil Co., Lloyd Barby #1	C SW NE Sec. 14-4N-25ECM
22.	Cabot Carbon Co., Lloyd J. Barby #B-1	C SE NW Sec. 12-4N-25ECM

Correlation Section E-E'

1.	Mid-America Minerals, Inc., Humble Oil & Refining Co., & Anadarko Production Co., Ondraccek #1	C NW SE Sec. 29-1N-24ECM
2.	Sun Oil Co., J. Getz #1	C SE NW Sec. 22-1N-24ECM
3.	Cleary Petroleum, Inc., Gheen #1	C NW SE Sec. 14-1N-24ECM
4.	Cleary Petroleum Corp., Boroden #1	C NW SE Sec. 12-1N-24ECM
5.	Petroleum, Inc., Cook #1	C NW SE Sec. 1-1N-24ECM
6.	Sun Oil Co., Cecil Cook #1	SW SW NW Sec. 32-2N-25ECM
7.	Ohio Oil Co., Baggerly Tract 29 #1	C SW NE Sec. 29-2N-25ECM
8.	Rip C. Underwood, Baggerly #1	C SE NW Sec. 21-2N-25ECM
9.	Oklahoma Natural Gas Co., Lula Baggerly #1	C NE SW Sec. 14-2N-25ECM

Correlation Section F-F'

1.	Superior Oil Co., Williams #1	C NE NW Sec. 30-3N-23ECM
2.	Harper Oil Co., Bartell #1	SW SW NE Sec. 6-2N-23ECM
3.	Shenandoah Oil Corp., James Parker #1	C NW SW Sec. 8-2N-23ECM
4.	Rimrock Exploration Co., Inc., Parker #1	C NE SE Sec. 9-2N-23ECM

No.	Operator and Well Number	Location
5.	Apache Oil Corp., Ermal Barker #1	C SW NE Sec. 15-2N-23ECM
6.	Union Oil of California, Blosser #1	C SW NE Sec. 14-2N-23ECM
7.	Parker Petroleum Co., Inc., Sleeper "A" #1	C NW SE Sec. 25-2N-23ECM
8.	Pan American Petroleum Corp., Elmwood State Gas #1	SE SE NW Sec. 36-2N-23ECM
9.	W. C. Payne, Simpson #1	C SW NW Sec. 7-1N-24ECM
10.	Cities Service Oil Co., Marshall "A" #1	C NW SE Sec. 8-1N-24ECM
11.	Apache Corp., Schlehofer #1	C NW NW Sec. 21-1N-24ECM
12.	Sun Oil Co., J. Getz #1	C SE NW Sec. 22-1N-24ECM
13.	Edwin L. Cox, Nelson #1	C NW NE Sec. 26-1N-24ECM
14.	Service Drilling Co., Walton #1	C SE NW Sec. 31-1N-25ECM

VITA

Steven Dale Lane

Candidate for the Degree of

Master of Science

Thesis: RELATIONSHIPS OF THE CARBONATE SHELF AND BASINAL CLASTIC DEPOSITS OF THE MISSOURIAN AND VIRGILIAN SERIES OF THE PENNSYLVANIAN SYSTEM IN CENTRAL BEAVER COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, February 1, 1952, the son of Mr. and Mrs. Frank Lane, Jr.

Education: Graduated from Capitol Hill High School, Oklahoma City, Oklahoma, in May, 1970; received a Bachelor of Science degree from Oklahoma State University, Stillwater, Oklahoma, in December, 1974, with a major in Mathematics; completed requirements for a Master of Science degree in Statistics, May, 1976, from Oklahoma State University, Stillwater, Oklahoma; received a Master of Science degree in Geology at Oklahoma State University in December, 1978.

Professional Experience: Graduate teaching assistant, Department of Geology, Oklahoma State University, 1976-1978; Exploration Geologist, Union Oil of California, Oklahoma City, Oklahoma, summer, 1977.