PETROLEUM GEOLOGY OF THE MISSISSIPPI LIME IN PARTS OF PAYNE AND PAWNEE COUNTIES, OKLAHOMA

By

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Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1979

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1982

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IN PARTS OF PAYNE AND PAWNEE
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ACKNOWLEDGMENTS

Sincere appreciation and gratitude is extended to several individuals and groups who contributed to this study. James E. O'Brien, a consulting geologist, who suggested the problem, provided assistance throughout preparation of the maps and writing of the text, contributed much in the form of experience, knowledge, and inspiration.

Dr. John D. Naff gave time, effort, and advice throughout the thesis preparation.

Dr. R. Nowell Donovan helped the writer interpret the thin-section and core described herein, along with other assistance throughout the thesis.

Mr. Joe J. Newcomb, a consulting geologist, provided valuable contributions in the form of specific experience, and knowledge of the problem. Dr. Steve Culver read the thesis and gave valuable advice.

I am grateful to Price Exploration Company, and its associates, for the use of data, for reproduction and drafting facilities, and for much of the funds that made this thesis possible.

Finally, I am sincerely grateful to my parents, Philip and Elizabeth McKenna, for their support and encouragement. I am also grateful to Debra Sue Anderson for her constant support and encouragement.

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CHAPTER I

ABSTRACT

In the area of investigation T17N, R4E, and R5E, Section 1 through 18, T18N through T19N, R4E, and R5E, and T20N, R4E, and R5E, Sections 19 through 36, the Mississippi Lime is present throughout, except where locally removed by Pennsylvanian erosion. Paleotopographic highs and lows show up as structural highs and lows.

The Mississippi Lime was deposited on a relatively flat Woodford surface in shallow, warm, and quiet marine waters as progradational carbonate mud accumulations building from north to south. The Osage is composed of three such units that are composed of pelsparites and biosparites. The lowermost unit has a chert horizon developed at the top. The Osage units are separated by calcareous siltstones which reflect changes in sea level. The Meramec consists of two units, the lowermost, a calcareous siltstone, and the upper a pelsparite.

Paleotopography can be related to better Mississippi Lime oil and gas production. The east-west paleotopographic trends can be areas of better matrix porosity related to biohermal build-ups. The basic kinds of hydrocarbon trapping conditions are (1) the top seal produced by Pennsylvanian shales, (2) the bottom seal produced by the Woodford shale, and (3) lateral seals developed by the discontinuous nature of the joint system. The joint system can be combined with increased matrix porosity in part related to biohermal build-ups and siliceous

replacement on the east-west structural trends. This combination can yield better Mississippi Lime oil and gas wells.

The risk reward relationships of exploring for Mississippi Lime oil and gas traps are relatively low and not attractive to many investors.

CHAPTER II

INTRODUCTION

Location of the Study Area

The specific area that this thesis covers includes T17N, R4E, and R5E, Sections 1 through 18; T18N through T19N, R4E, and R5E, and T20N, R4E, and R5E, Sections 19 through 36. The study area covers approximately 216 sq. mi. in parts of Payne and Pawnee Counties (Fig. 1).

Statement of the Problem

The Mississippi Lime has become an extensive petroleum industry play throughout North-Central Oklahoma in the past few decades. Its stratigraphic characteristics, structural characteristics, depositional environment, and trapping conditions have not been documented thoroughly in the geologic publications, except on regional scales. These problems can be stated as a series of questions which can give a specific view of the Mississippi Lime through the study area. The questions are:

1. What is the extent of the Mississippi Lime and its individual units within the study area?
2. What is the relationship of structure and paleotopography beneath and above the Mississippi Lime, and does it give an indication of the distribution of oil and gas?
3. What is the relationship of the isopach interval of the Mississippi Lime and isochore interval of the Pink Lime to

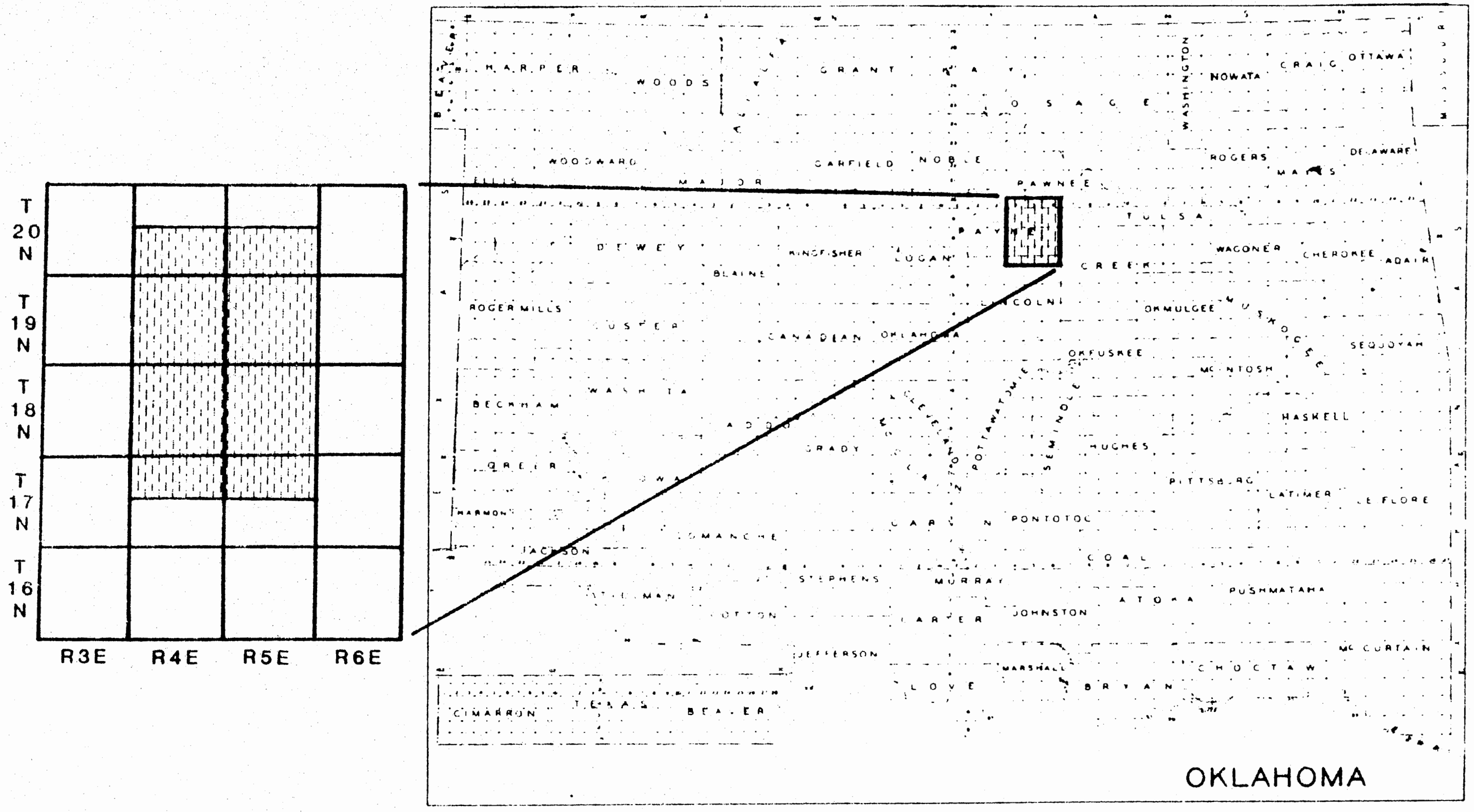

Figure 1.--Location of study area

Mississippi Lime, and do they give an indication of the distribution of oil and gas?

4. What is the relationship of the detailed stratigraphy related to thin section and core descriptions and do they give an indication of the distribution of oil and gas?
5. What was the depositional environment of the Mississippi Lime and is it related to the accumulation of oil and gas?
6. What kinds of petroleum traps and seals developed in the Mississippi Lime in the study area?
7. How productive are the Mississippi Lime Oil wells?
8. What are the risk-reward relationships for the exploration for oil and gas in the Mississippi Lime?

CHAPTER III

PREVIOUS INVESTIGATIONS

No paper has been written about Mississippi Lime oil production in this portion of the Northeast Oklahoma Shelf. Harris (1972) discussed the trapping mechanisms for Mississippian Oil accumulation in the Sooner Trend Area and Atoalah (1963) discussed Mississippian Oil production in general in T19N, R6W. Regional studies in Kansas by R. C. Moore (1951), Huffman (1953)(1958)(1959)(1964), Jordan and Rowland (1959), and many graduate students from the University of Oklahoma, Heinzelman (1957), Rhoads (1968), Hude (1957), Krueger (1957), Kitchen (1963), Darnell (1957), McDuffie (1959) and others, help set up Northeastern Oklahoma correlations in the Mississippian Section.

Older works by Aurin, Clark, and Trager (1921), Buchanan (1927), Cram (1930), Cline (1934), and Lee (1940) did establish much of the earliest work with sample descriptions and correlations that were the basis for later works.

Methods and Procedures

Data utilized in this study were obtained from approximately 570 electric logs, 250 Corporation Commission Driller's Logs, scout tickets, Vance Rowe-Petroleum Information Production Reports, one well core, and 6 sets of well samples.

An Isopach map of the Mississippi Lime (Plate I) was constructed to estimate its thickness and distribution. A structure map on the base of the Mississippi Lime - Top of the Woodford Shale (Plate II) was constructed to show the configuration of the Mississippi Lime. A structure map on the top of the Mississippi Lime (Plate III) was constructed to demonstrate the unconformity surface between the Mississippian and Pennsylvanian Systems. An isochore map of the Pink Lime to the top of the Mississippi Lime was constructed to demonstrate the configuration of the top of the Mississippi Lime at the beginning of Pennsylvanian deposition (Plate IV). Several cross-sections were constructed to aid in the stratigraphic correlation from both south to north and from east to west (Plates VII through XIII).

Vance Rowe-Petroleum Information Reports were the basis of the cumulative oil production data, for the Mississippi Lime (Plate V). Thirty-nine thin sections were prepared from 7 wells (including one core) to aid in the stratigraphic correlation and interpretation (Appendixes A and B, Plate XIV).

CHAPTER IV

REGIONAL GEOLOGY

The study area had a long history of mild and stable development throughout much of the Pre-Cambrian to late Devonian time. Much of the Pre-Mississippian deposition occurred in intercontinental basins wherein deposition of carbonate sediments accumulated in shallow marine conditions (Figure 2) (Nicholas and Rozendal, 1975). Transgressions and regressions were recorded in the Middle Ordovician Simpson Group by the influx of terriginous clastics. Simpson deposition thins to the east up onto the Ozark Uplift (Ireland, 1966). The Viola Limestone, Sylvan Shale, and Hunton Group were deposited as carbonates and shales in shallow quiet waters.

After deposition of the Hunton a major unconformity developed following tilting of the Pre-Woodford beds to the south and southwest. The Pre-Woodford unconformity extends across the study area and truncates the Simpson Group, Viola Limestone, Sylvan Shale, and further south, the Hunton Limestone (Figure 3) (Kochick, 1976). The Misener Sandstone was deposited on the unconformity surface in the lows and then covered by Woodford Shale deposition.

Mississippian Kinderhook time began with carbonate deposition in very shallow quiet waters with many islands of very low relief (Curtis and Champlin, 1959). Kinderhook deposition occurred over much of Oklahoma. To the North of the study area, the Woodford-Kinderhookian

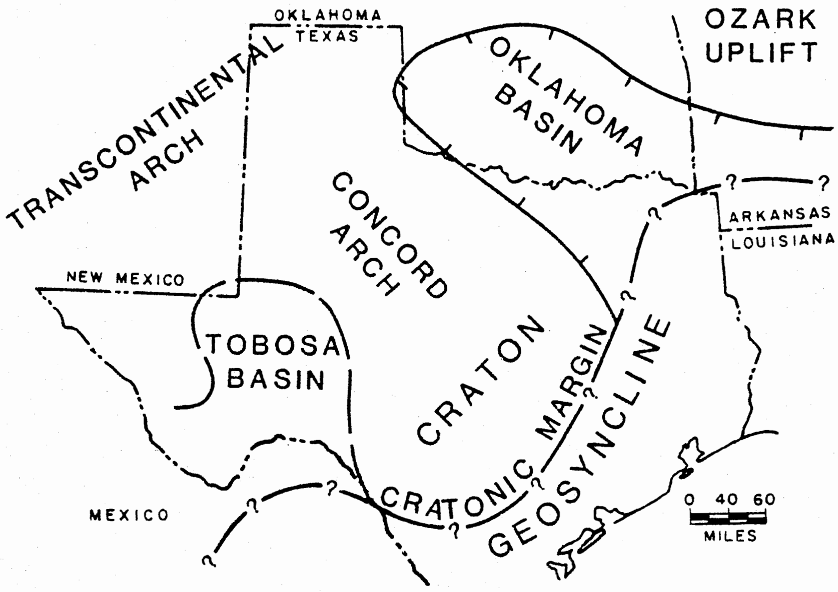

Figure 2.--Major depositional basins and uplifts of the southern Mid-Continent during late Cambrian through Devonian time (after Nicholas and Rozendal, 1975)

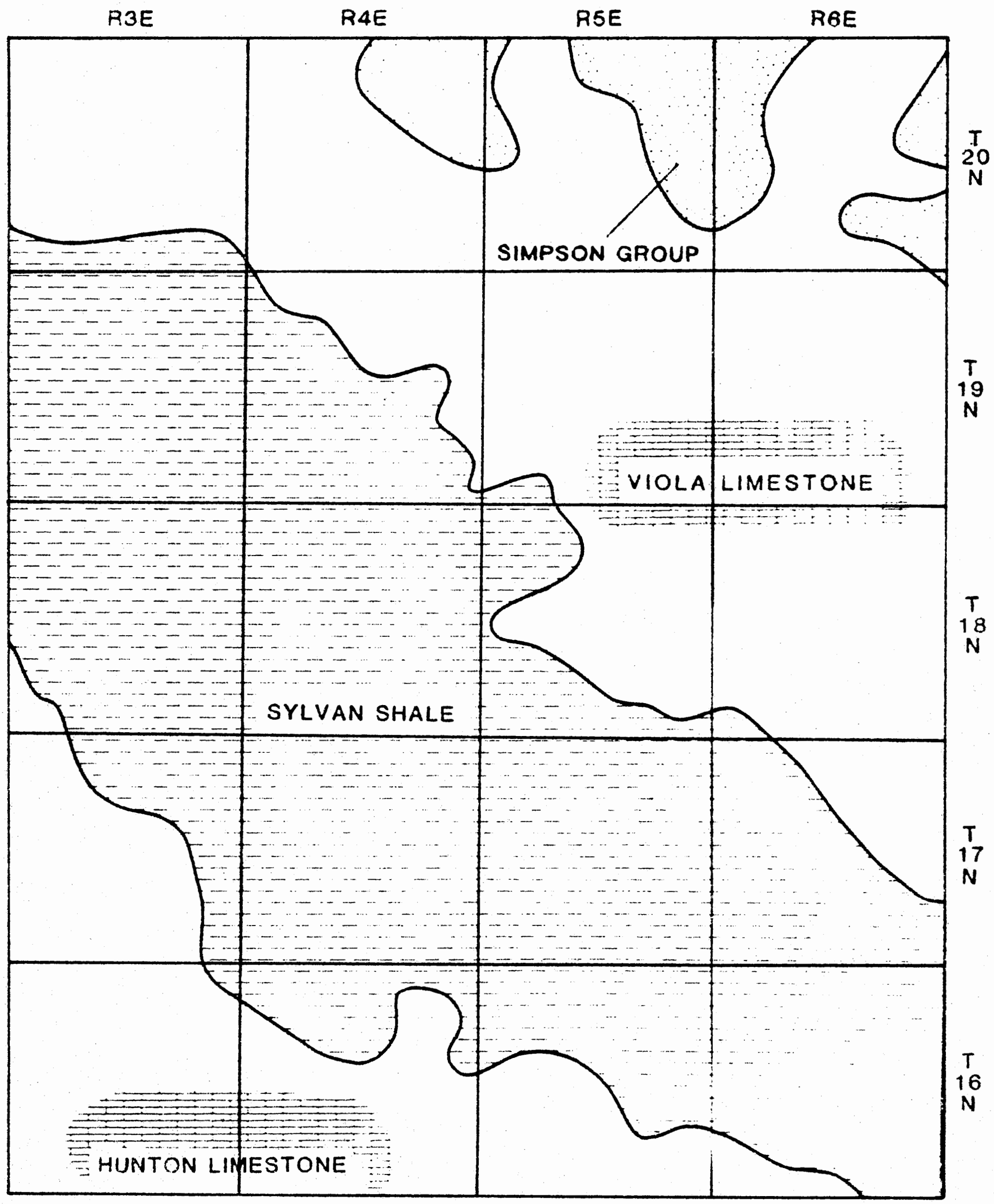

Figure 3.--Pre-Woodford subcrop map (after Kochick, 1976)

boundary is an unconforable surface. In the study area and to the south this boundary is conformable (Appendix B). The actual boundary between the Woodford, Kinderhookian, and Osagean can not be determined due to the lack of cores and good sample information within the study area.

Shallow seas were still prevalent in Osagean Time but subsidence began to occur in the northern and western parts of Oklahoma. Positive areas in East-Central and Southeastern Oklahoma continued, resulting in areas of little or no Osagean deposition. No clastic sedimentation occurred in the shallow basin except in the Northwest. The carbonates in other areas contained high amounts of chert (Curtis and Champlin, 1959). The Osagean makes up the major portion of the Mississippian section present within the study area and its top is the unconformity between the Mississippian and Pennsylvanian sections.

The Osagean was overridden by Meramecian Seas. This resulted from subsidence all over Oklahoma. A more recognizable shelf and basin complex resulted. Deposition of oolites and other high energy carbonates, such as highly crossbedded calcarenites and limestones with high silt and sand contents, occurred over the large areas that were affected by wave action. Some Meramecian deposition occurred below wave base (Curtis and Champlin, 1959). The Meramecian carbonates are only present in the southwestern portion of the study area, and only represent the very lowermost section. The top of the Meramecian in this area is the unconformity between the Mississippian and Pennsylvanian systems.

During Chesterian time more rapid subsidence occurred causing increased basin infilling in the Northwest and Southwestern portions of Oklahoma. With subsidence a large increase in clastic input occurred in the South and Southeast. Clastic input in other portions of Oklahoma remained relatively low. High energy environments, evidenced by oolites were widespread during Chesterian Time. The subsidence took place at a rate equal to infilling. These carbonates were deposited at wave base (Curtis and Champlin, 1959). No Chesterian rocks are present in the study area.

Subsidence was slow during Mississippian time, but increased, in rate from Osagean to Meramecian and reaching the greatest subsidence rate during Chesterian time, which made for more widespread seas. During all of the Mississippian the climate was warm temperate to subtropical. Tectonicaly, the whole area was stable, except where there was a large influx of clastic sediments in the Southeast related to increased tectonism in the South and East. A positive area was present in Eastern Oklahoma during Osagean time causing an onlap of Meramecian beds. The rate of subsidence generally was equal to the rate of deposition so that most of the Mississippian carbonates were affected by and deposited in or close to the wave base, while keeping a relatively uniform water depth (Curtis and Champlin, 1959).

The entire section of Mississippian rocks probably covered the study area at one time. With uplift of the Central Oklahoma Arch (Lowman, 1933), the Chesterian, and the greater portion of the Meramecian, plus some of the Oseagean section were removed by erosion during Pennsylvanian time (Jordan and Rowland, 1959), leaving a large portion of Oklahoma with only Osagean age rocks exposed (Figure 4).

Morrowan and Atokan age sediments may have been deposited over the study area and later eroded due to uplift of the Central Oklahoma Arch. They are present only on the flanks of the Arch to the southeast and southwest (Figure 4).

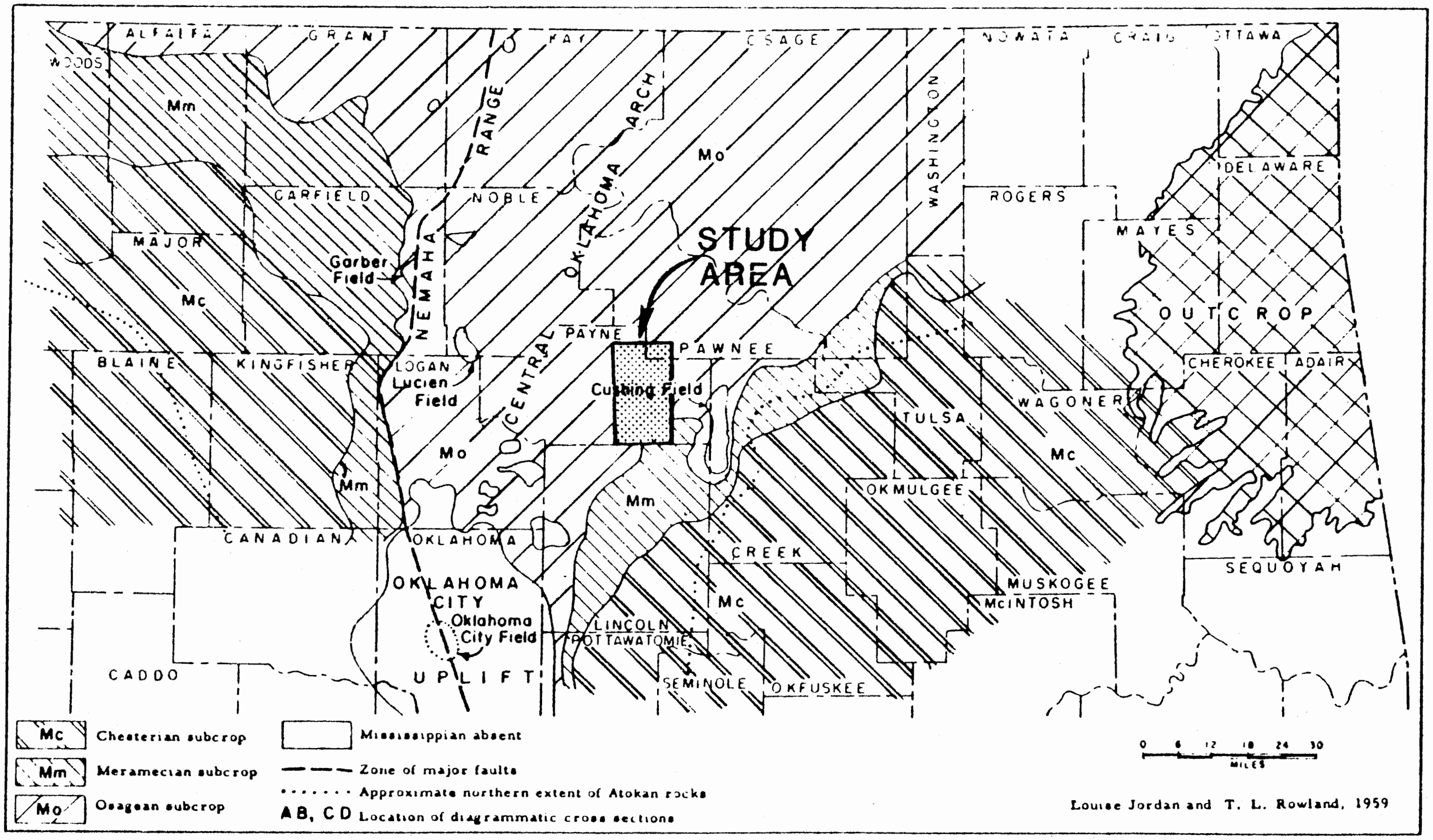

Figure 4.--Pre-Pennsylvanian subcrop map in Oklahoma (after, Jordan and Rowland, 1959)

The Central Oklahoma Arch may have been exposed as a landmass during Atokan time, but it most certainly was exposed during Early Desmonian time. The transgressing Pennsylvanian seas covered the Central Oklahoma Arch during Krebs time. There were some isolated landmasses close to the Nemaha Ridge that were not covered until Oswego Lime deposition.

With deposition of the Pennsylvanian a stratigraphic section was developed in the study area (Figure 5). All of the Atoka, Morrow, Chester, and a portion of the Meramec are not present in the study area.

System	Series	Group	Subgroup	Formation
Pennsylvanian	Desmoinesian	Cherokee	Cabaniss	Oswego Lime Verdigris Lime Pink Lime
			Krebs	Red Fork Sandstone Inola Lime Bartlesville Sandstone Booch Sandstone
	Atokan			
	Morrowan			
Mississippian	Chesterian			Pitkin Lime Fayetteville Shale Hindsville Lime
	Meramecian			Moorefield Lime
	Osagean			Boone Keokuk Lime Red Springs Lime St. Joe Lime
	Kinderhookian			Kinderhook Shale
Devonian				Woodford Shale Misener Sandstone
Silurian				Hunton Lime
Ordovician	Cincinnatian			Sylvan Shale Viola Lime
	Champlianian	Simpson		Simpson Dense Wilcox Sandstone Burgen Sandstone
	Canadian	Arbuckle		Arbuckle Dolomite

Figure 5.--Generalized stratigraphic section for the study area

CHAPTER V

STRATIGRAPHY

The Mississippian is represented in the study area by the Meramecian and Osagean series (Figure 5). These subdivisions of the Mississippian are based on the similarities of lithologies as discussed by Heinzelmann (1957) and Hyde (1957). The sub-divisions of the Osage and Meramec within the study area are based on lithologic and electric log characteristics.

In the study area, the Pre-Mississippian surface extended across the Woodford Shale. This surface was relatively flat at the beginning of Mississippian time (Kochick, 1976).

Rocks of Kinderhookian and Osagean age were deposited on the Woodford surface with continuous deposition (Appendix A, Plate XIV) following which rocks of Meramecian age were deposited on the Osagean with an apparent conformable relationship. In this area rocks of Chesterian age may or may not have been deposited.

The entire Mississippian section varies in thickness from 220 ft. in the extreme southeast section of the study area to 0 ft. in Section 26-20N-4E, and in Section 5-19N-5E. Generally over the entire area the thickness varies from 50 to 140 ft. (Plate I).

With rejuvenation of Pre-Woodford structures during Mississippian and Pennsylvanian time, the Mississippi Lime thinned over the major and minor structures (Plate I). The larger the structure, generally, the greater the amount of thinning.

The major portion of the Mississippian in the study area has been divided into the Meramecian and Osagean. The Osagean covers the entire study area, except where locally removed by Pennsylvanian erosion. It thickens below the Meramecian, which would represent at least a maximum depositional thickness, and ranges from 105 ft. in the extreme southeast corner of the study area to 160 ft. in the extreme Southwest portion of the study area (Plates VI, VII, VIII).

The Osage rocks in the majority of the study area are not overlain by Meramecian age rocks. Erosion removed whatever younger Mississippian rocks were present and the Pre-Pennsylvanian unconformity lies directly on Osagean age rocks. The Osagean that is not overlain by Meramecian age rocks only represents a partial thickness in those areas. It is assumed that at least a portion of it had been removed by Pennsylvanian erosion. Since the Meramecian is only present in portions of the southern one-third of the study area, the isopach map of the Mississippian represents the isopach of the Osagean at least in the northern two-thirds of the study area (Plate I). This thickness ranges from 0 ft. in locally eroded areas to a maximum of 150 ft. in the western portion of the Ripley-Cushing Syncline (Figure 6). In the synclines of the southern portion of the study area, the greatest thickness of Meramecian rocks are present and they decrease northward.

Locations of Cross Sections A-A' through G-G' (Plates VII through XIII) are shown on the study area Base Map (Plate VI).

Cross Sections A-A' and B-B' (Plates VII, VIII) show the maximum number of Mississippian units present. Units A and B are in the Meramecian, units C and D are in the Osagean, and unit E is in the Osagean

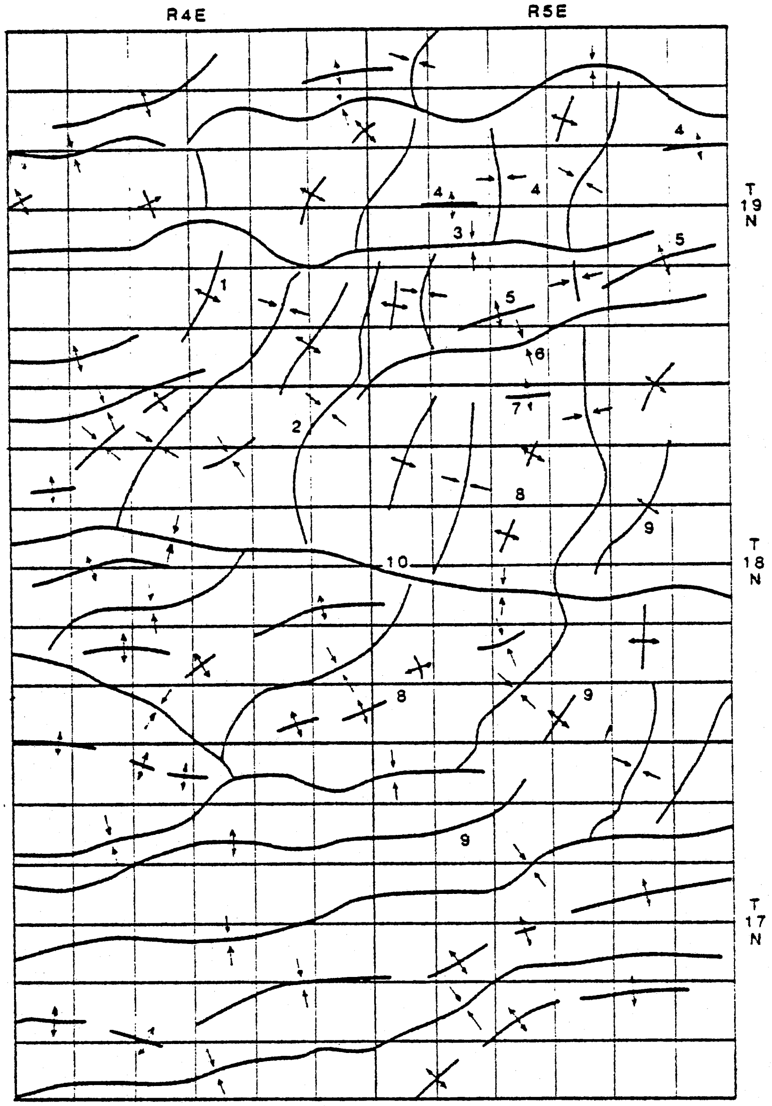

Figure 6.--Structural trend map, base of the Mississippi Lime-top Woodford Shale. 1-Ingalls Anticline; 2-East Ingalls Syncline; 3-North Ingalls Syncline; 4-North Ingalls Anticlineal Trend. 5-Pratt Anticlineal Trend; 6-Pratt Syncline; 7-Pratt Dome; 8-West Cushing Anticlineal Trend; 9-Cushing Anticlineal Trend; 10-Ripley-Cushing Syncline; 11-North Lincoln County Anticline (after Kochick, 1975)

and Kinderhookian. Generally in the study area depositional strike was east-northeast, this is shown by many regional studies and in the study area by the fairly constant thickness east-west with variations in thickness to the north-south (Harris, 1973; Harbaugh, 1957; Anglin, 1966).

This east-northeast depositional strike is present in the Sooner Trend area of Northwestern Oklahoma, and is represented as east-northeast trending Osage-Meramecian organic build-ups classified as biohermal mounds (Harris, 1973). These trends developed in response to marine currents and are reflected in the lithologic similarity between the known Mississippian facies in the area. A similar east-northeast trend was noted by Harbaugh (1957) and Anglin (1966) in studies of the Osagean rocks in outcrops of Northeastern Oklahoma.

Unit E of Osagean age, has a thickness of 17-20 ft. in Cross Section A-A' (Plate VII), a thickness of 20-30 ft. in Cross Section B-B' (Plate VIII), a thickness of 25 to 35 ft. in Cross Section C-C' (Plate IX), a thickness of 42-50 ft. in Cross Section D-D' (Plate X), and a thickness of 68-70 ft. when overlain by Unit D, in Cross Section E-E' (Plate XI). In the eastern half of Cross Section E-E' the Pennsylvanian unconformity lies directly on top of Unit E. Its thickness here can reach as much as 80 ft. Only the extreme western portion of Cross Section F-F' (Plate XII) is overlain by Unit D. Unit E reaches a maximum thickness of 130 ft. in the extreme northern portion of the study area.

Comparing the variations in the thickness of Unit E shows a fairly uniform east-west thickness in the southern half of the study area with a slight eastward thickening in the north half. Cross Section G-G' (Plate XIII) shows the gradual northward thickening of Unit E, both below Unit D and below the Pennsylvanian unconformity.

From the sample and core studies (Appendixes A and B, Plate XIV), it was determined that the top of Unit E changes from a calcareous siltstone in the south to a more pure carbonate to the north, with increasing amounts of chert. In T20N, the very top of Unit E is almost a pure chert. The basal portion of Unit E is a glauconitic sandstone which increases in quartz silt content to the north, from 5% to 15% and then back again to 5% in the northern portion of the study area. The glauconitic zone is absent in T20N. This glauconitic sandstone represents a period of continuous deposition from the Woodford Shale to the Mississippi Lime. The phosphate nodules present within the sandstone indicates long periods of slow deposition.

Unit D of Osagean age lies conformably on Unit E, and has a thickness of 45-48 ft. in Cross Section A-A' (Plate VII), a thickness of 65-75 ft., in Cross Section B-B' (Plate VIII), a thickness of 70-80 ft. when overlain by Unit C in Cross Section C-C' (Plate IX); 68-85 ft. when overlain by the Pennsylvanian unconformity in the central and eastern portion of the Cross Section. In Cross Section D-D' (Plate X) Unit D is all overlain by the Pennsylvanian unconformity, and varies in thickness from 18-80 ft. Unit D is present in the western half of Cross Section E-E' (Plate XI) and its thickness varies from 0 to 55'. In Cross Section F-F' (Plate XII) the thickness varies from 0 to 15 ft. and is only present in the extreme western portion of the study area.

The thickness of Unit D is fairly consistent in the east-west direction, when it is overlain by Unit C. It varies considerably in thickness when overlain by the Pennsylvanian unconformity. Cross Section G-G' (Plate XIII) shows a thickening of the unit from the south to the north to a maximum thickness in the middle of T18N of around 85 ft., and then decreasing in thickness to the north. When overlain by the Pennsylvanian unconformity, it decreases in thickness to zero in the northern portion of T19N and southern portion of T20N (Plates XI and XII).

From the sample and core study it was determined that Unit D changes very little from south to north (Appendixes A and B, Plate XIV). The whole unit is a biosparite with minor amounts of quartz slit and carbonaceous material, a few micrite pellets, and sponge spicules.

It is believed by the writer that in the study area the Pre-Pennsylvanian unconformity that rests upon Unit D represents an erosional topographic surface. The uppermost section of Unit D, when overlain by Unit C, does not have a corresponding section when overlain by the Pre-Pennsylvanian unconformity. This corresponding interval of deposition was deposited and then eroded off during Pennsylvanian time.

Unit C is the uppermost unit in the Osagean, and lies conformably on top of Unit D, has a thickness of 35 to 105 ft. in Cross Section A-A' (Plate VII), a thickness of 40 to 45 ft. when overlain by Unit B, and 30 to 65 ft. in thickness when overlain by the Pennsylvanian unconformity in Cross Section B-B' (Plate VIII). Unit C is overlain by Unit B only in the extreme western portion of Cross Section C-C' (Plate IX), and is approximately 45 ft. in thickness. When overlain by the Pennsylvanian unconformity, Unit C varies in thickness from 0 to 25 ft. and is only present in the eastern one-third of the Cross Section. None of Unit C is present in the north half of the study area.

Cross Section G-G' (Plate XIII) shows a northward decrease in thickness of Unit C from 85 ft. in the south to 0 ft. in the middle of T18N. Comparison of all the Cross Sections and thickness shows a depositional thickening to the west in the extreme southern portion of the study area, with an erosional thinning to the north.

From the sample and core studies (Appendix A and B, Plate XIV), it was determined that Unit C is a biosparite with intervals of pelsparite. Unit C contains minor amounts of quartz silt, carbonaceous material, and micrite. Unit C represents an erosional topographic surface when overlain by the Pre-Pennsylvanian unconformity. As with Unit D, the uppermost interval of Unit C, when overlain by Unit B, does not have a corresponding section when overlain by the Pre-Pennsylvanian unconformity. This corresponding interval of deposition was deposited and then eroded off during Pennsylvanian time.

Unit B lies conformably on top of Unit C, and is the lowermost unit of Meramecian age. Most workers in Northeastern Oklahoma recognize an unconformable surface between the Meramec and Osage, that is between Unit B and C. In the study area there was no evidence to support the existence of the unconformity, and the contact represents a period of continuous deposition (Appendixes A and B, Plate XIV). It has a thickness of 25 to 30 ft. in Cross Section A-A' (Plate VII) when overlain by Unit A, and thins to the west from 25 ft. to 0 ft., when overlain by the Pennsylvanian unconformity. In Cross Section B-B' (Plate VIII) its thickness is a maximum of 25' to 30' and thins to 0 ft. to the west. In Cross Section C-C' (Plate IX) it is present only in the extreme east and is only 6 to 8 ft. thick, thinning to 0 ft. The north-south Cross Section G-G' (Plate XIII) shows a maximum of 14 ft. in the extreme south, thinning to zero by the north of T17N. A comparison of all the Cross Sections and thicknesses, shows that Unit B is present at a maximum in the southeast corner of the study area and thins to the north and west due to Pennsylvanian erosion.

From the sample and core studies (Appendixes A and B, Plate XIV), it was determined that Unit B in the south is a silty biosparite changing to a calcareous siltstone to the north, before it is removed by erosion. Unit B is present in many of the synclines in the lower one-third of the study area. These areas were not as extensively eroded as the structural highs.

Unit A lies conformably on top of Unit B and is unconformably overlain by the Pennsylvanian sediments. Its maximum thickness is shown on Cross Section A-A' (Plate VII) in the extreme southeastern corner of the study area. Its thickness is 80 ft. and thins to zero by the western portion of the Cross Section A-A' (Plate VII). Cross Section B-B' (Plate VIII) shows a thinning of the unit to the north and is only present in the extreme eastern portion of the study area. The maximum thickness of 80 ft. is only an erosional thickness. The only sample of Unit A examined was from the Texaco, #3 Cardin. It consisted of a massive pelsparite (Appendix B, Plate XIV).

CHAPTER VI

STRUCTURAL GEOLOGY

The study area is in the west-central portion of the Northeastern Oklahoma platform. It is bound on the west by the Nemaha Ridge, the east by the Ozark Uplift, to the north by the Cherokee Basin, and on the south by the Seminole Arch (Figure 7). The study area is shown by the ruled area.

Regional dip, as shown on the Woodford Structural Map (Plate II) is west-southwest with a north-northwest strike. Local areas within the study area have variations in strike and dip due to locally folded and faulted features. These features can have dips as much as 350 ft./mile. Regional dip is from 40 to 80 ft./mile.

There are two major structural trends in the study area: an east-west and a north-northeast set of structural axes, that form an en-echelon pattern on the base of the Mississippi Lime (Figure 6, Plate II). East-west trending structures can be seen at the Pre-Woodford Boundary, but the north-northeast trend is absent (Figure 8).

These same structural trends that are present on the top of the Woodford-Base of the Mississippi Lime are present at the top of the Mississippi Lime (Plate VI).

The Ripley-Cushing syncline (Figure 6) is the most prominent structural feature in the study area and is thought by Kochick (1976) to be related to deep basement faulting. This deep seated faulting was first

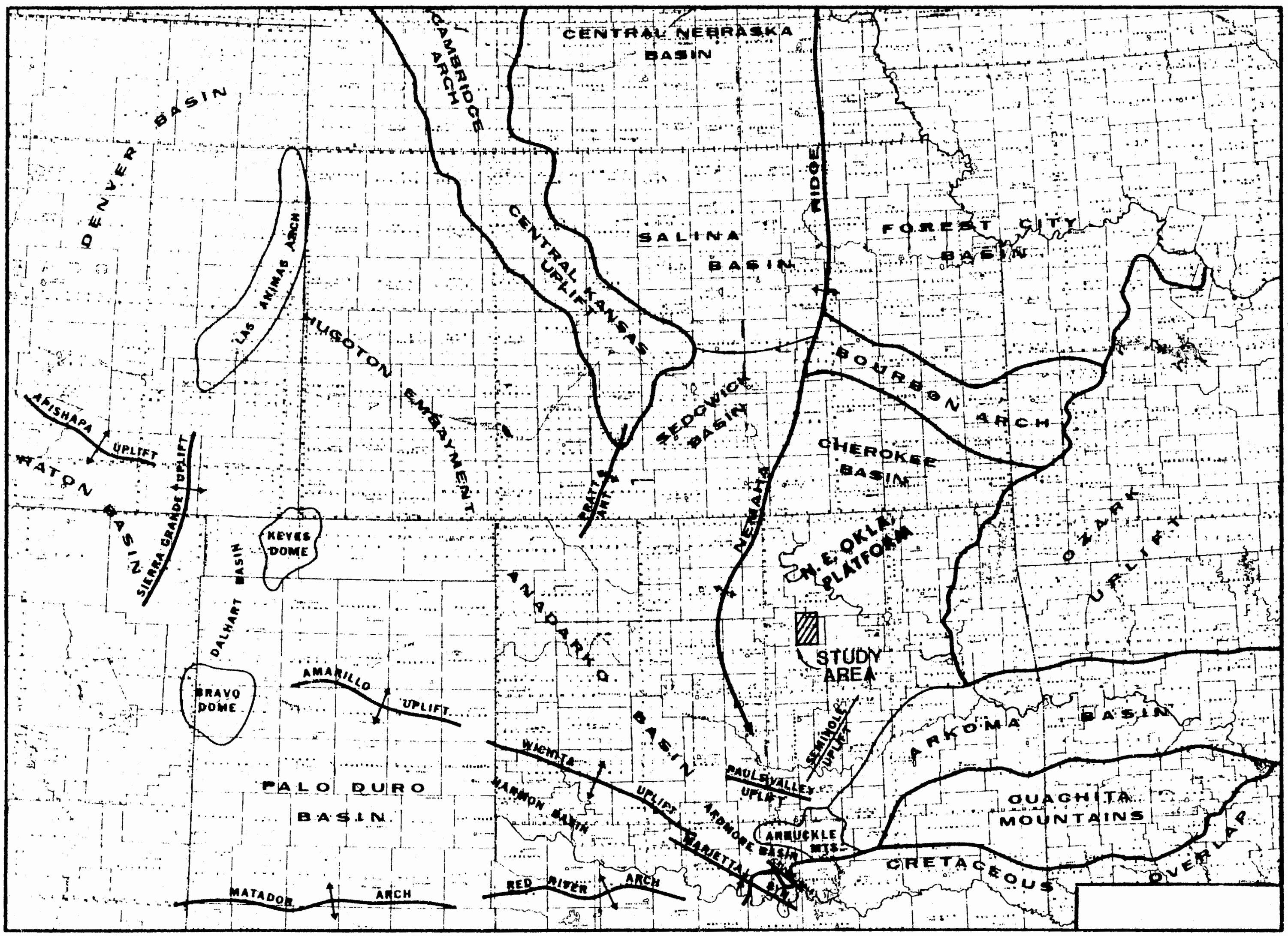

Figure 7.--Tectonic map of the Central Mid-Continent (source, W. C. McBride Inc.)

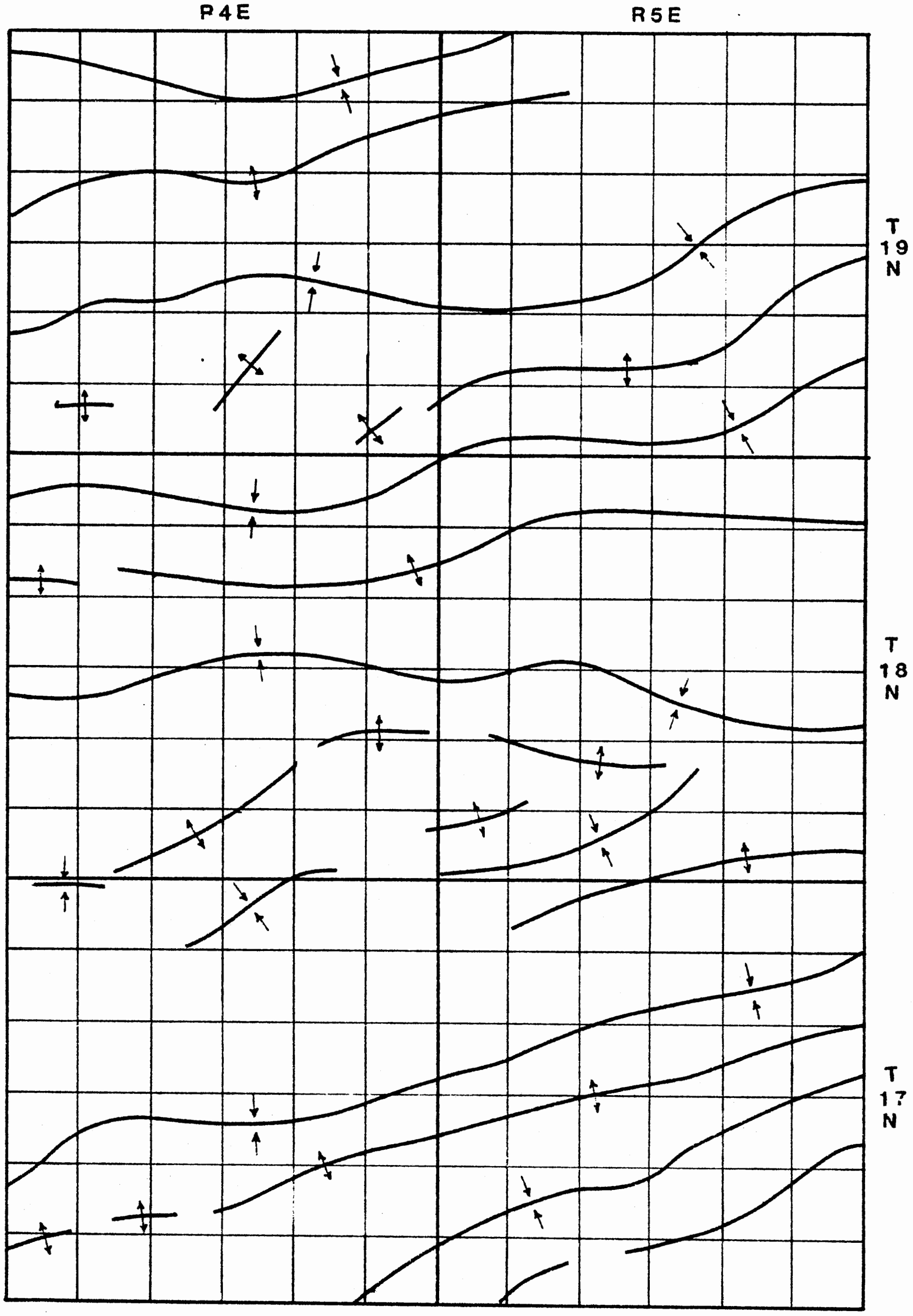

Figure 8.--Structural trend map on the pre-Woodford surface (after Kochick, 1976)

described by Lyons (1950) and is a possible extension of his Coyle Fault (Figure 9).

The east-west fold trends seem to offset the northeast folds. It is felt by the writer and others that this could be caused by movement along the east-west trend, which would cause folding in the northeast set, or folding in the east-west set after folding of the northeast set. The structures with the most closure are in the northeast trends. These folds have as much as 200 ft. of closure at the top of the Woodford-Base of the Mississippi, and as much as 150 ft. of closure at the top of the Mississippi Lime.

It is thought by the writer that the east-west structural movements influenced the deposition of the Booch channel. This channel is shown on Plate IV by the pronounced thickening in T20N, R4E, and T19N, R5E, and trends in a general east-west direction. This same channel was probably associated with the east-west low developed between an east-west high to the south (Figure 6) and an east-west high developed to the north.

Ireland (1955) suggested that the Ingalls Anticline and the Pratt Dome were related to topographic highs on the Pre-Cambrian erosional surface (Figure 10). Wells were drilled on the crests of the structures to the Pre-Cambrian and a topographic map of the Pre-Cambrian was constructed. Only three wells penetrated the Pre-Cambrian in the study area. Additional structures with large amounts of closure may be related to additional topographic highs in the Pre-Cambrian, as Ireland suggested for the Ingall and Pratt structures.

Hollrah (1977) stated that folding and faulting in Paleozoic strata of Western Payne County were related to faults in the basement rocks. His evidence was two fold: 1. The length and throw of faults generally

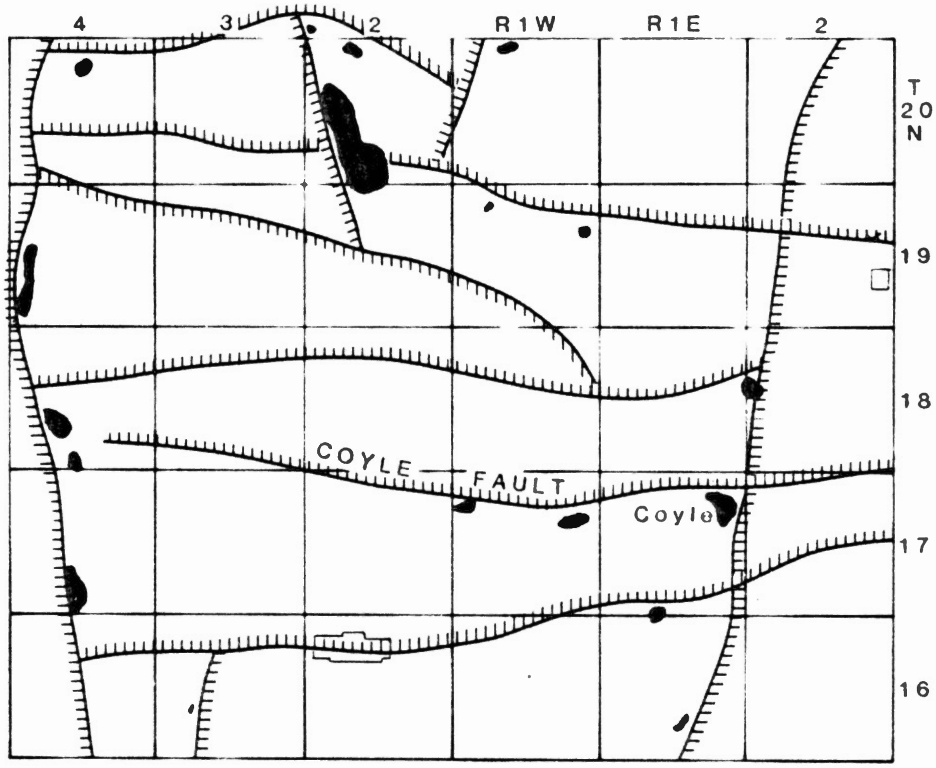

Figure 9.--General locations of major basement faults (hachured lines), and the major structurally controlled oil fields (black patches), north-central Oklahoma (after Lyons, 1950)

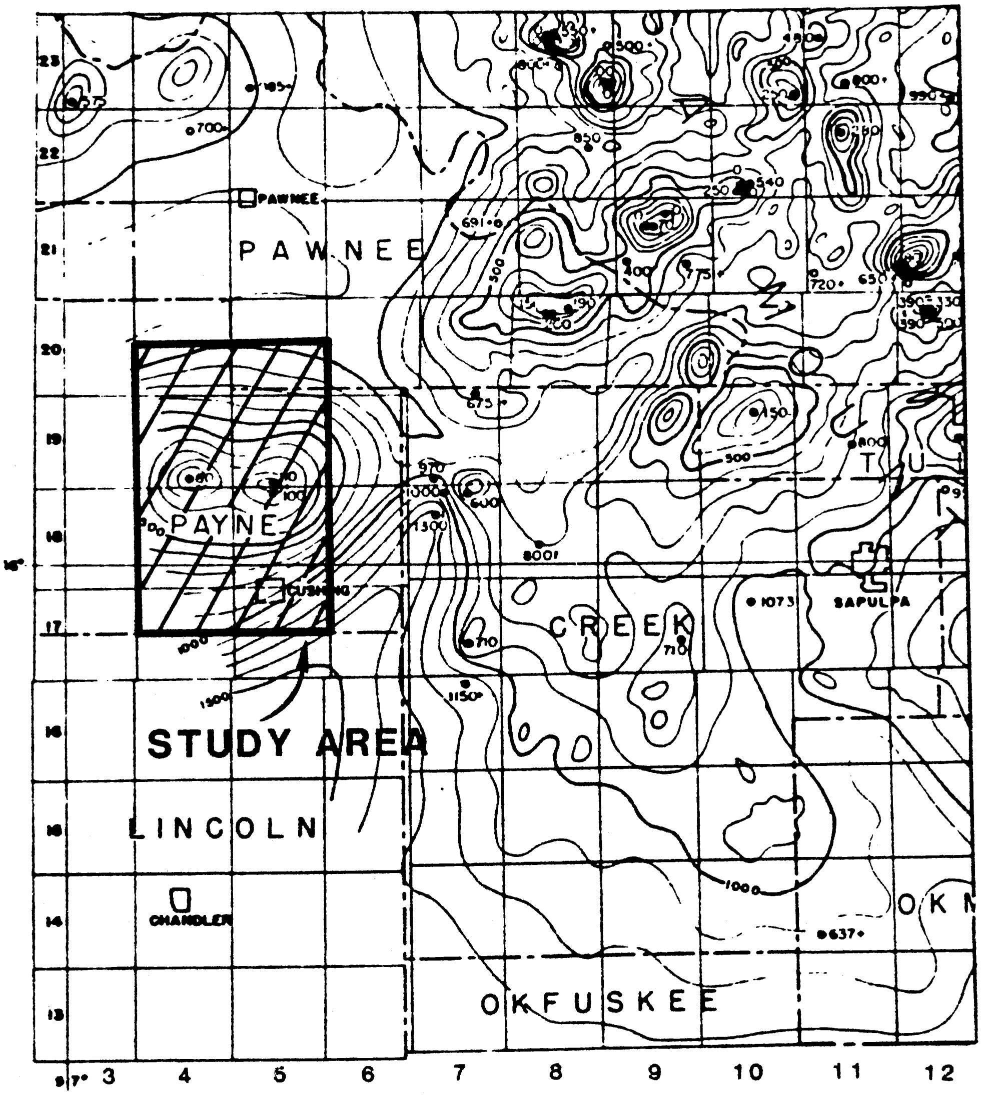

Figure 10.--Topographic map of the Pre-Cambrian surface in northeastern Oklahoma (after Ireland, 1955)

increases with depth and shows marked differences above and below major unconformities, and 2. Limbs of folds generally show steeper dip and more closure below the Post-Mississippian and Post-Hunton unconformities than above. The folds in the Post-Woodford beds are related to rejuvenation of stronger folds below the Pre-Woodford surface.

Kochick (1976) noted the same relationship as Hollrah in eastern Payne County while studying the Misener Sandstone.

The writer agrees with the folding and faulting mechanism set forth by Hollrah (1977) and Lyons (1950). A comparison of the Mississippi Lime structure map and the Woodford Shale structure map (Plates II and III) shows increased closure with depth on the major structures. The Cushing Anticlinal Trend fault (Figure 6) shows more throw with depth as does the fault in Section 31 of T20N, R4E. This fault is the only one in the study area that penetrates the Pennsylvanian.

CHAPTER VII

PALEOTOPOGRAPHY

Initial Mississippi Lime deposition was on a horizontal Woodford Shale surface. Kochick (1976) stated that the interval from the top of the Woodford Shale to the base of the Woodford Shale or base of the Misener Sand would approximate the paleotopography of the Pre-Woodford surface. Since that interval would thin over topographic highs on the Pre-Woodford surface and thicken above topographic lows, the uppermost Woodford Shale deposition would have been deposited horizontally.

For the same reasons stated above, the Isochore Map of the Pink Lime to the top of the Mississippi Lime should estimate the paleotopographic surface at the beginning of Pennsylvanian deposition (Plate IV).

As stated in the regional geology section there was probably a greater thickness of Meramecian and Osage in the study area, than is now present. There were probably rocks of Chesterian, Morrowan and possibly even Atokan age present. With erosion of the rocks of Lower Pennsylvanian and Upper Mississippian age, the topographic surface generated at the top of the Mississippian should be approximated by the isopach of the Pink Lime to Mississippi Lime. Plate IV shows thins over topographic highs and thicks over topographic lows in the study area. The general relationship in the study area is a thick Pink Lime to Mississippi Lime interval to a thick in the Mississippi Lime, and a thin

Mississippi Lime interval to a thin in the Pink Lime to Mississippi Lime interval.

It is believed that paleostructure had a lot to do with paleotopography. The initial Mississippian deposition was on a relatively horizontal surface. A combination of rejuvenation of Pre-Woodford paleostructures, and regional tilting to the south stripped the lower Pennsylvanian, if present, and upper Mississippian strata from the study area. This combination of structural movements, combined with Pennsylvanian erosion of the Mississippi Lime structural highs, formed the paleotopography on the Mississippian surface.

CHAPTER VIII

GEOLOGY OF THE MISSISSIPPI LIME

The depositional geology of the Mississippi Lime has been reported as a shelf limestone in the Kingfisher area (Harris, 1973), shallow shelf limestone in North Central Oklahoma (Curtis and Champlin, 1959), and shelf or outer shelf over much of Oklahoma (Heinzelman, 1957).

According to Curtis and Champlin (1959), there are three different categories of Mississippian carbonates in Oklahoma. Chemically precipitated lime muds, which are common in the Kinderhook and Osagean Section throughout the State and are carbonates composed of fine micro-to cryptocrystalline particles. These sediments were deposited in warm, quiet, saline, slightly alkaline waters of shallow depths. Climatic conditions resulted in evaporation causing a sufficient loss of CO_2 to cause rapid precipitation of very finely crystalline calcium carbonate from saturated waters. The depositional positions were either very shallow banks, or shoals, sheltered from winds and current free, or deeper areas, below local wave base, and current free. Fine mud that was precipitated was not washed away. These deposits accumulated on a stable platform or a slowly subsiding basin into which little or no terrigenous sediments were being introduced. The controlling factors were the petrophysical requirements and the low energy for retaining the microcrystalline precipitate.

The second type of carbonate present throughout Oklahoma, according to Curtis and Champlin (1959), were mechanically accumulated concentrations of locally derived carbonate with chemically precipitated cement. These carbonates were composed of fossils and fossil fragments, oolites, disturbed fragments or particles of lime mud, or carbonate pellets. The environment was the same as the chemical precipitates but required a higher energy environment with agitated water to produce the fragments and oolites. This type of Mississippian carbonate formed either in a less sheltered, shallower environment above local wave base, or in a current washed area. Most of these types of accumulations had little or no fine grained chemical or detrital material, and were cemented with clear crystalline sparry calcite, during diagenesis. These fragments; pellets, fossils, fossil fragments and oolites could have become incorporated in the low energy environment mud. These deposits accumulated on a stable shelf or a slowly subsiding basin, but had open water, near shore, with warm, shallow, agitated water. This type of Mississippian carbonate is found in the Osagean rocks of Northeastern Oklahoma and becomes more common in Meramecian and Chesterian Rocks (Curtis and Champlin, 1959).

The third type of carbonate present throughout the Mississippian Section, according to Curtis and Champlin (1959) is a coarsely crystalline or dolomitic limestone. These had been replaced or recrystallized during diagenesis. The authors did not speculate on the specific depositional environments.

Harris (1973) studied the Mississippian carbonates in Northwestern Oklahoma and described the Osage-Meramec Section as a micritic shelf limestone containing large amounts of chert. The section contains biohermal build-ups that relate to favorable food supply, proper water temperature and depth, to produce extremely numerous fossil populations.

The mounds were not wave resistant so were below wave base.

The Chesterian Section contains oolites and indicates high energy shelf limestones. Southward these limestones grade into a shale-sand sequence (Harris, 1973).

Heinzelmann (1957) stated that Mississippian rocks in Northeastern Oklahoma were shelf or outer shelf environment.

It is noted in many of the readings (Harris, 1973; Lee, 1940; Selk, 1948), that many authors define facies changes from north to south in the Meramec-Osage section of Oklahoma. Selk (1948) recognized these changes and interpreted them as facies belts with an east-northeast to west-southwest trend. These facies from north to south were "white lime", "siltstone", "siliceous", and "Mayes-Sycamore" (Figure 11). These are denoted as a progressive decreasing environment energy, either wave action or current velocity. The study area lies within his siliceous facies and would be basinward from the "white lime" facies.

Hoffman (1964), Thornton (1958), Rhoads (1968), and Jordan and Rowland (1959) all noted the facies variation within the Meramec-Osage as investigated by Selk.

Each worker examined samples along north-south lines and described rocks of pure carbonate to the north changing to impure carbonate and then to a silty facies to the south. The writer interpreted this as a change basinward to the south, with progressively deeper water and a lower energy environment.

The east-northeast to west-southwest facies belts recognized by Selk has been recognized in the Kingfisher Area of Oklahoma by Harris (1973). He was able to map depositional thicks in the "Meramec-Osage" that had the same trend. He was able to show that these thicks, when

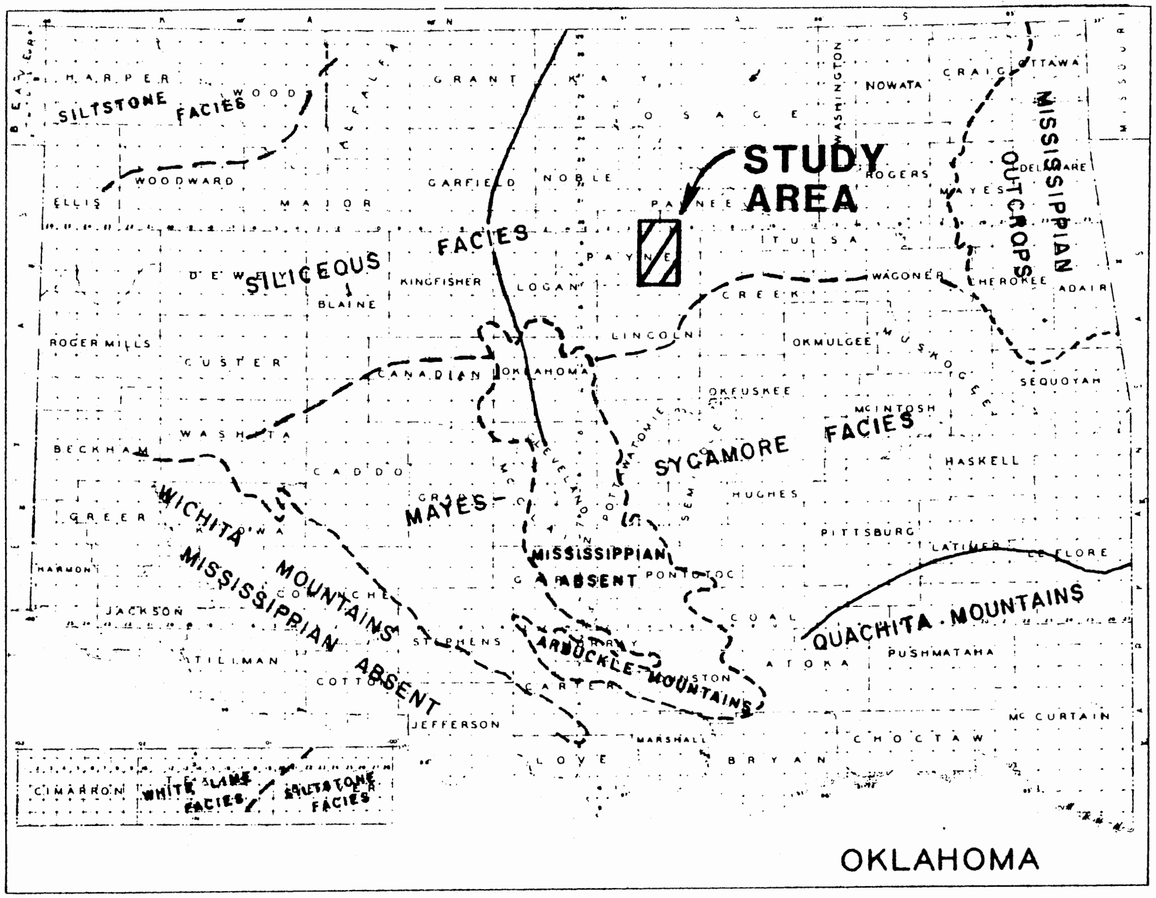

Figure 11.--Distribution of different Osage facies in Oklahoma (after Selk, 1947)

overlain by Chesterian Age Rocks, were depositional and not related to underlying structural features. The thicks are not considered reefs, but mounds of organic remains called bioherms, built above the surrounding sea floor.

Harris noted that these relate to favorable food supply, proper water temperature and depth. The writer feels that longshore currents could have supplied all of these; so the biohermal build-ups could follow depositional trends.

Laudon (1939), Starke (1961), Huffman (1963), and Arglin (1966) all noted biohermal build-ups in Northeastern Oklahoma. Laudon (1939) noted mounds that reached 60 feet thick and 1300 feet long. Harbaugh (1951) noted bioherms at the surface with an east-northeast trend up to 80 feet thick and 2 miles in diameter. Starke (1961) noted bioherms ranging in thickness from a few feet to 70 feet. Most of the bioherms of Northeastern Oklahoma are described as crinoidal limestones.

Heckel (1974) reviewed many Mississippian carbonate build-ups world wide, which he called "Waulsortian" Mounds. He stated that they consisted mainly of a calcilutite core with variable amounts of carbonate spar, and flanks of calcarenites. The "Waulsortian" Mounds studied were as short as .2 to 1.5 miles in length to a maximum 130 miles and between 10 to 3000 feet in thickness.

If the depositional trends in Northern Oklahoma are correct, then it would be expected that these trends of biohermal build-ups could be projected through the study area along trend. The biohermal mounds within the study area are on the order of one to five feet thick, a few hundred feet wide and a few hundred or thousand feet long.

The Mississippi Lime in the study area is thought to be a lime-mud build-up. Mississippian Unit "E" is a progradational feature from north to south which was likely produced in place by disintegration of algal or other organic carbonate materials, or derived from a pure carbonate source to the north.

Heckel (1974) noted that much of the modern lime mud is produced by green algae. These leave no trace of their existence but provide a potential source of CO_3 possibly as far back as the Cambrian.

Heckel's sloping sea bottom model could account for the gradual basinward accretion of carbonate mud in Unit "E". Shallow water conditions prevailed with favorable environmental conditions to aid in the accumulation of the lime-mud (Figure 12). The southerh half of the study area is covered by a thinning of Unit "E". This unit is not as clean a carbonate as it is in the north.

At the end of the depositional period of Unit "E", a raising or lowering of sea level occurred, causing a discontinuation of the purer carbonate deposition.

A thin calcareous siltstone was deposited between Unit "E" and "D". This is shown on the cross sections by a decrease in resistivity with or without a decrease in SP, and is only a few feet to a few inches thick.

A chert zone occurs at the top of Unit "E" in the north half of the study area, and is first present as this unit thickens in the south half of T19N, to the north (Appendix B, Plate XIII). The thicker Unit "E" is the greater the amount of chert present at the top of the unit. This indicates that the greatest amount of chert developed in the shallowest water. The chert probably developed at or near the water surface due to silica replacement of carbonate mud.

Highly alkaline waters caused silica to dissolve and saturate the near shore environments. The silica could have been derived from

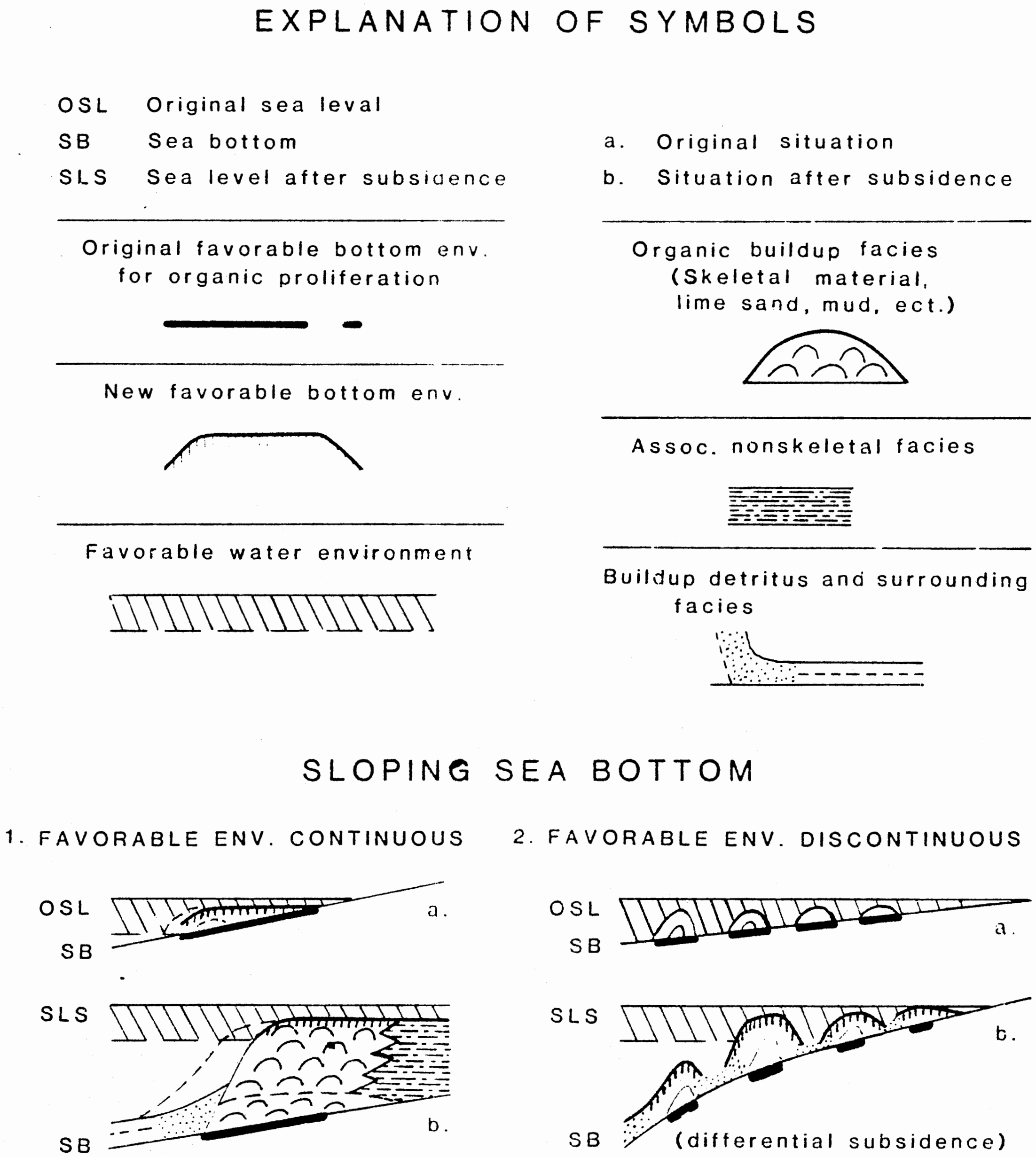

Figure 12.--General model for formation of carbonate build-ups (after Heckel, 1974)

siliceous sponge spicules, and/or could have come from outside the area and brought in by currents. As the pH dropped, producing a less alkaline environment, calcium carbonate would have gone into solution with the simultaneous precipitation of chert.

Units "C" and "D" were deposited in a similar manner as Unit "E". Unit "D" reaches a maximum thickness in the middle of T18N and decreased to zero beneath the Pennsylvanian unconformity. This unit probably continued to thicken to the north at the time of deposition, as did Unit "E".

Units "C" and "D" are separated by a calcareous siltstone (Appendix B, Plate XIV), which is similar to the siltstone between Units "E" and "D". This unit indicates a discontinuation of deposition due to a raising or lowering of sea level.

Unit "C" is similar to Unit "D" but due to Pennsylvanian erosion within the study area the depositional configuration of the section is not known to the north. Units "C" and "D" both thin in a similar fashion to Unit "E" when traced south outside of the study area.

Unit "B" represents a discontinuation of the pure carbonate deposition of Units "E", "D", and "C", and would be similar to the thin calcareous siltstone units that divide Units "E" and "D", and Units "D" and "C". The base of Unit "B" represents the boundary between the Osage and the Meramec. Most workers in Northeastern Oklahoma have recognized an unconformity between the two. No evidence to support this unconformity was present within the study area and so it represents a period of continuous deposition.

Unit "A" is not very extensive within the study area, and the origin of it is beyond the context of this thesis.

The Mississippi Lime in the study area represents a shallow water carbonate mud accumulation building from north to south with discontinuations of deposition due to fluctuations in sea level, depositing impure carbonates and siltstones.

After deposition of the Mississippian, Pennsylvanian erosion removed a portion of the Mississippian sediments. The east-west structural trends were present during this time interval which would have caused variations in water depth at the Mississippian Surface. Workers have noted algal mats and biostromes present at the Mississippian-Pennsylvanian boundary (Newcomb, Personal Communicaton, 1982) within the study area. The position of these organic build-ups occur along the east-west structural axes. It is thought by Newcomb that these deposits are similar to the bioherms and Waulsortian build-ups of other workers. There has been a high amount of siliceous material noted within these bioherms.

These build-ups could have developed due to the favorable water conditions near the water surface along the axis of east-west structural trends. Heckel (1974), developed a model which shows that on an even slope where favorable bottom environments are discontinuous (Figure 12) discrete build-ups form subject to the requirements of height, breath, slope angle, and wave resistance. The discontinuation factor influencing the build-up in the study area would have been the water depth variations related to the east-west structural trends.

The build-ups were elongated by gentle long shore currents which could have transported the organic detritus and deposited it along the structural trends.

Most of the fossils collected from the core (Plate XIV) were fragments and not identifiable. Those that were fairly complete were identified as brachiopods of the genus *Spirifer* and *Marginifera*, pelecypods of the genus *Astartella*, and some gastropod fragments only identifiable as such. All of the fauna are shallow water marine in origin.

The main fabric of the rocks studied within the study area, was mostly obliterated due to recrystallization of the lime mud to an overall anhedral mosaic of sparry carbonate. This occurred during diagenesis.

CHAPTER IX

PETROLEUM GEOLOGY

General Statement

In the study area forty-one fields produce oil and gas from the Mississippi Lime. Plate V shows all of the past and present production, the official fields outlines have been removed as they are related to geographical positions and their boundaries do not follow any reasonable geological pattern.

The first known Mississippi Lime production in the study area was the Sun Oil Co., #1 J. Kolb located in the NE NW SE Section 5-T19N-R5E. It was completed in August of 1920. Its initial potential was 30 barrels of oil a day. There are no records of cumulative production for this well.

The first surge of interest in the Mississippi Lime occurred during the mid 1950's when several operators took drill stem tests. These tests usually yielded a small amount of fluid, 10 to 50 ft. of drilling mud, and relatively low pressures, 0 to 40 psi flow pressure and 0 to 65 psi shut-in pressure. Gulf Oil Corporation took a drill stem test in their No. 1 Bennett (SE SE NE Section 31-19N-4E) drilled in 1954, in which the test yielded 2300 ft. heavily gas cut mud with flow pressures of 1165 psi and 1735 psi shut-in pressure. Despite the numerous tests no completion in the Mississippi Lime was reported during this time interval.

The next surge occurred during the mid 1960's. There were a number of wells on which drill stem tests were performed, again with low fluid recovery and low pressures, although there were a few tests run with larger fluid recoveries, and higher pressures. Generally, drill stem tests did not give any conclusive results in this area. There were around 20 attempted completions in the Mississippi Lime, of which a few were plugged with only a minor show of oil and gas and the rest made a few hundred to a few thousand barrels of oil.

The latest surge in interest in the Mississippi Lime began in the early 1970's and is still growing in 1981. There were approximately 70 completions or attempted completions in 1981.

The oil produced from the Mississippi Lime in the study area has a rather consistent gravity, averaging about 40 degrees API, with a range of 36 to 42 degrees API.

Cumulative Mississippi Lime Oil Production is shown on Plate V and was compiled using Vance Rowe-Petroleum Information Production figures up through June of 1981. The largest amount of Mississippi Lime Oil produced within the study area from a single well, is 58,924 barrels, from the Culp and Copple Inc., #1 Williams located in the N/2 SW/4 NW/4 SE/4 of Section 24, T18N, R4E. This well was completed in 1975 and is still productive. Within the study area there are only 21 wells that have each made above 19,000 barrels of oil, and only 16 wells that have made between 14,000 and 10,000 barrels of oil; this is out of a total of 183 wells with known Mississippi Lime production histories.

Much of the Mississippi Lime production in the study area is uneconomical. This oil production is from fractures in a joint system. These fractures are locally more abundant in those rocks containing more siliceous or cherty members. The best production is in those areas containing increased fracture density combined with increased matrix porosity.

Traps for Mississippi Production

Many people in the petroleum industry feel that the relationship to better Mississippi Lime oil production is related to the size of the fracture treatment used on completion. A study of these completion practices to the initial productions and to the cumulative productions of the wells shows no positive correlation. Table I is a sampling of the above parameters and is presented to show the large variations that occur within the study area. Many operators in the study area encounter large amounts of water after the fracture load is recovered. This water has been traced by surveys to come from water bearing formations above and below that were fractured into.

Other geologists believe that Mississippi Lime oil production is associated only with fracture density, the greater the number of fractures the greater the amount of oil production. Harris (1973) showed in the Sooner Trend that in the areas of greater oil production, which were associated with Meramec-Osage thicks, did not have a proportionate increase in the amount of oil produced to the proportionate increase in thickness relative to the thinner and less productive surrounding areas. He related the increased production to biohermal build-ups.

Although most of the Mississippi wells in the study area are fracture only reservoirs, Harris (1973) showed that this type of well in the Sooner Trend would have a large increase in oil after fracture treatment, followed by rapid declines due to the inability of the

TABLE I

COMPARISON TABLE OF COMPLETION PRACTICES TO INITIAL POTENTIALS AND CUMULATIVE PRODUCTION FOR SELECTED WELLS

Location	Operator Well Name	Fracture Treatment	Initial Potential	Cumulative Production	Years Productive	Mississippian Units Present	Mississippian Units Tested
NW NW NW Sec. 1-17N-4E	General Exp. #1 Kinzie	180 BW+ 800 # Sand	IPP 8 BOPD+ 30 BWPD	613	9/75 to 11/76	B,C,D,E	C,D
NE SW SE Sec. 23-18N-4E	Calvert Exp. #1 Broyles Est.	5600 BW	IPF 50 BOPD	4,458	6/72 to 6/76	C,D,E	C,D
SE SE NW Sec. 24-18N-4E	Berry Op. #1 Thompson	5000 BW	IPF 100 BOPD +100 BWPD	31,339	12/75 to 6/81	C,D,E	D,E
N/2 SW NW SE Sec. 24-18N-4E	Culp and Copple #1 Williams	900 BW	IPF 80 BOPD	58,924	5/75 to 6/81	C,D,E	Top E
NE NE NE Sec. 32-18N-42	Pierce & Carson #1 Holmes	6000 BW	IPP 42 BOPD	26,080	12/65 to 11/80	C,D,E	Middle C Middle D
NE NE NE Sec. 22-19N-4E	Thomas E. Berry #1 Schiefelbasch	2000 BW	IPP 25 BOPD+ 35 BWPD	26,780	5/76 to 3/81	A,B	Top D
SE SE Sec. 23-19N-4E	Vaughn Good #1 Ellis	8000 BW +15,000 # Sand	IPF 288 BOPD +200 BWPD	10,121	1/78 to 5/81	D,E	Top E
NE SW SE Sec. 28-19N-4E	Big Four Petro. #1-28 Mennen	1000 BW	IPP 60 BOPD +30 BWPD, +120 MCFPD	6,648	4/80 to 6/81	D,E	D

fracture to fill with oil at a rate equal to the withdrawal rate. The presence of vertical fracture allows a gravity drainage system. As drainage occurs in the high gas to oil ratio system, free gas begins to fill the upper part of the fracture. As the pressure drops, the differential pressure between the fractures and the oil and gas in the matrix porosity increases. This changes the relative permeability to gas and oil within the system. The gas moves toward the areas of less pressure, the fractures, which is below the bubble point. As the fracture fills with gas, oil cannot enter, and as the amount of oil starts to decline the gas to oil ratio increases. This causes the well to change from an oil to a gas well.

In the study area the same situation occurs in the fracture only system. As the oil decreases the gas to oil ration increases (Personal Communication, J. J. Newcomb, 1982), and the oil is not effectively removeable.

Some workers in the Payne County Area associate the better Mississippi Lime oil production to increases in matrix porosity at the top of the Mississippian along with increased fracturing (Personal Communication, J. J. Newcomb, 1982). The increases in matrix porosity is due to chert replacement of carbonate in thin units on the crests of the east-west structural trends. These units are the biohermal buildups recognized by other workers to the east and west of the study area. Newcomb and others were able to recognize increases in organic matter at the boundary between the Mississippian-Pennsylvanian. This was not observed in the sample study which included two good Mississippi Lime Oil Wells. The original fabric could have been obliterated by recrystalization during diagenesis.

Most of the oil and gas produced from the Mississippi Lime in the study area is in stratigraphic traps controlled by a lateral seal in the rock unit caused by the discontinuous nature of lateral permeability in a joint system, and the presence of good top and bottom shale seals, the Pennsylvanian Shales above and the Woodford Shale below.

The underlying unit, the Woodford Shale is persistent below the Mississippi Lime throughout the study area. This unit causes a seal in that oil and gas cannot migrate downward from the Mississippi Lime through the Woodford Shale into an underlying reservoir.

Harris (1973) speculated that Mississippian oil and gas in the Sooner Trend Area was unable to escape upward due to a seal created by the Post-Chester unconformity. In those areas where the Chester was absent and instead overlain by Pennsylvanian Shale, the seal was breached causing the escape of oil and gas. In the study area the upward seal is created by the Pennsylvanian Shales, which, although not an effective seal, in the Sooner Trend, are adequate to stop the migration of hydrocarbons into overlying porous rocks.

A barrier exists in the study area which creates a condition wherein oil and gas does not move from structurally low positions to structurally high positions. This is shown by the relatively random position of the larger Mississippi Lime oil wells to the major east-west structure on which they are orientated (Plates III and V).

Updip migration of Mississippi Lime oil and gas in the study area is prevented by the discontinuous nature of the joint system. This non-movement of hydrocarbons would not apply to those areas of increased matrix porosity caused by siliceous replacement in biohermal mounds.

McNaughton (1953) and Harris (1973) cited examples of fractured reservoirs having updip wells that tested water, although fracturing was apparently continuous from productive to non-productive areas. Both of these works indicated that oil and gas would not migrate laterally through fracture porosity alone over a large distance.

Economic Analysis of Exploration for Mississippi Lime

The major consideration for the exploration of Mississippi Lime oil, is its value as a potential target. Important factors influencing the economic potential are production histories of the wells, amount of time required to recover removable reserves, cost of drilling, completing, and maintaining wells, depth ranges, and profit-to-investment ratios. Table II shows data accumulated on five Mississippi Lime oil producers and is used to show a general relationship to economics within the study area. Values are based on $250,000 for drilling and completion costs, $30.00 net per barrel of oil, and $4,000 per year operating costs.

Production curves of the Culp & Copple, #1 Williams (Figure 13), Adair & Jenkins #1 Axtell (Figure 14), Calvert Exploration, #1 Howard (Figure 15), and the Nelson Petroleum, #1 Reedy (Figure 16), are typical of the better Mississippi Wells. They all show an overall gradual decline over the first few years of production.

The slight increase in production of the #1 Axtell in 1975 and the #1 Howard in 1975, are probably the result of restimulation when new operators, Ketal Oil and Sun Oil, assumed operations. The better wells could produce a fairly consistent amount of oil each year over a long

TABLE II

ECONOMIC EVALUATION, FIVE MISSISSIPPI WELLS IN THE STUDY AREA

Operator and Well	Production to Date (BBLS of Oil) Gross	Less-3/16 Royalty	Net Income (at $30/BBL)	Drill, Complete and Operating Expense	Profit Investment Radio
Culp & Copple Oil #1 Williams	58,924	47,876	$1,436,273	$274,000	5.2
Adair + Jenkins (Ketal Oil) #1 Axtell	27,946	22,706	$ 681,184	$322,000	2.1
Calvert Exploration (Sun Oil Company) #1 Howard	14,560	11,830	$ 354,900	$298,000	1.2
Nelson Petroleum #1 Reedy	7,942	6,435	$ 193,586	$274,000	.7
Calvert Exploration (Sun Oil) #1 Broyles	4,458	3,622	$ 108,664	$254,000	.42

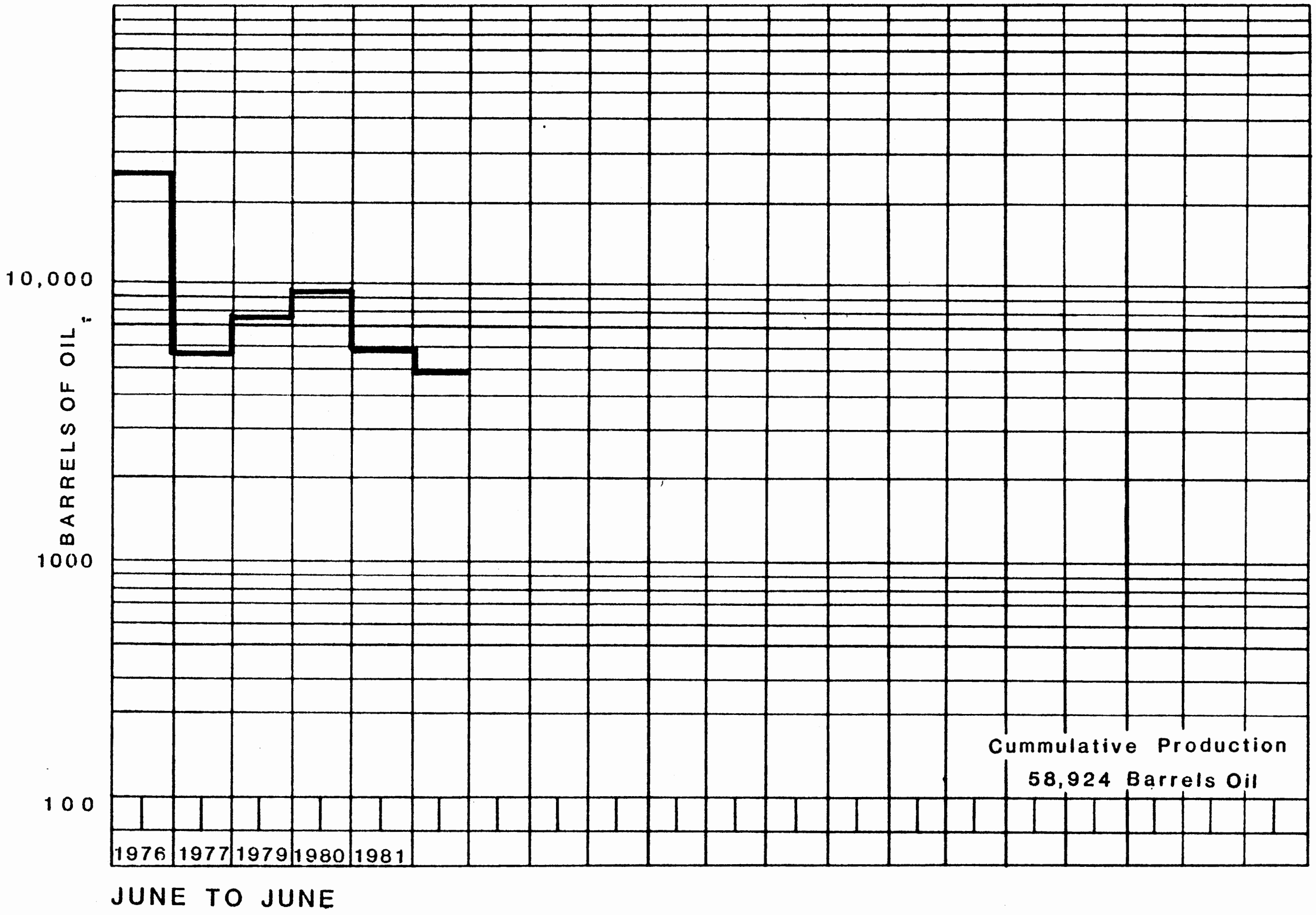

Figure 13.--Production curve, Culp and Copple Oil No. 1 Williams

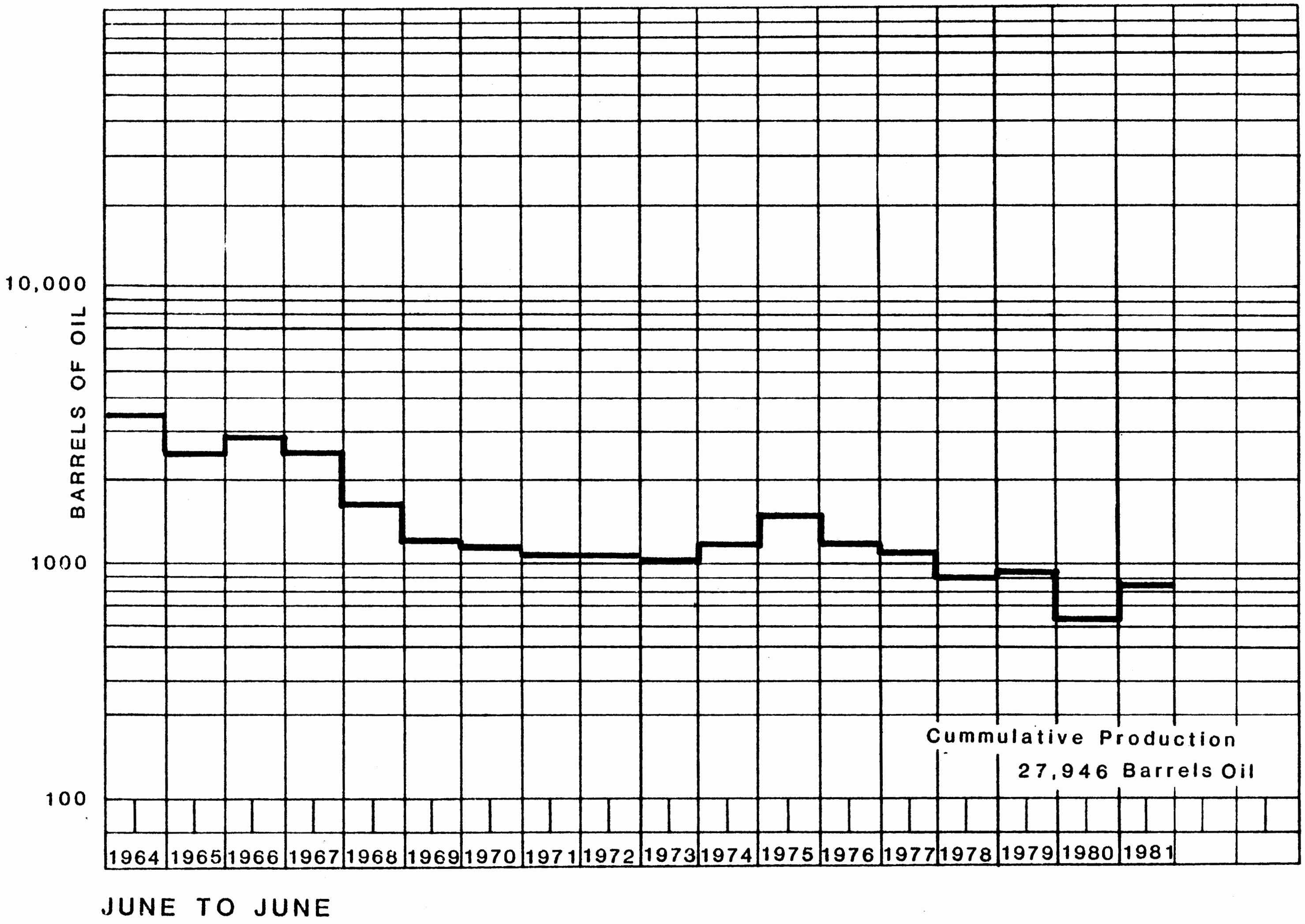

Figure 14.--Production curve, Adair and Jenkins (Ketal Oil) No. 1 Axtell

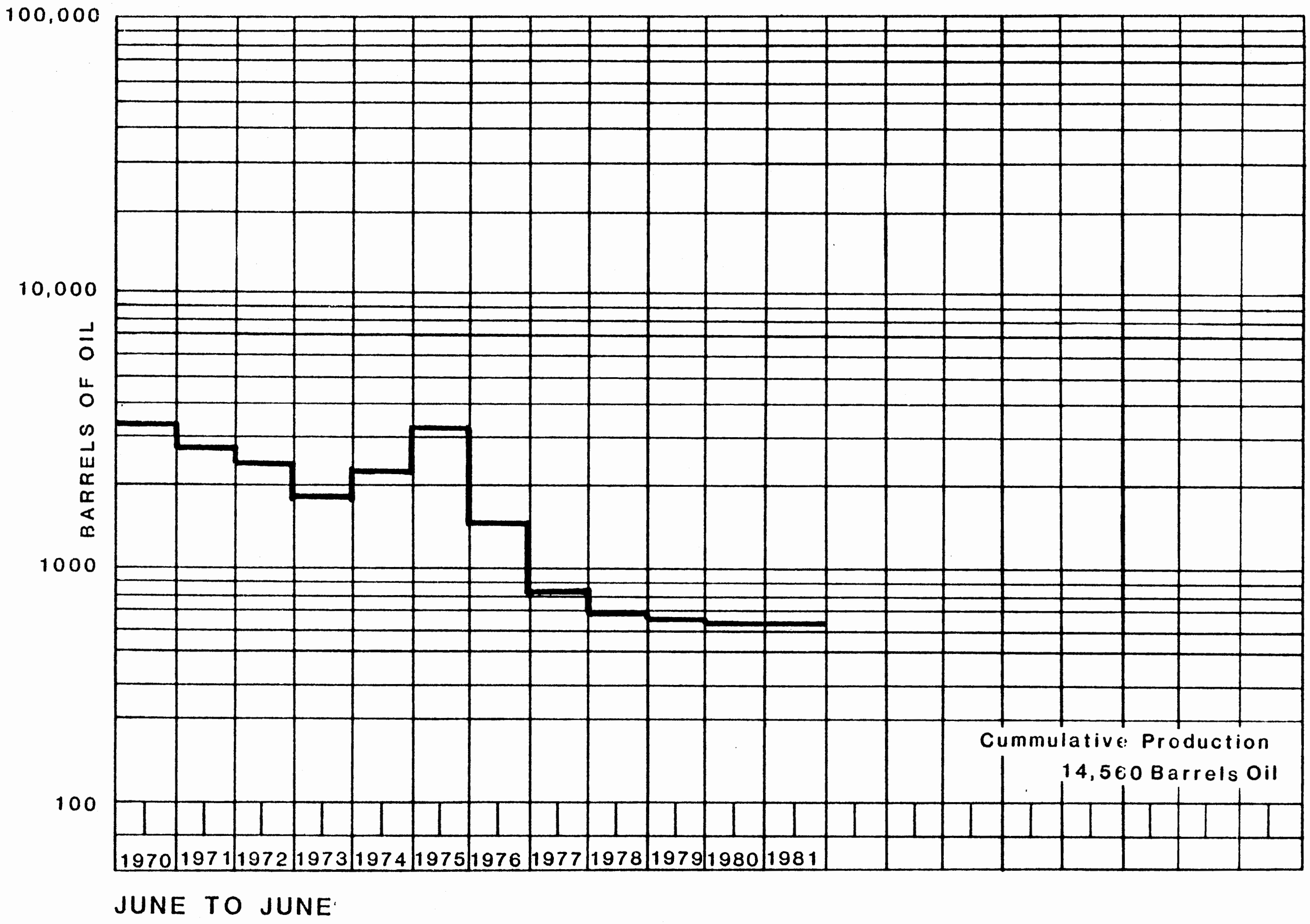

Figure 15. Production curve, Calvert Exploration (Sun Oil Co.) No. 1 Howard

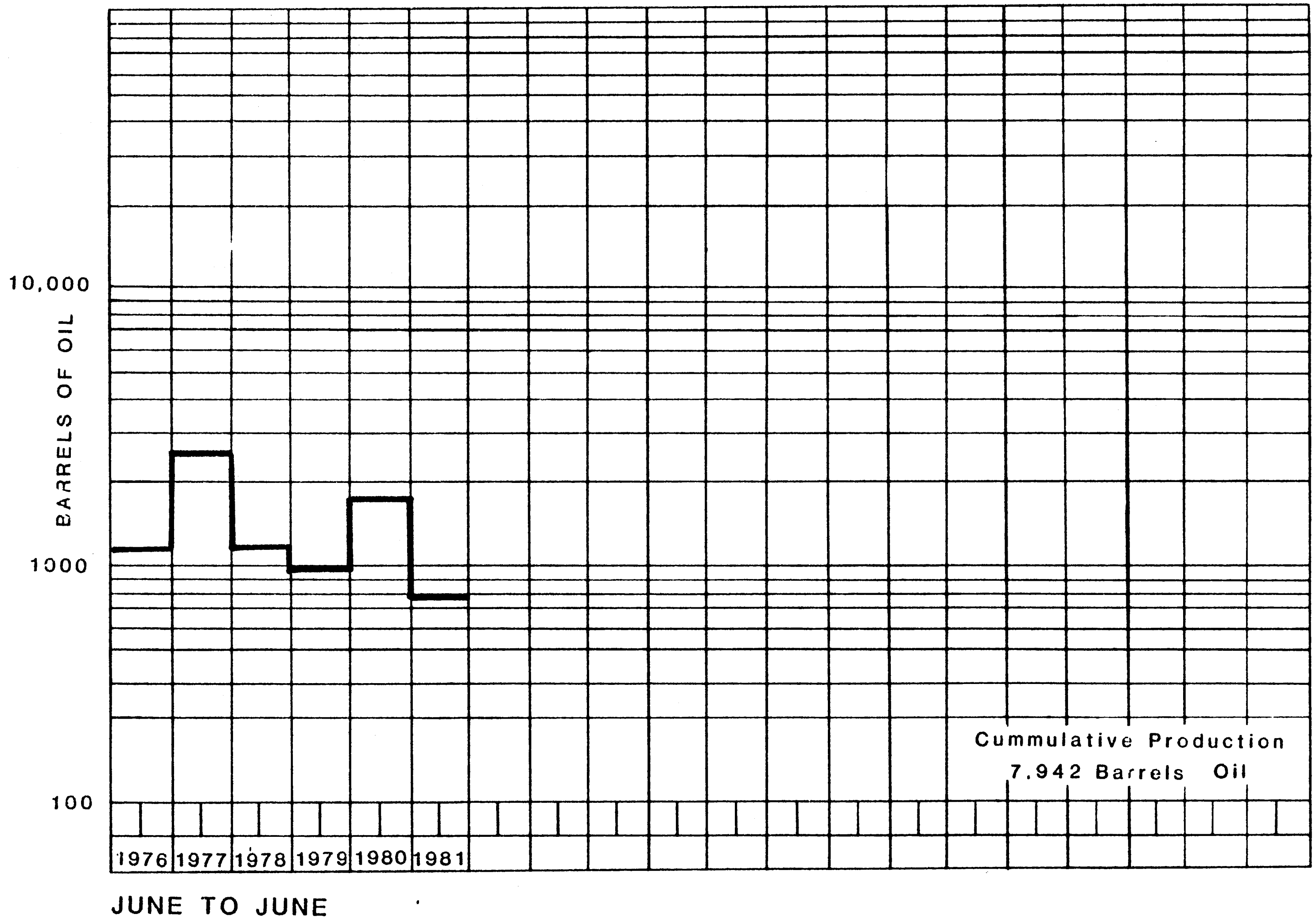

Figure 16.--Production curve, Nelson Petroleum No. 1 Reedy

period of time. All of the 37 wells that have currently produced over 14,000 barrels of oil are still producing.

The production history of the Calvert Exploration #1 Broyles (Figure 17), is typical of the majority of wells in the study area. Large initial productions followed by extremely rapid declines. The #1 Broyles probably produced oil for only a few months as it trailed off to a couple of barrels of oil a day, before being abandoned.

The origin of the oil that is being produced from the Mississippi Lime within the study area, is not a significant geological problem, due to the known existence of Mississippian oil. In some parts of the country the presence or absence of a source is the first geological question answered. There are many different theories in Northeastern Oklahoma as to the source material for the Mississippi Lime: 1. The oil was generated from within the Mississippi Lime. 2. The oil was generated from source beds in the Gulf Coast area and the oil migrated northward into Oklahoma. 3. The oil was generated from the overlying Pennsylvanian shales and migrated downward into the Mississippi Lime. 4. The oil was generated from the underlying Woodford shale and migrated upward into the Mississippi Lime. Although all of the above theories are plausible, the writer favors the theory that the source was from the underlying Woodford shale, because it is close to the Mississippian reservoir and is extremely organic rich. Future work will have to be done to prove or disprove any of the theories.

Depth of the Mississippi in the study area ranges from 3,700 ft. to 4,200 ft. Average drilling and completing costs, including an extensive stimulation treatment was approximately $250,000 in December of 1981.

Profit-to-investment ratio is based on net income, initial cost of

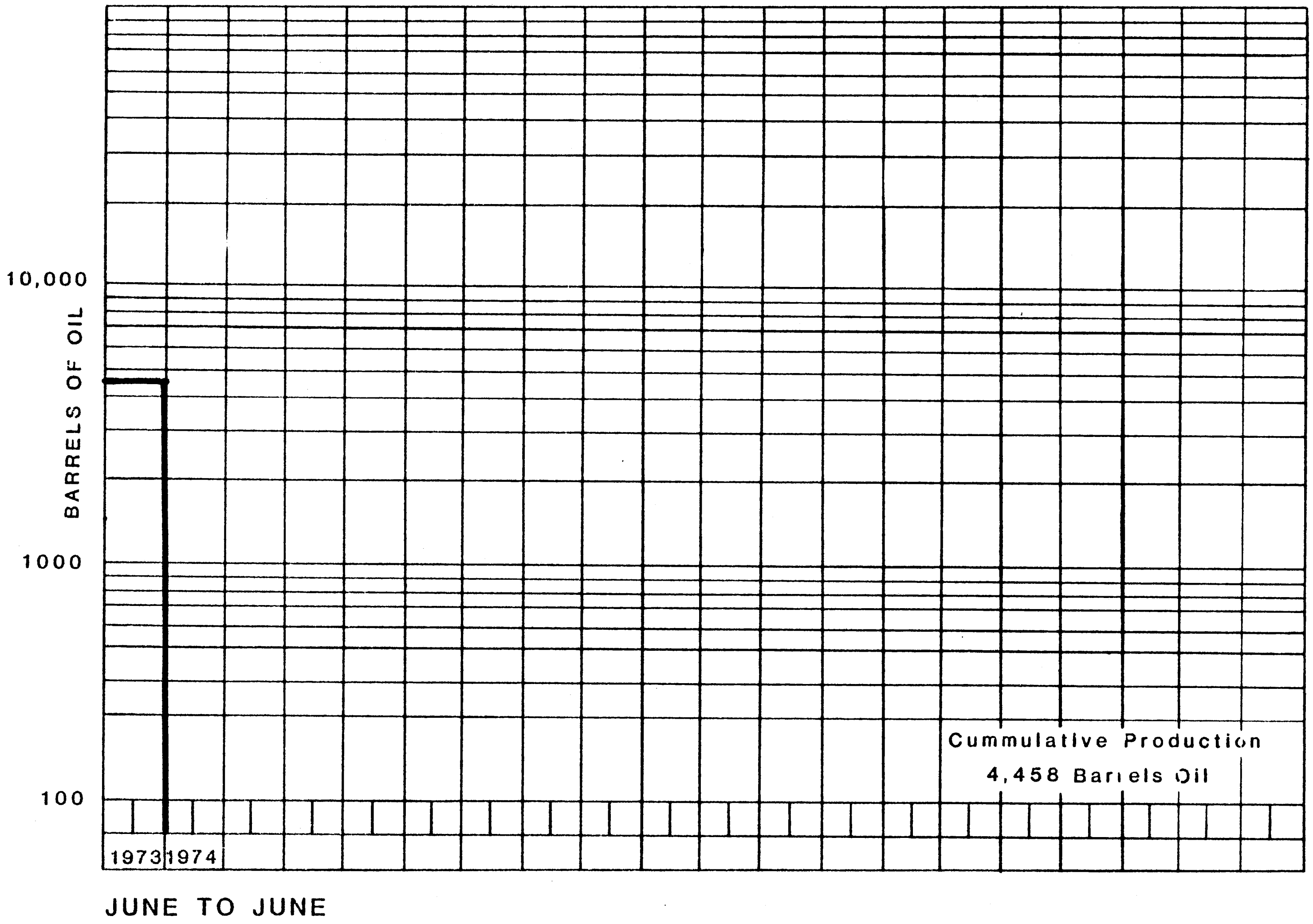

Figure 17.--Production curve, Calvert Exploration (Sun Oil Co.) No. 1 Broyles Estate

drilling and completion, and operation costs. The highest ratio obtained within the study area was 5.2 to 1. This well would not be attractive enough for many operators to pursue, except that this well could produce a consistent amount of oil and could continue to produce that way for years. Most of the wells in the study area are in the 1 to 1 and less than 1 to 1 profit-to-investment range, and would be considered by most operators not worthwhile to prospect for except as a secondary objective.

CHAPTER X

CONCLUSIONS

Principle conclusions of this study are as follows:

1. The Mississippi Lime covers the entire study area except in local areas where it was removed by Pennsylvanian erosion. Its overall thickness generally varies from 50 to 140 ft.
2. The Mississippi Lime is composed of three Osagean intervals which offlap to the south and thin both to the north and south. The thinning to the south is depositional, and the thinning to the north is erosional.
3. Paleostructure and paleotopography are related within the study area; paleostructural "highs" and "lows" correspond to paleotopographic "highs" and "lows" at the top of the Mississippi Lime.

   Paleotopography of the Mississippi Lime can be approximated by interpretations of an isopach map of the section from the top of the Pink Lime to the top of the Mississippi Lime and is related to the Pre-Pennsylvanian structures and Pennsylvanian erosion. The distribution of oil and gas is related to the paleotopography of the Mississippi Lime in that the east-west paleotopographic highs at the top of the Mississippi Lime can be areas of better matrix porosity and better oil and gas production.

4. The isopach interval of the Mississippi Lime and the isochore interval of the Pink Lime to the Mississippi Lime can give an indication of the possible areas of better Mississippi Lime oil and gas production. Mississippian paleotopographic highs correspond to thins in both the Mississippi Lime and the Pink Lime to Mississippi Lime intervals; and can be associated with areas of better Mississippian oil and gas production.
5. The basal Mississippian unit, which is Osagean in age, thickened from a calcareous siltstone in the southern portion of the study area, to a biosparite northward. A chert interval thickened at the top of this unit, from the middle of the study area, to the north. A glauconitic sandstone forms the base of the unit and is either Kinderhookian or Osagean in age. The upper two Osagean units are biosparites with intervals of pelsparites. These both are present in the southern portion of the study area and thin by erosion to the north. The lower Meramecian unit changed from a biosparite to a calcareous siltstone northward before it was removed by erosion in the middle of the study area. The upper Meramecian unit is limited to the southeastern corner of the study area and is a pelsparite. The detailed stratigraphies of the Mississippian units can give an indication of distribution of oil and gas. The better matrix porosities which result in better wells, tend to be associated with the silicious horizons which can be located on the east-west paleostructural trends. Those wells which are composed on only pelsparites and calcareous siltstones, are related to marginal oil and gas production, from fracture only porosity.

6. The depositional environment of the Mississippi Lime was shallow, warm, and quiet, marine shelf waters which had progradational carbonate units building to the south. The units are separated by siltstone intervals which represented fluctuations in sea level. Biohermal mounds developed on the east-west structural trends and had siliceous replacement which developed increased matrix porosity, and better oil and gas production.
7. The trapping mechanisms for the Mississippi Lime are: the (1) Woodford shale below, the (2) Pennsylvanian shales above, and (3) the lateral seal due to the discontinuous nature of the joint system.
8. Most of the production is from a joint system which results in low reservoir recoveries. Better production is related to a more densely developed joint system combined with increases in matrix porosity. Most of the wells within the study area have produced only a few thousand barrels of oil. Only 37 wells to date have production over 14,000 barrels of oils of which the greatest amount was 59,000 barrels of oil.
9. The risk-reward relationships of exploring for traps in the Mississippi Lime is low, and not attractive for many investors.

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APPENDIX A

MISSISSIPPI LIME SAMPLE DESCRIPTIONS

MISSISSIPPI LIME SAMPLE DESCRIPTIONS

Sample description for drill cutting thin-sections examined in the thesis area.

1) Texas Co., No. 1 Silkwood, SE SE SW Sec. 10, T17N, R4E, drilled in 1956.

   3985-4000: (Unit B), silty (10%) biosparite with minor amounts of micrite (5%) and carbonaceous material.

   4013 60 minute circulating sample: (Top Unit C), pelsparite (10% micrite pellets), with minor amounts of quartz silt (<5%).

   4040-50: (Middle Unit C), pelsparite (10% micrite pellets), with minor amounts of quartz silt (<5%) and carbonaceous material.

   4080-90: (Bottom Unit C), biosparite, with minor amounts of quartz silt (<5%).

   4100-10: (Top Unit D) biosparite, with minor amounts of quartz silt (<5%), chert, and silicious sponge spicules.

   4130-40: (Bottom Unit D) biosparite, with minor amounts of quartz silt (<5%), and carbonaceous material.

   4170-80: (Unit E) Sparry micritic glauconitic sandstone (30%-50% glauconite pellets), with minor amounts of quartz silt (<5%).

2) Josaline Production Co., No. 2 Mohler, SE NW SE Sec. 35, T18N, R4E, drilled in 1954.

   3790-3800: (Top Unit C) biosparite, with minor amounts of quartz silt (<5%), and micrite (5%).

   3840-50: (Bottom Unit C) biosparite, with minor amounts of quartz silt (<5%).

   3860-70: (Top Unit D) biosparite, with minor amounts of quartz silt (<5%), and carbonaceous material.

3890-3900: (Bottom Unit D) biosparite, with minor amounts of quartz silt (<5%), and carbonaceous material.

3950-60: (Unit E) sparry micritic glauconitic sandstone (30%-50% glauconite pellets), with minor amounts of quartz silt (5%-10%).

3) Thomas E. Berry, No. 1 Thompson, SE SE NW Sec. 24, T18N, R4E, drilled in 1975.

3590-3600: (Unit C) biosparite, with minor amounts of quartz silt (<5%), carbonaceous material, and micrite.

3620-30: (Top Unit D) biosparite with minor amounts of quartz silt (<5%).

3640-50: (Middle Unit D) biosparite, with minor amounts of quartz silt (<5%), and carbonaceous material.

3660-70: (Bottom Unit D) biosparite, with minor amounts of quartz silt (<5%), and carbonaceous material.

3710-20: (Unit E) sparry micritic glauconitic sandstone (30%-50% glauconite pellets), with minor amounts of quartz silt (5%-10%).

4) Skelly Oil Co., 4 Martha Berry, NE SW SE Sec. 22, T19N, R4E, drilled in 1951.

3680-90: (Top Unit D) biosparite, with minor amounts of quartz silt (<5%), carbonaceous material, and micrite pellets.

3710-20: (Bottom Unit D) biosparite, with minor amounts of quartz silt (<5%), carbonaceous material, and micrite pellets.

3740-50: (Top Unit E) biosparite, with minor amounts of quartz silt (5%-10%), carbonaceous material, and chert.

3785-90: (Bottom Unit E) silty (10%-15% quartz silt) sparry micritic glauconitic sandstone (30%-50% glauconite pellets), with minor amounts of carbonaceous material.

5) Coronado Oil, 1 Tathwell, NW NW NE Sec. 11, T19N, R4#, drilled in 1949.

3860-70: (Unit D) biosparite, with minor amounts of quartz silt (5%-10%), carbonaceous material, micrite, and siliceous sponge spicules.

3880-90: (Top Unit E) Chert (75%-85%) with a minor amounts of carbonaceous material, and siliceous sponge spicules, and no quartz silt.

3950-60: (Bottom Unit E) silty (10%-15% quartz silt) sparry micritic glauconitic sandstone (30%-50% glauconite pellets), with minor amounts of carbonaceous material. Micritic biosparite, with minor amounts of quartz silt (5%-10%) and carbonaceous material.

6) Ted F. Dunham, No. 1 Wittich, NE SW NE Sec. 32, T20N, R5E, drilled in 1956.

3590-3600: (Top Unit E) Chert (80%-90%) with minor amounts of sparite, dolomite rhombs, siliceous sponge spicules, and a few fracture healings with sparite.

5820-30: (Middle Unit E) biosparite, with minor amounts of chert, micrite, and quartz silt (<5%).

3670-80: (Bottom Unit E) biosparite, with minor amounts of chert, micrite, and quartz silt (<5%).

APPENDIX B

MISSISSIPPI LIME CORE DESCRIPTION

MISSISSIPPI LIME CORE DESCRIPTION

Texaco Inc. #3 W. E. Cardin
NE SW SE Sec. 32, T18N, R5E

3773-74: (Bottom Unit A) Massive light gray pelsparite, containing recrystallized micrite pellets, 20% quartz silt (sparite cement), carbonate is calcite with a possible few per cent of dolomite.

3774-3802: (Unit B) Interstratified dark gray calcareous siltstone, cement of micrite and microsparite, 50%-60% quartz silt, ripple marks are from 1/4 to 2 cm in height, amount of bioturbation increasing down, abundant fossil fragments, with some pyrite replacement.

3802-13: (Top Unit C) Horizontally stratified light gray to black calcarious siltstone, cement of micrite and microsparite, 50% quartz silt, minor amounts of bioturbation, stratification from 1/10 to 1 cm in thickness, minor amounts of fossil fragments and calcarious sponge spicules.

3813-24: (Middle Unit C) Massive light gray biosparite <10% quartz silt, carbonate is calcite with a possible few per cent of dolomite.

3824-30: (Middle Unit C) Horizontal stratified dark gray to black, silty pelsparite, cement of micrite and sparite, 20% quartz silt, 30% pellets stratification from 1/10 to 1 cm in thickness, minor amounts of flowage, few calcarious sponge spicules.

3830-38: (Bottom Unit C) Massive light gray biosparite <10% quartz silt, carbonate is calcite with a possible few per cent of dolomite.

3838-49: Interstratified black calcareous siltstone, cement of micrite and microsparite, 50%-60% quartz silt, ripple marks are from 1/2 to 2 cm in height, bioturbation throughout, abundant fossil fragments, abundant flowage.

3849-56: (Top Unit D) Massive light gray biosparite <10% quartz silt, carbonate is calcite with a possible few per cent of dolomite.

3856-62: (Top Unit D) Horizontal stratified dark gray to black silty biosparite, cement of microsparite with minor amounts of micrite, 30% quartz silt, stratification from 1/10 to 1 cm in thickness, abundant bioturbation, from 3859 to 61 are 6 inch sections of graded dark gray to black very silty micrite beds, with a small per cent of microsparite and quartz silt.

3862-64: (Top Unit D) Massive light gray biosparite <10% quartz silt, carbonate is calcite with possible few per cent of dolomite.

3864-68: (Top Unit D) Horizontally stratified with possible interstratified dark gray silty biosparite, cement of microsparite and minor amounts of micrite, 30% quartz silt, abundant bioturbation and flowage, oil stain along some fractures.

3868-3892: (Middle Unit D) Massive light to dark gray to black silty biosparite, sparite cement, 40%-45% quartz silt, large number of vertical fractures, oil stain on some fractures, some fractures healed with sparry calcite.

3892-3911: (Bottom Unit D) Massive and horizontally stratified light to dark gray to black silty biosparite, sparite cement, 20% to 45% quartz silt, large number of vertical fractures, oil stain on some fractures, some fractures healed with sparry calcite.

3911-36: (Unit E) Interstratified black calcarious siltstone, cement of calcite micrite and microsparite, 60%-70% quartz silt, abundant ripple marks that are 1/2 to 2 cm in height, bioturbation throughout, abundant fossil fragments.

3936-37: (Bottom Unit E) Massive black to green glauconitic sandstone, cement of early sparry calcite and micrite and late rhombs of dolomite, 5%-10% quartz silt, glauconite pellets 30%-60%, few fish scales, few granuals size well rounded phosphatic nodules.

3937-3938: (Bottom Unit E) Massive black to green glauconite sandstone, cement of early sparry calcite and micrite and late rhombs of dolomite, 5%-10% quartz silt, glauconite pellets 30%-60%, that are being calcified, few fish scales, many phosphate nodules from very course to pebble size, they are rounded with partial replacement by calcite.

3938-39: (Bottom Unit E) Massive black to green glauconitic sandstone, early cement of sparry calcite and micrite and late rhombs of dolomite, 5%-10% quartz silt, glauconite pellets 30%-60%, few fish scales, few granual size phosphate nodules.

3939-41: (Woodford Shale) Massive black shale, abundant pyrite.

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VITA

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