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# PETROLEUM GEOLOGY OF PAWNEE COUNTY, OKLAHOMA

*by*

PATRICK H. CLARE

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## ABSTRACT

Oil production in Pawnee County, approximately 125 million barrels since the initial discovery in 1904, is from 40 oil fields with about 25 pay zones ranging in age from Early Ordovician (Arbuckle) to Late Pennsylvanian (Endicott). Most of the oil entrapment is in rocks of Desmoinesian age and primarily is directly related to structure, although stratigraphic traps are being discovered. Depth of production ranges from 1,100 to 4,300 feet.

Westward-dipping Pennsylvanian rocks of Missourian and Virgilian ages crop out at the surface. The subsurface Pennsylvanian sequence, containing rocks of Desmoinesian, Missourian, and Virgilian ages, ranges in thickness from about 2,200 feet in the eastern part of the county to 3,900 feet in the western part. They overlie with angular unconformity the Osagean section of Mississippian rocks which attains a maximum thickness of about 350 feet. Anticlinal high areas developed prior to Pennsylvanian deposition were more deeply eroded, resulting in thinner sections or in the absence of Mississippian rocks on structure. Mississippian rocks rest upon the Devonian Woodford Shale which overlaps progressively older rocks of Ordovician age in a northeasterly direction. Rocks of the Hunton Group (Devonian-Silurian) are absent. Of the Ordovician rocks present elsewhere in Oklahoma, the Sylvan is absent. The Viola Limestone is present in the southwestern part of the county, but is absent in the northeastern part where successively older units of the Simpson Group are overlain by the Woodford. Thickness of the Simpson Group ranges from more than 350 feet in the southwest to less than 100 feet in the northeast where the Simpson was more deeply eroded. Six tests drilled on structure have penetrated basement rock below a thin (less than 420 feet) section of the upper part of the Arbuckle Group (Early Ordovician).


# Petroleum Geology of Pawnee County, Oklahoma


Patrick H. Clare*


## INTRODUCTION

Pawnee County, with an area of 591 square miles, is in north-central Oklahoma, and its rocks are part of the north-central Oklahoma platform, or shelf. The Arkansas River forms the northern and northeastern boundary of the county; Noble County is on the west, Payne County on the southwest, Creek County on the south, and Tulsa County on the extreme southeast (fig. 1). Geologically the county lies just west of the buried Tulsa Mountains and is 35 to 40 miles east of the Nemaha ridge.

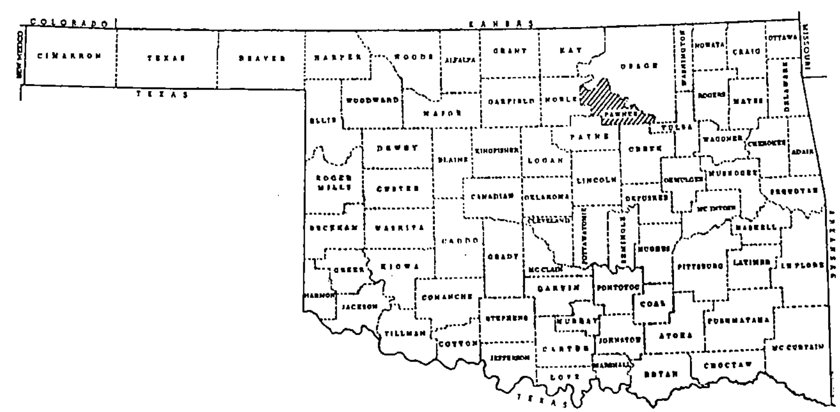

Figure 1. Index map of Oklahoma showing location of Pawnee County.

The lowest point in the county is about 650 feet above sea level in the southeastern part at the junction of the Arkansas and Cimarron Rivers, and the highest point is a little more than 1,050 feet, a difference of only 400 feet across the county. The regional


* Sinclair Oil & Gas Company.

dip in Pawnee County is approximately 50 feet per mile in a westerly direction locally increasing with depth. Information concerning the surface rocks of the county can be found in Oklahoma Geological Survey Bulletin 83, *Geology of Pawnee County, Oklahoma,* 1959, by Paul B. Greig, Jr.

About 125 million barrels of oil has been produced in Pawnee County since the initial discovery of oil in July 1904, just north of Cleveland, Oklahoma. The Cleveland Field is the largest in the county, having yielded about 42.5 million barrels of oil to the present time. The peak production year of Pawnee County was 1925, when about 6,375,000 barrels of oil was produced. Approximately 4,550 wells have been drilled in the county; about one-third are currently producing, one-third are abandoned producers, and one-third are dry holes. No major gas reservior has been discovered. Secondary recovery by waterflood now produces approximately half the annual production of the county, which has been slightly more than two million barrels per year for the last few years.

Oil production from about 40 oil fields is obtained from approximately 25 different pay zones which range in age from Early Ordovician (Arbuckle) to Early Virgilian (Endicott). All production in the county comes from depths between 1,100 and 4,300 feet. Most of the oil entrapment is related directly to structure. The search for oil in stratigraphic traps in Pawnee County has become currently the object of intensive study, all of the known apparent structures having been tested.

The primary purpose of the report was to make a study of the subsurface stratigraphy and structure of Pawnee County, Oklahoma, and to relate this study to the regional geologic history of the north-central and northeastern part of the State. The geologic structure of the county was studied by mapping the base of the Woodford Shale, top of the Mississippian System, and top of the Checkerboard Limestone. Data for all maps were taken from available electric logs, Herndon maps, *Research Oil Reports,* and Corporation Commission records. Stratigraphic studies were made with the aid of four electric-log cross sections, with driller's logs and well samples, and with two thickness maps, Mississippian-Woodford Shale unit (map F, pl. II) and Checkerboard Limestone-base Pennsylvanian unit (map E, pl. II). The maps (pl. II, B-F) are actually reconnaissance in nature in that all holes were not used in



areas of dense control. Accuracy of control points and interpretation of the data are the responsibility of the writer alone.

## Previous Investigations

The first publication covering the general subsurface geology of Pawnee County was by Frank C. Greene (1928). Included was a reprint of a special detailed study of the Morrison (now termed Watchorn) Field by Carpenter (1927). Later Carpenter (1958) finished an investigation of the faulted East Watchorn Field. Since then, four Master of Science theses have been completed on the subsurface geology of particular areas in the county. Gearhart (1958) studied the northwestern part of the county; Baker (1958), the southwestern part; Blakeley (1959), the north-central part; and Berryhill (1961), the south-central section. In particular instances these reports furnished information for this study.

Information was also obtained from regional studies that include Pawnee County entirely or in part. The regional studies include those on Precambrian rocks by Ireland (1955) and Dillé (1956); Early Ordovician rocks (Arbuckle Group) by Ireland (1955); the Simpson Group by White (1926), Dapples (1955), and Cronenwett (1956); pre-Woodford paleogeology by Tarr (1955); Mississippian rocks by Hyde (1957); and Pennsylvanian rocks by Oakes, (1951, 1953), Weirich (1953), Ware (1955), and Kirk (1957). A study by C. L. Jones (1960) on pre-Desmoinesian rocks in north-central Oklahoma included Pawnee County with little detail; but the lithologic descriptions, isopach maps, and paleogeological studies (with maps) were of use in this investigation in several instances.

It is hoped that this report will complete a detailed study of the geology of Pawnee County, this being the subsurface component or counterpart to Paul B. Greig's work (1959) on the surface rocks.

## Acknowledgments

Carl A. Moore suggested the area of study and gave aid during the preparation and writing of this report. Louise Jordan and William D. Pitt critically read the manuscript and offered constructive criticisms. W. C. McBride, Inc., made available electric

logs which, together with others obtained from the School of Geology of The University of Oklahoma, were used in the cross sections. The report, submitted as a Master of Science thesis at The University of Oklahoma, has been slightly revised and modified.

## STRATIGRAPHY

The sedimentary sequence in Pawnee County rests nonconformably upon an irregularly eroded westward-sloping surface of basement igneous rocks. In the sequence are rocks ranging in age from Late Cambrian or Early Ordovician through Early Permian, covered locally by unconsolidated Quaternary alluvium and terrace material. Except for the Quaternary deposits, the sequence is characterized by stable shelf deposits which were deposited upon the Central Oklahoma platform.

The major part of the sedimentary sequence of Pawnee County is in the Pennsylvanian System, which averages 3,500 feet in thickness, ranging from about 2,200 feet in the east to approximately 3,900 feet in the west. Thickness of the entire sedimentary sequence ranges from about 3,000 feet in the eastern part of the county to about 5,000 feet in the western part. The deepest test in the county is a dry hole in the western part, NW¼ NW¼ NW¼ sec. 19, T. 22 N. R. 3 E., where drilling ceased at 4,847 feet, in Arbuckle rocks. The dip of the beds in the entire county is normally slight and westerly, but the degree and direction differ within each system. The principal subdivisions and relative thickness of the rocks of each system are illustrated on the accompanying electric-log cross sections (pl. I).

### Basement Rocks

Basement rock is relatively shallow in Pawnee County. All five tests encountering basement rocks (table 1) were drilled on basement-rock "highs." The Flight-Beacon No. 1 Yowell penetrated 132 feet of igneous rock to a total depth of only 3,262 feet.

Basement rocks in northern Oklahoma are loosely called granite by the oil industry, but at most places the type of rock has not been determined petrographically. Although the common basement rock is thought to be granite, recent studies by staff members of the Oklahoma Geological Survey indicate that extrusive flow rocks are present. Ham (1961) reported extrusive andesite tuff and dacite present in the subsurface of Craig County in north-



Table 1. Basement Tests in Pawnee County

| Operator Lease Location | Year Drilled | Elevation (ft) | Top of Arbuckle (ft) | Top of Basement (ft) | Top Arbuckle to Top Basement (ft) | Total Depth (ft) | Penetration of Basement (ft) |
|---|---|---|---|---|---|---|---|
| Flight-Beacon No. 1 Yowell NW¼ NW¼ NE¼ 9-20N-8E | 1922 | 1,028 | 3,030 | 3,130 | 100 | 3,262 | 132 |
| Minnehoma No. 1 Richards NE¼ NW¼ NW¼ 9-20N-8E | 1925 | 1,019 | 2,995 | *3,058 | 63 | 3,072 | 14 |
| Porter Oil & Gas No. 20 Miller SW¼ SE¼ SW¼ 33-23N-3E | 1951 | 1,005 | 4,262 | **4,678 | 416 | 4,691 | 13 |
| Watchorn Oil & Gas No. 11 Miller NW¼ NE¼ SW¼ 33-23N-3E | 1924 | 967 | *4,195 | *4,570 | 375 | 4,581 | 11 |
| Tidal-Osage No. 8 Arnold NE¼ SE¼ SW¼ 3-20N-8E | 1926 | 901 | 3,105 | 3,208 | 103 | 3,217 | 9 |
| Magnolia Oil Co. No. 1 Montee SW¼ SW¼ SW¼ 29-23N-5E | 1926 | 928 | 3,850 | ......... | 785+ | 4,635 | ......... |
| Magnolia Oil Co. No. 1 Dawson NE¼ NE¼ NW¼ 10-22N-4E | 1927 | 1,005 | *4,245 | ......... | 495+ | 4,740 | ......... |

Source: Ireland (1955) with the exception of the Porter Oil and Gas well.
*Top based on samples, chiefly insoluble residues.
[illegible] R. E. Denison, Oklahoma Geological Survey.

eastern Oklahoma. R. E. Denison, who examined a core of igneous rock from depths of 4,686 to 4,691 feet in the Porter Oil and Gas. Co. No. 20 Miller (table 1) described the rock as a rhyolite porphyry containing large (up to 1 cm) phenocrysts of potash feldspar and smaller phenocrysts of plagioclase and quartz.*

## Ordovician System

Rocks of the Arbuckle Group, Simpson Group, and locally the Viola Limestone, all of Ordovician age, are present in Pawnee County. Ordovician rocks range in thickness from about 135 feet to about 1,135 feet, a range of 1,000 feet in the county.

### *Arbuckle Group*

A complete section of the Arbuckle Group in north-central Oklahoma is divisible into eight members. Only the upper parts of these (Gasconade Dolomite, Roubidoux Formation, Jefferson City Formation, Cotter Dolomite, and Powell Formation) are believed to be present in Pawnee County. A basal sandstone, possibly equivalent to the Upper Cambrian Reagan Sandstone of southern Oklahoma and resting locally upon the irregular basement surface, has been described in Noble County by Page (1955) and in Payne County by Stringer (1957). The sandstone described as Reagan by the above authors is said to be approximately 100 feet thick, white, glauconitic and dolomitic in places, and interbedded with gray, sandy dolomite. This sandstone body is difficult to correlate with the typical quartzitic Reagan of southern Oklahoma. As is true of the underlying igneous rocks, the sandstone has rarely been penetrated by the drill or examined in north-central Oklahoma, and all the recorded penetrations in Pawnee County in this zone have been on anticlines. Dolomite (either Cotter or Powell) rests nonconformably upon the igneous rocks on structural highs in Pawnee County where the wells were drilled to the basement (Ireland, 1955).*

Several geologists who have done subsurface work in Pawnee

* In 1962, Sinclair Oil & Gas Company drilled a basement test in the old Cleveland Field, the 46 Louisa M. Jones, SE¼ SW¼ sec. 20, T. 21 N., R. 8 E., elevation: 961 feet. The top of the Arbuckle was penetrated at a depth of 2,573 feet. Continuous cores were taken from 2,607 feet to the total depth of 2,945 feet into basement rock. The 356-foot Arbuckle section was primarily dolomite. Rhyolite, encountered at 2,929 feet, was overlain by seven inches of dolomite which contained rounded fragments of igneous rocks. The uppermost 10 feet of rhyolite was highly fractured and weathered.



County have assumed by projection that this so-called "Reagan" basal sandstone exists throughout the county. If the Reagan Sandstone is present in Pawnee County, it lies at the base of the thicker, off-structure sedimentary sequence. Because the thicker accumulations between structural highs have not been completely penetrated in Pawnee County tests and because local sandstones and sandy phases are known to be interbedded in the predominantly dolomite-limestone sequence of the Arbuckle Group, probably no well-based, widely accepted correlation between the locally present basal sandstones resting upon the basement surface of north-central Oklahoma and the true Upper Cambrian Reagan Sandstone of southern Oklahoma will be made for some time. These basal sandstones may be transgressive and, according to Ireland (1955), sandstones that rest upon Precambrian rocks are difficult to associate and correlate as few of them are the same in two different areas. Ireland called the basal sandstone below the Bonneterre Dolomite and resting upon the basement in northern Oklahoma and southern Kansas the Lamotte, which is of Late Cambrian age.

The thickest drilled section of the Arbuckle Group is in the Magnolia No. 1 Montee, sec. 29, T. 23 N., R. 5 E., where 785 feet of Arbuckle was encountered without reaching the basement. In contrast, in the eastern part of Pawnee County the Arbuckle thins over elevated basement areas (Ireland, 1955) and is probably locally absent. The minimum thickness of the Arbuckle drilled in the county was 63 feet in the Minnehoma No. 1 Richards, sec. 9, T. 20 N., R. 8 E.

The only oil production of any significance from the Arbuckle Group (Canadian Series) in Pawnee County is from the Turkey Mountain pay in the Lauderdale Field, SE¼ T. 21 N., R. 8 E., and NE¼ T. 20 N., R. 8 E., at an average depth of approximately 3,000 feet. The Turkey Mountain is the uppermost porous zone within the Arbuckle beneath the Simpson dolomite. The term "Siliceous lime" of northern Oklahoma is equivalent to the Turkey Mountain. Greig (1959) considered it to be a leached zone at the erosional surface of the first dolomite underlying the Simpson Group.

The Arbuckle section can be zoned on the basis of insoluble residues, but commonly the rocks of the group are treated as a single unit referred to simply as the Arbuckle Group. The group is undifferentiated on the cross sections of plate I.

## *Simpson Group*

Resting disconformably upon rocks of the Arbuckle Group is the shale-dolomite-sandstone sequence which forms the Simpson Group (Champlainian Series). In southern Oklahoma the Simpson Group is divided into five formations, but in Pawnee County rocks of this group are separated into three members which are, in ascending order, the Burgen Sandstone (Hominy pay or lower Simpson sand), Tyner Shale, and the Wilcox (Bromide) sands (table 2).

Generally in the county, a dolomite section in the upper part of the Simpson Group is called the Simpson dolomite. In eastern Pawnee County the Simpson Group is truncated by the post-Hunton, pre-Woodford unconformity; in the western part of the county the Simpson is overlain disconformably by the Viola Limestone (fig. 2).

The maximum thickness of the Simpson Group in Pawnee County is more than the 310 feet as this was the thickness penetrated in Gambal Oil No. 1 Cassidy (sec. 31, T. 21 N., R. 7 E. )without reaching Arbuckle rocks. The minimum thickness is 71 feet in sec. 5, T. 20 N., R. 8 E. Also only 136 feet of Simpson beds were reported in Brewer No. 9 Cotton, sec. 6, T. 20 N., R. 8 E. (well 7 in the cross section on pl. I). This lesser thickness of the Simpson Group

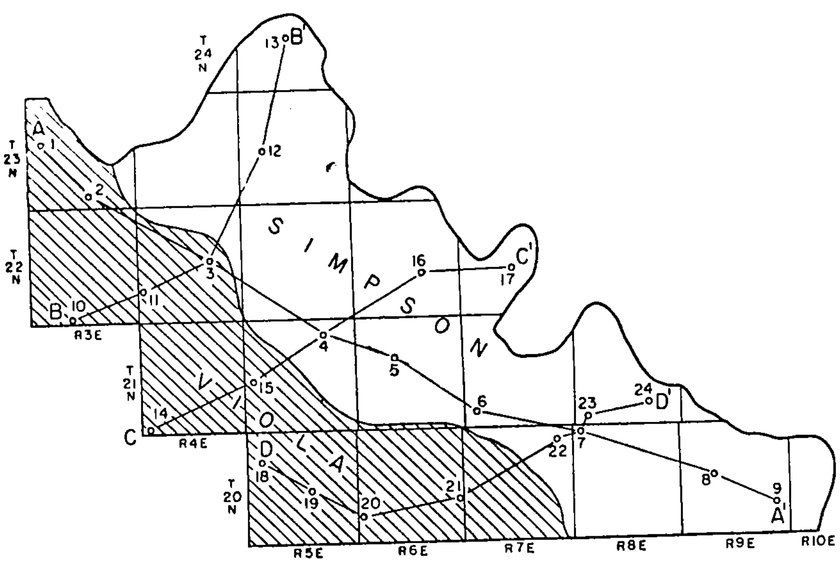


Figure 2. Pre-Woodford subcrop map of Pawnee County, showing areal extent of Viola Limestone and Simpson Group and locations of cross sections



TABLE 2. STRATIGRAPHIC SECTION OF PRE-PENNSYLVANIAN FORMATIONS IN PAWNEE COUNTY, OKLAHOMA

| *Epoch* | *Series* | *Group* | *Subsurface Terms* | *Subsurface Thickness in Feet* |
|---|---|---|---|---|
| Mississippian | Meramecian | | "Mississippi chat" | 0 - 95 |
| | Osagean | | "Mississippi lime" | 0 - 320 |
| | Kinderhookian | | | absent? |
| Devonian | | | Woodford Shale | 0 - 40 |
| | | | Misener sand | 0 - 25 |
| Silurian-Devonian | | Hunton | | absent |
| Ordovician | Cincinnatian | | Sylvan Shale | absent |
| | Trentonian | | Viola Limestone | 0 - 60 |
| | Champlainian | Simpson | | 70 - 310 |
| | *S. Okla.* | | *N. E. Okla.* | |
| | Bromide . . . in part . . . | | . "Wilcox" sand | |
| | Tulip Creek . . . | | ? | |
| | McLish . . . in part . . . | | . Tyner Fm (sh) | |
| | Oil Creek . . . in part . . . | | . Burgen sand (Hominy) | |
| | Canadian | Arbuckle | Siliceous lime or Arbuckle (Turkey Mountain pay) | 60-785+ |
| | | | Basal sandstone (Lamotte, Reagan) | 0 - ? |

in the two wells is due to post-Hunton, pre-Woodford erosion on a local anticline. Jones (1959) also reported only 106 feet of Simpson strata in Waggoner No. 1 Brodell, sec. 9, T. 20 N., R. 9 E.

The Burgen is a light-buff sandstone equivalent to basal Oil Creek Sandstone of southern Oklahoma. In Pawnee County, the Burgen lies below the Tyner Formation and rests upon Cotter or Powell Dolomite. This sandstone was encountered in wells 16 and 17 of cross section C-C′ and is 14 and 21 feet thick, respectively. The Hominy pay (equal to Burgen or lower Simpson sand) yields minor amounts of oil in several pools scattered about the county.

The name Tucker sand has been applied to the Wilcox (Bromide) sands of the Simpson, but this term should be eliminated as it is applied incorrectly throughout the county, being applied also to a Middle Pennsylvanian (Demoinesian) sandstone. The massive upper Simpson Wilcox sand, which overlies the Tyner Shale, is one of the principal reservoirs of Pawnee County and produces significantly in every large field of the county with the exception of the Maramec Field.

### ROCKS OF TRENTONIAN AGE

#### *Viola Limestone*

Overlying the Simpson Group is the Viola Limestone, the youngest (Trentonian age) of the Ordovician formations in Pawnee County. The Viola is present only in the western and southwestern third of the county. Its approximate areal extent is shown in figure 2.

The Viola possibly is absent locally because of pre-Woodford truncation. The uppermost coarsely crystalline member diminishes in the thickness northward, leaving only the light-tan, finely crystalline, typically cherty lower part in Pawnee County. This part extends northward but is also truncated by the post-Hunton erosion surface.

The thickness of the Viola ranges from zero (along the line of truncation) to 61 feet in Pawnee County. The thickest Viola shown on the cross sections is 41 feet in the Peters Petroleum No. 1 Foster (SW¼ SW¼ SW¼ sec. 31, T. 21 N., R. 4 E., well 14 of section C-C′). Jones (1959, pl. III) recorded 61 feet in sec. 32, T. 21 N., R. 4 E. In Pawnee County the Viola yields oil from only one well which is 4,179 feet deep in the West Watchorn Field, T. 23 N., R. 3 E.



The youngest Ordovician strata conformably overlying the Viola Limestone in north-central Oklahoma is the Sylvan Shale, which has been completely removed by post-Hunton erosion in Pawnee County (Tarr, 1955, fig. 1; Jones, 1959, pl. IV). Its northernmost extent is in central Creek County and northeastern Payne County.

If Hunton rocks of Devonian-Silurian age were deposited in Pawnee County, they were removed by pre-Woodford erosion. The present northern limit of the Hunton Group is in southwestern Payne County, in northeastern Lincoln County, and in the SW½ of T. 14 N., R. 7 E., southwesternmost township of Creek County (Tarr, 1955).

## DEVONIAN SYSTEM

### *Woodford Shale*

The Woodford Shale, usually called Chattanooga in northeastern Oklahoma, is dark brown to black with a brown streak, and has a blocky fracture. It is compact, at places pyritic and cherty, and locally contains conodonts. Dark reddish-brown microfossils called *Tasmanites* occur in the lower part. The Woodford is recognized readily on electric logs because of its abnormally high resistivity.

Nearly all of Pawnee County is underlain by the Woodford Shale, which averages about 25 feet in thickness, thickening to 35 to 45 feet southwestward and thinning to approximately 10 feet northeastward. The thickest Woodford encountered in the cross-section wells was 40 feet in wells 10 and 14.

Jones (1959) reported 72 feet of Woodford in sec. 5, T. 20 N., R. 8 E.; 76 feet in sec. 31, T. 21 N., R. 5 E.; and 84 feet (thickest reported in the county) in sec. 25, T. 21 N., R. 4 E. These thicknesses are abnormal. Driller's logs and service company reports include black shale which should be placed in the base of the overlying Osage Group. Berryhill (1961) reported a black, calcareous shale bed, approximately 32 feet thick, in the Osage Group, resting upon a 28-foot average section of Woodford Shale in the Bay Oil Corporation No. 1 Beetho, C S½ SE¼ SE¼ sec. 14, T. 20 N., R. 7 E. Glauconite is normally present at the base of this shale in wells south of Hallett and Jennings where Hyde (1957, pl. 4) included the section in the Osagean. Jordan (1957) also pointed out that the

Woodford underlies a glauconitic, dark-gray to black argillaceous limestone or calcareous shale unit of earliest Osagean age in western Creek County. The Woodford Shale is absent locally in sec. 6, T. 20 N., R. 8 E., of Pawnee County in the North Terlton Field (fig. 3). This absence is due to post-Mississippian, pre-Desmoinesian erosion of a topographic and structural high.

The Woodford is remarkably uniform in thickness throughout most of north-central Oklahoma, but is locally removed also in Osage County in an area north-northwest of the Ralston Field, called Osage Island (Leatherock and Bass, 1936). Northeastward thinning of the Woodford and its absence over Osage Island are cited as evidence of an unconformity at the top of the Woodford. Gearhart (1958) and Baker (1958) reported similar relationships in western Pawnee County.

The Woodford Shale rests upon the truncated members of the Simpson Group, the Wilcox sand or green shale or dolomite of the Simpson where the Viola Limestone is absent, and on the Viola in the western and southwestern part of Pawnee County.

Greene (1930) stated that the original substance of the abundant microfossil *Tasmanites* carried in the Woodford Shale, once spheres but now flattened into discs, was the source of most of the oil found in the Wilcox sand and associate strata.

The Misener sand, considered equivalent to the Sylamore Sandstone of surface nomenclature, is an unconformity sandstone which occurs locally in the lower part of the Woodford Shale. It grades laterally into the base of the shale. The term Misener is applied to a variety of lithic types, such as poorly sorted porous sandstone, dolomitic glauconitic sandstone, and dolomite or chert conglomerate.

According to Gearhart (1958), in the vicinity of the Northwest Watchorn Field, sec. 19, T. 23 N., R. 3 E., a bed of reworked limestone, chert, and quartz fragments, cemented by crystalline calcite, represents the Misener.

The source of much of the sand for the Misener member was the Simpson sandstones which were eroded in the northeastern part of the county. The Misener commonly contains coarse "golf ball" sand grains similar to those in the First Wilcox sand. In places where the Misener is present and lies directly upon Simpson sandstones, the contact between the sandstones is normally indistinguishable.



The only Misener sand shown in the cross sections is 23 feet and 7 feet thick in wells 16 and 17, respectively, and 10 feet thick in well 5. Ten feet is about the average thickness of this sandstone where present in Pawnee County.

The Misener pay is an important oil producer in Payne County to the southwest, and it produces minor amounts where present in Pawnee County. However, at some places, it is impossible to state definitely that a given sandstone is Wilcox or Misener. It is productive in the Southeast Blackburn, North Garr, Keystone, East Pawnee (abd.), and West Skedee Fields.

## Mississippian System

For the most part, Mississippian rocks, referred to as the Mississippi lime, underlying the Pennsylvanian section of Desmoinesian age and resting upon the Woodford Shale, are classified as belonging to the Osage Group. However, limestones of the Meramec Group are probably present in the southeastern part of the county. On the basis of a study of wells in sec. 34, T. 20 N., R. 9 E., and sec. 14, T. 19 N., R. 9 E., Hyde (1957, pl. I) showed the line of truncation of the Meramec Group, formed by pre-Desmoinesian erosion, as passing through secs. 24 and 34, T. 20 N., R. 9 E. Lukert (1949) placed an unconformity between the Osage Group and the underlying Woodford Shale. Rocks of Osagean age underlie most of north-central Oklahoma, whereas the strata representing Meramec and Chester deposition have been removed by extensive pre-Desmoinesian erosion from the northern part of the Oklahoma arch (Jordan and Rowland, 1959).

The Mississippi lime is a light- to dark-brown siliceous and dolomitic, and medium- to fine-crystalline limestone. However, it is variously logged as white, gray, brown, or black limestone with sandy phases. The basal part of the limestone locally may be argillaceous and pyritic, and it is normally more siliceous and of a darker gray color than the upper beds. The Mississippi lime of Pawnee County is thought to correlate with cherty limestones of the Keokuk and Reeds Spring Formations of the surface section in northeastern Oklahoma.

Normal thickness of the Mississippi lime averages between 200 and 300 feet, being thinner generally in the southern part of Pawnee

County. Anticlinal high areas were more deeply eroded than other areas, so that the amount of truncation is roughly proportional to the amount of structural closure.

A thickness map (pl. II, map F) of the Mississippian-Woodford section was constructed because the base of the Woodford and the top of the Mississippian are the two stratigraphic markers most accurately reported and recognized in old driller's logs. The unit is absent in the eastern part of the North Terlton structure (parts of sec. 31, T. 21 N., R. 8 E., and sec. 6, T. 20 N., R. 8 E.) where, on the upthrown east side of a fault, the Bartlesville sand rests direcly upon Simpson strata (fig. 3). The thickest section, 365 feet, is found in

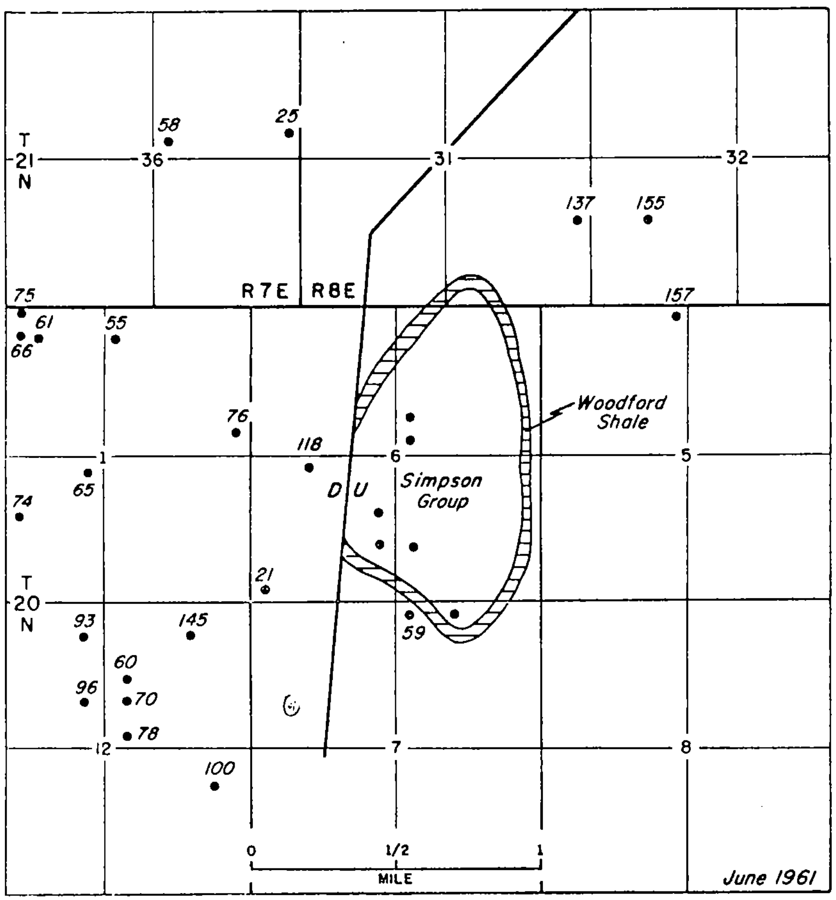


Figure 3. Map showing absence of Mississippian rocks on North Terlton structure. Thickness of Mississippian-Chattanooga unit given in feet above control point.



NE¼ NE¼ NE¼ sec. 29, T. 23 N., R. 4 E. The largest area in which the Mississippian-Woodford unit is thin (less than 150 feet) is along a northeastward-trending line passing through NE cor. T. 20 N., R. 7 E., and the Cleveland structure and southwestward toward the western part of the Terlton Field. This area probably is more complexly faulted than is shown in maps B and C (pl. II). Other prominent small areas where the unit is relatively thin are in the Watchorn, East Watchorn, Ralston, and Yale-Quay Fields. These and other areas where the Mississippian-Woodford sequence is relatively thin (map F, pl. II) are related to anticlines, or noses shown on the structure map of the base of the Woodford Shale and to lows on the map of the Pennsylvanian-Mississippian unconformity (maps B and C, pl. II).

Locally, the uppermost part of the Mississippian sequence in the county is a porous zone of blue to gray chert called Mississippi chat. More specifically, the chat consists primarily of weathered, tan, tripolitic chert that is present locally (up to 95 feet thick) upon the irregular surface of the limestone.

The Mississippi lime produces oil in the Greenup, Jennings, and Keystone Fields and in one well in the Terlton Field, and the chat is productive in the Greenup, Hallett, and Ralston Fields. Because of its normally high porosity, the Mississippi chat serves as an excellent petroleum reservoir in northern Oklahoma, especially to the west of Pawnee County in southern Noble County (Page, 1955). The upper porous part of the Mississippian limestone, called chat, constituted the "first break in the lime" of the old-time operators.

In 1961 activity in eastern Oklahoma was highlighted by the completion of a zone discovery in Pawnee County. Porter Producing Co. No. 1 State School Land, SE¼ SW¼ SW¼ sec. 13, T. 20 N., R. 7 E., in the North Terlton Field, was drilled to a total depth of 2,755 feet. Mississippi chat, new pay for the field, was perforated from 2,716 to 2,726 feet. Fracture-treated by the operator, the well flowed 3 barrels of oil an hour on a 16/64-inch choke. Regular pay in the field is from Prue and Inola (*Tulsa World*, May 28, 1961).

## Pennsylvanian System

Pennsylvanian rocks form approximately 75 percent of the sedimentary sequence in Pawnee County. The Pennsylvanian unit, containing rocks of Desmoinesian, Missourian, and Virgilian ages, ranges in thickness from about 2,200 feet in the eastern part of the county to 3,900 feet in the western part. However, post-Permian erosion has removed part of the sequence from the eastern half of the county. Map E of plate II is a thickness map of the Checkerboard Limestone and older Pennsylvanian rocks, and it shows that this unit increases in thickness from 625 feet in the northwest to 1,325 feet in the southeast, a divergence of 700 feet. As may be observed in the cross sections (pl. I), the increase in the interval to the south and southeast is due largely to a thickening of the Desmoinesian Nowata Shale which unconformably underlies the Seminole Formation of Missourian age. Also, the Seminole Formation, which includes the Cleveland sands, locally thicker at some places, is normally thickest in the southern and eastern part of the county.

TABLE 3. STRATIGRAPHIC SECTION OF DESMOINESIAN ROCKS IN PAWNEE COUNTY, OKLAHOMA

| Group | *Surface Formation and Selected Members* | *Subsurface Thickness in Feet* | *Subsurface Terms* |
|---|---|---|---|
| Marmaton | | 150-310 | |
| | Nowata Sh | 5-260 | |
| | Oologah Ls | | Big lime |
| | Labette Sh | 50-185 | Peru |
| | Fort Scott Ls | | Oswego=Wheeler |
| Cabaniss | Senora Fm | 180-275 | |
| | Breezy Hill Ls | 5-20 | |
| | Lagonda Ss | 40-110 | Prue |
| | Verdigris Ls | 5-20 | Verdigris |
| | Chelsea Ss | 80-165 | Skinner |
| | Tiawah Ls | 10-15 | Pink |
| Krebs | | 155-375 | |
| | Boggy Fm | 110-225 | |
| | Taft Ss | 40-110 | Red Fork |
| Burbank of Subsurface | Inola Ls | 5-20 | Inola |
| | Bluejacket Ss | 50-130 | Bartlesville |
| | Savanna Fm | 40-170 | Includes Brown limes |
| | McAlester Fm | 0- ? | Booch=Taneha, "Tucker," Burgess, basal sandstone |
| | Hartshorne Fm | absent | |



## ROCKS OF DESMOINESIAN AGE

Most of the oil-productive rocks of Pawnee County are of Desmoinesian age. They have an average thickness of 610 feet in the county, ranging from 530 to 750 feet. Rocks of Desmoinesian age are divided into the Krebs, Cabaniss, and Marmaton Groups (ascending order). Most of the divergence southeastward is within the Marmaton Group, but additional units of the Krebs Group onlap the Mississippian erosion surface from the southeast.

### *Krebs Group*

Rocks of the Krebs Group are dominantly dark-gray to black shales, with some silty lenticular sandstones and a few thin limestones. The group ranges in thickness from 155 to 375 feet in Pawnee County, averaging about 235 feet. According to Greig (1959), the Hartshorne Formation (lowermost Krebs) is not represented in the county. The Krebs Group includes the McAlester, Savanna, and Boggy Formations (ascending order).

A basal Pennsylvanian sandstone, the Burgess sand, is present locally, directly above the pre-Desmoinesian unconformity. It is a detrital sandstone and chert conglomerate, and, where present, it rests upon Mississippian rocks.

Loose usage of the names Burgess and Mississippi chat results in confusion. The Burgess is a transgressive unconformity sandstone, which is a pay zone of detritus upon the surface of the Mississipian rocks. Although it is difficult to separate the Burgess from the Mississippi chat by sample and electric-log studies in parts of the county, the term Burgess should be reserved for the detrital sand-conglomerate zone resting upon rocks of Mississippian age. The term Mississippi chat should be used only for the cherty residue of north-central Oklahoma (including Pawnee County) derived through the in situ weathering of Mississippian limestone (Jordan, 1957) at or near the pre-Pennsylvanian unconformity.

The Burgess sand yields oil in Jennings, Maramec, and Ralston Fields of Pawnee County. However, some of the production from the Ralston Field may be from the Mississippi chat that has been misidentified as Burgess.

## McAlester Formation

The McAlester Formation is absent in most of Pawnee County, and the oldest Pennsylvanian formation is in most places the Savanna. However, in the southeastern part of the county the McAlester Formation is present but is difficult to recognize except where a shale section underlies the Booch or Taneha sand. The Booch is considered equivalent to the Warner Sandstone Member, and at places it is called erroneously the Tucker sand. At other places the Booch is termed Burgess, the Burgess also being called Tucker. As stated before in this report, in the section on Ordovician rocks, the term Tucker is unsuitable in subsurface terminology when it is applied to basal Pennsylvanian sandstone as well as to the Simpson Wilcox sands. In the Cushing Field of Creek County, the term Tucker has been applied to Red Fork, Bartlesville, Misener, and Wilcox sands (Jordan, 1957). The sandstones termed Booch or Taneha yield oil in the Jennings, East Maramec, and Terlton Fields of Pawnee County.

## Savanna Formation

Rocks underlying the Bartlesville sand zone and overlying unconformably the Mississippi lime (or locally chat, Burgess, or Booch) consist of dark-gray shales interbedded with thin limestones and thin lenticular sandstones and are assigned to the Savanna Formation. The thin, discontinuous, dark-tan to brown, finely crystalline to microcrystalline dense limestones are the "Brown limes" of the subsurface and are correlated with limestones in the upper part of the Savanna.

The Savanna Formation ranges in thickness from about 40 feet to nearly 170 feet and averages 75 feet in Pawnee County. It forms the base of the Desmoinesian section and of the Pennsylvanian System over most parts of the county where the McAlester is absent.

## Boggy Formation

*Bartlesville sand zone.* The Savanna is overlapped by the Boggy Formation. The Bartlesville sand, which is found in the lower part of the Boggy Formation, is persistently well developed in the southeastern part of Pawnee County (as may be seen in the cross sections), wedges out to the northwest concurrent with the onlap in the same direction, and is present only locally in the northwestern part.



In the eastern and southeastern part of the county the Bartlesville, which underlies the Inola Limestone, is a greenish-white to gray, fine- to medium-grained, pyritic sandstone that is micaceous and calcareous in places and contains some green shale flecks. The sandstone grades northwestward in the county to a dark-gray to black shale.

The Bartlesville zone has an average thickness of about 80 feet, ranging from a minimum of 50 feet to a maximum of 130 feet. Locally, in north-central Pawnee County, this sandstone zone may be correlated with a shale and a thin, gray-white, medium-crystalline, arenaceous limestone.

The Bluejacket Sandstone Member of the Boggy Formation on the surface is equivalent to the Bartlesville sand of the subsurface. The sandstone most commonly is found in the uppermost part of the Bartlesville zone.

The Bartlesville has yielded large quantities of oil in the following fields: East Blackburn, North Bryan, Cleveland, Greenup, Hallett, Northwest Hallet, Jennings, Keystone, Lauderdale, Maramec, Northeast Maramec, North Quay, Ralston, Terlton, North Terlton, Southeast Terlton, and North Watchorn.

*Inola Limestone.* Separating the Bartlesville zone below from the Red Fork zone above is the Inola Limestone. A thin limestone member of the Boggy, it ranges from 4 to 19 feet in thickness and subdivides the Boggy Formation. The limestone is tan to gray and is finely crystalline. Two good illustrations of the Inola Limestone may be seen by the resistivity curves on the electric logs of wells 22 and 23 of cross section D-D′. It is difficult to distinguish the Bartlesville and Red Fork sand bodies where this high resistivity peak is absent on electric logs.

The Inola Limestone is typically 7 to 10 feet thick in Pawnee County, but locally the limestone grades laterally into a shale. Where a sandstone occurs near the top of the Bartlesville zone, it is normally associated with another sandstone in the basal part of the Red Fork zone and the Inola is represented only by a thin shale. It should be noted that in Pawnee County (and particularly in Osage County) the term Burbank is given to a sandstone body which occurs in the Inola zone and extends into parts of both the Bartlesville and Red Fork zones.

The Burbank sand is considered to be equivalent to the Red Fork in the upper part of the Boggy Formation. Recent stratigraphic work, however, suggests that it could be equivalent to the lower part of the Boggy or both Bartlesville and Red Fork. A good example of this may be seen in well 4 of cross section A-A′. A dashed correlation line is used to show possible Burbank development in this zone.

Burbank oil is produced in the Beaver Island Field, NW¼ NE¼ NE¼ sec. 17, T. 23 N., R. 3 E., and in the Bryan Field, secs. 1 and 12, T. 20 N., R. 5 E., and sec. 6, T. 20 N., R. 6 E. It is also produced in a local porosity zone within the Inola Limestone zone in the North Terlton Field.

*Red Fork sand zone.* Above the Inola and below the Pink lime (Tiawah Limestone) is the Red Fork sand zone, which is in the upper part of the Boggy Formation or lower part of the Senora Formation and is equivalent to the Taft sandstones of the surface.

The Red Fork zone ranges from 40 to 110 feet in thickness, averaging 70 feet over the county. An example of the Red Fork sand where it occurs throughout the thickness of the zone is illustrated in well 18 of cross section D-D′. At other places sandstone may be thin (less than 10 feet) or present only in the lower or in the upper part of the zone.

The lithology of the Red Fork varies considerably throughout the county, grading from an off-white or salt and pepper, fine-grained, slightly calcareous and micaceous sandstone to a light-brown, very fine-grained, argillaceous sandstone. The Red Fork zone is also commonly represented by calcareous and arenaceous shale where the sandstone is absent. Wright (1941) believed this change in lithology to be the result of sorting by waves and tides along a strand line of the Cherokee sea.

Locally, the Red Fork is a massive 50- to 75-foot-thick, medium to coarse-grained, porous sandstone which produces significant quantities of oil in several pools in Pawnee County. Production from the Red Fork is found in the fields here listed: Bryan, North Bryan, Northeast Bryan, Southwest Cody, North Garr, Greenup, Jennings,



Keystone, Lauderdale, Maramec, East Terlton (abd.), and East Watchorn.

## *Cabaniss Group*

Rocks of the Cabaniss Group consist of interbedded sandstones, gray shale, and several thin limestone and coal beds. This group ranges in thickness from 180 to 275 feet with an average thickness of about 215 feet.

Lukert (1949) referred to the rocks from the base of the Marmaton Group (top of Cabaniss Group) to the top of the Mississippi lime (base of Krebs Group) as the "Cherokee formation," a term used by many subsurface geologists. The Cherokee section in Pawnee County ranges in thickness from approximately 335 to 650 feet, averaging 450 feet.

### Senora Formation

*Pink lime.* The Pink lime is equivalent to the Tiawah Limestone of the surface. It lies above the Red Fork and marks the base of the Skinner sand zone above.

The Pink is a gray, tan or buff to dark-brown, mottled, fine-crystalline to dense, locally granular, fossiliferous limestone. It averages about 12 feet in thickness.

Because of its uniform thickness and its distinctive elecrtic-log characteristics, the Pink lime provides the best subsurface marker bed in the Cabaniss Group and is second in importance for correlation purposes only to the younger Checkerboard Limestone for the entire section. It is used as a reliable marker bed throughout Pawnee County.

*Skinner sand zone.* The Skinner sand zone lies between the Pink and Verdigris limestones and is composed of an average of approximately 105 feet of sandstone interbedded with thin shales and minor limestones and coal. The zone ranges from 80 to 165 feet in thickness. Within the zone are three sandstone bodies, termed the lower, middle, and upper Skinner sands (well 8 of cross section A-A′). The lower Skinner is generally the thickest and best defined in southern Pawnee County, whereas the upper Skinner is thickest in the northern part.

Normally the Skinner sandstones are gray to an oil-stained brown, fine grained, calcareous, slightly micaceous and argillaceous, and have slight porosity. The lower sandstone is typically buff to dark brown, locally calcareous, medium to coarse grained, with rounded and frosted grains at places. The upper sandstone is dull white or gray to light tan, fine grained with subrounded grains, and is calcareous. The Skinner sand zone is correlated with the Chelsea Sandstone of the surface.

The Skinner pay is a major source of oil in Pawnee County, especially in the southern and southeastern part of the county. Most of the production in the Skedee and Hallett Fields is from this zone. North Garr, Watchorn, and East Watchorn are the only major fields in the county that do not have production from the Skinner.

*Verdigris Limestone.* The Verdigris Limestone marks the top of the Skinner sand zone and the base of the Prue sand zone. The Verdigris is a mottled-gray or tan to brown, microcrystalline to coarsely crystalline limestone, which ranges in thickness from 7 to 20 feet (averaging 11 feet) in the county. Because of its relatively uniform thickness and persistence across Pawnee County, it can be used as a marker bed in the subsurface.

*Prue sand zone.* Located between the Verdigris and the overlying Oswego lime is the Prue sand zone. The Prue is thick in wells 5 and 6 in cross section A-A′ and also in wells 19 and 20 in cross section D-D′ (pl. I). The zone averages 65 feet in thickness but ranges from 40 feet in the north to 110 feet in central Pawnee County.

The Prue is a clear to light-gray, locally shaly, calcareous and micaceous, very fine- to medium-grained sandstone which is equivalent to the Lagonda Sandstone of the surface. It is discontinuous in the county and at places grades laterally into dark-gray or black shale.

A shale and limestone sequence only a few feet thick normally separates the Prue from the Marmaton Group above. The thin (5- to 20-feet-thick) limestone overlying the Prue sand zone and just underlying the base of the Fort Scott Limestone is equivalent to the Breezy Hill Limestone of the surface. It is normally 10 feet thick in Pawnee County but locally is little more than a thin shaly interval.

The Prue yields a fair amount of oil in a few pools in the



county, those being: Boston, Northwest Bryan (abd.), Casey, North Casey, Maramec, North Maramec, North Quay, Skedee, and North Terlton.

## *Marmaton Group*

The Marmaton Group in Pawnee County consists of the Fort Scott Limestone (termed Oswego lime), Labette Shale, Oologah Limestone (termed Big lime), and the Nowata Shale. This sequence of interbedded limestone and shale beds ranges in thickness from 150 to 310 feet in the county, averaging 210 feet.

### Big lime-Oswego lime

The Big lime and Oswego lime are correlated as one unit because the position of the intervening Labette Shale is difficult to place. Normally the Big lime and Oswego lime consist of a series of limestones and interbedded black shales. The upper limestones of this section grade successively eastward into shale. For this reason the unit is not a reliable regional marker but can be used locally for structure control.

The Oswego lime was described by Baker (1958) as a gray-mottled to brown, normally finely crystalline and nonporous, pyritic, locally granular limestone. Stringer (1957) described the Oswego as being oölitic near the base, cherty, and locally weathered on structural highs in adjoining Payne County to the southwest.

The Labette Shale lies between the Big lime and the Oswego lime, but its position is not everywhere determinable within a predominant limestone or shale section. In the shale and thin limestone interval of the Labette, a local lensing sandstone called the Peru sand (equivalent to the Englevale Sandstone of the surface) may be present.

The upper bed of the unit, the Big lime, is a locally porous, gray to brown, fine- to coarse-crystalline, locally cherty or granular, silty, relatively soft limestone with interbedded dark-gray shale. The Big lime is absent in southeastern Pawnee County, where it grades laterally into a shale, leaving only the lower limestone, the Oswego, in this area.

The entire Big lime-Oswego lime interval, including the Labette Shale, averages 140 feet in thickness in the county, ranging from 50 feet in the southeast to 185 feet in the southwest. The lesser thickness of limestone in the interval in the southeast [illegible] to an increase in shale content. The unit is 170 to 175 feet [illegible] the northern part of T. 23 N., R. 5 E., and T. 24 N., R. 5 [illegible]

The Oswego lime yields oil in the Cleveland, Maramec, [illegible] East Masham, and North Quay Fields, and in the [illegible] where it is called Wheeler. The Peru sand yields oil in the [illegible] Garr, Greenup, Hallett, Keystone, and East Maramec Fields.

## Nowata Shale

Above the Oologah Limestone is the Nowata Shale, which marks the top of the Marmaton Group and the top of the [illegible] esian Series. The Nowata is a compact, dark-gray to black shale [illegible]

The Nowata Shale averages approximately 70 feet in [illegible] in the county but has a considerable range from 5 feet in well [illegible] A-A′ to 260 feet in the southeastern part of the county in [illegible] 8 and 9 of the same cross section where this thickness probably includes shales equivalent to the Big lime and Labette. [illegible] occurrence of the overlying Cleveland sand and variations in the [illegible] ness of the underlying shale section indicate an unconformity between rocks of Desmoinesian and Missourian age.

Locally in the county sandstone, considered by many to be equivalent to the Wayside sand, is present within the Nowata Shale (Berryhill, 1961). This sandstone is oil-productive in the North Garr Field.

On the basis of the work of Jordan (1959) in Creek County [illegible] the south, it is concluded that the two uppermost formations of the Marmaton Group, the Lenapah Limestone and the Holdenville Shale, are probably absent in Pawnee County.

## ROCKS OF MISSOURIAN AGE

If an unconformity is assumed at the top of the [illegible] Formation and at the base of the Cheshewalla (Tonkawa) Sand-stone (Douglas Group of the Virgil), the Missouri section averages 1,500 feet in thickness in Pawnee County, ranging from 1,330 feet in the north to 1,660 feet in the southeast, a difference of only [illegible] feet. The Missouri unit is more than twice as thick as the Des Moines unit and is divided into the Skiatook and Ochelata Groups (table 4).



### *Skiatook Group*

The Skiatook Group includes all rocks in the section from the base of the Cleveland sand zone (the unconformity at the top of the Nowata Shale), to the top of the Dewey Limestone. In the north-western part of the county the group has a thickness of 405 feet, whereas in the southern part it has a maximum thickness of 690 feet. The average thickness is 555 feet.

TABLE 4. STRATIGRAPHIC SECTION OF MISSOURIAN AND EARLY VIRGILIAN ROCKS IN PAWNEE COUNTY, OKLAHOMA

| *Epoch* | *Group* / *Surface Nomenclature* | *Subsurface Thickness in Feet* | *Subsurface Terms* |
|---|---|---|---|
| Virgilian | Douglas | 340-1,490 | |
| | Vamoosa Fm | incomplete | |
| | Wynona Ss | 45-115 | Endicott |
| | Cheshewalla Ss | 80-150 | Tonkawa |
| Missourian | | 1,330-1,660 | |
| | Ochelata | 870-1,015 | |
| | Tallant Fm | 80-220 | |
| | Bigheart Ss | | |
| | Barnsdall Fm | 45-165 | |
| | Okesa Ss | | |
| | Wann Fm | 360-565 | Wildhorse lime<br>Perry Gas sand |
| | Iola Fm | 20-130 | |
| | Avant Ls | 5-55 | Avant=Oil City |
| | Muncie Creek Sh | 10-115 | |
| | Paola Ls | absent? | |
| | Chanute Fm | 80-220 | Mussellem=<br>Peoples=<br>Cottage Grove=<br>Osage Layton |
| | Skiatook | 405-690 | |
| | Dewey Ls | 5-35 | Dewey=<br>Avant-Dewey |
| | Nellie Bly Sh | 30-110 | |
| | Hogshooter Ls | 5-25 | Hogshooter=<br>Lost City |
| | Coffeyville Fm | 250-330 | Layton |
| | Checkerboard Ls | ±10 | Checkerboard |
| | Seminole Fm | 70-240 | Cleveland, Jones,<br>Dillard |

## Seminole Formation

*Cleveland sand zone.* Overlying the Nowata Shale and underlying the Checkerboard Limestone in the subsurface is the Seminole Formation, which includes the Cleveland sand zone. The formation consists of thin limestones, argillaceous sandstones, and dark-gray to black calcareous and arenaceous shales. The Cleveland sand is locally present at the base of the formation, as seen in wells 4 (channel sand?) and 14 on cross section C-C′ (pl. I).

The Cleveland is a clear to dull-white or gray, locally tan to "salt and pepper," fine- to coarse-grained, porous, micaceous, and calcareous sandstone containing green shale fragments. It is lenticular and the zone ranges from 70 to 240 feet in thickness in the county. The average is 155 feet. The Seminole thins (by approximately 140 feet) by onlap northwestward, as shown by cross section A-A′. Baker (1958) pointed out that the increased angularity and coarseness of the grains in the basal part of the Cleveland sand together with some oxidation particles (ferruginous coating of sand grains) are other evidences of the unconformity separating the Missourian and Desmoinesian Series.

The Cleveland sand of the Seminole Formation was named for the town of Cleveland (secs. 8 and 9, T. 21 N., R. 8 E.) and the oil field just south of it. The lower Cleveland sand locally is called the Dillard and the upper sand is called the Jones; both sands locally produce oil in Pawnee County. At many places the Dawson coal lies between the two sandstone bodies.

The Cleveland sand produces considerable amounts of oil or gas in the Cody, Cleveland, North Garr, Hallett, Keystone, Lauderdale (Jones sand), Maramec, Masham (gas), and Terlton Fields, which are for the most part in the southeastern part of the county.

## Checkerboard Limestone

Resting upon the Seminole Formation and underlying the Coffeyville Formation is the Checkerboard Limestone. The limestone has been described in different parts of the county as being varicolored, fine to medium crystalline, arenaceous, and nonporous. Also locally represented in the Checkerboard Formation is an unnamed calcareous sandstone above the limestone. The Checkerboard consists of one, two, or locally three limestone beds overlain by black fissile shale.



The Checkerboard Limestone is the most distinctive and widely used subsurface marker bed in Pawnee County, where it averages 10 feet thick. Berryhill (1961) stated that the Checkerboard is chosen as a structural or stratigraphic datum because: (1) the limestone is readily recognized on electric logs by its charcteristically high resistivity curves, (2) it is persistent over a large area with a relatively constant thickness, and (3) the top is correctly reported by nearly all geologists. For these reasons, the limestone also makes an excellent horizon on which to contour.

## Coffeyville Formation

*Layton sand zone.* The name Layton was first applied to a sandstone in the Cleveland Field (Greig, 1959). Sandstones above the Checkerboard Limestone and below the Hogshooter Limestone (=Dobbs Creek Sandstone Member of the Coffeyville Formation, Jordan, 1957) are called True Layton sands to distinguish the sandstones from miscalled units. The sandstone is well represented in cross-section wells 2 and 5 on A-A′, well 12 on B-B′, and in wells 14 and 17 on C-C′. Well 14 shows an especially thick section of the Layton sand as well as the Osage Layton sand 70 feet above it.

The Coffeyville Formation consists of two members composed of interbedded calcareous and noncalcareous sandstones and of arenaceous and calcareous shales. The formation ranges in thickness from 250 to 330 feet and averages 300 feet in Pawnee County. The lower member is composed of dark-gray, arenaceous to calcareous, micaceous shale, which has an average thickness of 185 feet, ranging from 120 to 225 feet. The upper member is the Layton sand zone, which ranges in thickness from 85 to 165 feet, averaging 120 feet. The sandstone is clear, white or gray or locally even "salt and pepper" in appearance, very fine to coarse grained, subangular, normally nonporous, micaceous, calcareous, and well cemented. It contains green shale fragments and is interbedded with dark-gray, thin shale beds and locally minor thin, tan, finely crystalline limestone beds.

It is locally difficult to distinguish the upper part of the Layton from the Hogshooter Formation where the latter is not thick and well represented. According to Gearhart (1958), thickening of the Layton sand is accomplished at the expense of the underlying shale section.

The Layton sand produces oil in several Pawnee County fields. These are the Cleveland, Lauderdale, Maramec, Southeast Osage City, Terlton, Watchorn, and Northwest Watchorn Fields.

## Hogshooter Limestone

Resting directly above the Layton zone and below the Nellie Bly Shale is the Hogshooter Formation, normally a useful and widely used subsurface marker bed in Pawnee County, as it is in all central and northeastern Oklahoma. Locally termed the Lost City lime, the Hogshooter is represented by a gray calcareous, arenaceous or silty shale and a thin, gray-white or buff-tan, locally granular, microcrystalline to medium-crystalline limestone. Also locally, a white, calcareous sandstone is present in the upper part of the formation. The Hogshooter Formation, where present, normally is from 10 to 25 feet thick.

The limestone exhibits complementary thickness relationships with the underlying Layton sand. Where the Layton sand is thick, the Hogshooter is represented by calcareous shale and sandstone (Gearhart, 1958); but where the Layton is thin, the Hogshooter is a fairly thick limestone. Likewise, irregular variations in the thickness of the overlying Nellie Bly Shale commonly are complementary with those of the Hogshooter Formation. It should be noticed that increases in the thickness of the Layton zone coincide with both a thinning of the Nellie Bly Shale and an increase in the shale content of the Hogshooter; the opposite is true where the Layton zone is thin.

## Nellie Bly Shale

The Nellie Bly Formation rests upon the Hogshooter and underlies the Dewey Limestone. It consists of a gray or dark-gray, compact, calcareous, and locally micaceous shale. This shale unit ranges in thickness from 30 feet in the northwest to 110 feet in the southeast and averages 60 feet. Lukert (1949) stated that the Nellie Bly Shale thins westward from Osage County.



## Dewey Limestone

Marking the top of the Skiatook Group is the Dewey Limestone zone, which is represented by calcareous gray to dark-gray, arenaceous, and slightly micaceous shale with a number of thin, multicolored (white to brown), locally developed, finely crystalline to microcrystalline limestones. Also locally present in the zone is a thin, light-gray, medium-grained calcareous sandstone.

The Dewey appears to be better represented where the Nellie Bly Shale is thin. Blakeley (1959) reported that this zone is difficult to recognize where the overlaying Cottage Grove Sandstone (Osage-Layton sand) is well developed, possibly because erosion may have removed the upper part of the Dewey. This relationship may be observed on the cross sections. The Dewey zone is from 7 to 37 feet thick and averages 20 feet across Pawnee County.

## *Ochelata Group*

The Ochelata Group includes all rocks from the base of the Cottage Grove Sandstone of the Chanute Formation to the top of the Tallant Formation. The group averages 940 feet in thickness in Pawnee County, ranging from 870 to 1,015 feet, thinning slightly from west to east. The Ochelata has approximately twice the thickness of the Skiatook Group, the two of them constituting the Missourian Series.

## Chanute Formation

*Cottage Grove Sandstone zone.* Rocks from the top of the Skiatook Group to the base of the Iola Formation belong to the Chanute Formation. The formation is primarily sandstone but is also characterized by interbedded thin discontinuous limestones and shales. The Cottage Grove Sandstone (Osage-Layton sand) is the principal member, making up the major part of the Chanute Formation.

The Cottage Grove is a white, locally gray to tan, fine- to coarse-grained, commonly porous, locally calcareous sandstone, the basal part of which is cherty and glauconitic. The zone averages approximately 155 feet in thickness, ranging from 80 to 220 feet, whereas the actual sandstone body ranges from zero to 125 feet. This lensing sandstone is thick in the western part and especially in the northwestern part of the county. It is thin locally, and is absent in the southeast as can be seen in cross-section wells 7 and 8 and also in sec. 30, T. 23 N., R. 5 E. Where the sandstone is absent, the interval is composed almost entirely of gray to dark-gray, silty to sandy, compact shale.

An increase in thickness of the sandstone in the zone is accomplished at the expense of the overlying shale. However, basal variations of the sandstone appear to be a result of depositional differences. Although quite variable as to the lithologic impurities, porosity, and lateral continuity of the individual beds, the Cottage Grove has a wide and persistent distribution (Berryhill, 1961, p. 4).

According to Lukert (1949), the Chanute Formation rests disconformably upon the underlying Skiatook Group. Oakes (1959) also stated that the Chanute is unconformable with the underlying Dewey Formation of the Skiatook Group in Creek County. The Cottage Grove Sandstone is locally absent or at best, poorly represented where the Dewey is thick, but the Cottage Grove is a thick and well-represented sandstone. Therefore, it appears that the Cottage Grove developed in complementary thickness to the underlying Dewey Limestone zone.

Baker (1958) found an excellent sandstone development in the basal part of the Chanute Formation in a well in southwestern Pawnee County where both the Dewey and Hogshooter Limestones were absent. This suggests that the basal sandstone member of the Chanute Formation may have been deposited in erosional valleys or channels. An increase in grain size and presence of green grains and even chert fragments (Gearhart, 1958) in this basal sandstone also suggest the existence of a disconformity at the top of the Skiatook Group. Greig (1959) stated that an unconformity within the Missouri section is indicated by the marked thinning of the section between the Coffeyville and Chanute Formations toward the north and west. He thought this may correspond to the unconformity reported by Lukert (1949) separating the Skiatook and Ochelata Groups.

The ambiguities of the synonymous terminology applied to the Osage-Layton sand should be eliminated. This is not the True Layton sand of Creek County, which is equivalent to the Dodds Creek Sandstone. Some of the terms applied to the Cottage Grove zone are: Layton, Peoples-Layton, Osage-Layton, Broyles-Layton, Layton of Ponca City, Peoples sand, lower Tonkawa, Mussellem (by Bass), and Watchorn sand. Mussellem and Osage-Layton are fairly consistently used terms applied to the Cottage Grove sand, the term now in general usage. The name Osage-Layton was first applied in the Cushing Field in Creek County but is misidentified as True Layton in Osage County.

The sandstone called Peoples produces in the Cleveland and Lauderdale Fields. The Watchorn sand, which is probably Cottage Grove, was named and produces in SW¼ NW¼ SW¼ sec. 33, T. 23 N., R. 3 E., at a depth of 2,750 feet.



## Iola Formation

The Iola Formation is composed of the Paola Limestone, Muncie Creek Shale, and the Avant Limestone. Lukert (1949) stated that the Paola can be recognized at few places in the subsurface. The Paola Limestone was questionably identified at the base of the Iola Formation in a few of the cross-section wells and in a few well samples that were run. In Pawnee County, the Iola Formation ranges in thickness from 25 to 185 feet, averaging 85 feet.

*Muncie Creek Shale.* The Muncie Creek is a gray or dark-gray to black, bituminous, fissile to platy, highly radioactive shale underlying the Avant Limestone. The shale is normally about 55 feet thick in Pawnee County, ranging in thickness from 10 feet in the northwest to 115 feet in the southeast.

*Avant Limestone.* At the top of the Iola Formation lies the Avant Limestone. The limestone is thickest in the southwestern part of the county, where it is 55 feet thick. It thins to 5 feet in the northern part. Its thickness averages approximately 25 feet in Pawnee County. The Avant is a white, light-gray or tan, somewhat mottled, microcrystalline to medium-crystalline, arenaceous and dolomitic limestone that grades into shale and sandstone northward and westward.

Jordan (1957) reported that the name Avant as used in the subsurface is most often misapplied to the Wildhorse Dolomite, but also is given incorrectly to limestone in the upper part of the Nellie Bly Formation or to the Dewey Limestone. The Avant of the surface is not necessarily the Avant described in the subsurface in many locations.

The surface Avant Limestone is equivalent to the subsurface Oil City lime. This limestone yields oil in minor amounts in southeastern Pawnee County in the Lauderdale, Southeast Osage City, and Northeast Terlton Fields.

## Wann Formation

The Wann Formation was described by Oakes (1952) in eastern Pawnee County as being composed of 400 to 425 feet of heterogeneous rock types which intergrade laterally and vertically. Lukert (1949) treated the Okesa Sandstone and Wann Formation as one unit because it is not normally practical to separate them. However, in Pawnee County they are easily distinguishable.

The entire Wann Formation is normally 450 feet thick in Pawnee County, ranging in thickness from 360 feet in the southwest to 565 feet in the north. The lower Wann consists of an average thickness of 130 feet of gray silty calcareous platy shale. It ranges from 100 to 190 feet. This is overlain by what is considered to be the Perry Gas sand zone by many subsurface geologists, including Lukert (Clinton, 1957).

The Perry sand is any sandstone between the Wildhorse Limestone above and the Avant Limestone of the Iola Formation below. Normally 100 to 200 feet thick, this is a zone of lenticular sandstones containing thin shale partings. Locally it is a massive sandstone 100 feet thick. The sandstone is a white or buff-brown (with some dark grains described as "salt and pepper"), locally slightly argillaceous and calcareous, very fine- to coarse-grained, tight to porous, friable sand.

The Perry Gas sand has not been reported as productive anywhere in Pawnee County. The Washington Irving and Clem Creek Sandstones of the surface occur within the Wann Formation in the Perry Gas sand zone of the subsurface.

The upper part of the Wann Formation consists of 50 to 150 feet of gray shale which locally contains the Wildhorse Limestone. The Wildhorse is a white to gray or buff, dense to finely crystalline or granular limestone. Rapid lateral facies changes make it difficult to trace in the subsurface. The erratic Wildhorse Limestone or Dolomite contained in the chocolate and gray shale member of the upper



Wann Formation is often erroneously reported as the Avant or Avant-Dewey Limestone. Locally, the Wildhorse is represented by two limestones separated by a shale interval of 25 to 40 feet.

The Wildhorse Limestone, where present, normally is from seven to nine feet thick across the county except in the northwestern part, where it is 30 feet thick in cross-section well 2 and 45 feet thick in well 1, both on line A-A′. Gearhart (1958) reported a maximum thickness for the Wildhorse of 120 feet in the northwestern part of the county but, if this questionable thickness is correct, it is an unusually abnormal and local deposit.

Greig (1959) placed an unconformity in the lower part of the Wann Formation in eastern Pawnee County. His work revealed almost complete truncation of the lower part of the Wann in easternmost Pawnee County. The unconformity seems to die out westward and is not apparent in the subsurface in the larger part of the county to the west.

## Barnsdall Formation

Oakes (1951) defined the Barnsdall Formation to include "the rocks from the base of the Birch Creek Limestone* upward through a section composed largely of shale to the base of the Bigheart sandstone." Oakes also believed that the Barnsdall was underlain with slight disconformity by the Wann Formation, but no evidence of this was observed in the subsurface of Pawnee County. The Barnsdall Formation ranges in thickness from 45 to 165 feet, averaging 95 feet across the county.

*Okesa Sandstone.* The Okesa (Greig, 1959, and Berryhill, 1961) is a white, fine- to medium-grained, locally massive, calcareous cemented sandstone. No calcareous members are reported in the Barnsdall Formation in eastern Pawnee County, but in the remainder of the county thin dolomites and dolomitic limestones are encountered locally.

## Tallant Formation

The interbedded, chocolate and gray sandy shales and thick sandstones, characteristic of the Tallant Formation, lie conformably upon the Barnsdall Formation. The Tallant Formation crops out southward from the Kansas-Oklahoma line in a relatively narrow

* Subsurface term.

strip across Osage, eastern Pawnee, and Creek Counties into Okfuskee County, where it is truncated by pre-Virgilian erosion. The Tallant ranges in thickness from 82 feet in the north to 220 feet in the south, averaging 160 feet in the county.

*Bigheart Sandstone.* The basal unit of the Tallant is the Bigheart Sandstone. Because of the lenticularity of the beds within this interval, there is no agreement as to the upper limit of the sandstone body, but Oakes (1952) reported that the base is well defined. In Pawnee County the Bigheart is a fairly thick bed of fine- to coarse-grained sandstone. It is normally massive but contains silty or shaly streaks. Resting upon the Bigheart Member is an unnamed section consisting of maroon and gray shales and thin, lenticular beds of light-colored siltstone and fine-grained sandstone.

*Revard Sandstone.* According to Greig (1959), above the unnamed shale section is the Revard Sandstone Member, limits of which are defined with difficulty even at the type locality in Osage County; consequently, the term is of little value. It is applied to the persistent sandstone normally present in the upper part of the Tallant Formation. However, the lenticular nature of upper Missourian sandstones makes it doubtful that the Revard of one locality is the exact equivalent of the Revard of an adjacent locality. The Revard of Pawnee County is normally a massive sandstone containing thin lenses of shale and white siltstone. Above the Revard is another unnamed sequence of shale containing thin lenticular beds of light-colored siltstone and fine-grained sandstone. This sequence is the uppermost unit of the Tallant Formation.

Until the Tallant Formation was named, the beds of which it is composed were considered to be of Virgilian age. However, work by Oakes (1952) demonstrated that the basal Virgilian unit of Kansas, the Tonganoxie Sandstone, correlates with the Cheshewalla Sandstone of northern Oklahoma, not with the Bigheart Sandstone as previously supposed. Other subsurface geologists believe that if there is an unconformity at this horizon in Pawnee County, it is local. However, probably enough evidence of an unconformity separating the Missourian and Virgilian Series has been reported and substantiated in several parts of the county.

## ROCKS OF VIRGILIAN AGE

Lukert (1949) stated that the basal sandstone beds of the Douglas Group overlying the Tallant Formation offer some evidence



that an unconformity separates rocks of Missourian and Virgilian ages. In northwestern Pawnee County, Gearhart (1958) reported that the basal part of the Tonkawa sand contains weathered chert fragments and a zone of coarse basal sand which appears to be widespread. Baker (1958) suggested an unconformity here also, based upon an increase in the number of sandstone beds at the base of the Douglas Group in southwestern and south-central Pawnee County. A few oxidized particles (iron-oxide-coated sand grains) in the north-central part of the county in the basal Tonkawa sand may also indicate an unconformity (Blakeley, 1959). Increased coarse grain size and presence of some green grains in the basal Tonkawa also suggest an unconformity separating the two mentioned series.

### *Douglas Group*

### Vamoosa Formation

*Cheshewalla Sandstone (Tonkawa sand zone).* The Cheshewalla Sandstone, basal member of the Virgil unit, is referred to in the subsurface as the Tonkawa sand (or Stalnaker sand of southern Kansas) and is a persistent sandstone zone which can be traced fairly well throughout Pawnee County.

The Tonkawa zone is a section of interbedded shale and sandstone. The upper part of the Tonkawa zone is mostly shale but locally is sandstone with thin shale partings, whereas the lower Tonkawa section is a white to light-gray, fine- to coarse-grained, porous, friable, slightly calcareous sandstone, which becomes a locally cherty sandstone with clear or frosted grains near the base. Some green grains are found near the base also. Local and minor channeling is present on the uneven erosional surface. The channeling, upon which the Cheshewalla (Tonkawa) Sandstone was deposited, is fairly well verified in Pawnee County. Because of the absence of limestone marker beds and the lenticularity of the sandstone in the overlying Endicott zone, it is difficult to determine the boundary between the Tonkawa and Endicott sand zones in Pawnee County.

The Tonkawa sand zone averages 105 feet in thickness throughout the county, ranging from 80 feet in the northwest to 150 feet in the north. The Tonkawa sand yields some gas in the Watchorn

Field. Carpenter (1927) mentioned two unnamed sandstones below the Cheshewalla (Tonkawa) Sandstone, which yielded gas in the Watchorn (Morrison) Field. These sandstones are possibly the Okesa and Bigheart.

*Wynona Sandstone* (*Endicott sand zone*). Overlying the Cheshewalla (Tonkawa) Sandstone, still within the Douglas Group, lies the Wynona Sandstone, referred to in the subsurface as the Endicott sand. The Endicott sand zone averages approximately 65 feet in thickness in Pawnee County, ranging from 45 feet in the northwest to 115 feet in the southwest. Greig (1959) reported that the Wynona is the lowest member of the Vamoosa Formation that can be identified in Pawnee County, and placed the unconformity higher in the section than it is considered to be in this subsurface investigation.

The Endicott is a white to light-gray or brown, fine- to coarse-grained, locally massive and slightly calcareous sandstone. Near the base of the sandstone locally are several thin beds of dull-white, finely crystalline, porous limestone. The Endicott zone underlies a thick sequence of dark fossiliferous shales or a zone of gray shales and thin discontinuous limestones. Greig (1959) described the Endicott zone as a complex interfingering of red silty shales, light-colored thin siltstones, and lenticular sandstones. In the cross sections this zone is primarily shale.

The Endicott sand yields some oil in the East Watchorn Field. In appearance, the Endicott is similar to the overlying sandstones of the Elgin-Hoover zone which yield gas in the East Watchorn Field.

The subsurface cross sections in this study were not extended above the Wynona (Endicott) sandstone zone. For the description of the remainder of the Pennsylvanian section (middle and late Virgilian Series) and the Permian section of the surface in Pawnee County, refer to *Geology of Pawnee County, Oklahoma,* Oklahoma Geological Survey Bulletin 83, by Paul B. Greig, Jr., 1959.



# STRUCTURE

## Regional Structure

Pawnee County is on the north-central Oklahoma platform, bounded on the east and northeast by the Ozark uplift, on the south and southeast by the Arkoma basin, and on the west by the Nemaha ridge. The county lies a few miles west of the buried Tulsa Mountains and approximately 35 to 40 miles east of the Nemaha ridge. Pawnee County also forms a part of the Prairie Plains homocline, a regional post-Permian structure in the Pennsylvanian and Permian beds west of the Ozark dome.

The formations within the county have a homoclinal westerly or southwesterly dip which is locally interrupted by a number of minor uplifts. The features found on the homocline, locally modifying it, are gentle plains-type folds in the form of structural noses or plunging anticlines, small domes, synclines, terraces, and anticlinal folds (Powers, 1931). Other structural features found in the county include faults without preferred orientation and Osage-type structures, which occur mostly in the eastern part (Ireland, 1955). Many of these structures become more pronounced with depth and the regional dip increases. According to Powers (1931), the structures are the result of recurrent uplift of topographic highs of the Pre-cambrian basement. Lateral compression in the basement rocks was resolved into vertical movement, uplifting basement highs along pre-existing lines of weakness. The greater amount of flexuring was thus produced in the pre-Pennsylvanian beds, and folding decreases upward within the Pennsylvanian, becoming barely discernible in the surface beds which were subjected to the least number of uplifts.

According to Greig (1959), most of the significant structural highs in pre-Pennsylvanian strata are reflected in the overlying Pennsylvanian beds but less sharply. It is generally true that pre-Pennsylvanian structures of relatively great amplitude occur as closed highs in the surface beds, those of medium amplitude occur as noses, and those of small amplitude are largely or completely masked. The Otoe anticline (Watchorn Field) in northwestern Pawnee County is an example of a pre-Pennsylvanian structure of relatively great amplitude. This structure has about 100 feet more vertical closure (Carpenter, 1927) in pre-Pennsylvanian horizons than it has in the Permian Fort Riley Limestone.

Whereas the regional dip of the Late Pennsylvanian and Early Premian strata in Pawnee County is due west, the dip of pre-Missourian beds normally is southwesterly. This dip is the result of southerly and southwesterly dips imparted to the beds by three stages of pre-Pennsylvanian tilting combined with the westerly dip imparted by post-Wolfcampian (Permian) tilting. Post-Cretaceous rejuvenation steepened the westerly tilt.

On the surface in eastern Pawnee County are two belts of a series of north-northeastward-trending echelon faults striking northwest-southeast. These echelon faults, first studied by Fath (1920), normally are less than three miles long with throws less than 100 feet (Jones, 1959). Many geologists have postulated conflicting theories as to the origin of these faults. Most agree, however, that they are the surface expression of faulting originating in the underlying Precambrian basement rocks (Sherill, 1929; Foley, 1926). Greig (1959) thought that perhaps the actual echelon faulting occurred in post-Wolfcampian time.

In summary, after the Precambrian, the times of major regional movements were post-Arbuckle, pre-Simpson; post-Simpson, pre-Viola; post-Hunton, pre-Woodford; post-Osage, pre-Hartshorne (Desmoinesian); and post-Permian (Eardley, 1951; Powers, 1931; Disney and Cronenwett, 1955). Two periods of movement are clearly shown in the subsurface of Pawnee County. Pre-Woodford erosion removed all Hunton and Sylvan rocks and Viola rocks from part of the county (fig. 2). Mississippian rocks of the Chester Group and those of the Meramec, except those in the southeastern part of the county, were removed before deposition of the earliest rocks of Desmoinesian time. The absence of Mississippian rocks on the North Terlton structure (fig. 3) and the removal of part of the Mississippian rocks on the upthrown side of a fault and from other structures, indicate that folding and faulting occurred after Mississippian deposition but before deposition of the overlying rocks of Desmoinesian age. The exact time of movement is not revealed in Pawnee County because Morrowan and Atokan rocks are absent. Evidence in other parts of the State indicate that movements ocurred after deposition of the Mississippian, Morrowan, and Atokan rocks. In southern Oklahoma post-Morrowan, pre-Atokan movement correlates with the main Wichita orogeny.



## Local Structure

A reconnaissance study of subsurface structure in Pawnee County was made by constructing three maps (pl. II, maps B-D) contoured on a 25-foot interval. For reasons of clarity, the printed maps show only 50- and 100-foot contours. No area on any map should be considered contoured with the degree of accuracy needed to delineate prospects for oil and gas. Map B shows structure at the base of the Woodford Shale (Devonian), which lies unconformably upon Ordovician rocks. Map D is contoured at the top of the Checkerboard Limestone (Pennsylvanian), a marker bed in the lower part of the Skiatook Group, 100 to 300 feet above the unconformity separating rocks of Missourian and Desmoinesian age. Map C, contoured at the top of the Mississippi lime, shows an erosion surface and not a true structural datum. However, map C differs from map D (base of Woodford) primarily only in the amount of closure shown. Thickness maps, Mississippian-Woodford unit (map F) and Checkerboard Limestone-base Pennsylvanian unit (map E) were contoured without indication of faults. Close spacing of contours on map F at many places indicates the presence of faults shown on maps B and C as well as other faults where insufficient structural control did not justify placement of a fault.

Southwesterly homoclinal dip, interrupted by anticlines, structural noses, and faults, is approximately 40 feet per mile at the base of the Woodford and at the top of the Mississippian, whereas the dip at the top of the Checkerboard Limestone is generally due west and amounts to about 50 feet per mile.

Northeastward-trending faults are mapped at the base of the Woodford Shale (map B) and at the top of the Mississippian (map C) in the North Morrison Field (T. 22 N., R. 3 E.), East Watchorn Field (T. 23 N., R. 3 E.), Yale-Quay (T. 22 N., R. 3 E.), Cleveland-North Terlton area (T. 20, 21 N., R. 8 E.), and Lauderdale-Southeast Terlton area (T. 20 N., R. 8 E.). Production of oil is from closure on the upthrown side of the fault which is west of the fault except in the North Terlton area. Throw of these faults ranges from 100 to 210 feet at the base of the Woodford Shale. The East Watchorn fault has a throw of 210 feet at the south end and of 85 feet near the north end. Closure amounts to 150 feet. However, at the top of the Mississippian (map C) the maximum throw is 100 feet and the closure is reduced to 75 feet as a result of erosion of Mississippian rocks during Early and part of Middle Pennsylvanian time.

In the Cleveland-North Terlton area (maps B, C) the structure probably is more complex than is shown. Discovery and development drilling of this area were made in the early years of oil exploration, and well records are of poor quality. Northwest of Cleveland, just across the Arkansas River in Osage County, lies the Boston anticline with 150 feet of closure at the base of the Woodford. South of the town of Cleveland is the Cleveland structure with approximately 225 feet of closure. The structure has a small westerly extension into secs. 13 and 24, T. 21 N., R. 7 E., with only 50 feet of closure. A northwestward-trending fault cuts the southeast side of the Cleveland structure with approximately 380 feet of throw. This fault intersects, in sec. 31, T. 21 N., R. 8 E., a north-south fault which extends southward into the east side of the North Terlton Field. Woodford and Mississippian rocks are absent on the top of the North Terlton structure in part of sec. 6, T. 20 N., R. 8 E. (fig. 3). The fault, upthrown on the east, has a measurable throw of about 200 feet at the base of the Woodford and about 160 feet at the top of the Mississippian.

The Watchorn, East Watchorn, Masham (T. 23 N., R. 4 E.) and Cleveland Fields show less closure at the top of the Checkerboard Limestone (map D) than at the base of the Woodford Shale or at the top of the Mississippi lime. A fault with a throw of about 55 feet is shown to cut the East Watchorn Field. Carpenter (1958) doubted that Pennsylvanian or Permian rocks are involved, but thought that the slight reversal in dip of the surface beds increases with depth and may have resulted from movements in the fault plane subsequent to Mississippian time. At the surface a northwestward-trending echelon fault crosses the fault in the pre-Pennsylvanian beds at an angle of about 35 degrees (Carpenter, 1958, pl. 1).



# HISTORY OF PETROLEUM DEVELOPMENT

Oil was first discovered in Pawnee County on the Bill Lowery farm on the south edge of Cleveland in the north half of sec. 17, T. 21 N., R. 8 E., in July 1904. This initial well of the present Cleveland Field was drilled by John Shell and W. J. Fellows and was located in Indian Territory at the time of discovery. Drilled to 1,615 feet, the well was completed in the Cleveland sand. Initial production was approximately 50 barrels of oil per day. Development of this field spread rapidly, and within a year 255 wells had been drilled. Additional production was discovered in the Layton, Skinner, Bartlesville, and Wilcox sands and in the Oswego lime. The Cleveland Field is presently productinng from 163 wells on 5,100 acres (table 6). Some parts of the field are now being waterflooded. The discovery of the Cleveland Field established the county as one of the earliest oil-producing regions in Oklahoma.

The discovery and rapid development of the Cleveland Field brought on an intensive exploration campaign for additional new fields. The most significant result of this search was the discovery of the Glenn Pool (second major oil field to be found in Oklahoma) late in 1905 and the Cushing Field (third major field of the State) in March 1912, both of these fields being in Creek County. The discovery of the Cushing Field, which reached a productive peak of 300,000 to 330,000 barrels daily in April 1915, had a particularly profound effect on the exploration and development of adjacent areas. Activity continued to be brisk in Pawnee County for nearly two decades after the discovery of the Cleveland Field.

The order in which the fields were discovered in Pawnee County is as follows: Cleveland (1904); Ralston (1909), Terlton (1912); Lauderdale (1915); Jennings (1916); Casey, North Terlton, and Watchorn (1917); Keystone (1919); East Blackburn, North Garr, and Maramec (1920); Hallett (1922); Masham (1924); Skedee and East Watchorn (1942); five minor fields (1944, 45, 48); North Bryan (1951); Cody, South Crescent Star, and Northeast Bryan (1954); South Blackburn (1955); and 21 minor fields (1950-51, 53-58). In the periods from 1924 to 1942, from 1943 to 1951, and from 1955 to the present, only minor discoveries were made within the county. The period from 1924 to 1942 was one of marked declined activity, not a single field being discovered in the thirties. The latest two small discoveries are the Northeast Maramec (SE¼ sec. 26, T. 21 N., R. 6 E.) and Beaver Island (NE¼ NE¼ sec. 17, T. 23 N., R. 3 E.) Fields in 1958. The minor fields discovered in the forties and fifties were mostly extensions of larger fields (table 5).

Approximately 55 fields (with about 40 active in 1960) are in Pawnee County. The East Watchorn Field, producing primarily from the Layton and Wilcox sands (table 5), discovered in May 1942, is now the third largest field of the county, with a yield of more than 10 million barrels of oil.

In 57 years Pawnee County has produced approximately 125 million barrels of oil from nearly 40,000 proved acres (table 6). Currently 1,500 wells are active producers, approximately the same number are abandoned, and about 1,550 are dry holes, for an approximate total of 4,550 wells drilled. This is an average of about 80 wells drilled per year (table 8) and about 7.7 wells per 640 acres.

TABLE 5. LARGER OIL FIELDS OF PAWNEE COUNTY, OKLAHOMA

| Rank | Field Name* | Cumulative Production to 1/1/61 (bbls) | Discovery Date |
|---|---|---|---|
| 1 | Cleveland | 42,447,250 | 1904 |
| 2 | Lauderdale | 20,031,600 | 1915 |
| 3 | East Watchorn | 10,262,700 | 1942 |
| 4 | Watchorn | 8,389,900 | 1917 |
| 5 | Maramec | 7,254,300 | 1920 |
| **6 | Keystone | 7,083,600 | 1919 |
| **7 | Jennings | 5,864,000 | 1916 |
| **8 | Garr, includes North Garr | 5,274,800 | 1920 |
| 9 | North Terlton | 4,516,000 | 1917 |
| 10 | Hallett | 2,252,100 | 1922 |
| 11 | Terlton | 1,447,400 | 1912 |
| 12 | Masham | 732,000 | 1924 |
| 13 | Northeast Bryan | 475,000 | 1954 |
| 14 | Skedee | 467,200 | 1942 |
| 15 | Ralston | 405,800 | 1909 |
| 16 | North Bryan | 354,800 | 1951 |
| 17 | East Blackburn | 276,500 | 1920 |
| 18 | South Blackburn | 215,800 | 1955 |
| 19 | Casey | 163,200 | 1917 |
| 20 | South Crescent Star | 124,000 | 1954 |
| 21 | Cody | 108,000 | 1954 |
| | Total | 118,145,950 | |

Sources: *National Association of Oil Scouts and Landmen's Yearbooks* and *Vance-Rowe Reports.*
*For locations of all county fields, see plate I.
**Pawnee and Creek Counties.



In 1959, 14,014 undrilled acres were under lease by petroleum companies in Pawnee County. The county presently has a daily average production of about 6,000 barrels.

Production in Pawnee County is predominantly oil. Gas is produced in small quantities for local consumption, but no major gas reservoir has been discovered. Greig (1959) stated that oil production is second only to agriculture as the chief source of income in the county.

The history of development of an area is revealed by the amount of crude oil produced and the number of development and exploratory wells drilled each year. The numbers of development and wildcat completions for about the last ten years in Pawnee County are listed in table 8. A compilation of the annual crude oil production for the county is shown in table 7 accompanying the graph of figure 4. The all-time high for production in Pawnee County was in 1925, when 6,372,600 barrels of oil were produced. Three other yearly peaks were during 1920, 1934, and 1943. The lowest yearly production within this interval was in 1949, when only 1,377,200 barrels were recorded for the county. The 1915 figure was less than 1.5

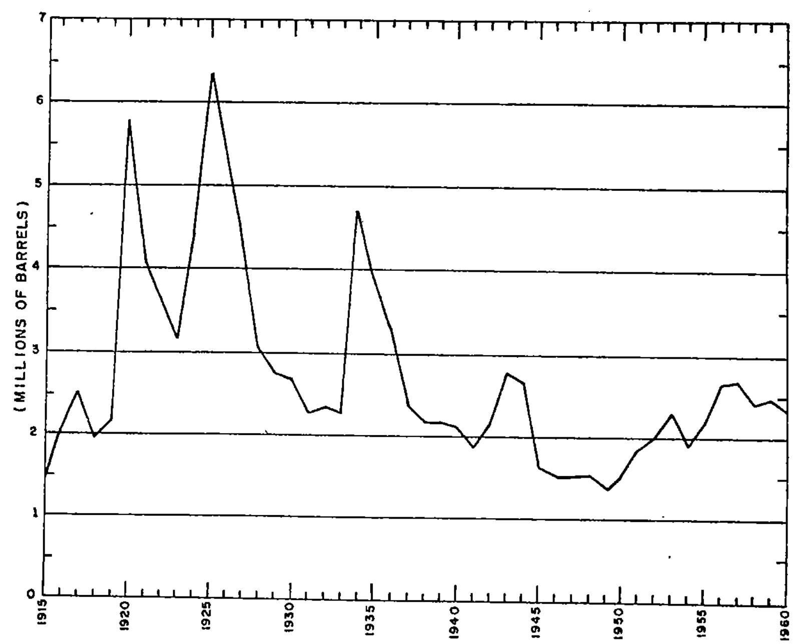


Figure 4. Graph of annual petroleum production in Pawnee County, 1915-1960.

TABLE 6. PRODUCTION STATISTICS AND PRODUCING SANDS OF OIL FIELDS IN PAWNEE COUNTY, OKLAHOMA

| Field or Pool | Discovery Year | Total Proved Acres | Total Wells Prod'g 1960 | Total Prod. 1959 (bbls.) | Cumulative Production to 1/1/'61 (bbls.) | Important Producing Zones |
|---|---|---|---|---|---|---|
| Beaver Island | 1958 | 10 | 4 | *10,220 | 17,832 | Skinner, Burbank |
| Blackburn, E | 1920 | 710 | 16 | 10,685 | 276,474 | Bartlesville, Wilcox |
| Blackburn, S | 1955 | 320 | 6 | 35,405 | 215,800 | Wilcox |
| Blackburn, SE | 1954 | 40 | Abd. | 0 | 4,657 | Misener, Simpson |
| Boston | ........ | 80 | 0 | ............ | ............ | Prue, Bartlesville |
| Bryan | 1954 | 80 | 0 | 0 | ............ | Peru, Red Fork |
| Bryan, N | 1951 | 70 | 10 | 43,587 | 354,760 | Red Fork, Bartlesville |
| Bryan, NE | 1954 | 760 | 29 | 101,105 | 475,028 | Red Fork |
| Bryan, NW | 1953 | 40 | Abd. | 0 | 9,795 | Prue |
| Bryan, SE | 1953 | 160 | 5 | 14,153 | 66,643 | Skinner |
| Casey | 1917 | 120 | 6 | 24,090 | 163,228 | Prue, Skinner |
| Casey, N | 1951 | 30 | 2 | 2,492 | 39,576 | Prue, Skinner |
| Cleveland | 1904 | 5,100 | 163 | 143,080 | 42,447,250 | Layton, Cleveland, Oswego, Skinner, Bartlesville, Wilcox |
| Cody | 1954 | 120 | 3 | *6,205 | 107,998 | Cleveland |
| Cody, SW | 1955 | 20 | Abd. | 0 | 3,804 | Red Fork |
| Crescent Star, S | 1954 | 200 | 5 | 5,533 | 124,025 | 1st Wilcox |
| Garr, N (Pawnee-Payne) | 1920 | 750 | 68 | 132,130 | 5,274,807 | Cleveland, Wayside, Peru, Red Fork, Misener, Wilcox |
| Greenup | ........ | 520 | 1 | NR | 12,279 | Peru, Prue, Skinner, Red Fork, Bartlesville, Mississippi (chat?) |
| Hallett | 1922 | 3,260 | 100 | 183,960 | 2,252,089 | Cleveland, Peru-gas, Skinner, Bartlesville, Wilcox |
| House Creek, N | ........ | 400 | ........ | ............ | ............ | Red Fork |
| Jennings (Pawnee-Creek) | 1916 | **840 | 137 | 262,435 | 5,864,014 | Skinner, Red Fork, Bartlesville, Taneha (Booch), Burgess, Mississippi (chat?), Wilcox |
| Jennings, W | 1955 | 40 | 1 | NR | 7,065 | |
| Keystone (Pawnee-Creek) | 1919 | 5,000 | 204 | *377,775 | 7,083,624 | Cleveland, Peru, Skinner, Red Fork, Bartlesville, Mississippi, Misener, Wilcox |
| Lauderdale | 1915 | 5,190 | 303 | *419,000 (467,565) | 20,031,581 | Layton, Cleveland, Skinner, Red Fork, Bartlesville, Wilcox, Turkey Mountain |
| Mannford, N | ........ | 480 | ........ | ............ | ............ | |
| Maramec | 1920 | 3,820 | 165 | *295,285 | 7,254,253 | Layton, Cleveland, Oswego, Prue, Skinner, Bartlesville, Burgess |
| Maramec, E | 1948 | 120 | Abd. | 0 | 18,612 | Peru, Tucker (Taneha) |
| Maramec, N | 1944 | 120 | 1 | *2,555 | 72,593 | Prue |
| Maramec, NE | 1958 | 80 | 3 | 16,425 | 33,867 | Bartlesville |
| Masham | 1924 | 400 | 21 | *28,835 | 732,003 | Cleveland (gas), Oswego, Skinner, Simpson |
| Masham, E | 1948 | 120 | Abd. | 0 | 2,183 | Oswego |
| Masham, NE | 1956 | 40 | Abd. | 0 | 1,258 | Skinner |
| Morrison, N | 1956 | 40 | 1 | 1,460 | 6,082 | Skinner |
| Osage City, SE | 1955 | 540 | 1 | NR | 729 | Oil City, Layton |
| Pawnee, N | 1957 | 160 | 4 | 9,067 | 25,911 | Skinner |
| Price | ........ | 40 | Abd. | 0 | ............ | Skinner |

TABLE 6. (Cont.)

| Field or Pool | Discovery Year | Total Proved Acres | Total Wells Prod'g 1960 | Total Prod. 1959 (bbls) | Cumulative Production to 1/1/'61 (bbls) | Important Producing Zones |
|---|---|---|---|---|---|---|
| Quay, N*** | 1955 | 80 | 6 | 3,481 | 37,306 | Oswego, Prue, Skinner, Bartlesville, Simpson |
| Ralston | 1909 | 520 | 12 | *12,775 | 405,828 | Skinner, Bartlesville, Burgess, Simpson, Mississippi chat, Wilcox |
| Ralston, NW | 1956 | 20 | 1 | 140 | 5,012 | Wilcox |
| Skedee | 1942 | 320 | 11 | 30,295 | 467,183 | Prue, Skinner, Simpson |
| Skedee, N | 1953 | 40 | 2 | *2,555 | 33,152 | Wilcox |
| Skedee, W | 1950 | 80 | 1 | 1,824 | 86,581 | Misener, Wilcox |
| Sunny Slope, SW | 1955 | 40 | 2 | 12,236 | 17,887 | L. Skinner |
| Terlton | 1912 | 1,850 | 52 | 62,780 | 1,447,444 | Layton, Cleveland, Wheeler, Skinner, Bartlesville, Tucker (Taneha), Wilcox |
| Terlton, E | 1950 | 10 | Abd. | 0 | ............ | Red Fork |
| Terlton, N | 1917 | 3,190 | 92 | 53,655 | 4,516,000 | Prue, Skinner, Red Fork, Inola, Bartlesville, Wilcox |
| Terlton, SE | 1951 | 30 | 3 | 4,063 | 60,772 | Bartlesville |
| Watchorn | 1917 | 800 | 18 | *49,640 | 8,389,864 | Tonkawa (gas), Layton, Wilcox |
| Watchorn, E (Pawnee-Osage) | 1942 | 1,000 | 35 | 307,840 | 10,262,682 | Endicott, Layton, Red Fork, Wilcox |
| Watchorn, N | 1945 | 10 | Abd. | 0 | 4,107 | Bartlesville |
| Watchorn, NW | 1945 | 240 | 3 | 5,278 | 67,171 | Layton |
| Watchorn, W | 1953 | 60 | 1 | 0 | 29,606 | Viola, Wilcox |
| TOTAL | | 38,110 | | | 118,810,424 | |



Sources: 1959 and 1960 *National Oil Scouts and Landmen's Association Yearbooks* with the exception of the total wells producing in 1960, and the starred (*) figures in the 1959 yearly total representing 1960 statistics which were obtained from the latest *Vance-Rowe Reports.* The cumulative totals for most of the fields were compiled by combining the most recent *Vance-Rowe Reports'* yearly figure (in some particular fields, the most recent two years' figures) to the cumulative total of the *Oil Scouts Yearbook of 1960* or to the *1959 Oil Scouts Yearbook* total).

* = 1960 statistics. NR = No runs.

** = Total proved acres for North Jennings Field in Pawnee County only.

*** = Only includes the North Quay Field statistics of Pawnee County; does not include the total wells producing, yearly, or cumulative production of the 1,680 proved acres in Pawnee County of the larger Yale-Quay Field of Creek and Pawnee Counties.

The figures for the Garr, Jennings, Keystone, and East Watchorn Fields include production and acreage in parts of adjoining Payne, Creek, and Osage Counties. This lessens the accuracy of the totals of Pawnee County. However, this is in part compensated for by the omission of statistics from the present Quay Field of which the northern part is in Pawnee County, some previous early production in now abandoned fields, statistics of which were lost in the records, and production from a few wildcats now producing from stray lensing sands (stratigraphic traps) and not included within a named field. Therefore, the figures in the table above are an approximation.

million barrels. These statistics are only approximate, but they do define the important periods of the history of oil and gas development in Pawnee County.

Secondary recovery is important in Pawnee County. As shown in tables 9 and 10, secondary recovery accounted for 1,374,000 barrels of oil in 1958 and for 923,000 barrels in 1959. This is approximately half of the yearly producton of the county. Production from secondary recovery alone in 1958 was nearly equal to the total production of 1949 in the county. In the Hallett Field, secondary recovery was started as early as September 1947.

Almost all of the early production from the larger fields in the county was closely associated with easily mapped surface structures. These surface structures, according to Berryhill (1961), were instrumental in the early exploration and development. Greene, as early as 1930, believed that all the closed structures (anticlines and small

TABLE 7. CRUDE OIL PRODUCTION IN PAWNEE COUNTY BY YEARS, 1913-1960

| Year | Barrels Produced | Year | Barrels Produced | Year | Barrels Produced |
|---|---|---|---|---|---|
| 1913 | * 16,157 | 1929 | 2,761,247 | 1945 | 1,620,328 |
| 1914 | ............... | 1930 | 2,684,791 | 1946 | 1,515,562 |
| 1915 | *1,487,695 | 1931 | 2,287,962 | 1947 | 1,534,738 |
| 1916 | *2,014,850 | 1932 | 2,337,410 | 1948 | 1,514,730 |
| 1917 | *2,512,970 | 1933 | 2,279,418 | 1949 | 1,377,230 |
| 1918 | 1,993,988 | 1934 | 4,711,723 | 1950 | 1,506,083 |
| 1919 | 2,170,513 | 1935 | 3,900,077 | 1951 | 1,882,478 |
| 1920 | 5,789,627 | 1936 | 3,306,332 | 1952 | 2,012,612 |
| 1921 | 4,092,438 | 1937 | 2,375,526 | 1953 | 2,306,826 |
| 1922 | 3,595,335 | 1938 | 2,183,178 | 1954 | 1,916,325 |
| 1923 | 3,161,345 | 1939 | 2,175,924 | 1955 | 2,201,675 |
| 1924 | 4,385,541 | 1940 | 2,116,545 | 1956 | 2,633,350 |
| 1925 | 6,372,612 | 1941 | 1,875,841 | 1957 | 2,688,300 |
| 1926 | 5,391,966 | 1942 | 2,141,333 | 1958 | 2,409,557 |
| 1927 | 4,368,621 | 1943 | 2,791,333 | 1959 | 2,476,345 |
| 1928 | 3,054,039 | 1944 | 2,652,333 | 1960 | 2,308,110 |
| | | Total of above figures | | | 124,892,919 |
| | | Total from other sources | | | 118,810,424 |

Sources: 1913, 1915-1944, *Oil and Gas Journal;* 1945-1949, 1953-1958, *Amer. Inst. Mining, Metal. Petrol. Eng.:* 1950-1952, 1954, 1955, *National Oil Scouts and Landmen's Assoc. Yearbook;* 1959, 1960, *Vance Rowe Reports.*
* Cleveland Field only.



domes) and most of the obvious prominent structural features, including noses and terraces, had been tested. The development and use of the seismograph as an important exploratory tool increased exploratory activity and helped find oil in the county. The perfection of new completion methods in the 1950's also caused an upswing in activity. A part of this new activity was directed toward the discovery of stratigraphic traps, principally lenticular sandstones. Most of the recent discoveries and extensions have been from this type of trap.

Several wells of fields discovered since 1950 in the county were originally abandoned (Berryhill, 1961). When reworked, using new methods of perforating, acidizing, and sand fracturing, these wells were completed with good initial potentials.

Productive zones range in age from Ordovician-Cambrian (Turkey Mountain) to Virgilian or Late Pennsylvanian (Hoover sand) and most productive areas produce from more than one zone

TABLE 8. DEVELOPMENT COMPLETIONS IN PAWNEE COUNTY

| Year | Crude Oil | Gas | Dry | Service | Total Wells | Total Footage Drilled | Average Footage Per Well |
|---|---|---|---|---|---|---|---|
| 1952 | 69 | 0 | 55 | 0 | 124 | 320,782 | 2,595 |
| 1953 | 149 | 1 | 62 | 0 | 212 | 575,705 | 2,716 |
| 1954 | 98 | 3 | 69 | 0 | 170 | 457,901 | 2,694 |
| 1955 | 123 | 3 | 72 | 0 | 198 | 509,693 | 2,574 |
| 1956 | 98 | 1 | 72 | 0 | 171 | 444,939 | 2,602 |
| 1957 | 69 | 0 | 43 | 0 | 112 | 276,124 | 2,465 |
| 1958 | 54 | 0 | 35 | 13 | 102 | 232,522 | 2,280 |
| 1959 | 55 | 0 | 21 | 1 | 77 | 182,844 | 2,375 |
| 1960 | 16 | 1 | 15 | 9 | 41 | 101,963 | 2,487 |
| WILDCAT COMPLETIONS, PAWNEE COUNTY | | | | | | | |
| 1949 | 1 | 0 | 11 | | 12 | 40,330 | 3,361 |
| 1950 | 5 | 0 | 23 | | 28 | 88,857 | 3,173 |
| 1951 | 3 | 0 | 27 | | 30 | 95,310 | 3,177 |
| 1952 | 1 | 0 | 14 | | 15 | 50,859 | 3,393 |
| 1953 | 1 | 1 | 27 | | 29 | 101,334 | 3,494 |
| 1954 | 1 | 1 | 23 | | 25 | 90,553 | 3,622 |
| 1955 | 6 | 1 | 23 | | 30 | 94,381 | 3,146 |
| 1956 | 0 | 0 | 34 | | 34 | 83,412 | 2,453 |
| 1957 | 2 | 0 | 13 | | 15 | 49,854 | 3,324 |
| 1958 | 2 | 0 | 16 | | 18 | 61,058 | 3,392 |
| 1959 | 1 | 0 | 8 | | 9 | 33,004 | 3,667 |
| 1960 | 0 | 0 | 3 | | 3 | 9,777 | 3,259 |

Source: *Oil and Gas Journal* (annual review and forecast issues).

TABLE 9. SECONDARY RECOVERY IN PAWNEE COUNTY, 1958

| Field | Number of Wells at End of Year | Total Oil Production 1958 (bbls) | Producing Zone | Date Begun |
|---|---|---|---|---|
| Bryan, NE | 18 | 95,991 | Red Fork | 11/57 |
| Cleveland | 52 | 50,788 | Bartlesville | |
| Cody | 8 | 8,662 | Cleveland | |
| Hallett | 96 | 310,250 | Skinner | 9/47 |
| Keystone | 72 | 119,370 | Cleveland | 6/50 |
| Lauderdale | 71 | 399,539 | Bartlesville | 5/51 |
| Maramec | 62 | 132,207 | Red Fork | 9/57 |
| Ralston | 6 | 6,930 | Misener | 3/55 |
| Terlton | 9 | 5,780 | Skinner | 10/58 |
| Watchorn, E | 22 | 244,504 | Wilcox | 3/53 |
| Total: | 416 | 1,374,021 | | |

Source: 1959 *National Oil Scouts and Landmen's Assoc. Yearbook.*

TABLE 10. SECONDARY RECOVERY IN PAWNEE COUNTY, 1959

| Pool | Producing Formation | Acres | Active Oil Wells | Avg. Daily Oil Prod. | Input Wells | 1959 Total Production (in bbls.) |
|---|---|---|---|---|---|---|
| Bryan, N | Red Fork | 720 | 19 | 192 | 5 | 70,080 |
| Cody | Cleveland | 136 | 5 | 16 | 1 | 5,840 |
| Hallett | Skinner | 2,314 | 52 | 528 | 34 | 192,662 |
| Jennings, N | Skinner | 1,040 | 13 | 247 | 4 | 90,155 |
| Keystone | Cleveland | 960 | 44 | 250 | 12 | 91,250 |
| Lauderdale | Red Fork & Bartlesville | 1,182 | 40 | 644 | 21 | 235,060 |
| Maramec | Red Fork | 880 | 35 | 210 | 8 | 76,650 |
| Ralston | Misener | 160 | 4 | 11 | 2 | 4,099 |
| Skedee | U. Skinner | 160 | 3 | 59 | 1 | 21,535 |
| Terlton | Skinner & Bartlesville | 1,080 | 52 | 179 | 17 | 65,393 |
| Watchorn, E | First Wilcox | 360 | 11 | 138 | 2 | 50,370 |
| Yale-Quay (Pawnee-Payne) | Bartlesville | 83 | 6 | 56 | 2 | 20,407 |
| | Total | 9,075 | 284 | 2,530 | 109 | 923,501 |

Discontinued Floods: Hallett Pool (594 Acres)
Terlton Pool (220 Acres)

Source: *Research Oil Reports* (Analysis of available data on secondary recovery in Oklahoma, 1959).



(table 6). The most prolific zones are the Wilcox (Simpson) sand of Ordovician age and the following Pennsylvanian sands: Bartlesville, Red Fork, and Skinner sands of Desmoinesian age, and the Cleveland and Layton sands of Missourian age. The reservoir beds are part of a westward-dipping sedimentary sequence, the thickness of which increases from about 3,000 feet in the east to about 5,000 feet in the west. Productive zones range in depth from 1,100 to 4,300 feet (Greig, 1959). Because of the westerly dip of the beds, wells in the western part of the county normally are deeper than those in the eastern part.

Most of the established oil- and gas-producing areas in Pawnee County are in the eastern part (pl. I) although many significant discoveries have been made in the central and western parts during the last few years. Oil entrapment is primarily structural, the oil occurring in small anticlines and domes, and locally against faults. The stratigraphic traps commonly occur on the flanks of known structures. The proportion of oil produced from stratigraphic reservoirs is expected to grow as exploration in the county continues.

# FUTURE OIL AND GAS POSSIBILITIES

Perhaps all of the obvious or major structural features have been tested for oil and gas in Pawnee County. However, most recent discoveries have been wildcats or field extensions from stratigraphic traps. Stratigraphic traps commonly occur on the flanks of known structures. In an old shelf area such as this, the possibilities of stratigraphic traps are numerous. Exploration will continue for shallow sandstones where changes in depositional and post-depositional conditions have caused variations in porosity to form stratigraphic traps. The proportion of oil produced from stratigraphic reservoirs is expected to grow in the future, and the possibilities of continued production in this area are favorable.

Production from the Mississippi lime and the Arbuckle Group has been limited, but carbonate studies, such as those recommended by Clinton (1959), may reveal zones of primary and secondary porosity that are favorable to oil accumulation in these formations.

Although production from the Misener and Simpson (Bromide-"Wilcox") sands is small in comparison with that of the Middle Pennsylvanian (Desmoinesian) sandstones, future pools may be discovered as a result of additional deep drilling. Lack of control on the deeper producing horizons does not rule out the possibility of discovering new pools at these depths.

Many wells initially abandoned as nonproductive have been completed for commercial production by deeper drilling or by using modern improved completion techniques.

Another and perhaps most important source of future oil production in Pawnee County is through secondary recovery. This method of production by waterflooding presently produces nearly half the oil of the county. Berryhill (1961) reported that other areas geologically comparable to this one have produced more oil by secondary recovery than by primary methods.

Re-evaluation of the data supplied by many nonproductive wells and sound geological application of the information should result in discovery of quantities of oil that may have been overlooked. Many new types of logs such as sonic, gamma-ray, neutron, flowing neutron, and micrologs have been invented and, when they are used together with regular electric logs, should provide an excellent opportunity through analysis of the data obtained for application to future exploration for oil in the area.



Subsurface structural and thickness studies will be useful in the future exploration of Pawnee County. Isopach maps will show areas of thinning over probable structures or of thickening in conjunction with possible stratigraphic sand lenses. Structural maps used in conjunction with isopach maps may point out particular areas for seismic, gravity, or magnetic investigations. Paleogologic maps used in conjunction with isopach and structural studies will indicate possible locations of strand lines, belts of updip wedgeouts of porosity and permeability (particularly in carbonate rocks), and stratigraphic traps. Lithofacies studies and analyses of particular groups and formations will be useful for determining the future oil and gas possibilities of an area.

With the aid of these many techniques, devices, and basic geologic interpretations, many more stratigraphic-type reservoirs may be found in Pawnee County in the future. Large areas in the western part of the county are virtually untested for oil. Townships 21-22 N., R. 3 E., presently do not have one producing well. This area is believed to have a good discovery potential.

The Keystone Field (sixth largest oil field in Pawnee County, with a total production of more than seven million barrels of oil) produces largely from the Red Fork sand in stratigraphic traps. Locally in this area, reported high salinity of water in the Red Fork lensing sands is suggestive of connate water. The oil ordinarily occurs in the lower, well-sorted phase and the gas in the upper, poorly sorted phase; therefore, it might be useful to cement casing through the upper sand and produce only the lower sand, thus giving a longer flowing life and a better gas-oil ratio to the well. Where there is no water drive of the oil, the gas present assists in driving the oil toward the well. The Red Fork in the Keystone Field and surrounding area is nearly ideal for secondary recovery. Gas-injection and waterflood projects point toward increasing the ultimate recovery from 90 percent to as much as 300 percent of primary production.

The lenticular shoestring sands, such as the Red Fork in Pawnee County, hold opportunity for the diligent operator. Costs of leasing are relatively small in many areas because they have already been prospected for structural accumulations. For the same reason, a wealth of subsurface data in the form of well logs and samples is available to the investigator.

Search for continuations of the known shoestring trends by cross-section and thickness studies will involve study of the strand lines along which they formed. This search will make use of microscope sample studies and logs of abondoned wildcat tests in seeking clues from the nature of the deposits to determine whether they formed landward or seaward from the strand line (Wright, 1941). The search for new trends may also include the scanning of intervals to detect thinning which may show nondepositional interims.

The Red Fork shoestring sand in Pawnee County, like similar trends, was formed through uniform geologic processes which can to some extent be visualized. Exploration for its productive continuations can be based on reasoning from knowledge of these processes. Folding has played an important role in placing the water table in certain parts of this trend, and the use of structural information will help prevent the drilling of wells in the water-filled parts of the trend.

The major oil production is concentrated presently in the eastern part of the county, but most of the recent discoveries have been made in the central and northwestern parts. The county has continued to produce oil at the rate of at least 1.5 million barrels annually since 1916 (with the exception of 1949). The future looks relatively bright for production of petroleum and some gas in Pawnee County, an area which already has yielded approximately 125 million barrels of oil. With continued production from the major fields and future extensions along the flanks of structures and wildcat discoveries of stratigraphic type from channel sands or lenticular shoestring sands along old strand lines, the county should continue to be a good source of petroleum and assure continuing growth for many years from the Oklahoma shelf.



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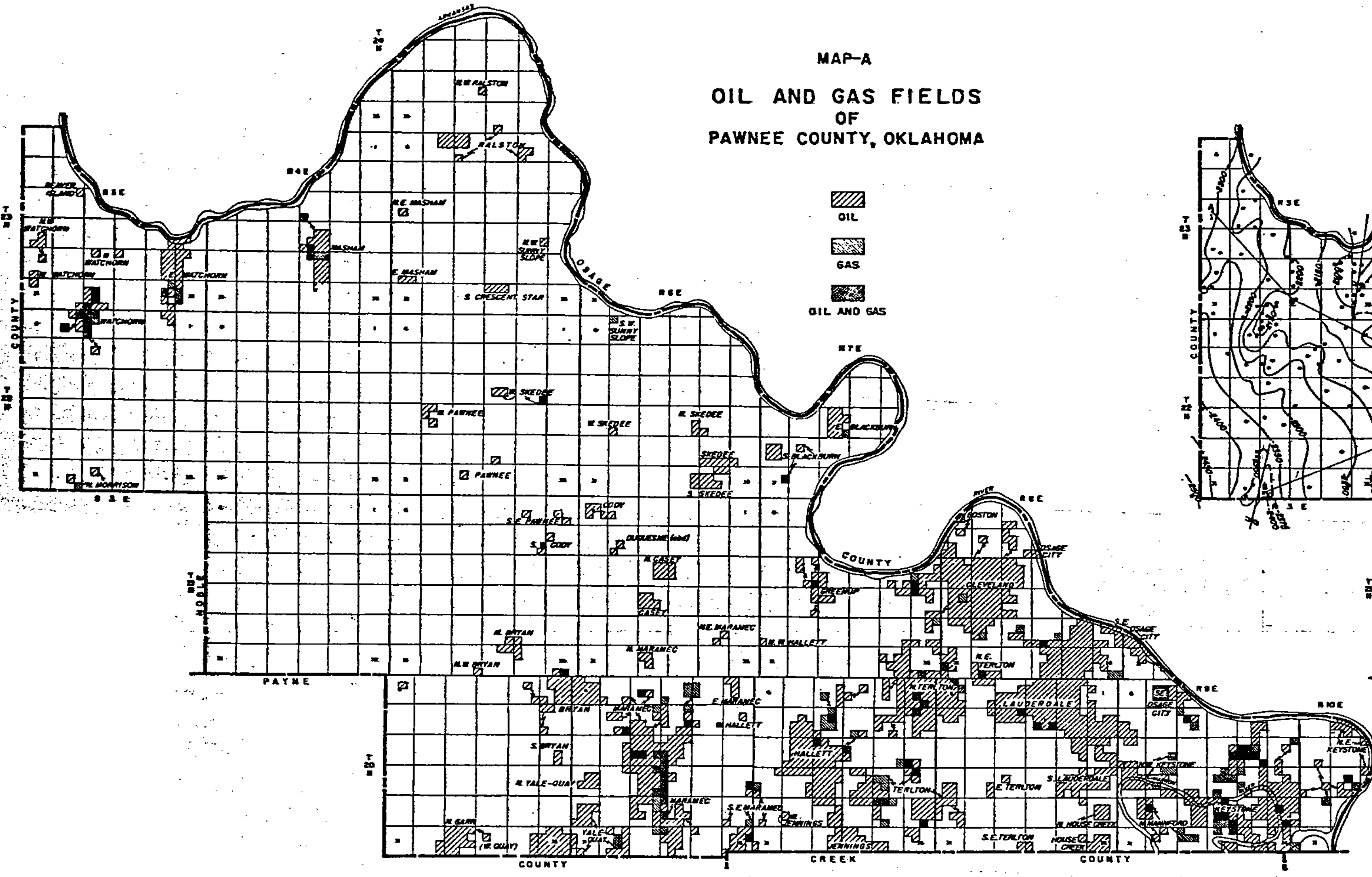
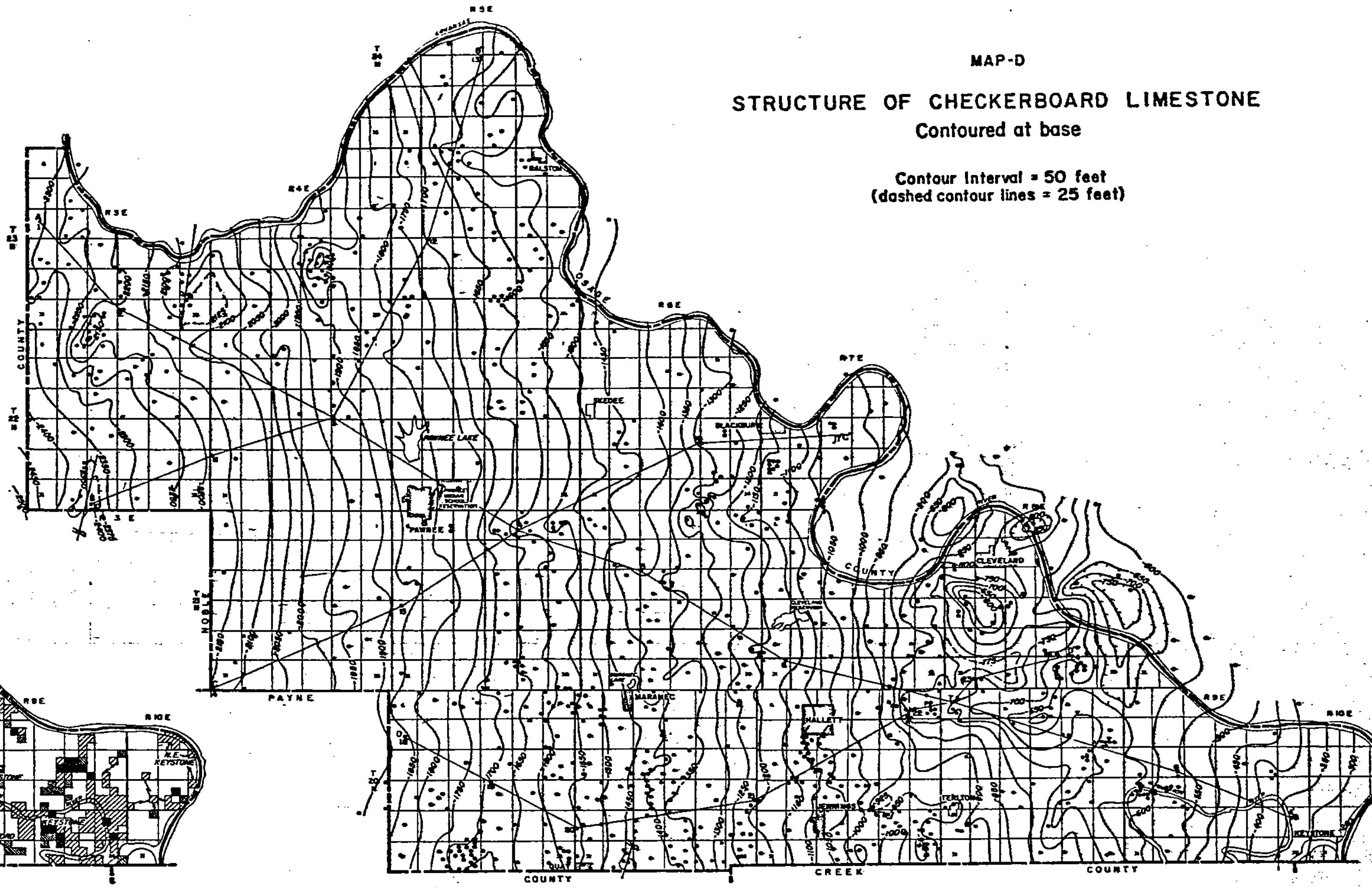



MAP-A

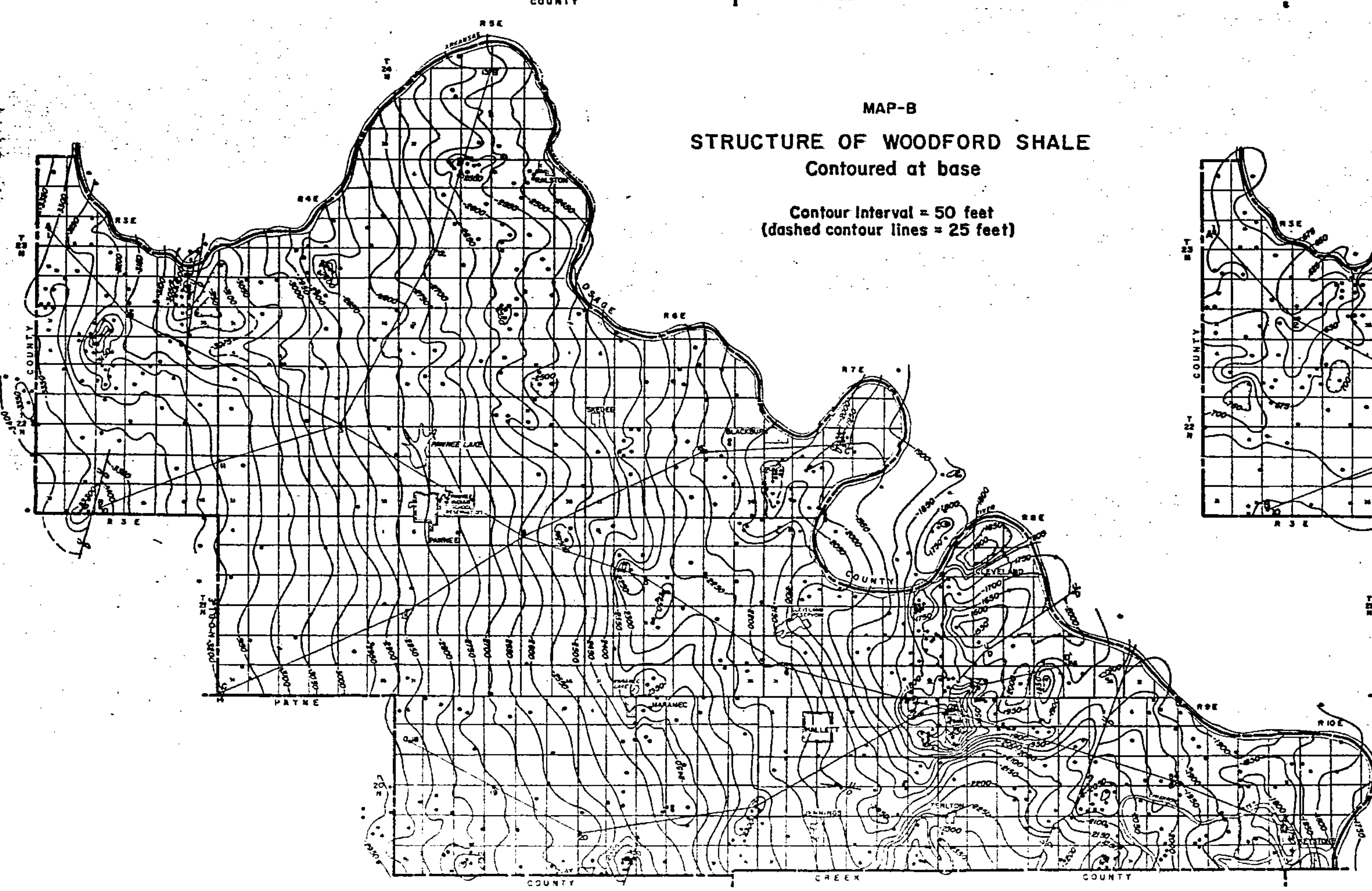
OIL AND GAS FIELDS
OF
PAWNEE COUNTY, OKLAHOMA




MAP-D

STRUCTURE OF CHECKERBOARD LIMESTONE
Contoured at base

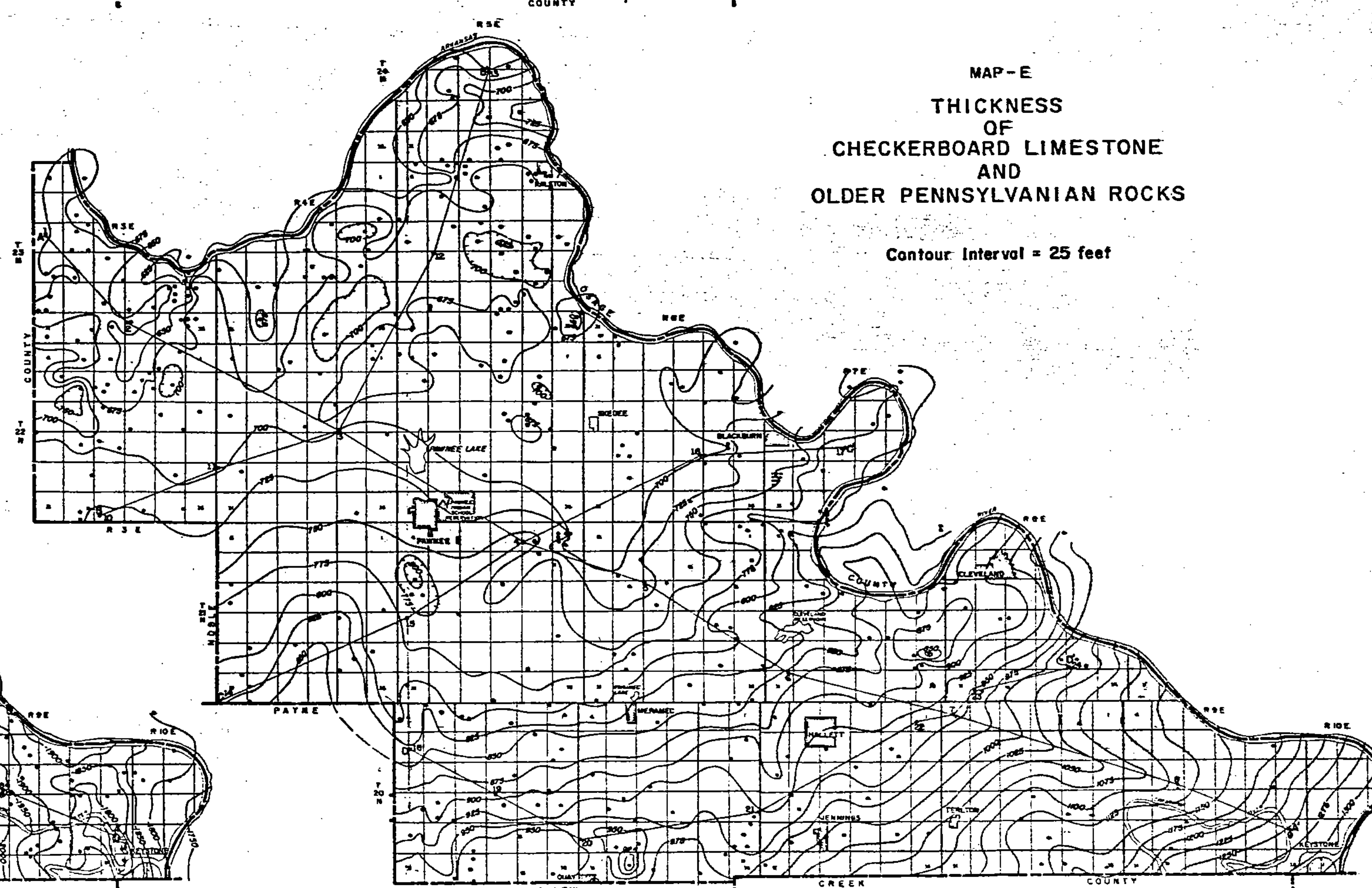
Contour Interval = 50 feet
(dashed contour lines = 25 feet)




MAP-B

STRUCTURE OF WOODFORD SHALE
Contoured at base

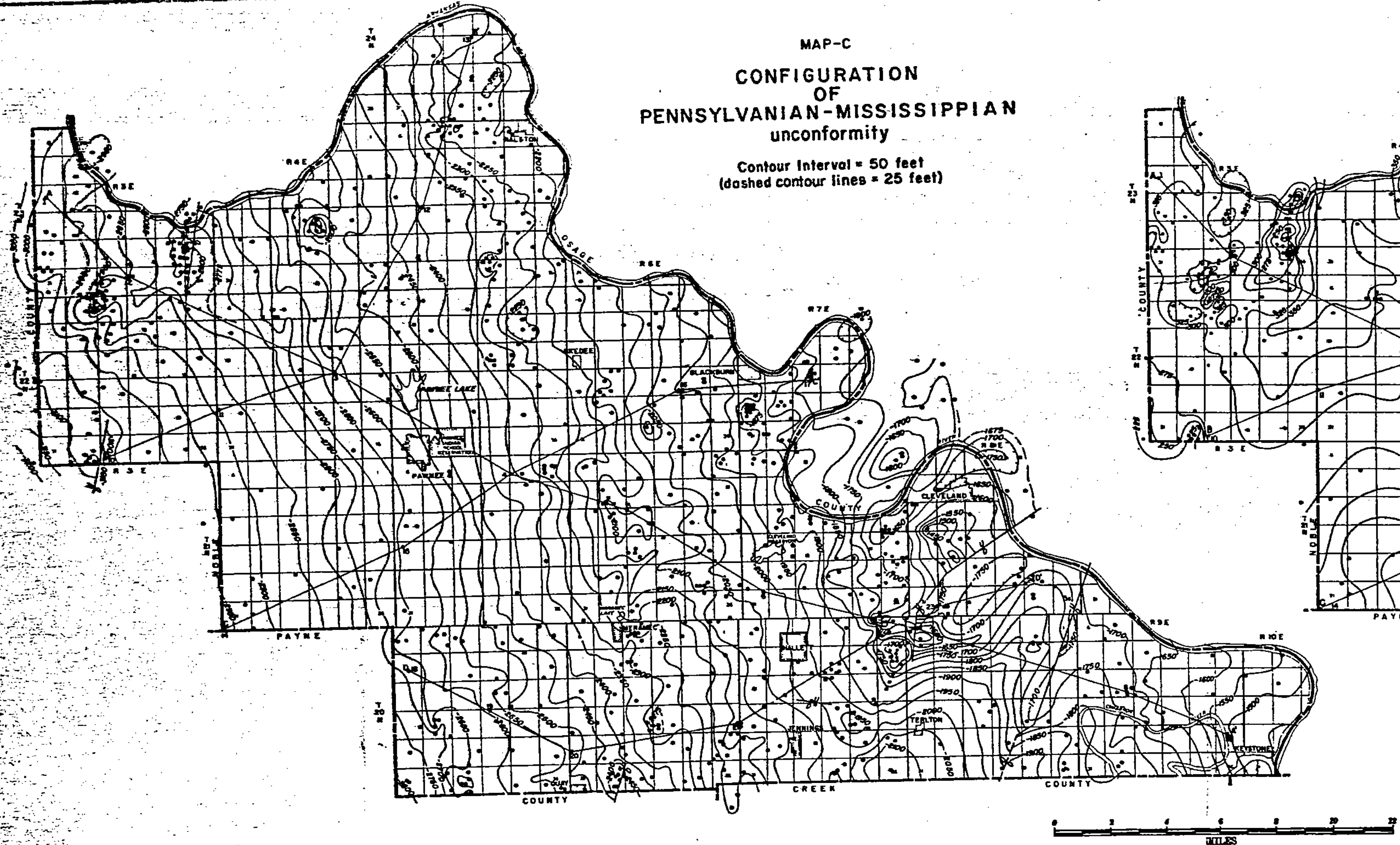
Contour Interval = 50 feet
(dashed contour lines = 25 feet)

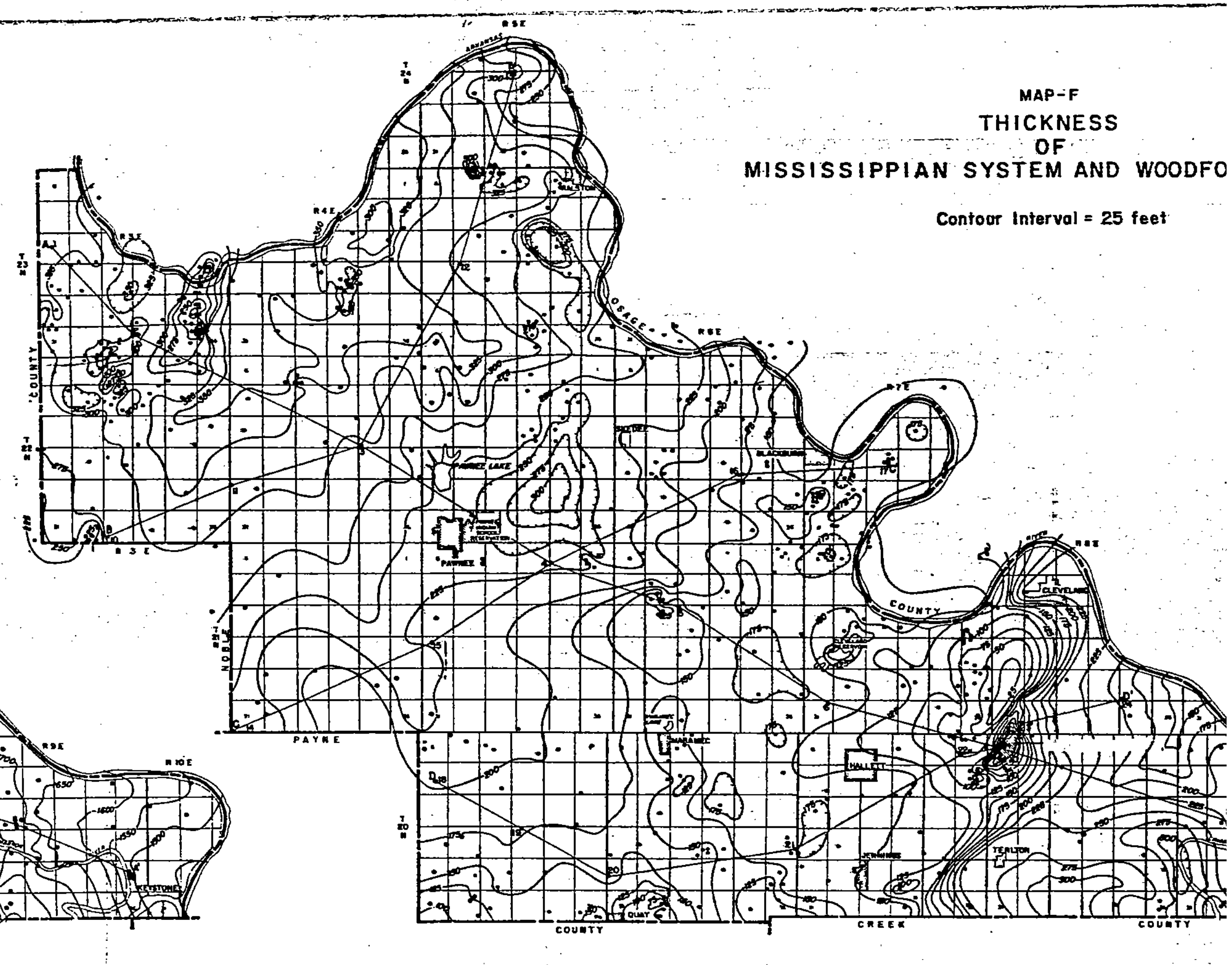


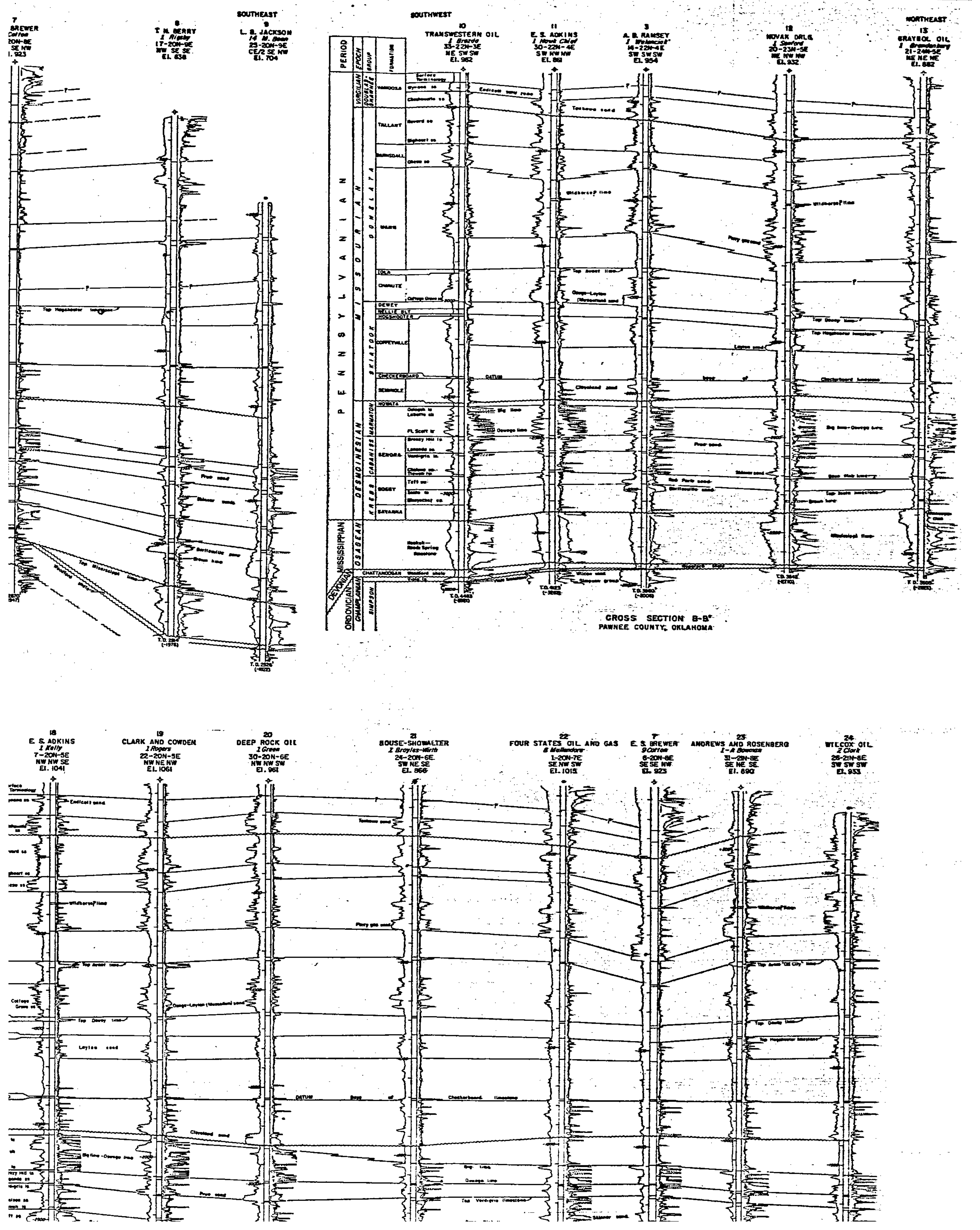

MAP-E

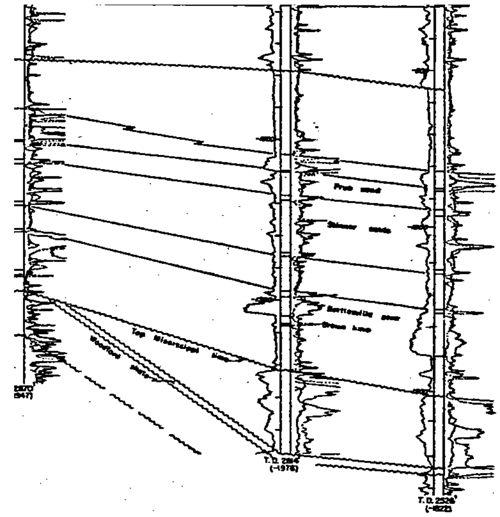
THICKNESS
OF
CHECKERBOARD LIMESTONE
AND
OLDER PENNSYLVANIAN ROCKS

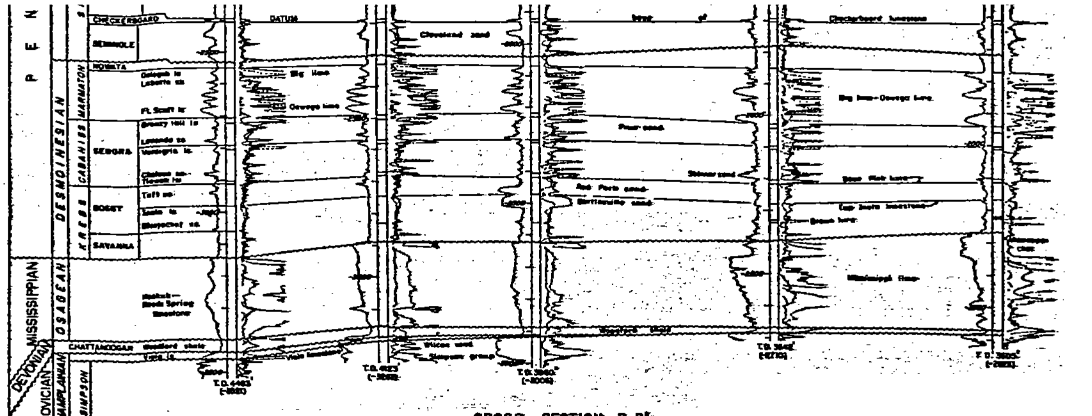
Contour Interval = 25 feet


MAP-C
CONFIGURATION
OF
PENNSYLVANIAN-MISSISSIPPIAN
unconformity
Contour Interval = 50 feet
(dashed contour lines = 25 feet)
OSAGE
COUNTY
PAWNEE LAKE
PAWNEE
BLACKBURN
CLEVELAND
HALLETT
JENNINGS
TERLTON
KEYSTONE
PAYNE
CREEK
COUNTY
MILES

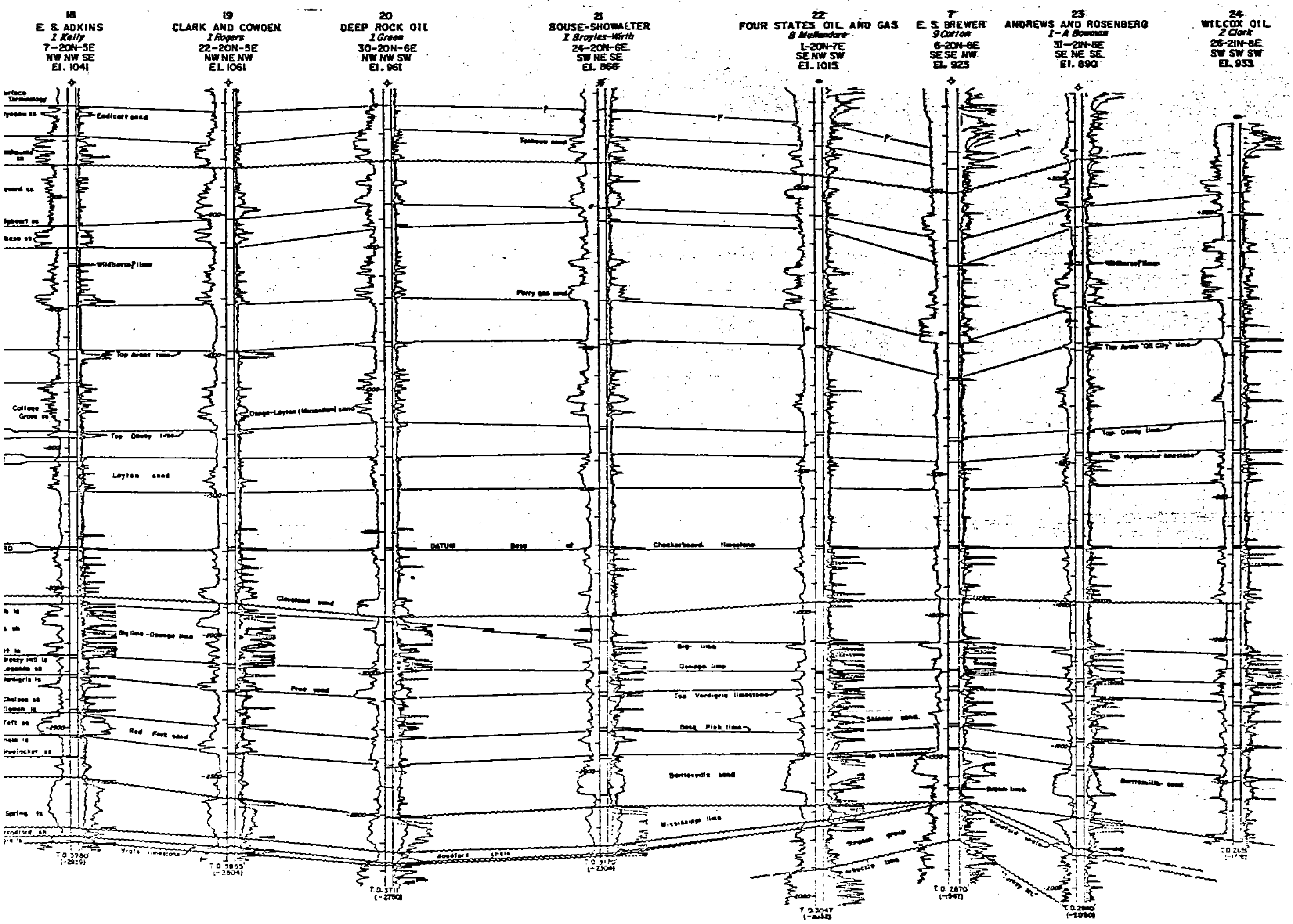

MAP-F
THICKNESS
OF
MISSISSIPPIAN SYSTEM AND WOODFO
Contour Interval = 25 feet
OSAGE
COUNTY
PAWNEE LAKE
PAWNEE
BLACKBURN
CLEVELAND
HALLETT
JENNINGS
TERLTON
PAYNE
CREEK
COUNTY


SOUTHEAST
7
BREWER
8
T. N. BERRY
1 Rigsby
17-20N-9E
NW SE SE
El. 838
9
L. B. JACKSON
14 M. Bean
25-20N-9E
CE/2 SE NW
El. 704
SOUTHWEST
10
TRANSWESTERN OIL
33-22N-3E
NE SW SW
El. 962
11
E. S. ADKINS
1 Hawk Chief
30-22N-4E
SW NW NW
El. 861
3
A. B. RAMSEY
14-22N-4E
SW SW SW
El. 954
12
NOVAK DRLG.
20-23N-5E
NE NW NW
El. 932
NORTHEAST
13
GRAYBOL OIL
21-24N-5E
NE NE NE
El. 882
PERIOD
EPOCH
GROUP
FORMATION
PENNSYLVANIAN
VIRGILIAN
MISSOURIAN
DESMOINESIAN
MISSISSIPPIAN
OSAGEAN
DEVONIAN
ORDOVICIAN
CHAMPLAINIAN
SIMPSON
TALLANT
BARNSDALL
IOLA
CHANUTE
DEWEY
NELLIE BLY
HOGSHOOTER
COFFEYVILLE
CHECKERBOARD
SEMINOLE
NOWATA
SENORA
BOGGY
SAVANNA
CHATTANOOGA
DATUM
Wildhorse lime
Top Avant lime
Top Hogshooter limestone
Checkerboard limestone
Cleveland sand
Big lime
Oswego lime
Prue sand
Skinner sand
Red Fork sand
Bartlesville sand
Top Mississippi lime
Woodford shale
Wilcox sand
Simpson group
Mississippi lime
Top Dewey lime
Layton sand
Top Inola limestone
Brown lime
CROSS SECTION B-B'
PAWNEE COUNTY, OKLAHOMA
18
E. S. ADKINS
1 Kelly
7-20N-5E
NW NW SE
El. 1041
19
CLARK AND COWDEN
1 Rogers
22-20N-5E
NW NE NW
El. 1061
20
DEEP ROCK OIL
1 Green
30-20N-6E
NW NW SW
El. 961
21
BOUSE-SHOWALTER
24-20N-6E
SW NE SE
El. 866
22
FOUR STATES OIL AND GAS
1-20N-7E
SE NW SW
El. 1015
7
E. S. BREWER
9 Cotton
6-20N-8E
SE SE NW
El. 923
23
ANDREWS AND ROSENBERG
31-21N-8E
SE NE SE
El. 890
24
WILCOX OIL
2 Clark
26-21N-8E
SW SW SW
El. 933
Endicott sand
Tonkawa sand
Cottage Grove ss
Oswego-Layton (Mussellem) sand
Big lime-Oswego lime
Top Verdigris limestone
Skinner sand

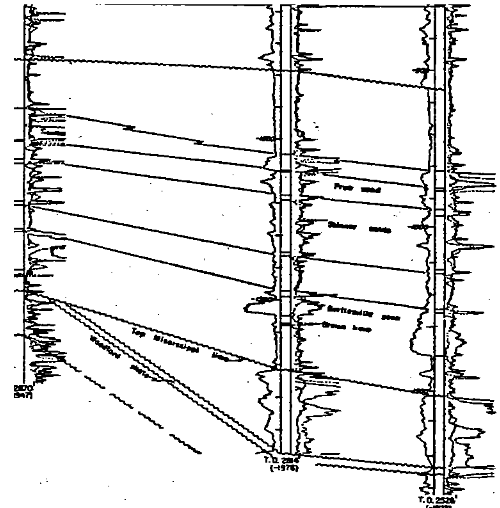


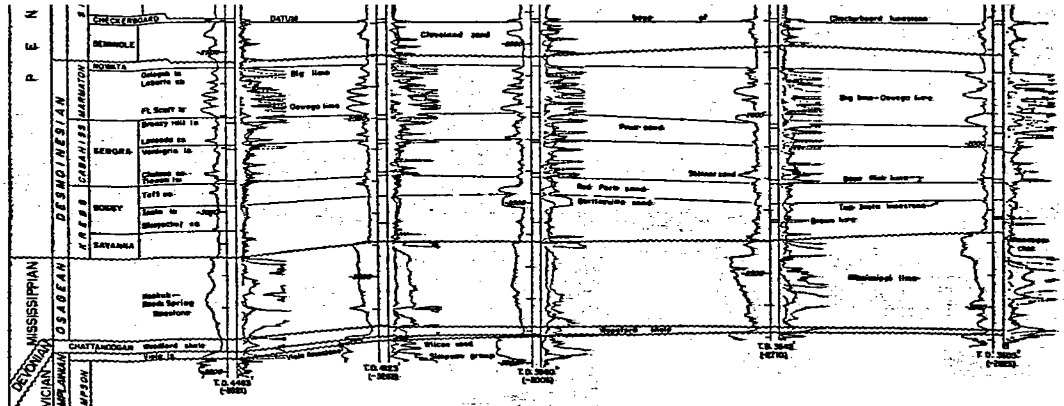



CROSS SECTION B-B'
PAWNEE COUNTY, OKLAHOMA

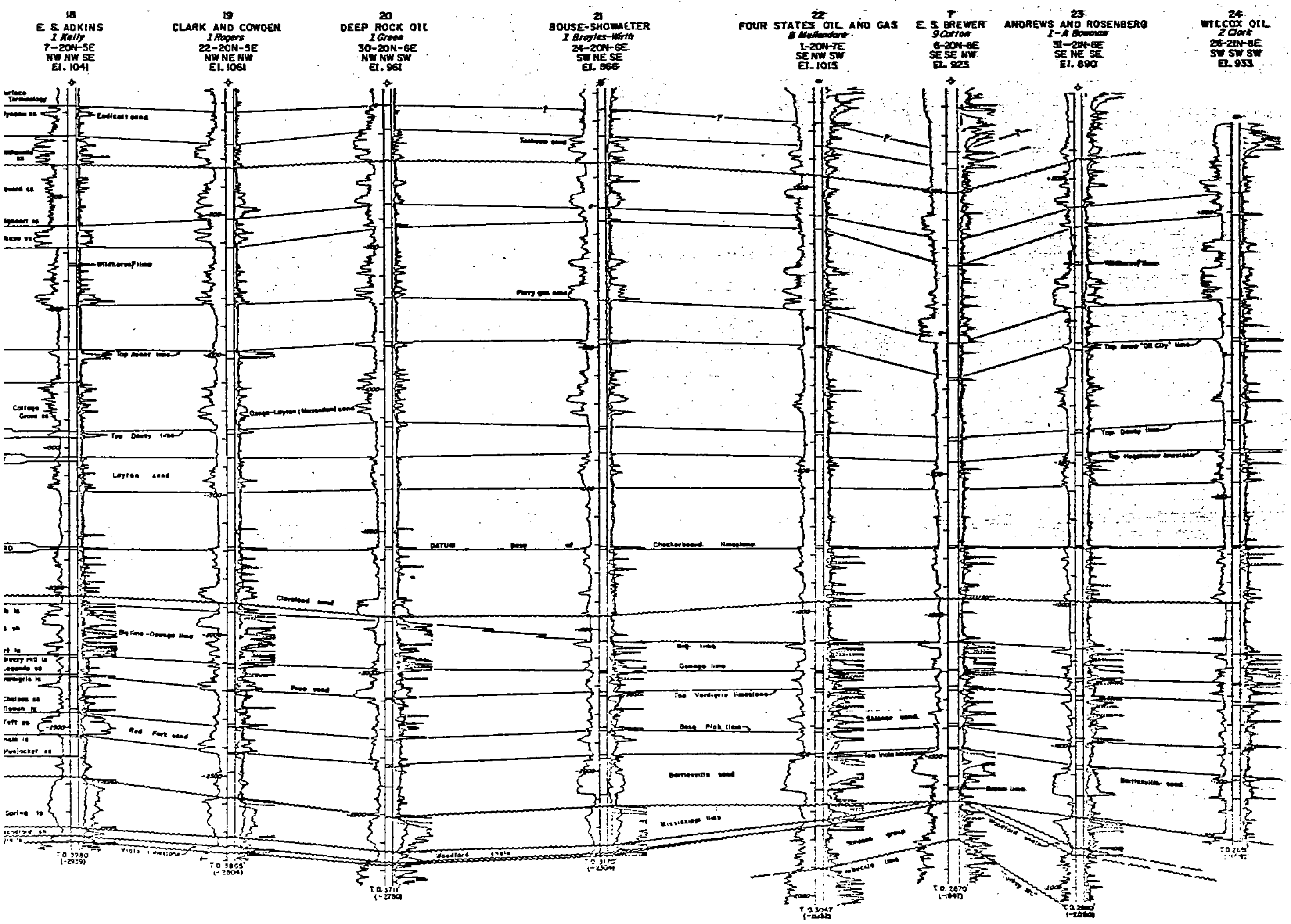



CROSS SECTION D-D'

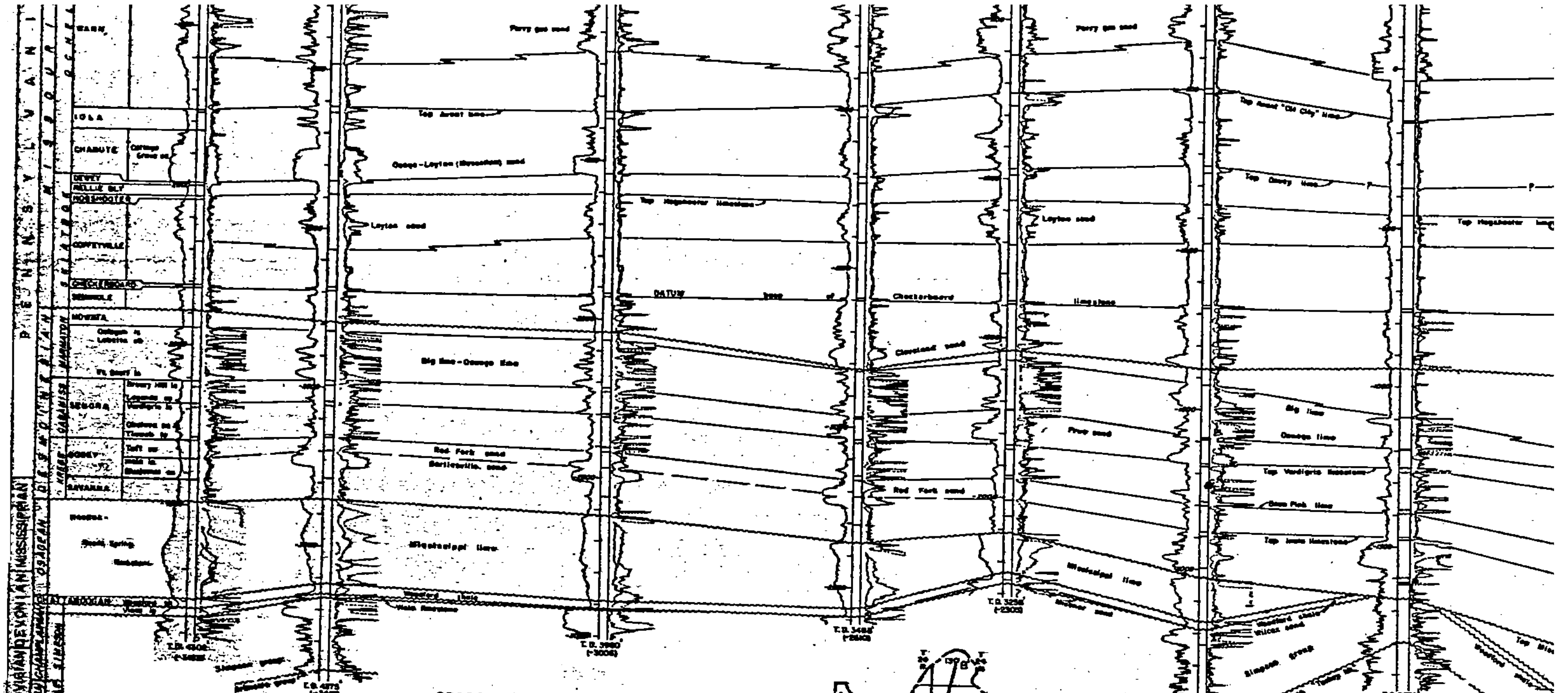




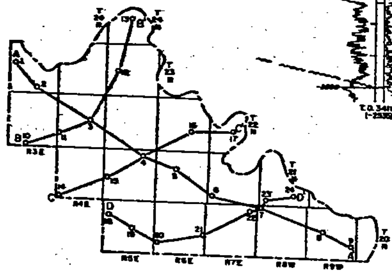
CROSS SECTION B-B'
PAWNEE COUNTY, OKLAHOMA

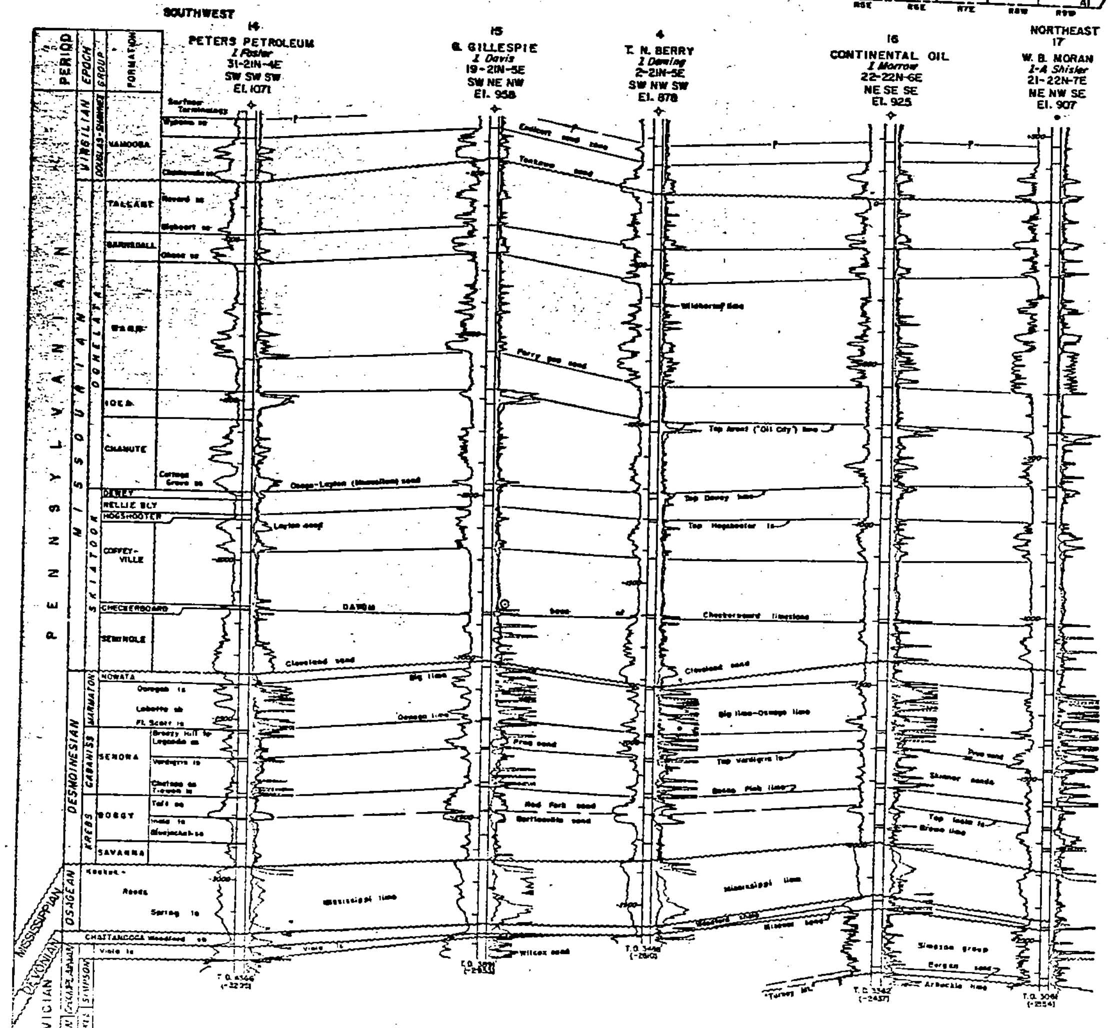



CROSS SECTION D-D'




CROSS SECTION A-A'
PAWNEE COUNTY, OKLAHOMA






CROSS SECTION C-C'
PAWNEE COUNTY, OKLAHOMA