GEOLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE RESERVOIR SANDSTONE, KINCAID OIL FIELD, ANDERSON COUNTY, KANSAS

by

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ABSTRACT

In the Kincaid Oil Field, located in southeastern Anderson County, Kansas, oil is produced from a Middle Pennsylvanian (Cherokee) sandstone. This sandstone is correlated with the Skinner sandstone, which in eastern Kansas most commonly occurs as a "shoestring" sand enclosed within the Cherokee shales. In the Kincaid Field, the Skinner sandstone is an elongate north-south trending combination stratigraphic-structural trap. Oil is produced from the sandstone in fields along the same trend north and south of the Kincaid Field. Core and electric log data indicate that the sandstone in the Kincaid Field was deposited in fluvial channel and associated channel and overbank environments.

The sandstone is a litharenite with approximately 70% quartz, 20% metamorphic rock fragments, and 10% accessory minerals. It has a sharp basal contact with conglomerate or sandstone overlying either shale or coal and grades from a medium to fine-grained sandstone upward into interbedded siltstones and shales. The producing sand has a convex downward shape, and becomes finer grained upward, a characteristic of a fluvial channel sand. The sand body was deposited on the Cherokee platform, which formed a shelf-like extension of the Arkoma Basin. During Cherokee time this shelf area (eastern Kansas and northeastern Oklahoma) fluctuated from a non-marine to marine environment, resulting in cyclic sedimentation. Due to this relatively rapid

fluctuation of depositional environments, sands were deposited in different sedimentary environments, producing elongate "shoestring" sandstones throughout the Cherokee interval.

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INTRODUCTION

Purpose of Investigation

The elongate, lenticular, discontinuous sandstone bodies within the Cherokee Group (Desmoinesian) in southeastern Kansas and northeastern Oklahoma are known as "shoestring sands". These sandstones are important as reservoirs for oil and gas in the subsurface, but their occurrence is often unpredictable. Because of this irregular occurrence, prospecting for oil in the Cherokee rocks becomes very difficult, and, often, random drilling is the only method of exploration. However, with a greater understanding of the depositional environments of these sand bodies, occurrences of oil and gas may become more predictable.

The purpose of this detailed study of the reservoir rock of the Kincaid Field has been to determine: (1) the origin of the sandstone body, (2) the geology of the area at the time of sand deposition, (3) the present attitude of the sandstone body, (4) the relation of sandstone geology to petroleum accumulation.

Interpretations

Based on evidence presented in following sections, this study has led to the following conclusions: 1. The sandstone body of the Kincaid Field was deposited as fluvial channel and overbank sands and silts. 2. The paleogeographic setting was on the Cherokee Platform which fluctuated from a marine to a non-marine environment throughout Cherokee time. 3. The sandstone at present forms a porous, elongate, lenticular body enclosed within Cherokee shales. 4. Petroleum accumulation resulted from both stratigraphic changes and structural closures within the sandstone.

Location

The Kincaid Oil Field is located in the extreme southeastern corner of Anderson County, in eastern Kansas (Figure 1).

The first oil discovered in Kansas was found near Paola in Miami County in 1860 (Haworth, 1908). These first wells were drilled near surface tar or oil springs used by Indians, but resulted in very little production (Powell and Eakin, 1953).

In the early 1900's oil production in eastern Kansas began to increase with the finding of the Paola and Rantoul fields in Franklin and Miami Counties. The first "shoestring" sandstone pool in eastern Kansas to produce oil was probably the Paola or Pressonville shoestring, which was discovered in 1917 (Powell and Eakin, 1953). The Centerville shoestring was first drilled in 1919, and the Colony field, the Garnett field, and the Bush City field were all discovered in 1921.

Numerous other oil and gas fields have been discovered since that time (Figure 2), and southeastern Kansas is now the most mature producing province in the state. Waterflooding and other methods of enhanced recovery have been

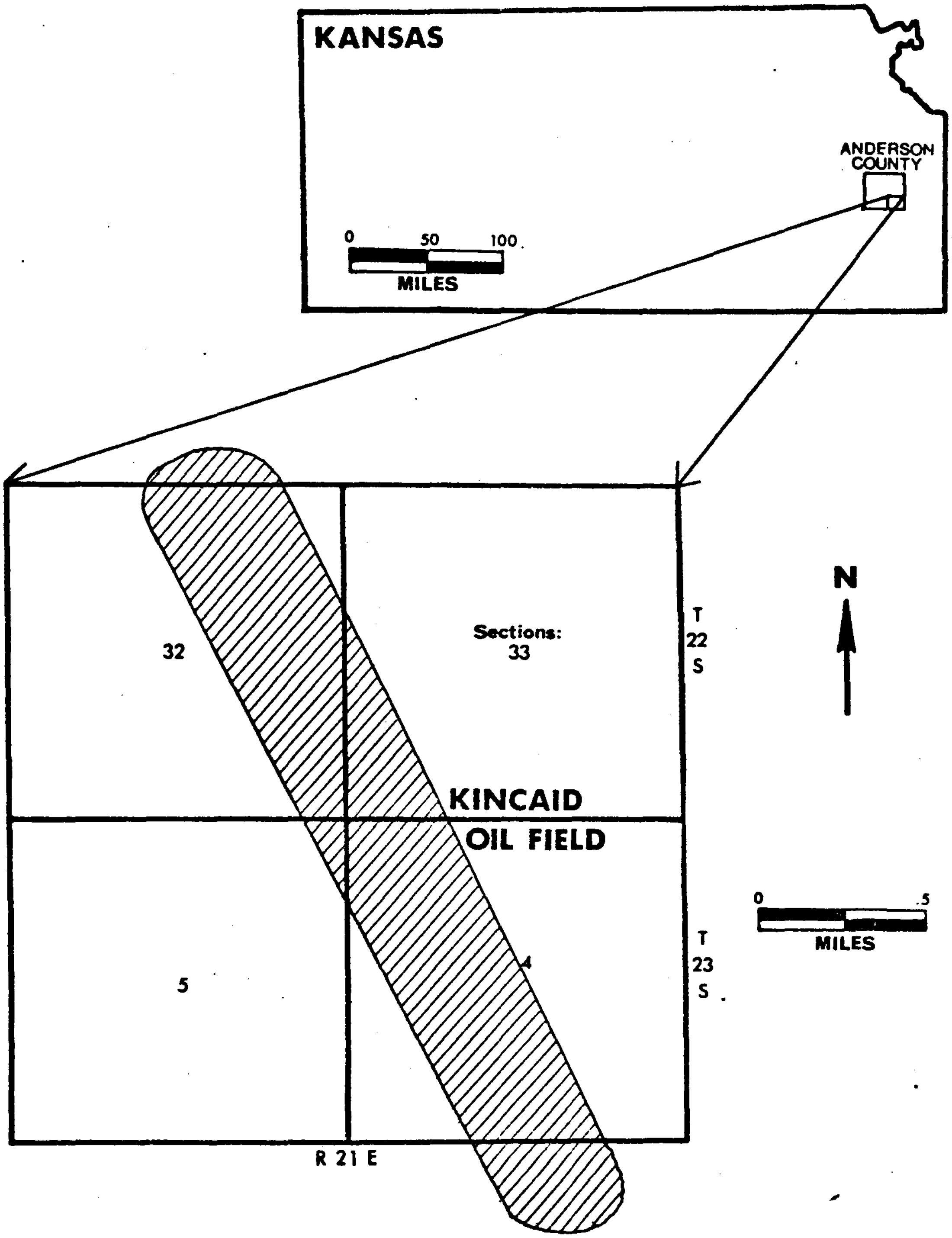

Figure 1. - Index map showing area of study.

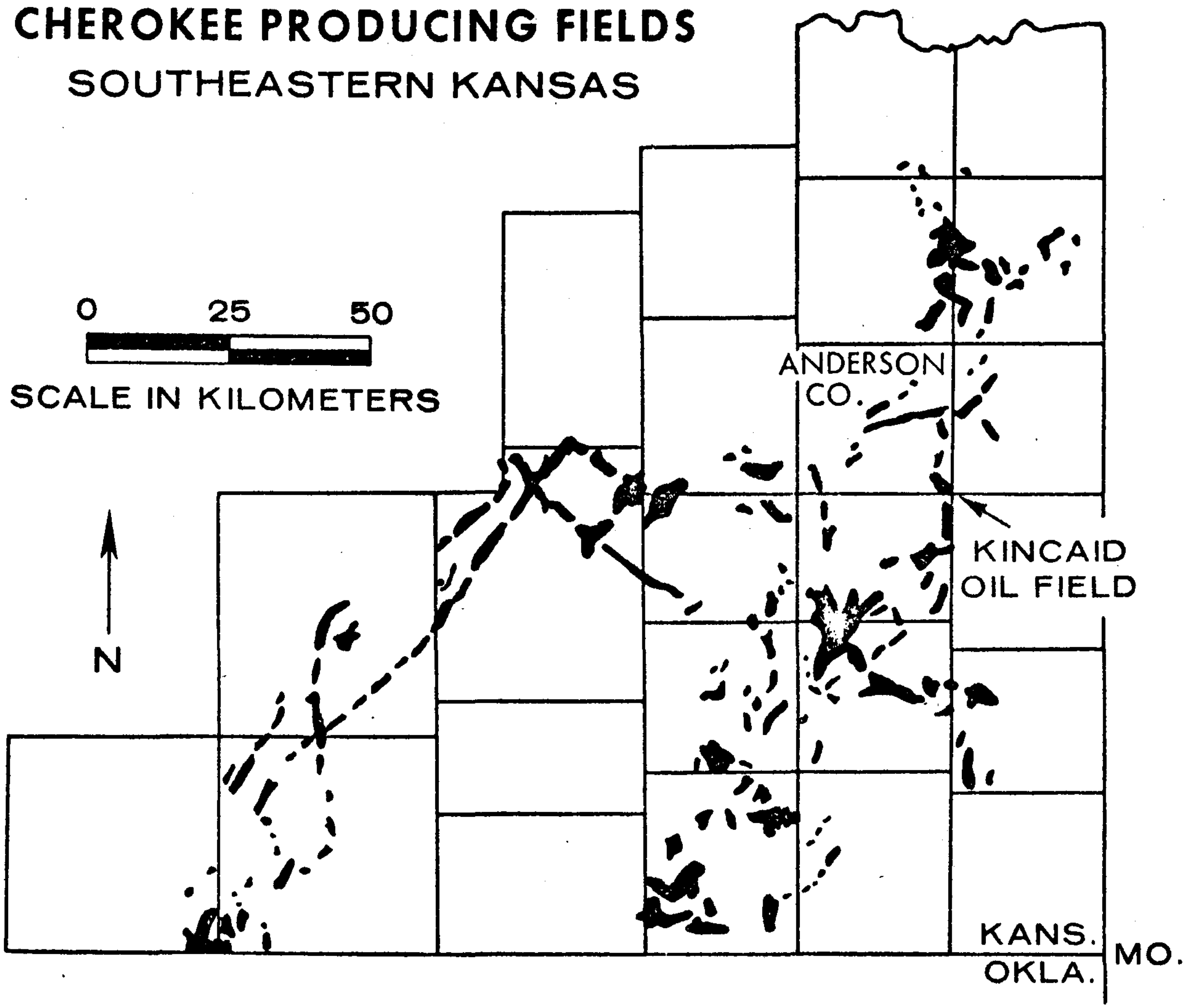

Figure 2. - Map of southeastern Kansas showing distribution of oil fields producing from the Cherokee Group (from Hilpman, 1958).

widely practiced in this area since the mid-1930's. Numerous attempts to recover more oil from these old fields by tertiary recovery methods began in the mid-1960's. Revival of interest in these methods is occurring now.

The Kincaid Oil Field (Figure 2) was first drilled in 1934 and was operated by M. W. Shriver and Associates. Waterflooding in the Kincaid Field began in 1946, and the field was purchased by Texas Consolidated Oil Company in 1949 (Powell and Eakin, 1953). In 1969, the Kincaid Field was purchased by the Richard Engineering Company of Chanute, Kansas. Approximately one half million barrels of oil have been produced from the Kincaid Field. In 1972, production from the field was about 20,000 barrels of oil, from 42 producing wells covering 400 acres (Beene, 1972). The oil currently has an average gravity of 26° A.P.I., in 1934 the average gravity of the oil was 29.5° A.P.I.

Previous Investigations

Regional stratigraphy and petroleum geology of the Forest City Basin and Cherokee Basin areas have been the subject of studies by Weller (1930, 1958), Moore (1931, 1964), Lee (1943), Searight, et al. (1953), Weirich (1953), and Anderson and Wells (1968). The formal stratigraphy of the Middle Pennsylvanian rocks of the mid-continent area has been established by Condra (1949), Moore, et al. (1951), Howe (1956), Howe and Koenig (1961), and Zeller (1968).

Geology of the Cherokee Group of southeastern Kansas has been studied by Abernathy (1937), and Ebanks and James (1975).

Some of the earliest studies of the "shoestring sands" of eastern Kansas were made by Rich (1923, 1926, 1938). Cadman (1927), Charles (1927), Cheyney (1929), and Bass (1934, 1936, 1937), also made early studies concerning the origins of the "shoestring sands". Very little recent detailed work has been done on these "shoestring sands" of eastern Kansas. However, there are many papers concerning the Desmoinesian sandstones of northeastern Oklahoma, including those of Visher (1968, 1971), Saitta (1968), Dogan (1969), Phares (1969), Scott (1970), and Valderrama (1974). The only recent studies of these sandstones in Kansas are by Maderak (1960), McQuillan (1969), and Hudson (1969).

Acknowledgements

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I wish to thank Drs. M. J. Brady (Chairman), W. J. Ebanks, Jr., and M. E. Bickford for serving as master's thesis advisors. I would also like to thank Dr. E. F. McBride for his helpful suggestions, and Cindy Van Dyke for typing the manuscript.

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GEOLOGY OF THE CHEROKEE GROUP IN SOUTHEASTERN KANSAS

Stratigraphy

The Cherokee Group, as defined by the Kansas Geological Survey, is the lowest division of the Desmoinesian Stage, Middle Pennsylvanian Series, Pennsylvanian System. The Cherokee Group includes both marine and non-marine rocks between the base of the Fort Scott Limestone and the Mississippian Limestones (Figure 3). Lithologically, the group is composed mostly of shale, with some sandstone and sandy shale, numerous, thin coal beds, and rare limestone beds. The group is between 130 and 150 meters thick in eastern Kansas.

The Cherokee Shales were first described by Haworth and Kirk (1894) and given formational rank in Iowa by C. R. Keyes in 1896 (Searight, 1955). The type area is in Cherokee County, Kansas. Abernathy (1937) divided the Cherokee of southeastern Kansas into 15 cyclothems or formations, each formed during a "single sedimentary cycle". In 1953, Oakes divided the outcropping Cherokee rocks of eastern Oklahoma into the Krebs and Cabaniss Groups. Howe (1956) recognized 18 formations within the Cherokee Group of southeastern Kansas. The lower 6 formations were grouped in the Krebs Subgroup, and the overlying Cabaniss Subgroup contained the other 12 formations. Jewett (1959) was the first to use the terms Krebs and Cabaniss as formations of the

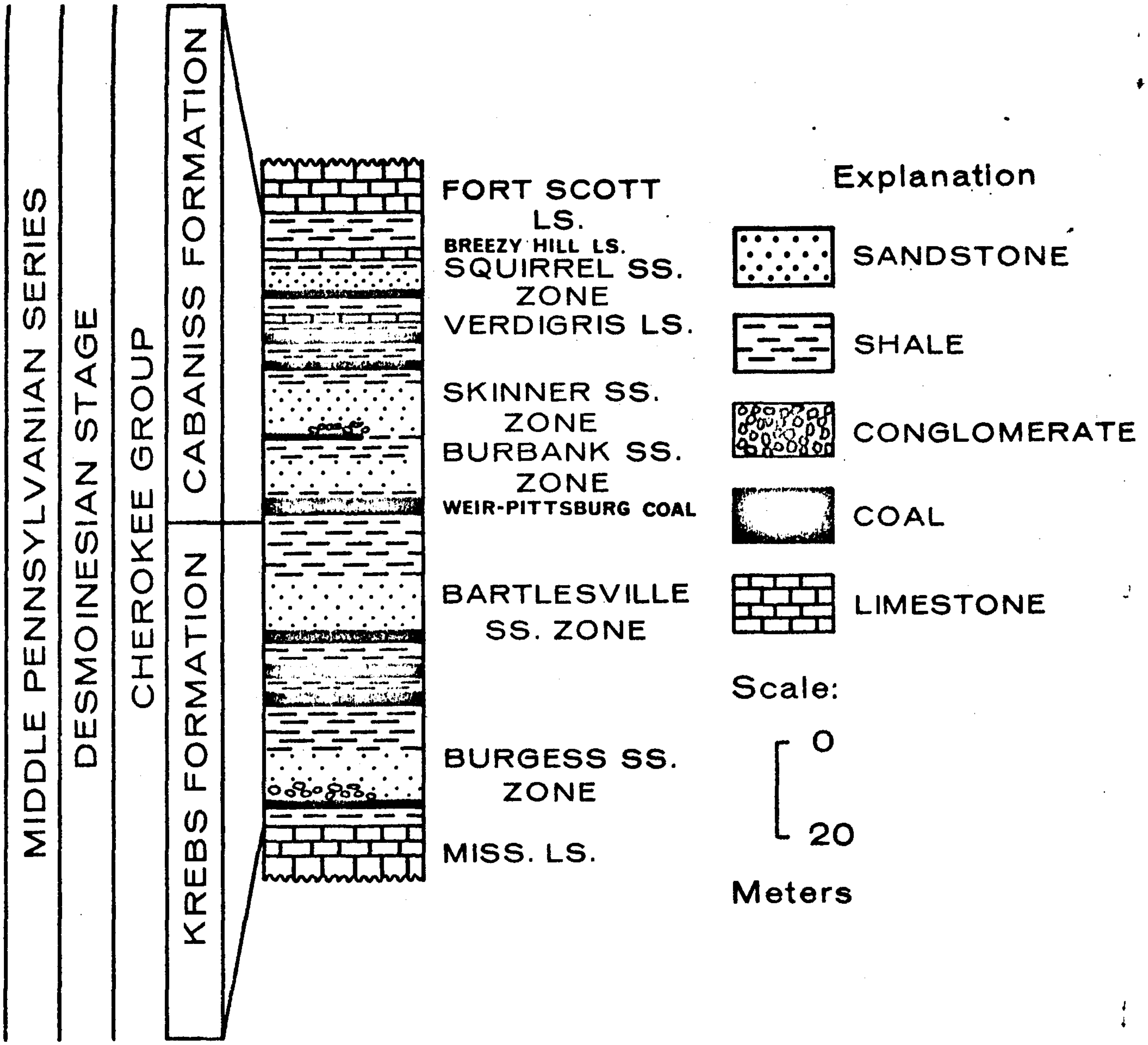


Figure 3. - Stratigraphic column of the Cherokee Group of southeastern Kansas.

Cherokee Group. The Cherokee Group in Kansas is presently divided into the Krebs and Cabaniss Formations (Zeller, 1968).

In many cases it is not possible to recognize the individual surface mapping units in the subsurface; therefore, the 18 formational subdivisions of Howe (1956) have been lumped together to make up the Cherokee Group. Although shales predominate in the Krebs and Cabaniss formations, none of the shales have been named. For these reasons, it is common practice among petroleum geologists working with subsurface Cherokee Group rocks to use the informal term, "zone", to indicate those sections which can be correlated from place to place by recognition of subsurface marker beds. These "zones" typically are named for the oil producing sandstones they include (Figure 3). This practice is not completely satisfactory, because the marker beds are not everywhere recognizable in Kansas and the sandstones overlap in vertical extent in some areas. Because of the common difficulty in recognizing these various producing sandstones in the subsurface, they and some of the associated sediments are described in the following paragraphs.

Burgess Sandstone

The Burgess Sandstone is one of the well-known oil and gas sands in the Cherokee Group and generally occurs as a basal conglomerate. It was first described by Ohern and

Garret in 1912 (Jordan, 1957, p. 31), and is equivalent to the Warner or Little Cabin Sandstone (Wilson, 1935, p. 508) of the surface in Kansas and Oklahoma, and the Booch Sandstone of the subsurface in Oklahoma (Howe, 1956, p. 33). It occurs in an interval about 6 to 10 meters thick above the unconformable contact of the Cherokee with the underlying Mississippian Limestone surface. The Burgess is a sandstone consisting of coarse quartz sand, sometimes including chert fragments from the weathered Mississippian Limestones. It is composed of whatever detrital materials were available, eroded from the unconformable Mississippian Limestone surface.

Bartlesville Sandstone

The Bartlesville Sandstone is one of the most productive and widely studied of the Cherokee shoestring sands. It was first described by Hutchinson in 1911 from its occurrence in the Bartlesville Pool of Washington County, Oklahoma (Jordan, 1957, p. 14). It is equivalent to the Bluejacket Sandstone, originally described in outcrop in Kansas and Oklahoma by Ohern (1914, p. 28-29). The sand body is lenticular and discontinuous in occurrence, having a range of thickness from zero to 30 meters. It is a light gray, very fine to medium-grained, angular to subangular, massive or cross-bedded sandstone containing fragments of shale and chert. The base of the Bartlesville Sandstone zone is from 70 to 90 meters below the Fort Scott Limestone, below the

Burbank Sandstone zone and above the Burgess Sandstone zone. Detailed studies of the Bartlesville sandstones have been made by Bass (1936), Bass, et al. (1937), Berg (1963), Hawisa (1965), Saitta (1968), Visher (1968, 1971), and Phares (1969).

Burbank Sandstone

The Burbank Sandstone is equivalent to the subsurface Red Fork Sandstone and the surface Taft Sandstone in Oklahoma (Jordan, 1957). It is a gray, very fine to medium-grained, subangular to subrounded, micaceous, massive and cross-bedded sandstone. The Burbank Sandstone occurs in a zone below the Tiawah Limestone and above the Bartlesville Sandstone. The thickness of the Burbank-Red Fork Sandstone zone varies from zero to about 60 meters. Detailed studies of this sandstone have been made by Bass, et al. (1937), Clements (1961), Cruz (1963), Hawisa (1965), Withrow (1968), and Hudson (1969). Like most of the eastern Kansas shoestring sands, the Burbank occurs as elongate, lenticular sandstone bodies.

Skinner Sandstone

The Skinner Sandstone in the subsurface of Oklahoma is equivalent to the surface Chelsea Sandstone of Kansas and Oklahoma. It was first described by Wood (1913) from its occurrence in the Skinner lease in the Lauderdale Pool in Pawnee County, Oklahoma. According to Oakes (1944), the

Chelsea Sandstone was named by Ohern (1914) from exposures in the Vinita quadrangle near the town of Chelsea, Oklahoma. Howe (1956) places the Chelsea Sandstone within the Scammon Formation (Cabaniss Subgroup). The current classification (Zeller, 1968) has the Chelsea in the Middle of the Cabaniss Formation (Cherokee Group).

The Skinner Sandstone occurs in the zone from 10 to 30 meters below the Verdigris Limestone and above the Tiawah Limestone. The producing sandstone of the Kincaid Pool is correlative with the Skinner, and a detailed discussion of the sandstone will be included later. Other detailed studies of the Skinner Sandstone have been made by Clements (1961), Hawisa (1965), McQuillan (1968), and Valderrama (1974). Briefly, the sandstone zone may consist of as many as three or four sandstones with shale between each. The sandstones are tan to brown, fine grained, carbonaceous, micaceous, and well sorted, with a conglomeratic base. The total thickness of the sandstones within the zone ranges from zero to 20 meters in the Kincaid Field. In northeastern Oklahoma, the Skinner Sandstone zone thickens, and multiple sands are more distinct and more widely separated by shales.

Verdigris Limestone

The Verdigris Limestone was first described by D. C. Smith in 1914 (Woodruff and Cooper, 1930) from its outcrop along the Verdigris River in Rogers County, Oklahoma. The

Verdigris is a very continuous unit with a thickness of approximately 1.5 meters in eastern Kansas; it consists of three thin dark gray limestone beds with shale between them. The limestones are finely crystalline, compact, and highly fossiliferous (Clayton, 1965, p. 9). The Verdigris is an easily correlated marker bed between the overlying Squirrel Sandstone zone and the underlying Skinner zone. Another marker bed, which is easily recognized on gamma ray logs as a strong positive deflection, is a thin, phosphatic black shale bed lying directly beneath the Verdigris Limestone. This black shale is also recognized in Oklahoma, Missouri, and Iowa; and its presence facilitates regional subsurface correlations. In northern Oklahoma the Verdigris thickens to about 4.5 meters (Phares, 1969).

Squirrel Sandstone

The Squirrel Sandstone is the uppermost producing sandstone in the Cherokee Group. It lies 8 to 30 meters below the top of the Fort Scott Limestone and has a thickness of 3 to 25 meters (Lee, 1943). It was first described by Shanon and Trout (1915) from its occurrence in the Bartlesville Field of Washington County, Oklahoma (Jordan, 1957, p. 184). The Squirrel Sandstone is the equivalent of the Prue Sandstone of Oklahoma. The squirrel is a gray to buff, fine-grained, micaceous, argillaceous, cross-bedded sandstone which varies in thickness from zero to about 12 meters. It occurs within the interval between the overlying

Breezy Hill Limestone and the underlying Verdigris Limestone and has the same lenticular, discontinuous nature as sandstones in the Cherokee section.

Breezy Hill Limestone

The Breezy Hill Limestone was first described by Pierce and Courtier (1937, p. 33) from an outcrop in Crawford County, Kansas. It is an irregularly bedded, dark gray, sandy limestone with a thickness of about 1 meter (Howe, 1956, p. 80-81).

Coals

Coal is economically an important rock in the Cherokee Group. The beds are usually about one foot thick, and rarely as thick as five feet. The Weir-Pittsburg Coal is the thickest and the most important commercially. Quality and lateral extent of the coal beds are variable (Howe, 1956).

Shales

Shale, which makes up the majority of the Cherokee interval (approximately 80%), is the least studied of all the Cherokee rocks. Although, stratigraphically, the shales are undifferentiated, there are several types of shales that may be distinguished. Baker (1962) summarized the four main types of shales found in the Cherokee Group as follows:

1) Greenish-gray, silty, unfossiliferous, non-fissile shale containing quartz, chlorite, sericite and siderite.

2) Gray, organic, pyritic shale composed of quartz, chlorite, sericite and containing plant remains and a marine fossil fauna.

3) Black, phosphatic, organic, pyritic, fissile shale containing quartz, illite, and chlorite, with numerous conodonts and orbiculoid brachiopods.

4) Olive-gray underclay, containing quartz, various clay minerals, limestone nodules, pyrite veins, and carbonized plant fragments.

Paleogeography and Regional Tectonics

In southeastern Kansas and northeastern Oklahoma, rocks of the Cherokee Group were deposited on the Cherokee Platform (Figure 4) which was part of the Mid-Continent craton. This Cherokee Platform (or Cherokee Basin) is a shelf-like extension of the Arkoma Basin of Oklahoma. The Ozark Uplift forms the eastern boundary of the basin while the Nemaha Uplift forms the western boundary. Northward, the Cherokee Basin is separated from the deeper Forest City Basin by the Bourbon Arch, which was a pre-desmoinesian low-relief paleotopographic feature (Merriam, 1963).

According to Baker, et al. (1969), the most important influence on Cherokee Platform sedimentation was the adjacent Arkoma Basin to the south, which was actively subsiding during Desmoinesian time. Consequently, Cherokee sedimenta-

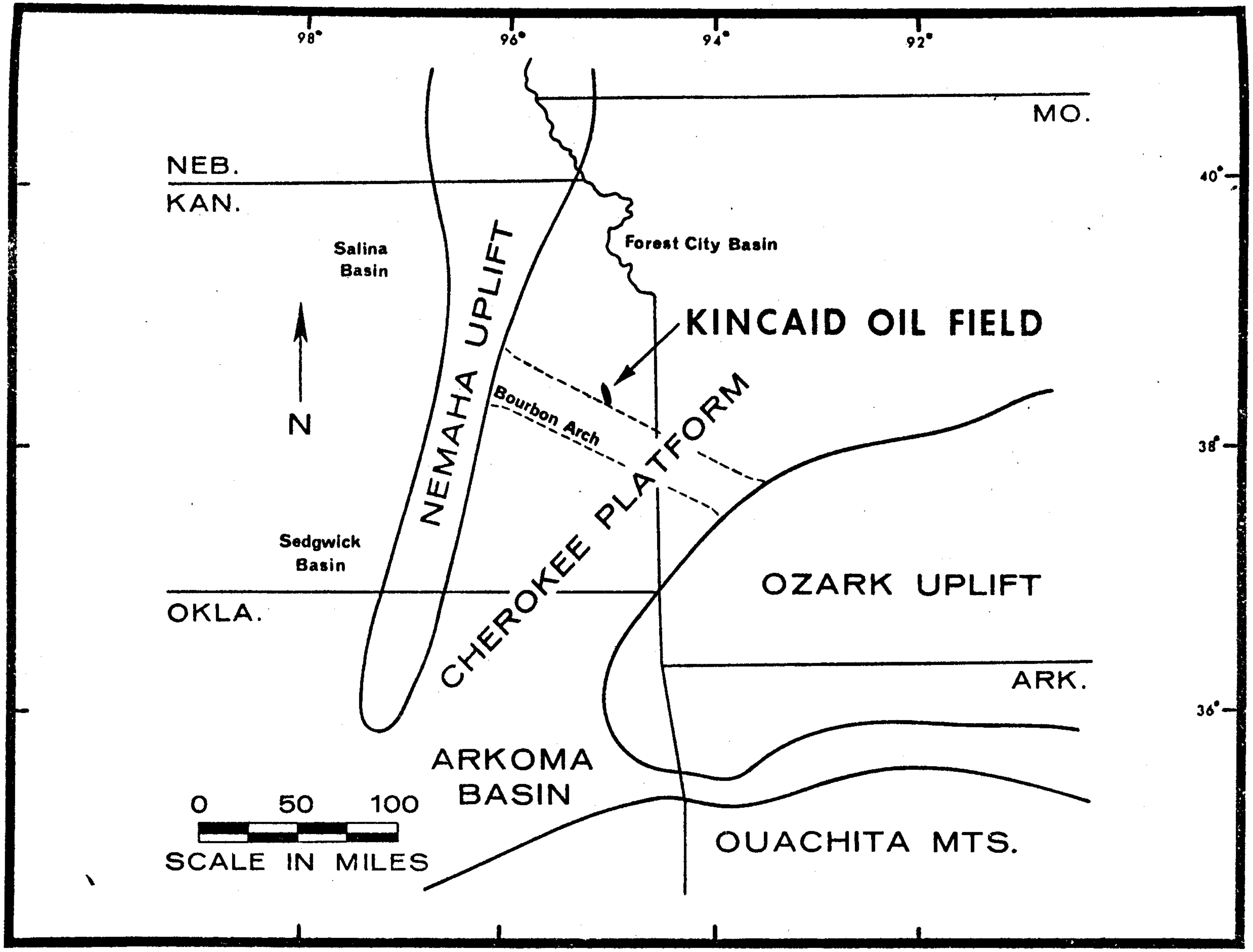


Figure 4. - Paleogeographic map showing major tectonic features present during Middle Pennsylvanian time.

tion was characterized by fluctuating marine and non-marine environments as the interplay between rates of subsidence and sediment supply varied.

Northward on the Cherokee Platform the Pennsylvanian section thins by transgressive onlap of younger sediments over the eroded Mississippian surface (Weirich, 1953; Visher, et al., 1971; Ebanks and James, 1975). The Cherokee Group rocks were the earliest of the Middle to Upper Pennsylvanian and Permian cyclic sequences to be deposited in the Midcontinent area (Howe, 1956). During the deposition of the Cherokee Group the water was probably never deeper than 60 meters; and, at least 20 times, part of the shelf area was emergent, as proven by the occurrences of coal (Branson, 1968). Most of the Cherokee section is shale, with sandstones, coals and underclays, and a few thin limestone beds. Later cyclic sequences (Upper Desmoinesian Marmaton Group) contain a greater amount of limestones and very little coal, indicating a widespread, increased marine transgression throughout middle and later Pennsylvanian time. The Cherokee sea transgressed the shelf area from the south-southeast; minor regressions were accompanied by deposition of continental deposits of lenticular sandstones and thin coal.

The Arkoma Basin was filled with deltaic deposits of shale and sand, and the platform area of Kansas, Oklahoma and Missouri was an area of prograding alluvial and deltaic plains and shallow marine shelf environments (Visher, et al., 1971). Many different environmental interpretations have been given to the individual sandstones of the Cherokee Group, giving an indication of the fluctuations in depositional environments that existed at this time.

The Nemaha Uplift was the most prominent positive structural feature in this area and trends in a north-south direction from eastern Nebraska through Kansas and into central Oklahoma. It separates the Salina and Sedgwick Basins on the west from the Forest City and Cherokee Basins to the east. Early Pennsylvanian movement along the Nemaha Uplift raised the area west of it while downwarping to the east formed the Forest City Basin (Lee, 1943). Movement along the Nemaha Uplift may have begun during the late Early Ordovician, but it was definitely mobile during Early Mississippian time and continued to be active intermittently until at least the Early Permian (Anderson and Wells, 1968).

The Forest City Basin reached its maximum structural development and was filled with sediments by the end of the Desmoinesian Stage of Early Pennsylvanian time when the Nemaha Ridge was inundated (Anderson and Wells, 1968). Initially, the Forest City Basin was filled with sediments eroded from the Nemaha and surrounding emergent areas. Tectonic movement during post-Permian time resulted in a tilting to the west of the strata of eastern Kansas.

GEOLOGY OF THE SANDSTONE BODY IN THE KINCAID FIELD

Geometry

The sandstone body which forms the reservoir in the Kincaid Field, is an elongate, linear, generally north-south trending "shoestring" sand. The Kincaid Oil Field is about 4.5 kilometers in length and approximately 360 meters in width, with an average thickness of about 4 to 5 meters. The sandstone trend continues north and south of the Kincaid Field where it produces oil in other pools, including the Centerville, Selma, Davis-Bronson, and Elsmore shoestrings, shown in Figure 5. The producing sandstone is correlative with the subsurface Skinner Sandstone. Laterally, the sandstone changes abruptly into shale or silty shale, which is not productive of hydrocarbons.

Attitude of the Sandstone Body

Thirty-six gamma ray-neutron logs and numerous driller's logs and core analyses were used to construct cross sections and maps of the sandstone body in the Kincaid Field. One source of error in these data was the lack of elevations for the wells of the Kincaid Field. Elevations used were estimated from topographic maps. There were no wells for which an electric log and a core or a driller's log were available. These sources of error, however, did not seriously limit the research conducted in this study. Figure 6 is a map of the Kincaid Oil Field showing well locations and lines of cross sections.

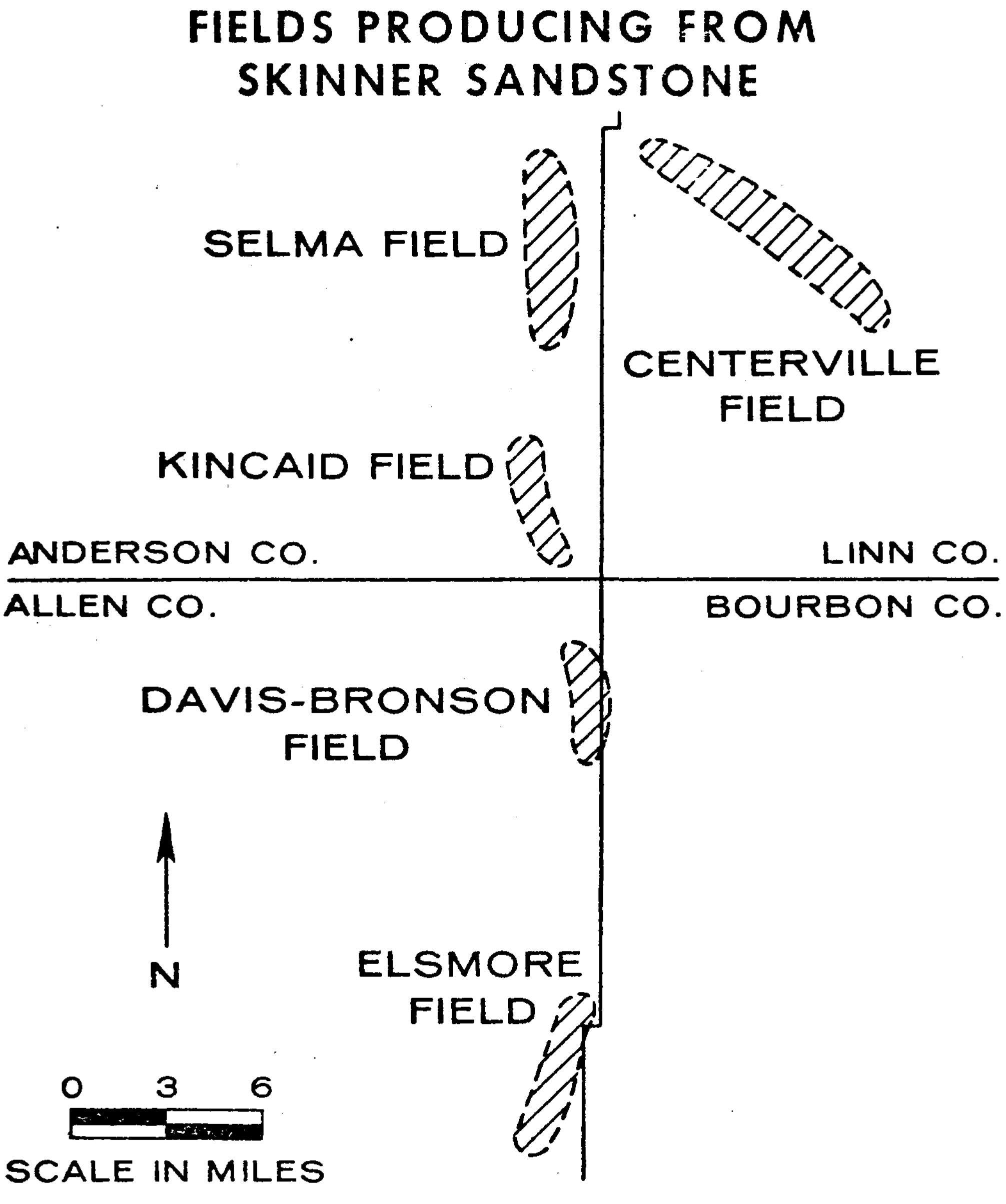


Figure 5. - Map of the study area showing oil fields producing from the Skinner Sandstone.

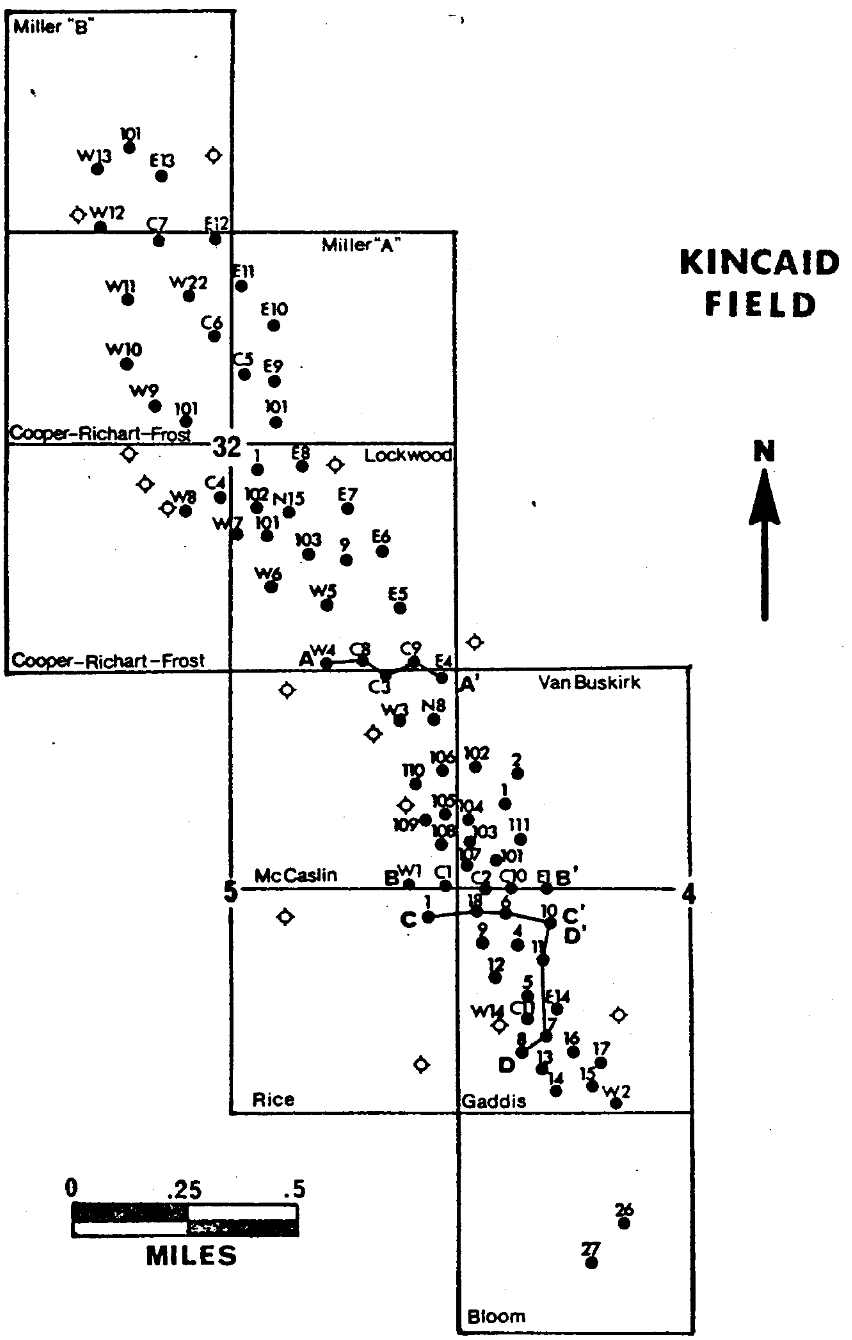


Figure 6. - Map of the Kincaid Oil Field showing leases, locations of wells, and lines of cross sections.

The Verdigris Limestone marker bed was used as a datum in constructing stratigraphic cross sections. This was based on the assumption that the thin limestone bed did not transgress time, i.e., it ideally represents a level sea floor during an instant in geologic time. The overlying Fort Scott Limestone marker could also have been used in the same manner.

The cross sections, shown in Figure 7, were constructed perpendicular to the length of the sandstone body in the areas of the field with the best well control. Each cross section drawn shows that the thickest sand is in the center of the field. There is a gradation to shale on each side of the field where the sandstone interfingers with the shale. Also shown is a cross-sectional shape which has a convex down lower surface and a flatter upper surface.

These stratigraphic cross sections indicate a sand which thickens downward at the expense of the underlying shales and interfingers with shales near the edges of the field.

Structural cross sections (Figure 8) show the present subsurface orientation of the sand body. These cross sections were also drawn at right angles to the trend of the sandstone body.

The shape of the sandstone in structural cross sections is similar to that shown in the stratigraphic cross sections, but the sandstone seems to be flatter with a less convex base (Figure 8). This flattening is caused by dif-

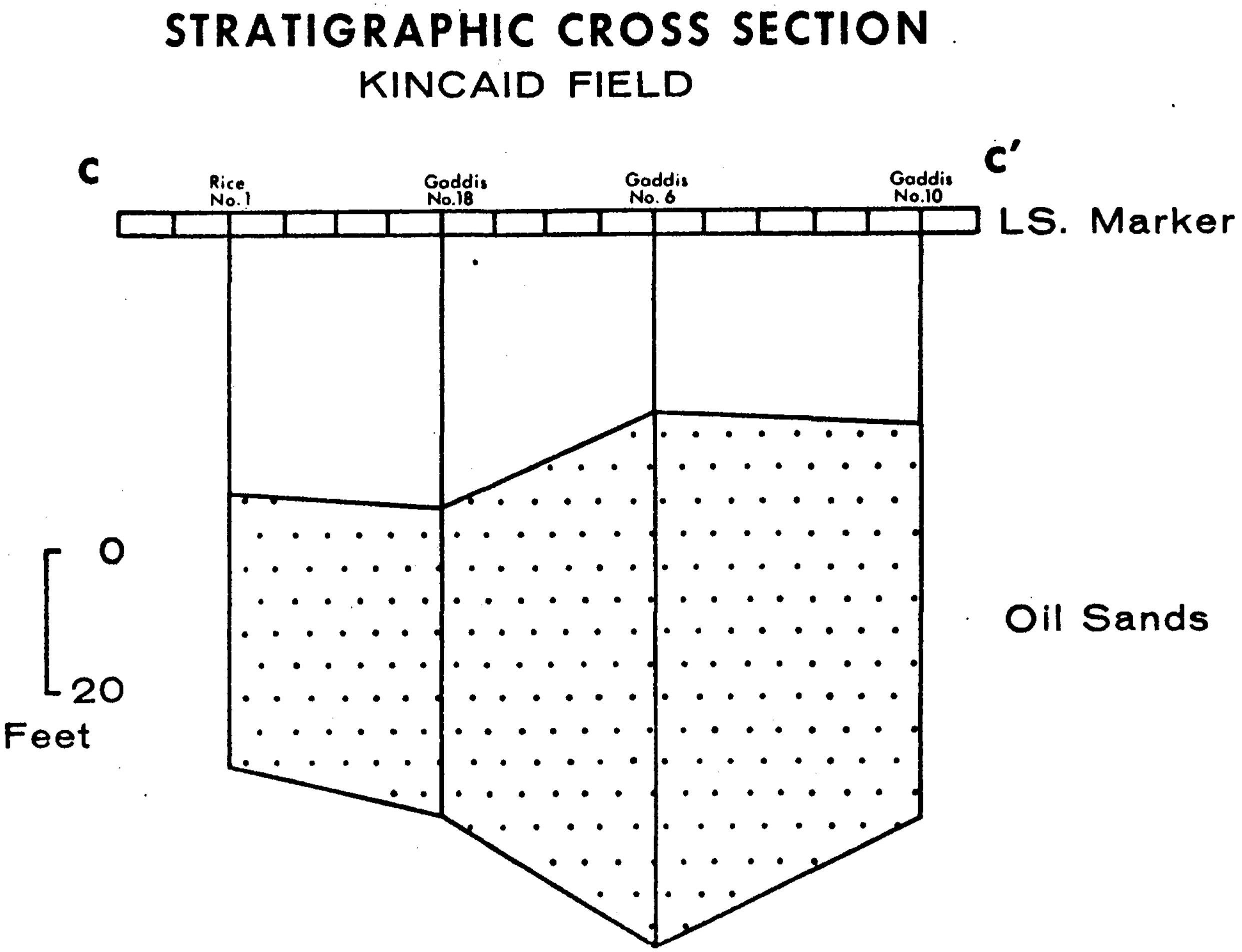
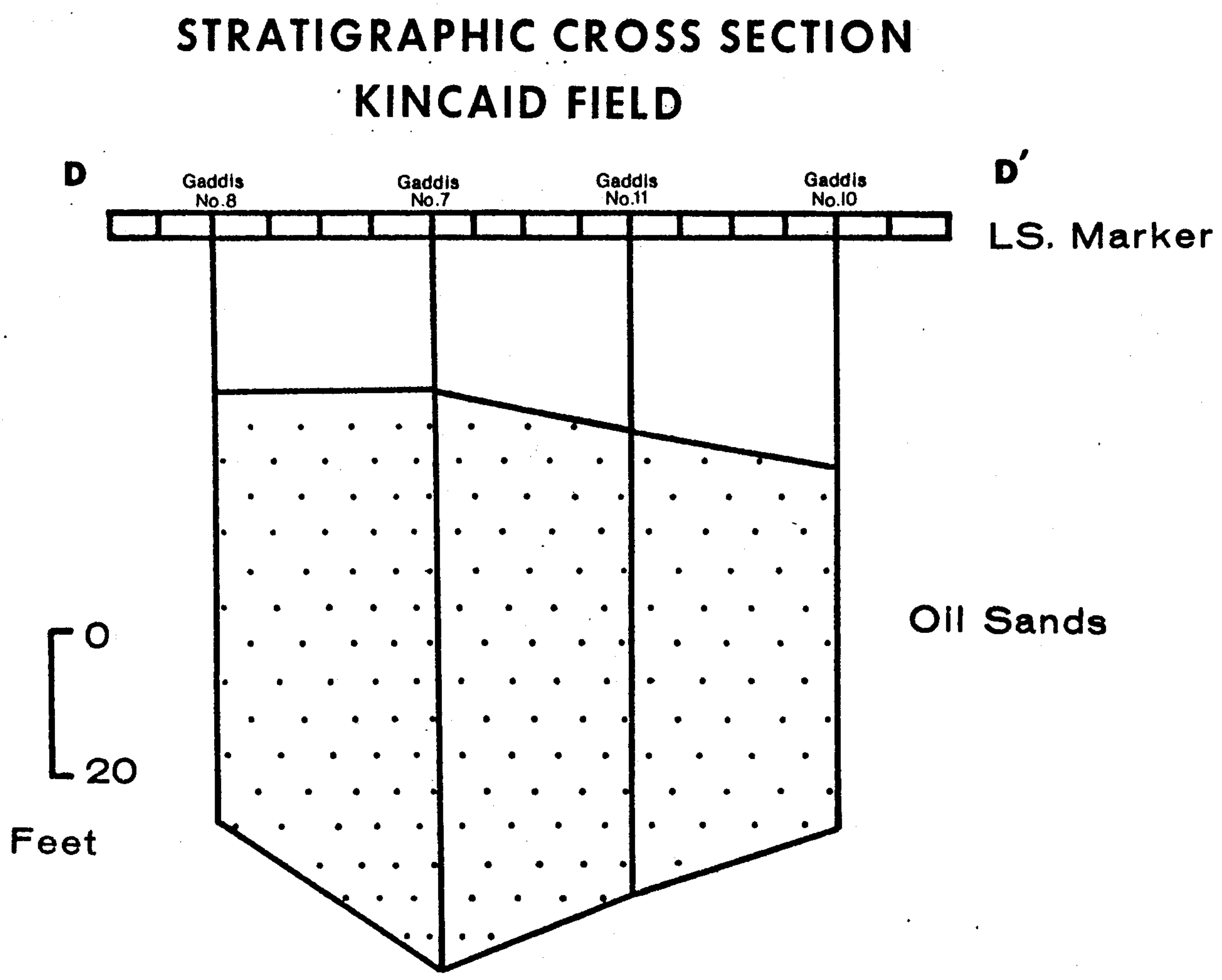


Figure 7A. - Stratigraphic cross section of the Kincaid Oil Field along line C-C' (Verdigris Limestone used as datum line).



STRATIGRAPHIC CROSS SECTION
KINCAID FIELD

Figure 7B. - Stratigraphic cross section of the Kincaid Oil Field along line D-D' (Verdigris Limestone used as datum line).

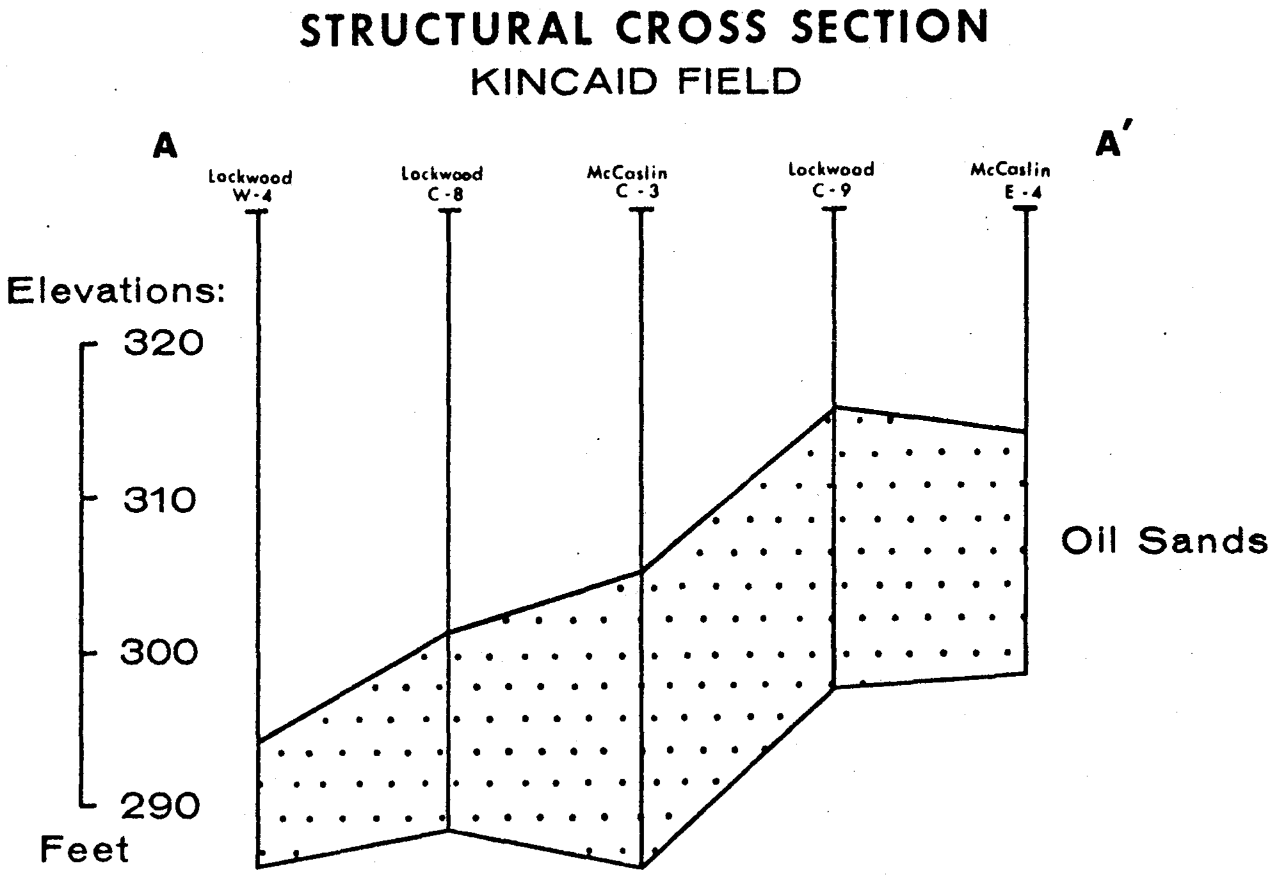


Figure 8A. - Structural cross section of the Kincaid Oil Field along line A-A' (elevations used as datum).

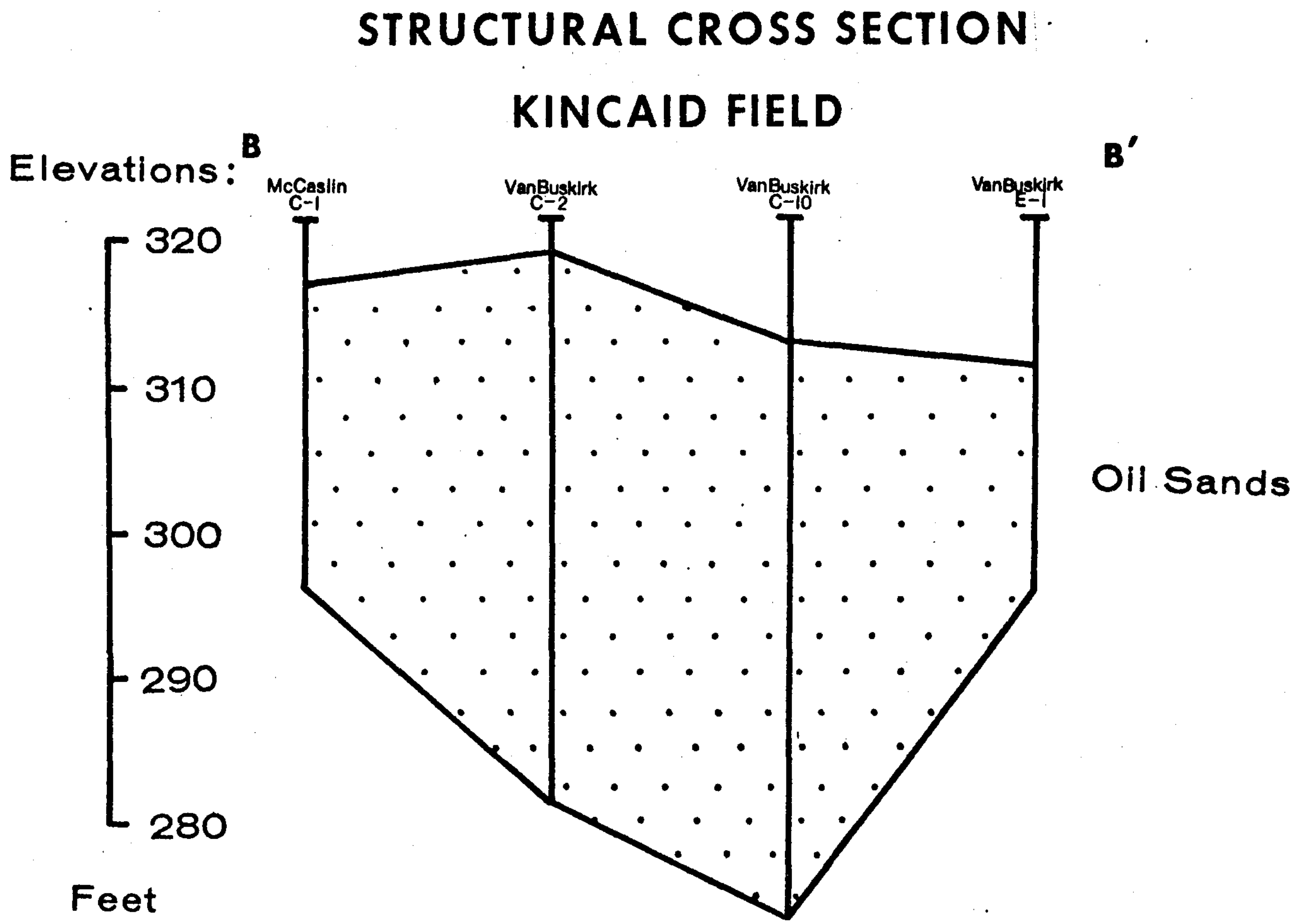


Figure 8B. - Structural cross section of the Kincaid Oil Field along line B-B' (elevations used as datum).

ferential compaction of the sandstone and the enveloping shales. The surrounding shales, are compacted more than the sand body. This compaction causes the thinner outer margins of the sand body to be forced downward more than the thick main sand body. The same effect is shown in draping of the Verdigris and Fort Scott Limestones over the sand body (Figure 11). Also shown in the structural cross sections is a slight tilting of the strata to the west as a result of regional uplift to the east of the study area.

Shape of the Sandstone Body

An isopach map of the interval from the Verdigris Limestone marker bed to the base of the sandstone was constructed to show the orientation of the sand body soon after deposition (Figure 9). The same assumptions made in drawing the stratigraphic cross sections apply also to the drawing of the isopach map.

The isopach map shows a thickening toward the center of the field and an abrupt thinning of the sand near the edges. The exact lateral extent of the sandstone body cannot be determined because of a lack of well control. Dry holes surround the main producing sandstone; however, there is no data for these wells. The presence of a dry hole does not mean that there is an absence of sand in those wells.

A structural contour map of the base of the sandstone body was constructed to show its present attitude (Figure 10). The basal structure of the sandstone may then be

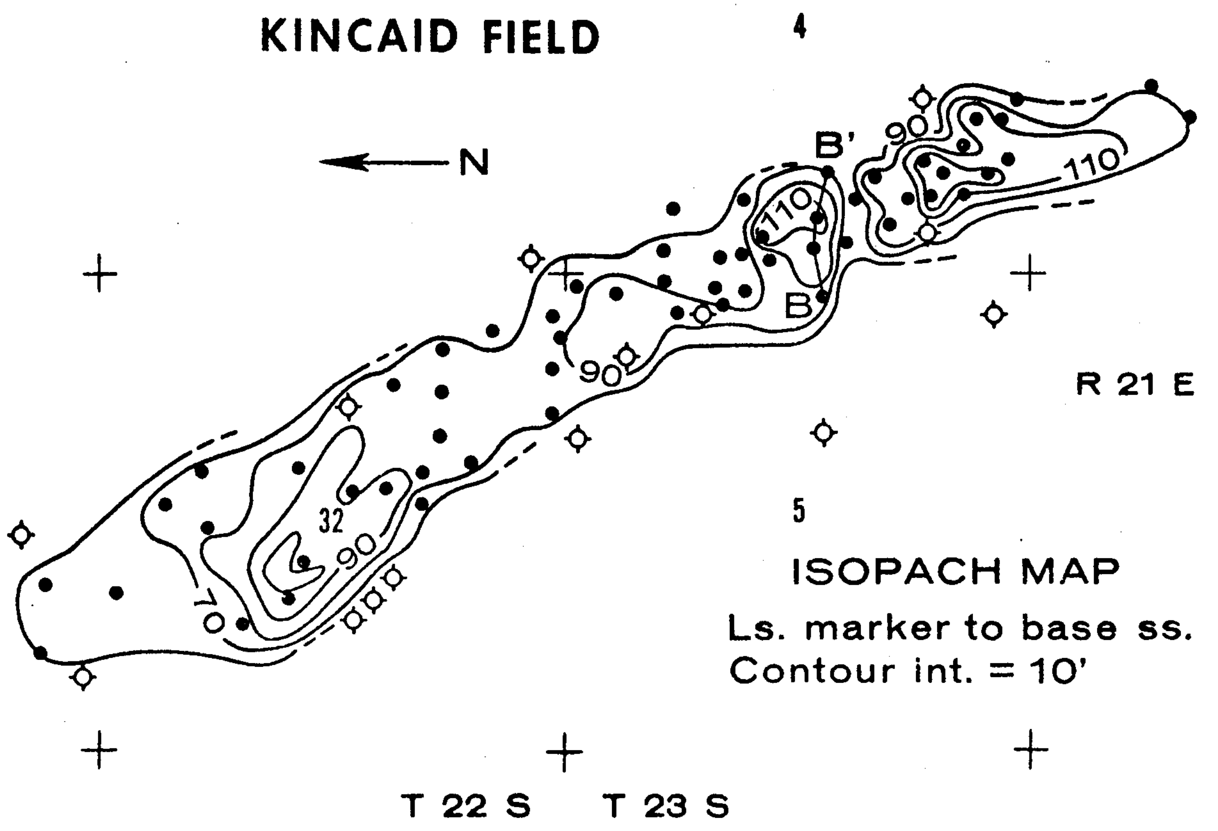


Figure 9. - Isopach map of the interval from the Verdigris Limestone to the base of the Skinner Sandstone in the Kincaid Oil Field.

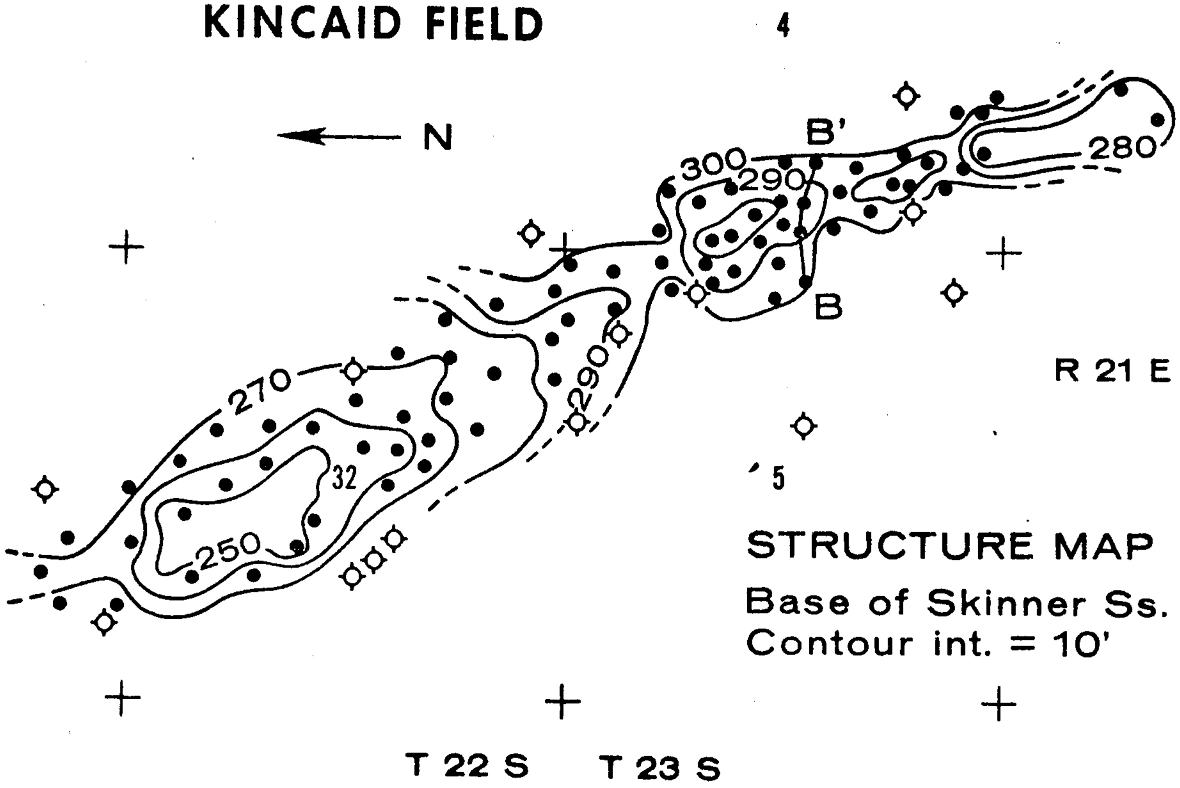


Figure 10. - Structural contour map of the base of the Skinner Sandstone in the Kincaid Oil Field (elevations are above sea level).

compared to modern sand bodies for environmental interpretations. This structure map shows the same general shape of the sandstone body as the isopach map; that is, the base of the sandstone body is canoe-like in form. However, the present attitude of the sandstone has been changed by minor folding and regional tilting. These minor structural highs and lows depicted may have been produced by differential compaction of the underlying Cherokee shales over irregularities on the eroded Mississippian Limestone surface. Another possible explanation is that of minor compressional folding causing the shoestring sands to bend upwards in local areas also producing hydrocarbon traps.

A structural contour map of the base of the Verdigris Limestone (Verdigris marker bed), was constructed to show the effect of its draping over the sandstone body (Figure 11). This draping is the result of differential compaction of the shales which surround the sandstone body.

Petrography

Results of point counts of five thin sections (200 counts per section) are shown in Table 1. Figure 12 is a histogram showing the average composition of the sandstone. The five sandstone samples were taken from the producing sand of one well at evenly spaced intervals and demonstrate vertical changes in composition of the sand body. Locations of samples are shown in the lithologic column of the well, Miller "B" No. W-12, in Appendix I.

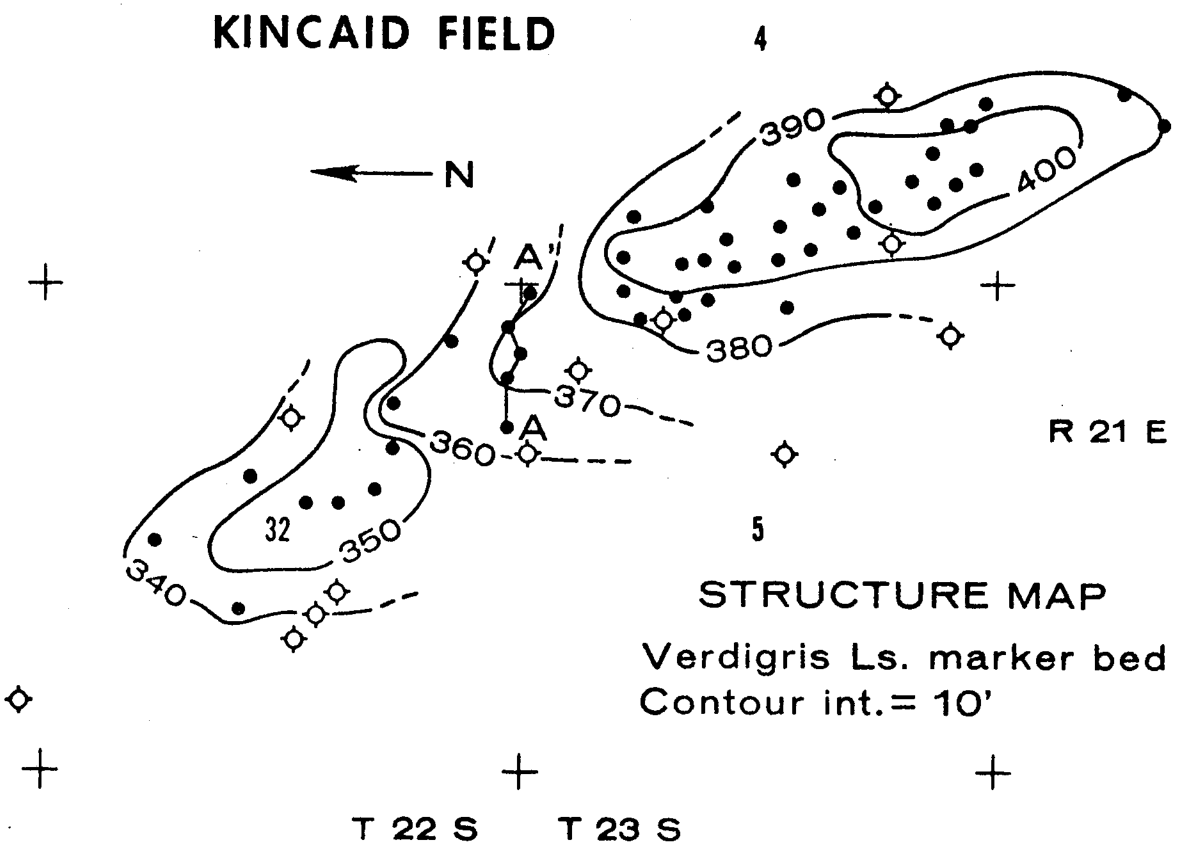


Figure 11. - Structural contour map of the Verdigris Limestone marker bed (elevations are above sea level).

Constituent	% of total rock volume Samples W12A	 W12B	 W12C	 W12D	 W12E
Monocrystalline quartz	37	31	42	36	38
Recrystallized metaquartz	1	1	1	6	0
Schistose metaquartz	3	0	0	0	0
Stretched quartz	1	0	0	0	0
Quartz overgrowth	10	9	9	6	8
Schist metamorphic rock fragment	8	23	11	6	8
Phyllite metamorphic rock fragment	0	0	2	8	5
Muscovite	3	1	1	1	2
Chlorite	0	1	1	0	0
Plagioclase	0	0	0	1	1
K-feldspar	5	1	4	2	2
Detrital opaques	0	3	0	0	0
Authigenic opaques	1	0	2	0	4
Siderite	1	0	0	1	0
Kaolinite	1	0	0	1	0
Calcite grain	1	0	0	0	0
Calcite cement	1	1	0	0	0
Organic matter	0	0	0	4	14
Pore space	18	22	20	14	3
Unidentifiable	9	7	7	14	15

Table 1. - Constituent composition of the five sandstone samples from well Miller "B" W-12 estimated from point counts of thin sections of impregnated rock.

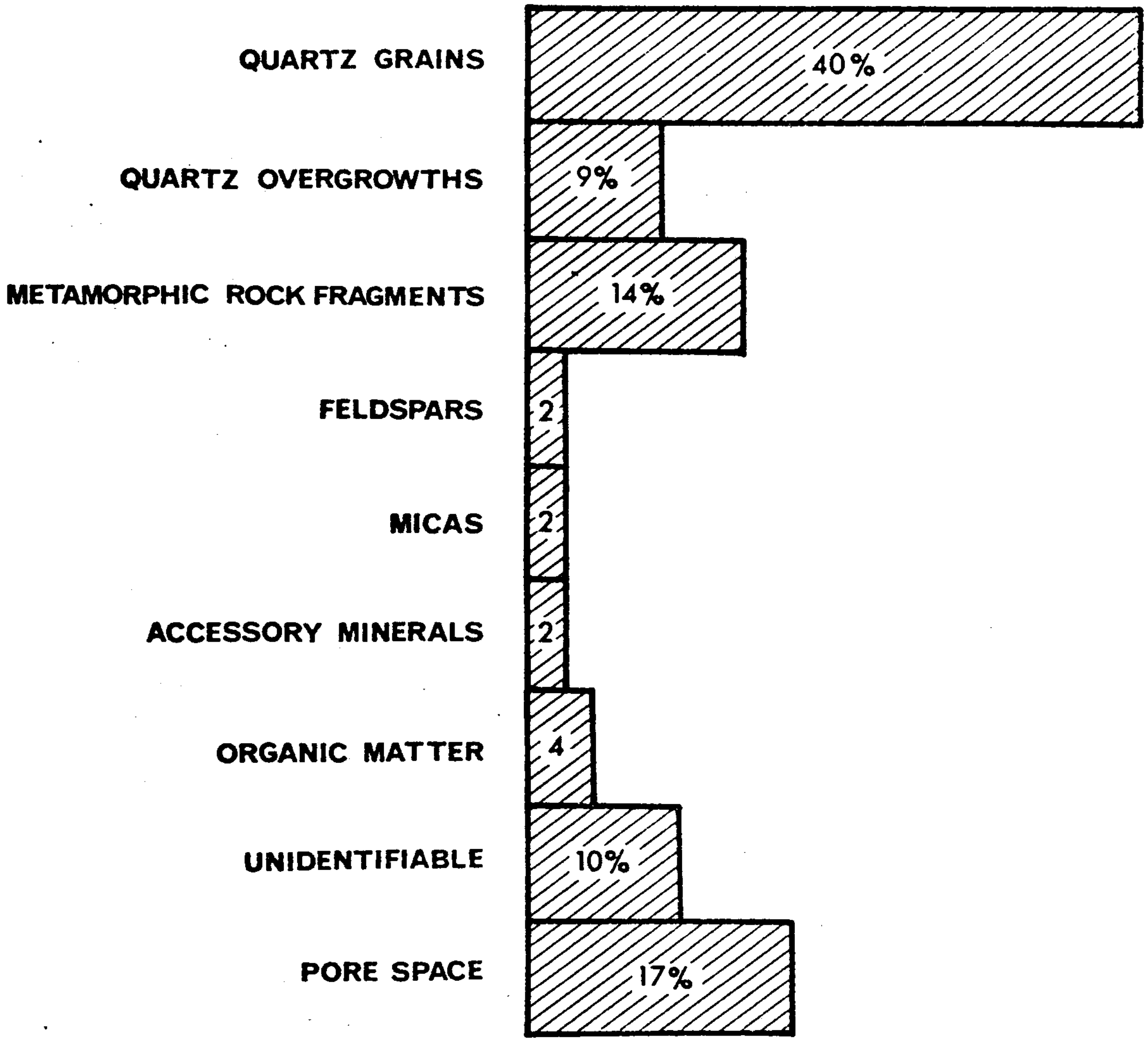


Figure 12. - Average composition of the sandstone in well Miller "B", W-12, from point-counts of five thin sections (see Table 1).

Mineralogy

Mineralogical characteristics of the sandstone were determined by studying approximately 50 thin sections, petrographically.

Quartz - Quartz is the dominant mineral found in the sandstone. It comprises an average of 57% of the detrital fraction of the rock and 40% of the total volume. It occurs most commonly as monocrystalline grains, but also as polycrystalline quartz (recrystallized metaquartz), "stretched" quartz, and schistose quartz. Relative amounts of each type of quartz are shown in Table 1. Monocrystalline quartz (about 52% of the detrital fraction) is generally interpreted as igneous or common quartz derived from granites. The common monocrystalline quartz grain with slightly undulose extinction is non-diagnostic of the origin of the grain, although most originate from either a granitic or a gneissic source rock (E. F. McBride, 1975, personal communication). Recrystallized metaquartz grains characteristically are derived from metamorphic rocks, as are the stretched and the schistose types. Most of the monocrystalline quartz grains in the sandstone studied probably are derived from a metamorphic source. The sandstone is well sorted; however, this may be the result of a source rock which produced similar sized grains rather than a hydrodynamic sorting. Almost all of the quartz grains have moderate to strong undulatory extinction, which is generally not indicative of the type of source rock. Original roundness (before formation of quartz overgrowths) is very difficult to determine, because the original grain boundaries are difficult to see. Ordinarily, a luminoscope is a valuable tool in determining original grain shape and roundness by distinguishing secondary (overgrowth) from primary quartz in the grains (Sipple, 1968; Long and Agrell, 1965; Smith and Stenstrom, 1965). In many instances, the original quartz grain will l~~i~~uminesce when subjected to electron bombardment, while the secondary quartz overgrowth will not; but, in the sandstone studied here, the grains do not l~~i~~uminesce at all. Consequently, no original grain boundary can be seen.

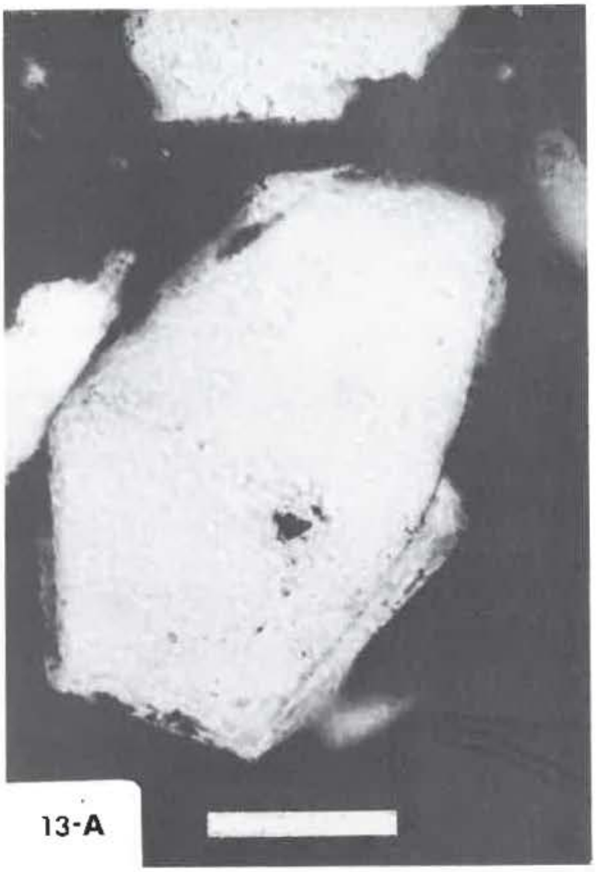
Rarely, the overgrowth on a quartz grain is distinguishable from the original grain by the roughened or etched surface of the original grain (Figure 13). In these cases, the original shape varies from angular to subrounded. Most quartz grains are nearly spherical; however, about 5% of the quartz grains are very elongate and tabular in shape (Figure 14). The average grain size of quartz in the sandstone is approximately .1 to .2 mm (fine to very fine sand-size). Because of the extensive quartz overgrowths, however, original grain size can only be approximated. Inclusions within the quartz grains are very common and occur as either mineral inclusions or gas (vacuole) inclusions (Figure 15). Common mineral inclusions are apatite (Figure 16), zircon, and rutile needles.

Figure 13 A. - Quartz grain with euhedral overgrowth (x-nicols; 500 x); scale = .05 mm.

13 B. - Quartz grain with subhedral overgrowth (x-nicols; 500 x); scale = .05 mm.

13 C. - Quartz grains with overgrowths forming a mosaic (x-nicols; 200 x); scale = .1 mm.

Figure 14. - Elongate quartz grain (x-nicols; 200 x); scale = .1 mm.



13-A

13-B

13-C

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Polycrystalline quartz (recrystallized metaquartz), stretched quartz, and schistose quartz each make up about 3% of the quartz grains in the rock. Polycrystalline quartz has equant interlocking grains with straight boundaries forming a mosaic (Figure 17). The stretched quartz, also polycrystalline, has elongate crystals with crennulated boundaries. The schistose quartz is similar to stretched quartz but has straight boundaries and mica inclusions. The various types of quartz are well described by Folk (1968). Chert, though present in tract amount, was not included in the point count.

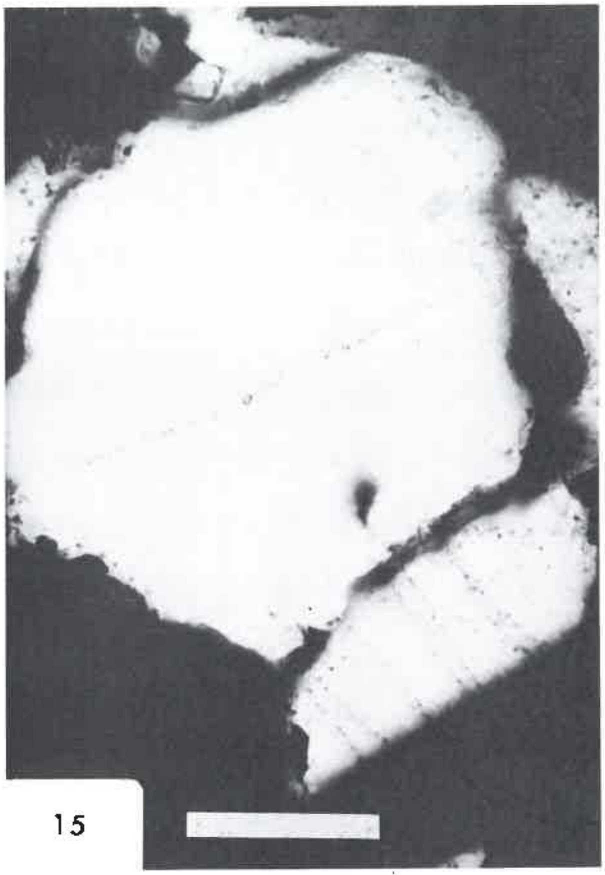
Metamorphic rock fragments - Metamorphic rock fragments make up about 20% of the detrital fraction of the sandstone. Of that percentage, about 75% is schist (Figure 18) and 25% is phyllite. Parallel orientation of the micas and quartz crystals are characteristic of these grains. These grains are slightly to moderately altered and most are rounded and elongate. The average grain size is slightly larger than that of the host grains. Because of their relative softness, the metamorphic rock fragments sometimes are squeezed between surrounding quartz grains during compaction of the rock to form a pseudomatrix. This type of fragment is tabulated here as a metamorphic rock fragment and not as part of the matrix of the rock.

Figure 15. - Quartz grains with vacuole inclusions (x-nicols; 500 x); scale = .05 mm.

Figure 16. - Quartz grain with an elongate apatite inclusion (x-nicols; 500 x); scale = .05 mm.

Figure 17. - Recrystallized metaquartz (polycrystalline); grain is circled by white line (x-nicols; 500 x); scale = .05 mm.

Figure 18. - Metamorphic rock fragment (probably schist); grain is circled by white line (x-nicols; 500 x); scale = .05 mm.



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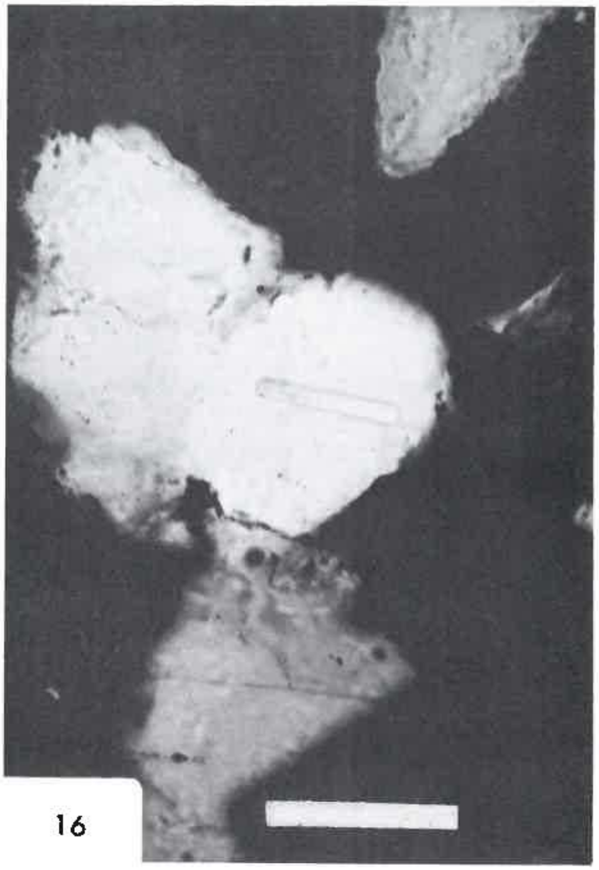

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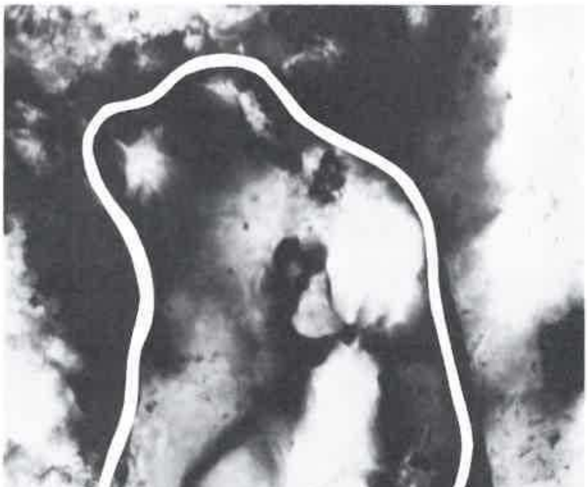

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Micas - Micas comprise about 3% of the detrital fraction of the sandstone. Muscovite is by far the most common mica found, and chlorite and biotite are rarely present. The most striking feature about the muscovite grains is their lath shape, with length commonly exceeding 2 mm, and width being less than .2 mm. Another characteristic of the micas is their orientation parallel to laminations or bedding planes within the sandstone. Most of the micas are fresh and angular without much alteration (Figure 19).

Feldspars - Feldspars comprise about 4% of the detrital fraction of the samples studied. Of that, 3% is K-feldspar (Figure 20), and 1% is plagioclase (Figure 21). Both types occur as angular, blocky, slightly to moderately altered grains. The average grain size (.2 to .25 mm) is slightly larger than that of the quartz grains. Most of the plagioclase seen was only slightly altered and was identified petrographically as oligoclase. No K-feldspar displaying microcline twinning occurs in the samples examined. There are a few grains of polycrystalline feldspar, but these are less than 1% of the total sample.

Accessory minerals - Opaques, and accessory non-opaques such as apatite, zircon, and tourmaline, constitute about 1% of the total minerals point counted in the thin sections. Apatite and zircon are also present as inclusions within quartz grains. Detrital and authigenic opaques are also a very minor percentage of the sandstone. Pyrite is the most common opaque mineral, occurring both as a detrital and as a subhedral or euhedral authigenic mineral.

<u>Clay minerals</u> - Clay minerals (kaolinite and chlorite) make up about 1% of the sample, occurring as both detrital and authigenic minerals. The kaolinite (Figure 22) occurs as slightly vermicular "books" or angular blocks and is commonly stained by a brown organic (?) material. It forms an authigenic pore filling, and also occurs as a detrital mineral. Authigenic kaolinite is recognized as a pore filling while the detrital kaolinite has the shape of clastic grains. According to E. F. McBride (personal communication, 1975), the detrital kaolinite may be an alteration product of feldspar.

An x-ray study of the clay minerals in a sandstone of similar age and origin as that studied here was made by McQuillan (1968). He found kaolinite to be the most abundant clay mineral, with lesser amounts of chlorite and illite.

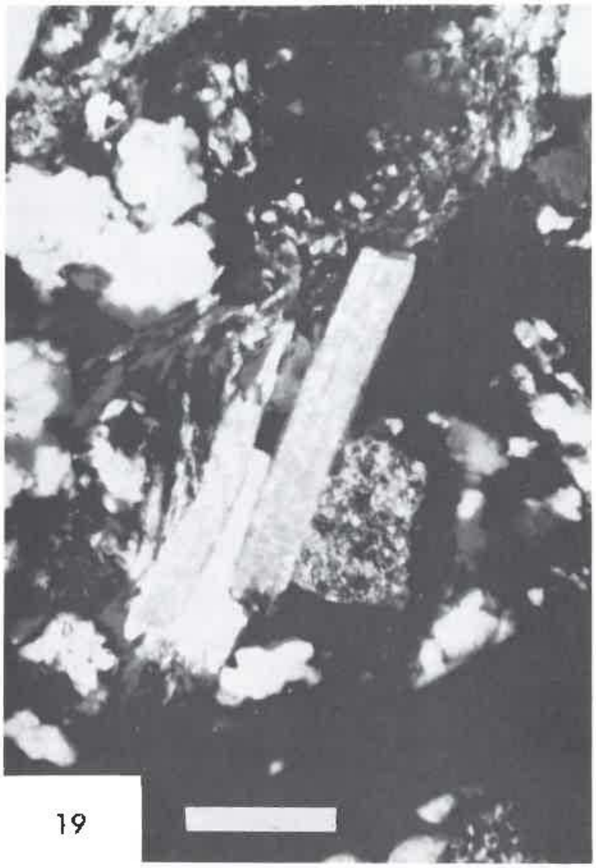
<u>Matrix</u> - If the rocks examined in thin-section ever included real matrix material, it must have made up less than 1% of the rocks. The rock samples sectioned, however, were purposely chosen from intervals of clay-free sandstone, and are therefore not representative of the entire sandstone. Actually, the sandstone contains much clay matrix, espe-

Figure 19. - Elongate muscovite grain (x-nicols; 200x); scale = .1 mm.

Figure 20. - K-feldspar grain (slightly altered)(x-nicols; 500x); scale = .05 mm.

Figure 21. - Plagioclase feldspar grain with albite twinning (x-nicols; 500x); scale = .05 mm.

Figure 22. - Kaolinite (slightly vermicular), occurring as an authigenic pore filling (unx-nicols; 500x); scale = .05 mm.



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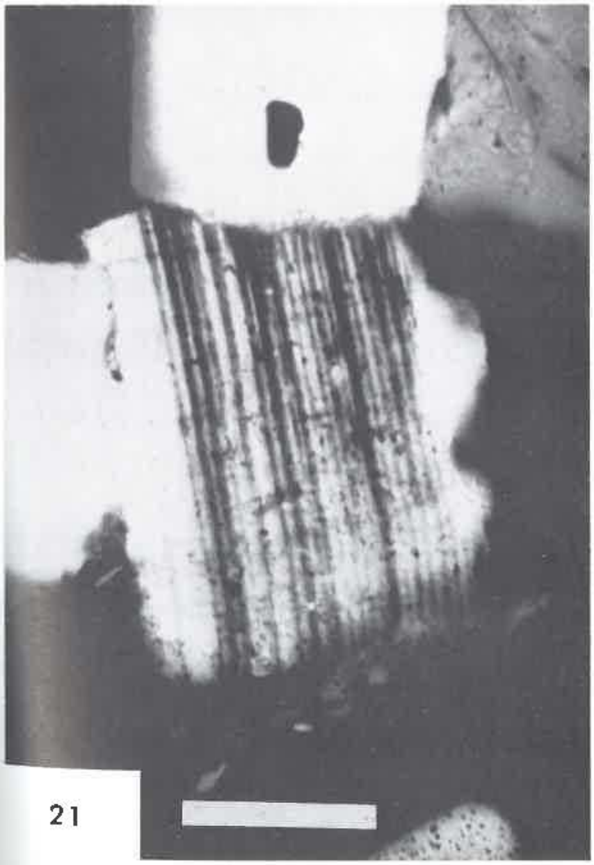

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cially near the margins of the field and in the upper silty zone (discussed below). Although no matrix was positively identified, a considerable amount of pseudomatrix was noted and counted as part of the metamorphic rock fragments. The pseudomatrix consists of compacted metamorphic rock fragments, squeezed between much harder quartz grains.

Quartz overgrowths - Quartz overgrowths (Figure 13) are the main cement in these rocks, forming a tight mosaic of grain boundaries. They comprise about 9% of the total volume of the rock and about 20% of the total amount of quartz in the sandstone. These percentages can be only approximated, however, because of the difficulty in distinguishing the secondary overgrowths from the original quartz grains.

Calcite - Calcite occurs as cement and amounts to only about 1% of the total volume of the rock. It occurs scattered throughout the thin sections. Calcite replacement of feldspar grains also occurs rarely, as shown by some of the feldspars being partially "consumed" or altered by the calcite.

Siderite - Siderite is an important cementing agent only in the conglomeratic beds (Figure 31). In other parts of the sandstone the siderite forms thin bands or layers (less than 1 inch thick), and also occurs as concretions and pebbles.

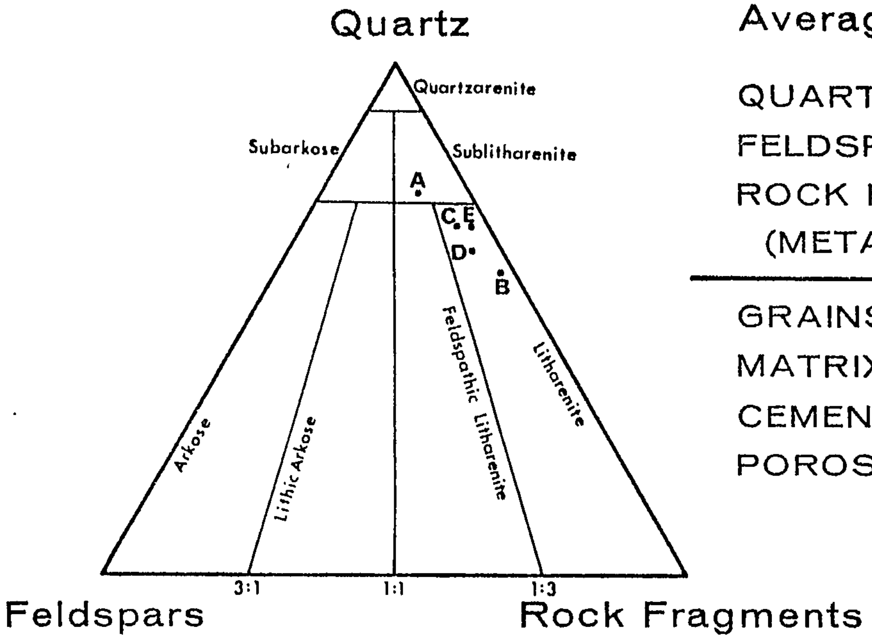
Organic material - Organic material, probably carbonized plant debris, occurs throughout the sandstone body as brown stringers and partings, commonly along laminations or bedding planes. It is not common in the middle and top of the sand body, but near the base of the sand organic matter makes up about 10 to 15% of the total volume of the samples. Organic matter was not confused with oil in thin section since the oil had been extracted from the sandstone samples before sectioning.

Classification of the Sandstone

A clear method of describing a specific sandstone and its constitutents is by using the symbols F M C P : Q F R, representing: Framework, Matrix, Cement, Porosity: Quartz, Feldspar, and Rock fragments, respectively (McBride, personal communication, 1975). Each symbol is followed by a percentage, with F + M + C + P = 100%, and Q + F + R = 100%. In the Kincaid Field the average sandstone composition is $F_{70}M_{2}C_{10}P_{18}:Q_{70}F_{5}R_{25}$.

Using a widely accepted sandstone classification such as Folk's (1968) ternary diagram (Figure 23), this sandstone plots in the area of the litharenite or sublitharenite classes. The sandstone has a submature texture, comprising fairly well-sorted subangular grains with some clay matrix (approximately 5-10% of the sandstone).

MINERALOGY



Averages:

QUARTZ	=75%
FELDSPARS	=5%
ROCK FRAGMENTS (METAMORPHIC)	=20%

GRAINS	=65%
MATRIX	=5%
CEMENT	=10%
POROSITY	=20%

Figure 23. - Folk's (1968) ternary sandstone classification with five sandstone samples from Kincaid Field plotted.

Petrophysics

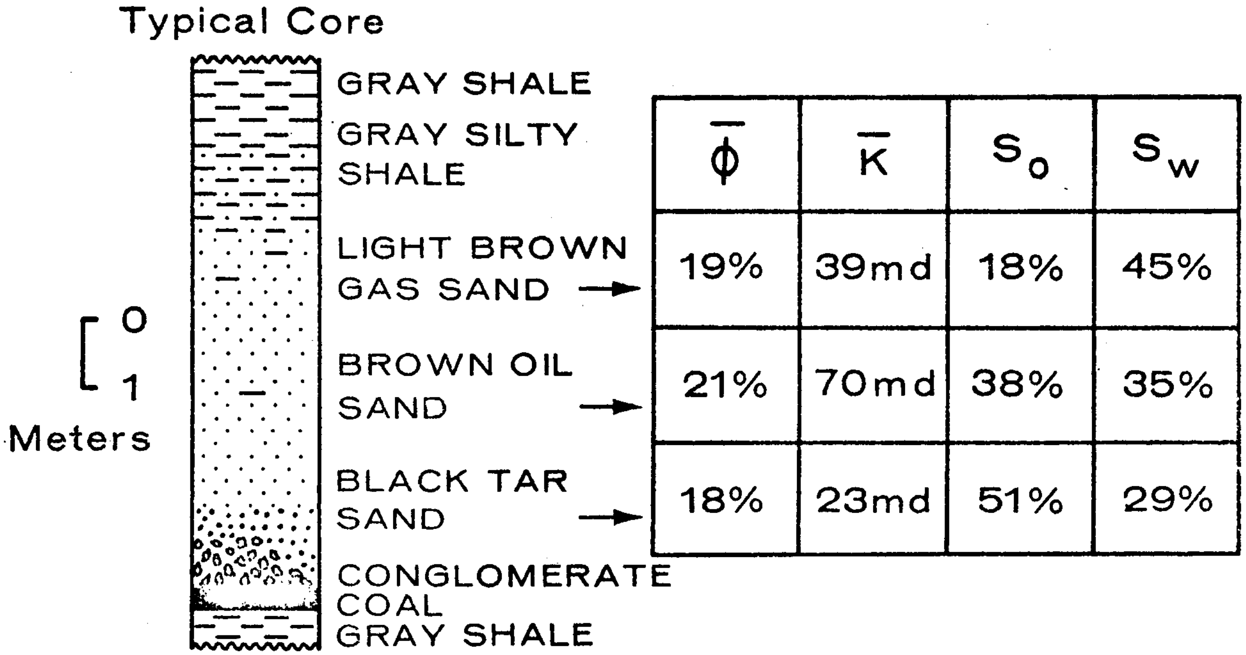
The reservo~~u~~ir rock of the Kincaid Oil Field is a fine-grained sandstone with average porosity (from core analyses) of about 19% (Figure 24). Diagenesis has altered the original porosity of the rock in several ways. Secondary quartz overgrowths, which cement the sandstone, have reduced the porosity considerably. Other minor factors, including compaction, interstitial authigenic clays and organic matter, have also reduced the original porosity of the rock.

The average permeability of the oil-bearing sands is about 70 millidarcies, but it varies quite drastically throughout the reservoir, with no pattern. Most of the variability in permeability is caused by shale inclusions and laminations within the sandstone. Mapping zones of high and low permeability would be extremely difficult because of their unpredictability but may be aided by recognition of the environment of deposition of the sandstone. However, in the Kincaid Field no permeability patterns were seen within the sandstone. Figure 2~~7~~4 shows a typical analysis of cores from the producing sand zone in the Kincaid Field.

Sedimentary Structures

Cores from thirteen wells in the Kincaid Oil Field were used for description and interpreation of the reservoir rock. The cores were logged and sampled, but, because most are cable tool cores, and pieces were missing or disoriented, it was often difficult to see complete vertical

RESERVOIR PROPERTIES
KINCAID OIL FIELD



$\bar{\phi}$	$\bar{K}$	S_o	S_w
19%	39md	18%	45%
21%	70md	38%	35%
18%	23md	51%	29%

Figure 24. - Typical core description of the sand zone in the Kincaid Oil Field with corresponding average reservoir properties from core analyses.

sections and sedimentary structures. Even with these limitations, however, the thorough study of cores has been of great value. Logs of all cores examined are included as Appendix I.

The cores from the Kincaid Oil Field generally include a single sandstone body, which sometimes is interrupted by a thin shale layer or shaley sand segment in the middle (Figure 25). The sand body is not very homogeneous, having silty and shaley zones throughout; but these are most numerous in the upper part of the sand unit. The sandstone body is enveloped in shale with a sharp basal contact and a gradational, alternating upper contact. The main sandstone body from which oil is produced is beneath the upper zones of interfingering siltstones and shales. This upper zone is generally gray in color in contrast with the underlying brown, oil-saturated sandstone. The sharp basal contact of the sand body overlies either shale or coal, and in several wells near the center of the field conglomerate occurs at the base of the sand zone.

Grain-size of the sandstone itself decreases upward, from the basal conglomerate to medium and fine-grained sand, then to the interfingering siltstones and shales, and finally to the overlying shales. This upward decrease in grain size reflects an overall decrease in the energy of the sand-transporting medium. That is, high energy conditions are necessary to channel out underlying sediments and to deposit a conglomerate; a subsequent decrease in energy will allow

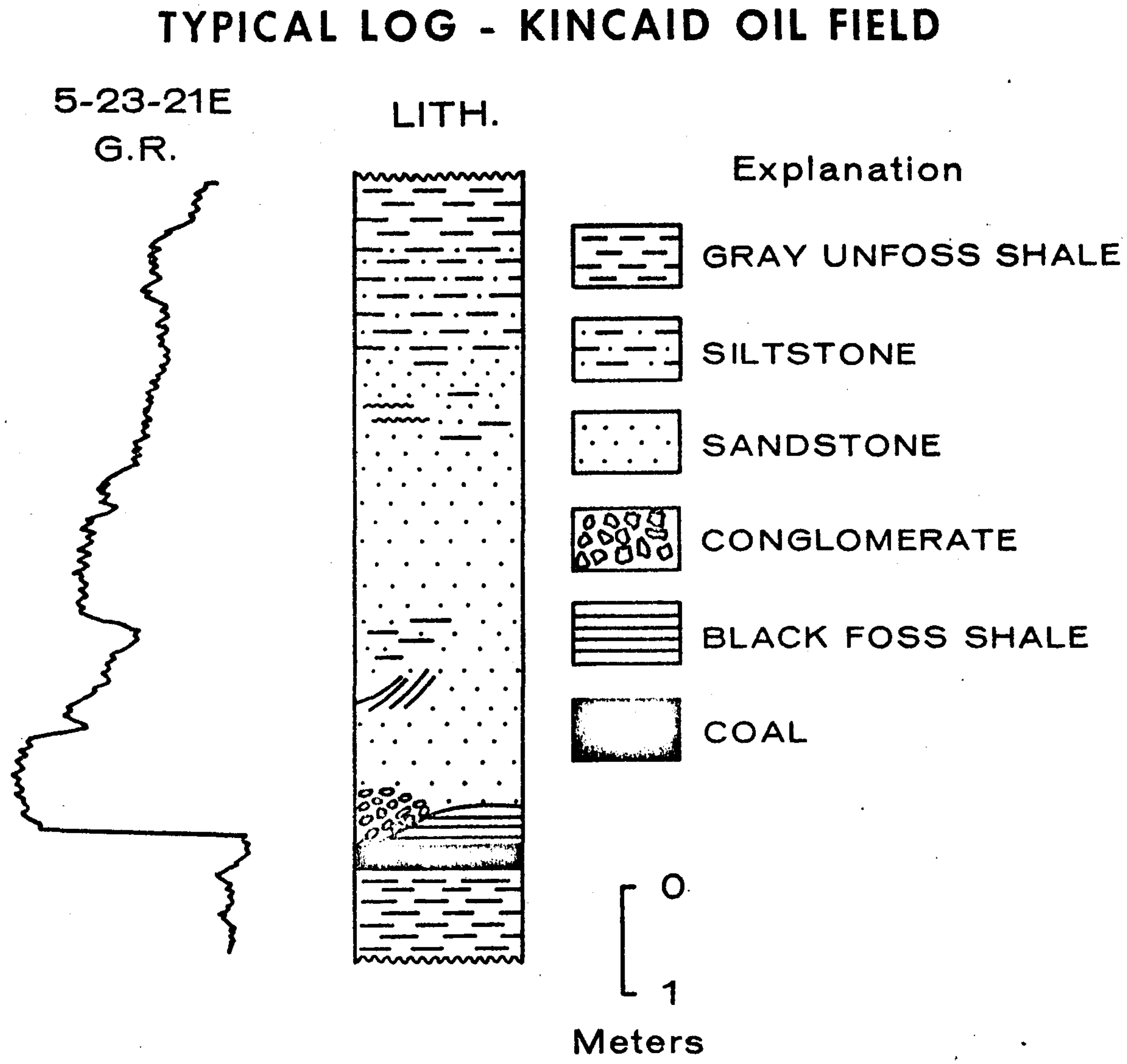


Figure 25. - Typical log of the producing interval of the Kincaid Oil Field.

finer grained sediments to be deposited above the conglomerate. This type of vertical sequence is common in the cores of the sandstone zone of the Kincaid Field.

Sedimentary structures in the thick sands above the conglomerate layer include low to medium angle cross-bedding (up to 15-20° dip) (Figure 26) grading upward into horizontal laminae (Figure 27). These structures would be deposited in energy conditions somewhere in the lower upper or upper lower flow regime (McKee, 1957). Above this zone is a fine-grained, ripple-laminated zone. These current ripples (Figure 28) originate in lower flow regime conditions. At the top of the sequence is a zone of siltstones and mudstones which are generally parallel laminated and sometimes intermixed with current ripples of sand which sometimes resemble flaser bedding.

In summary, the sequence of structures in the Kincaid Oil Field cores consists, from the base upward, of:

1) a basal conglomerate;
2) a lower zone of massive, laminated sand;
3) a zone of current-laminated and current-ripple cross bedded sand;
4) an upper zone of interlaminated silts and clays.

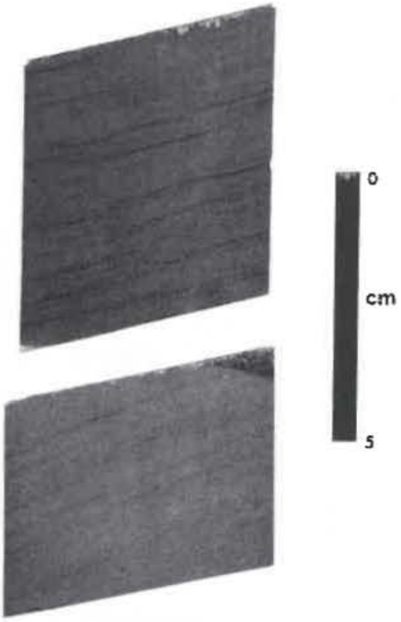
Coal and shale pebbles are common throughout the sandstone sequence; and organic debris deposited with the sand accentuates the bedding structures, especially in the lower sands. Other structures in the sand zone are small scale compaction faults (soft sediment deformation), disturbed and

Figure 26. - Sandstone with inclined bedding shown by organic material along bedding planes.

Figure 27. - Parallel-laminated siltstone (light-gray) and shale (darker-gray).

Figure 28. - Current-rippled sandstone.

Figure 29. - Shale and siderite clasts and siderite nodules in sandstone.



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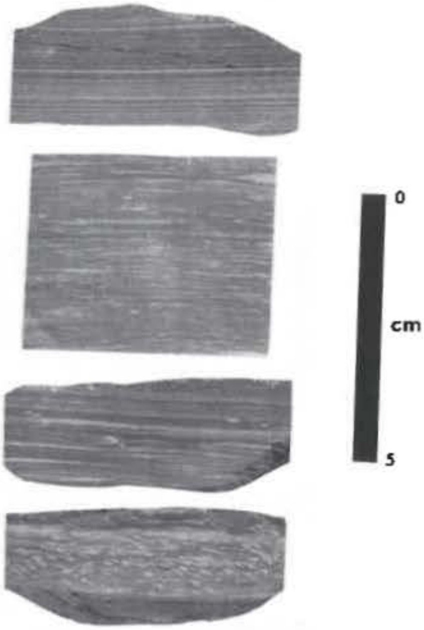

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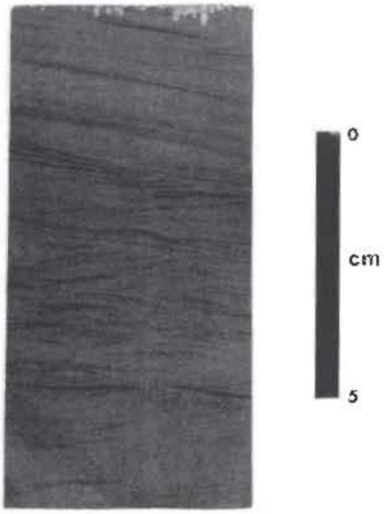

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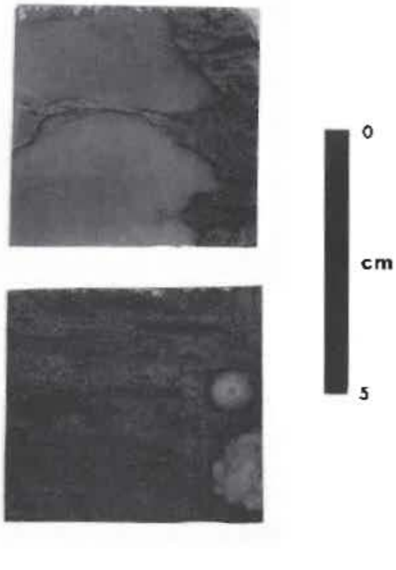

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contorted bedding (especially in the upper section), and shale clasts and carbonaceous debris (plant fragments) which are most common in the extreme lower sand and conglomerate. Organic burrow structures are conspicuously absent from these sediments. Conglomeratic layers occur at the base of the sandstone body in several wells in the Kincaid Field. The constituents of the conglomerate range in size from coarse sand (1 mm) to medium sized pebbles (15-20 mm). The conglomerate is composed of shale clasts, dolomite (Figure 31), limestone, and quartz pebbles (Figure 32), siderite (pebbles and concretions), coal fragments, and plant fossils (Figure 33). The constituents of the conglomerate were most likely derived from the surrounding Cherokee Shales and the underlying coal and limestone beds.

Environment of Deposition

Cherokee Sandstones

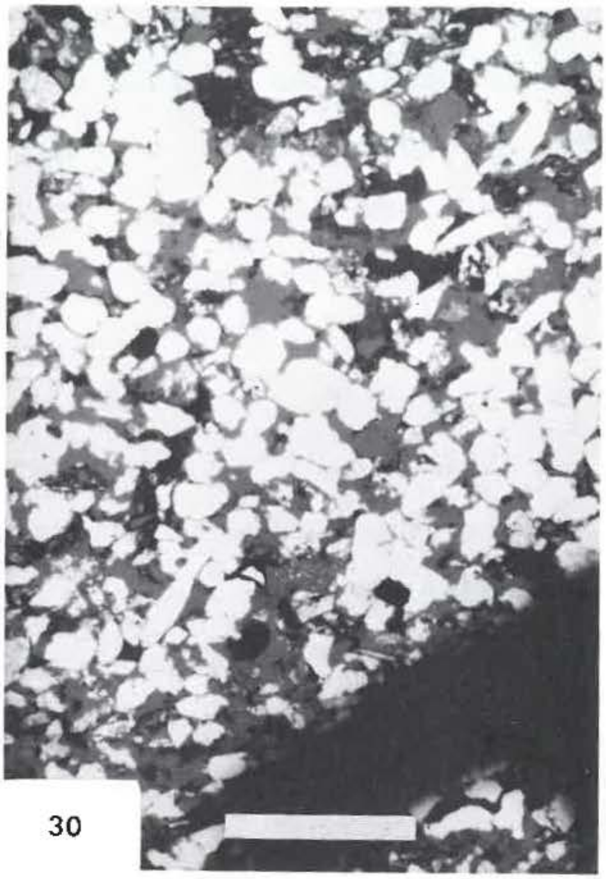
Interpretation of the depositional environment of a sandstone body requires determination of the composition, texture, sedimentary structures, and morphology of the unit. Each of these properties has been discussed in previous sections of this paper. Each property can be a significant indicator of sedimentary processes; however, they must be used in conjunction with one another. In this respect, some earlier studies of Cherokee sandstones have been deficient, as they failed to consider all aspects of the sandstone under study. In order to establish the conditions under

Figure 30. - Large field of view showing porosity (light-gray) and organic matter (black) (unx-nicols; 50x); scale = .5 mm.

Figure 31. - Dolomite pebbles cemented with siderite (black) (x-nicols; 50x); scale = .5 mm.

Figure 32. - Quartz pebble (x-nicols; 50x); scale = .5 mm.

Figure 33. - Plant fossils (carbonized) (unx-nicols; 50x); scale = .5 mm.



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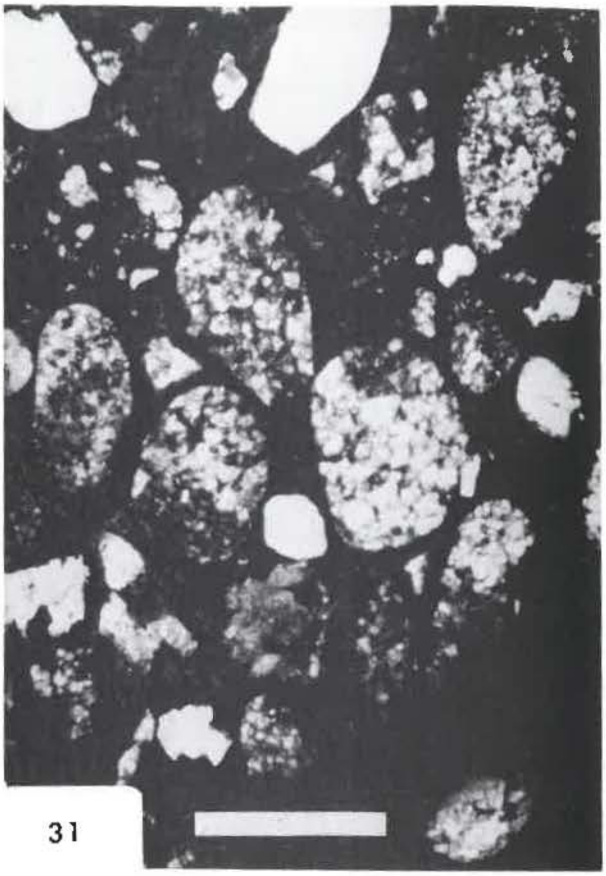

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which ancient sediments were deposited, it is also helpful to have a thorough knowledge of recent sedimentary processes and environments. Progress in recent years toward establishing models of sediment deposition has greatly improved our ability to analyze ancient deposits (Shelton, 1973).

Cherokee Sandstones throughout the Midcontinent have been variously interpreted as fluvial channels, deltaic distributary channels, tidal channels, and barrier islands. All of these interpretations may be correct, because during this time the Cherokee Basin and Platform was the site of shifting and prograding alluvial and deltaic plains and shallow marine shelf environments which may have been the sites of many different types of sand deposits. The Cherokee sandstones have very similar characteristics, in general. These sandstones contain mostly quartz and metamorphic rock fragments, with some feldspars and micas. This suggests a similar source for the sandstones. Most of the sands have paleocurrent indicators which suggest southward movement of transporting media, also supporting the idea of similar source areas. The sandstones are generally fine-grained, porous, carbonaceous, sideritic, and shaley; and they grade laterally into siltstones and shales. Most are also cemented by secondary quartz overgrowths. The general morphology of the sand bodies is alike, with discontinuous, lenticular lenses of sandstone enclosed in shales.

Many environmental studies of Cherokee sandstones have proposed a southward flowing river system and deltaic complex, prograding to the south. The Skinner Sandstone in northeastern Oklahoma (or a section of it) has been interpreted to be this type of deposit by Scott (1970). Farther south, in east-central Oklahoma, Valderrama (1974), Clements (1961), Clayton (1965), Berry (1963), and Hawisa (1965) have described a prograding deltaic complex in the Skinner Sandstone zone.

The Burbank (Red Fork) Sandstone is described by Hudson (1969) as being of fluvial origin in Kansas and deltaic in eastern Oklahoma. Other authors interpret the Burbank Sandstone to be offshore barrier islands, beach ridges, cheniers, and deltaic deposits in east-central Oklahoma (Wright, 1941; Withrow, 1968; Dillard, et al., 1941; Cruz, 1963; and Hawisa, 1965).

The Bartlesville Sandstone has been similarly interpreted as fluvial in Kansas and deltaic southward in Oklahoma (Visher, et al., 1971; Phares, 1969; Berg, 1963; Saitta, 1968; Hudson, 1969; and Johnson, 1973). However, there have been contradictory interpretations by Cadman (1927), Cheyney (1929), and Bass (1934) concerning the Bartlesville Sandstone in Greenwood County, Kansas. Cadman's conclusions were that the sands were fluvial, Cheyney declared that they were deltaic, and Bass has called the sands offshore bars.

Kincaid Oil Field

The reservoir sandstone of the Kincaid Oil Field is interpreted here as a fluvial channel deposit. Evidence to support this interpretation includes:

1) The isopach map (Figure 9) shows the sand body to be much thicker in its center than along its margins.

2) The sandstone body thins very abruptly laterally into interbedded siltstones and shales.

3) Wells on each side of the field have similar lithologies (interbedded siltstones and shales); i.e., there are no dissimilar facies on opposite sides of the sandstone, as would be expected in a barrier island sand deposit.

4) Cross sections (Figure 7) show that the body has a generally flat upper surface and a convex (canoe-shaped) lower surface.

5) Marine fossils or burrows are absent in both the sandstone and the surrounding siltstones and gray shales.

6) Glauconite and pyrite are absent in the sandstone.

7) Carbonaceous material (organic debris and terrestrial plant fragments including Calamites) is abundant, especially near the base of the sand body.

8) The sand body overlies a coal layer (approximately .2 to .4 meters thick), but in most wells located in the center of the field the coal is not present (probably having been eroded away).

9) Small-scale scour and fill structures are found in the siltstones and sandstones.

10) The lower contact of the sandstone with the underlying sediments (either shale or coal) is very sharp.

11) The upper contact of the sandstone is gradational and interfingers with siltstones and shales.

12) The electric log pattern of the sandstone generally shows an abrupt lower boundary and maximum deflection grading upward into an irregular serrated upper pattern. This represents a basal clean sand (with no shale), overlain by interbedded siltstones and shales at the top of the sand zone. This type of electric log pattern reflects an upward decrease in the energy of the depositional environment.

13) The vertical sequence of textures and structures in the sandstone zone indicates deposition in progressively weaker currents, substantiating evidence gained from the electric log patterns.

14) The sandstone is texturally submature (subangular grains and a considerable clay matrix in some parts) and mineralogically immature (high percentage of metamorphic rock fragments, micas and feldspars).

Comparison with Modern Environments

Modern alluvial deposits generally consist of relatively coarse-grained point bars that are built in stream channels by lateral sedimentary processes, and of finer-grained floodbasin deposits that accumulate by vertical sedimentary processes.

Channel Facies - Channel deposits are those laid down within the confines of the stream channel. They include: 1) channel-lag sediments deposited by high velocity stream currents, 2) point-bar deposits left by migrating meander belts, and 3) midchannel-bar deposits, which are more common in braided streams. Channel facies are commonly fine to medium-grained and immature with abundant clays, carbonaceous debris, and shale pebbles, especially in the lower few feet of the sandstone body. Common sedimentary structures include tabular and trough cross bedding, with current-ripple marks throughout. The basal contact of the channel deposit truncates strata of the underlying unit, and the upper contact is gradational into siltstones and shales of the overbank facies. The only fossils found are plant fragments and sparse fresh water bivalves and fish plates.

Overbank facies - Overbank (floodplain or floodbasin) deposits are laid down when the water overflows the banks of the channel. The two main types of overbank deposits are: 1) levee deposits composed of sediment dropped from suspension when floodwaters overtop the bank and decrease their velocity, dropping part of their load, and 2) floodbasin deposits composed of very fine-grained sediment (silts and clays) dropped by the stream after it has spread over the floodplain. Overbank sediments are composed of siltstones, musdstones, and shales with carbonaceous lenses and plant material. Bedding is generally very thinly laminated and parallel. The overbank facies commonly occurs interbedded with the channel sandstones, interfingering laterally. The only fossils are palnt material and rare burrows.

Relationships between flow conditions, bedforms, and sedimentary structures in ancient stream deposits are described by Simmons, et al., (1965), Allen (1965), Harms (1963, 1965), Visher (1965a, 1965b), Potter and Pettijohn (1963), and McKee (1957). Also used in environmental interpretation of clastic rock units is the vertical sequence of bedding units produced by certain sedimentary processes (Figure 34). Visher (1965a) stated that: "The profiles are indicators of a general historic development; and the interruptions, repetitions, and other variations reflect local and/or transient modifications of the idealized depositional sequence. Every stratum within the profile is interpretable, as an historic event, and deviations from the expected sequential pattern are important in the detailed historical reconstruction."

The basal conglomerate layer would represent a channel lag deposit in a modern stream, and the overlying massive and cross-bedded thick sand section would be the point-bar sands of a river deposit. Overlying and laterally from the thick sand deposit is an interfingering siltstone and shale zone which correlates with a modern fiver floodbasin deposit of silts and clays. These fine grained sediments are generally deposited in parallel laminations and are undisturbed by any burrowing or stream currents.

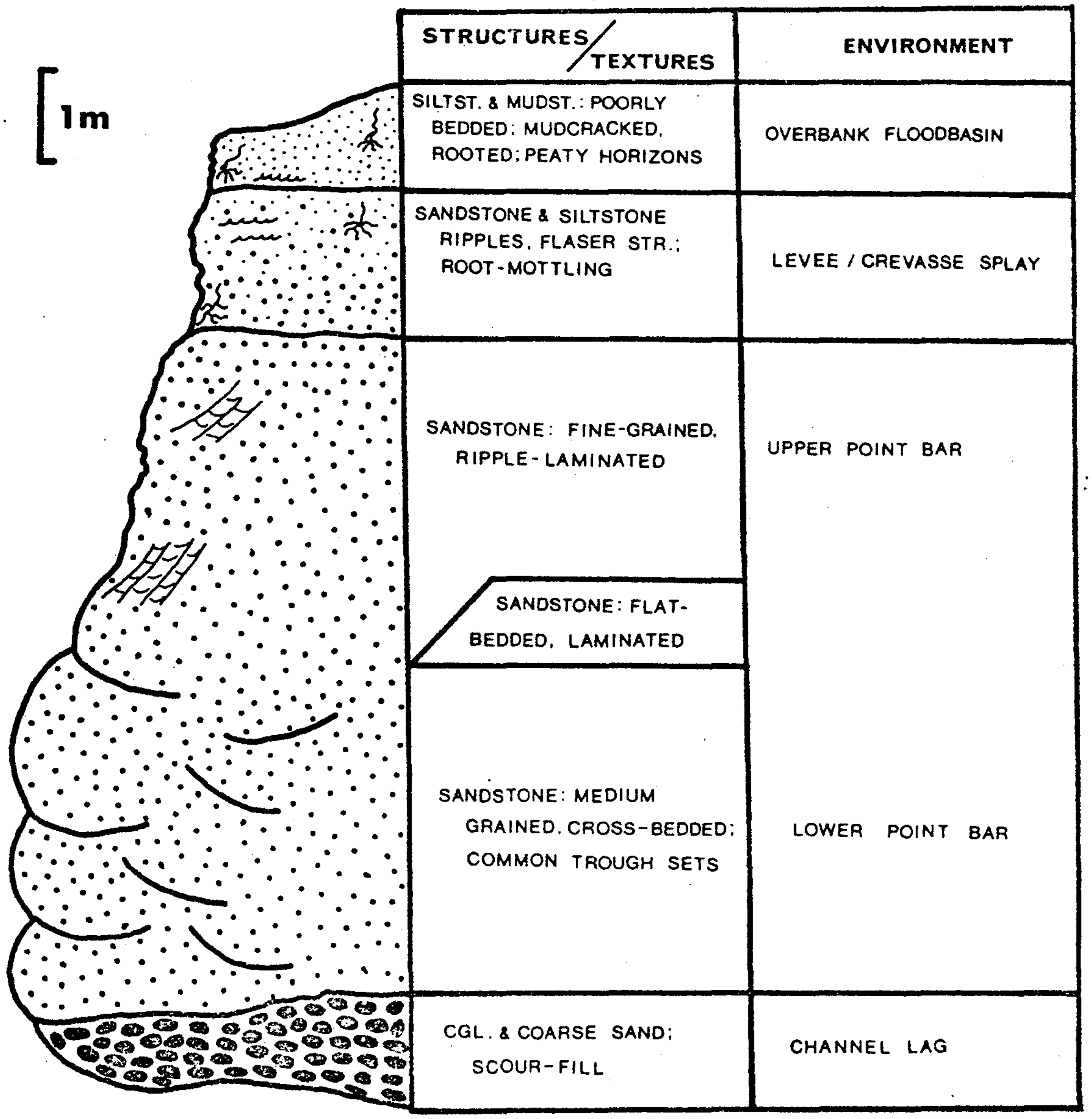

Figure 34. - Idealized meander-belt fluvial fining upwards sequence (Dickinson, 1975); very similar to typical Kincaid sequence.

The stratigraphic and structural cross-sections indicate a channel type sand in which the sand thickens downward at the expense of the underlying shales, interfingering with shales and siltstones near the margins of the field. An isopach map of the sandstone interval shows a thick lenticular sandstone which abruptly thins near its edges. The contour lines of the isopach map are sinuous and irregular, as would be expected in a fluvial channel deposit. In areas where the contour lines have a close spacing, downcutting of the stream and maximum sand thickness is indicated. A wider spacing of contour lines indicates a slip off slope such as on the inside of a meander bend. Structural contour maps indicate a canoe-shaped sandstone base, characteristic of erosional fluvial channel sands.

Electric log shapes are commonly used to support the environmental interpretation of sedimentary facies. This approach for environmental reconstruction was used by Saitta (1968), Berg and Davies (1968), Fons (1969), Ekebafe (1973), and Valderrama (1974). Both the gamma ray curve and the spontaneous potential curve show maximum values opposite thick and "clean" sand horizons, and minimum values corresponding to shaley sands or shale. In this way, electric log responses to variations in lithology will show the general patterns of a vertical sequence.

For example, the electric log curve shown in Figure 25 indicates an abrupt basal contact of the sand with shale followed by a serrated maximum deflection, and then a transitional gradation into the overlying shales. This type of electric log shape reflects the upward decrease in energy of deposition in a vertical section, which is characteristic of a fluvial point bar (Nanz, 1954; Visher, 1965a; Cannon, 1966; and Shelton, 1967). The abrupt base may be a result of scour produced by high energy currents and it is overlain by a massive well sorted clean sand. The upper transitional contact is composed of interbedded silt, sand, and clay, with amount of clay increasing upward. This pattern of electric log responses is confirmed by description of textures and structures observed in cores, as described above.

Alternative Interpretations

Tidal sediments (tidal flats and tidal channels) are deposited along the margins of protected coastal water bodies such as lagoons, estuaries, and bays. The sedimentary processes at work in tidal channels are essentially the same as those found in fluvial channels. Therefore, sedimentary structures present in the tidal channel facies are essentially the same as those of the fluvial channel facies, but can be distinguished by the presence of a basal channel lag which is a coquinoid pebble conglomerate consisting largely of allochthonous brachiopod shells (Johnson and Friedman, 1969). Also commonly present is extensive burrowing and well developed mud cracks, which are not common in a fluvial channel environment. Hayes (1963) interprets some of the sands of the Krebs Subgroup of western Missouri as tidal channel deposits.

An estuary, or tidal mouth of a river, contains sediments and structures very similar to that of fluvial channels. According to Klein (1967), the idealized vertical sequence of a fluvial channel sandstone is also characteristic of both estuary and tidal channel deposits. He concluded that the only way to distinguish among them was on the basis of the composition of the channel lag. Estuaries commonly contain a mixture of shell debris, clay pebbles, and plant material. Estuary sands are also highly bioturbated, which is uncharacteristic of fluvial sands. Studies of both modern and ancient estuary deposits have been made by Howard and Frey (1973), and Campbell and Oaks (1973).

Barrier island sands are similar to fluvial channel sands in their geometry, but most other characteristics are dissimilar. They are relatively "clean" (less than 10% clay matrix) and contain a high percentage of quartz (about 90%), in contrast to fluvial sediments which have a relatively low quartz content (50%), and an abundance of matrix and rock fragments (Davies and Berg, 1971). Other dissimilarities with fluvial sands are the presence of glauconite, a decreasing clay content upwards, low-angle cross strata, burrowing, an abundance of marine organisms, gradational lateral change, and a transitional basal contact (Exum and Harms, 1968). Three excellent references concerning ancient barrier bar deposits include Berg and Davies (1968), McGregor and Biggs, (1968), and Davies, Ethridge and Berg (1971).

Environments of Deposition of Associated Facies

Gray Shales - Gray, carbonaceous, unfossiliferous, silty, non-fissle, pyritic shales make up the majority of the section in the cores from the Kincaid Oil Field. Most of the shales of this type are interpreted as being prodelta deposits in the shallow, open Cherokee sea. Circulation in the sea was sufficient to oxidize most of the organic matter brought in from the highly vegetated coast; and deposition may have been too rapid to support bottom-dwelling organisms.

Black Shales - Black, phosphatic, pyritic, fossiliferous, carbonaceous, fissile shale about .5 meters thick underlies the sandstone in a few wells. Marine fossils recognized in the shale include abundant *Orbiculoidea* (inarticulate brachiopod), with scarse conodont fragments, *Listracanthus*, and questionable fish teeth (?), plant stems (?), and fish scales (?). The black color of the shales is due to finely disseminated iron sulphide and partly decomposed plant matter (Moore, 1929). The black shale facies have been interpreted by Moore (1949) and Weller (1957) as having been deposited in a widespread shallow marine environment in which circulation was restricted due to a choking effect caused by the abundance of vegetation. The sea was shallow and brackish with anaerobic, reducing bottom conditions. As the seas trangressed, this zone of vegetation probably migrated with the shoreline, which accounts for the widespread distribution of the black shales.

Coals - The origin of the coal layer beneath the sandstone of the Kincaid Field is probably typical of most of the Pennsylvanian coals of the Midcontinent. Most were probably deposited as thick layers of vegetation along swampy coastal zones and floodplains. These coal swamps flourished in the humid, sub-tropical climate along the coastal areas of the Cherokee platform. Migration of the swamps produced by marine trangression resulted in the widespread nature of most of these coals.

History of the Skinner Sandstone in the Kincaid Field

The river which carried the sediments of the Skinner Sandstone zone was a moderately slow-moving stream. Because it was cutting down into older shales and coals (peat beds), the stream's load contained much mud and organic debris along with fine-grained sands. The stream flowed across a low, swampy landmass, into a shallow Cherokee sea which had a highly vegetated coastline. The stream's course was relatively straight because of its youthfulness. Meandering would have resulted with more time; however, rapidly changing Pennsylvanian environments gave the stream little time to develop broad, sinuous channels.

During a regression of the sea the stream advanced southward lengthening its course. The stream cut a relatively straight and deep channel into the soft, freshly exposed shales. During this stage, the channel lag deposits were laid down under more rapid flow conditions (possibly upper flow regime). Next, point bars and overbank sediments were deposited as the stream valley was filled.

Later, when the sea began to transgress the low coastal areas, it advanced first up the river channels. The sands which the river was carrying were dropped as the seas rose, filling the channels. Finally, as the seas covered the entire area, a thick blanket of shale was deposited. In conclusion, the sandstone of the Skinner zone in the Kincaid Field represents the aggradational channel-fill and flood-basin deposits of a perennial, low-gradient, slightly meandering stream.

Provenance

Many different opinions have been expressed concerning the provenance of the Cherokee sandstones (Moore, 1931; Hayes, 1963). Most commonly, the Nemaha Uplift has been suggested as a logical source. Parts of the ridge were above sea level and subject to erosion during Early and Middle Pennsylvanian time. Other possible local sources were older sedimentary rocks, ranging in age from Cambrian to Mississippian, which may have been exposed at that time, such as the sandstone of Simpson age.

The Nemaha Uplift is the most likely source for many of the sandstones of the Cherokee Group. Most of these sandstones are very similar in composition, that is, they are fine-grained, and composed mostly of quartz and metamorphic rock fragments, with some micas, feldspars and minor accessories. This suite of constituents could have been derived from the igneous and metamorphic rocks exposed on the N~~a~~emaha Uplift during Cherokee deposition. Farquhar (1957) made a study of the basement rocks of Kansas and found that several wells in the northeastern part of the state encountered Precambrian schist and phyllite. According to Farquhar, "the typical Kansas schist is composed principally of quartz but contains lesser amounts of feldspar, both biotite and muscovite micas, and such accessory constituents as hornblende, chlorite, epidote, tourmaline, garnet, sillimanite, graphite, and magnetite". In the sandstone of the Kincaid Field the grains are subangular, indicating a nearby source, and most of the grains seem to be derived from a metamorphic source rock, with metamorphic rock fragments comprising a good percentage of the sandstone.

A few authors have suggested a southward source for the Cherokee sandstones (Moore, 1931); however, this seems to be unlikely. Most authors feel that a northern source (either the Nemaha Uplift of the Canadian Shield) for the sandstones is most likely, considering paleocurrent data. Hayes (1963) states: "Most of the Pennsylvanian sands of the Western Interior Basin were carried across a shelf extending southwesterly into the basin, although some of the sands were derived from local sources. A combination of distant and local source areas is suggested as the provenance of the Krebs sandstones. The distant source was the Canadian Shield. The Nemaha Uplift is suggested as the local source because it was undergoing erosion while the Krebs was being deposited. . ."

PETROLEUM GEOLOGY OF THE KINCAID FIELD

Accumulation of oil in commercial quantities in the Cherokee section is limited to rocks of the Cherokee Platform, with little coming from rocks of the basinal facies. Weirich (1953) argued that the hydrocarbons originated in the shelf sediments and not in the basin because there were no migration routes. Most of the oil and gas accumulating in the Cherokee rocks of southeastern Kansas and northeastern Oklahoma was probably derived from marine shales, rich in organic matter, which make up the majority of the Cherokee sequence (Baker, 1962). These same shales from the seals enclosing the reservoir sandstones.

During early Desmoinesian time, in the Midcontinent region, rapid sedimentation produced thick transgressive marine shales overlying numerous regressive lenticular sandstones. These shales were the source of the hydrocarbons which migrated into the sandstones (Gould, 1975).

Most of the Cherokee sandstone oil fields (and the Kincaid Field in particular) represent combination structural-stratigraphic traps (Busch, 1959). In the Kincaid Oil Field, production is limited northward by a lack of clean sand, and southward by a structural high (J. Richard, personal communication, 1974). Impermeable shales, which surround the porous reservoir sandstone, form an excellent barrier to migrating oil and gas. In combination traps such as this one, structure is important only in localizing oil and gas accumulations within updip closures such as in the south end of the Kincaid Field. The stratigraphic extent of the porous sandstone is more important in the accumulation of petroleum. In the Kincaid Field, very little gas has been produced; however, the Davis-Bronson Field, farther south in the same sandstone trend, produces some gas in the structurally highest areas of the field (McQuillan, 1968).

Secondary recovery operations have been applied to the Kincaid Oil Field since 1946, when waterflooding was initiated. Waterflooding has long been a successful method of improved recovery of hydrocarbons in the relatively shallow sandstone reservoirs of eastern Kansas (Powell and Eakin, 1953). Primary production (gas cap or dissolved gas drive) is limited because of the quick loss in reservoir energy. In the low pressure reservoirs of southeastern Kansas such as the Kincaid Oil Field, means other than primary production are initiated early in most fields in order to recover an economical amount of oil. Repressuring of the oil-saturated reservoir rocks by the injection of water, air, or gas has become the most widely used method of secondary recovery.

The Kincaid Oil Field is a very old producing field, having first been drilled in 1934. Since 1946, the Kincaid Field has been fractured and waterflooded by independent oil producers. No other secondary recovery methods have yet been used to stimulate oil production. In a very mature area such as this, where most areas surrounding the field have been drilled, there is little chance for the discovery of a new sand body or an extension of the main trend. However, the most likely location for undiscovered sandstone reservoirs would be laterally from the field where an isolated sand pocket may have been deposited as an abandoned river meander belt. Further exploratory drilling and detailed mapping are necessary. Tertiary oil recovery methods may be used in the future for the Kincaid Oil Field. Factors which are favorable for enhanced recovery include the shallowness of the reservoir, the good quality of the oil, and the relatively thick sand zone without many thick shale breaks.

SUMMARY

Interpretations of depositional environments can be of great value in the exploration for hydrocarbon traps. In petroleum exploration and exploitation, environmental criteria are needed in predicting the location and extent of oil-bearing sands in a sedimentary province and in the determination of subsurface trends of reservoir sands already discovered by drilling.

The Cherokee Basin is an excellent region to study combination traps in a clastic sequence of rocks. Frequently changing paleogeography during Middle Pennsylvanian time produced lenticular, discontinuous sand bodies in a variety of depositional environments. For this reason, care must be taken when making environmental interpretations of a specific sandstone, because that sandstone body may have been affected by several different environmental conditions.

The Skinner Sandstone, which forms the reservoir rock of the Kincaid Oil Field, was deposited by a southward-flowing, slightly meandering stream. This stream brought fine-grained sediments derived from the Nemaha Uplift and deposited them as fluvial channel point-bar, mid-stream bar, and overbank sediments. Later, these sands were covered by marine shales (deposited by the transgressing Cherokee sea) which supplied and trapped hydrocarbons within the sandstone reservoir.

Additional detailed studies of the sandstones and shales of the Cherokee interval in southeastern Kansas are needed, especially concerning depositional environments. Through these sedimentologic studies, an original depositional framework of the sequence may be devised which should make petroleum occurrences more predictable.

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APPENDIX I

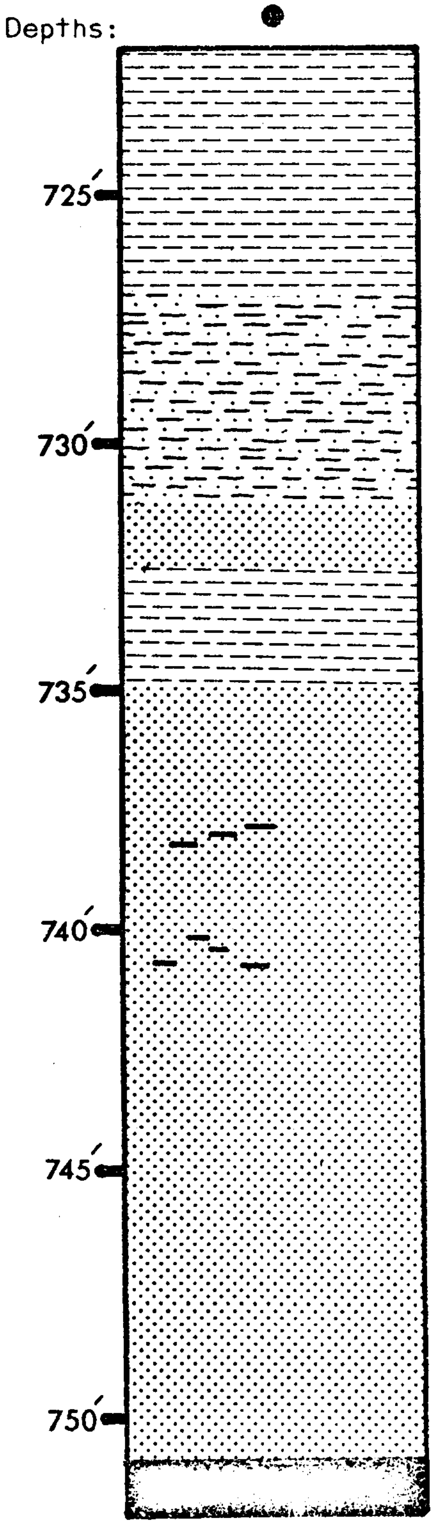
<u>Core Descriptions</u>

(Vertical Scale: 1" = 4')

LEGEND

░	Massive sandstone
░	Cross-bedded sandstone
≈	Ripple cross-bedded sandstone or siltstone
░	Carbonaceous or shaley sandstone
┅	Siltstone
☰	Black shale
┅	Gray shale
○	Conglomerate
▓	Coal

Richard Eng. C-1-McCaslin
SE SE NE 5-23-21 E
elev. 1049'



Mas. dk.-gr. slty. sh.

Gy. to brn. par.-lam. sltst. & sh.

Mas. v. fn.-gr. brn. oily ss.

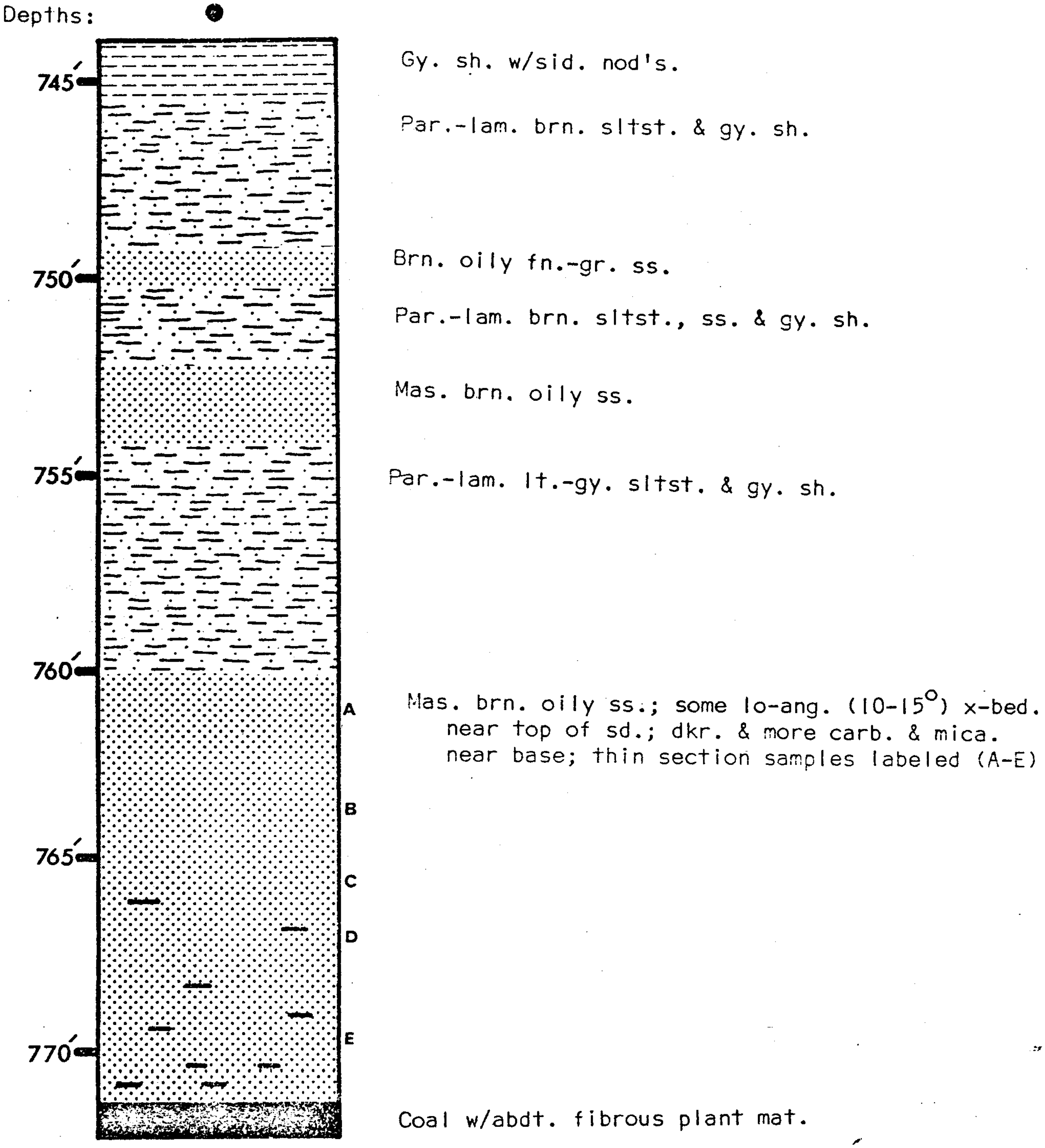
Mas. dk.-gy. sh.

Mas. brn. oily ss. w/few sid. layers & carb. ptgs.

Ss. becomes v. oily & blk. (tar sds.)

Coal; v. fri.

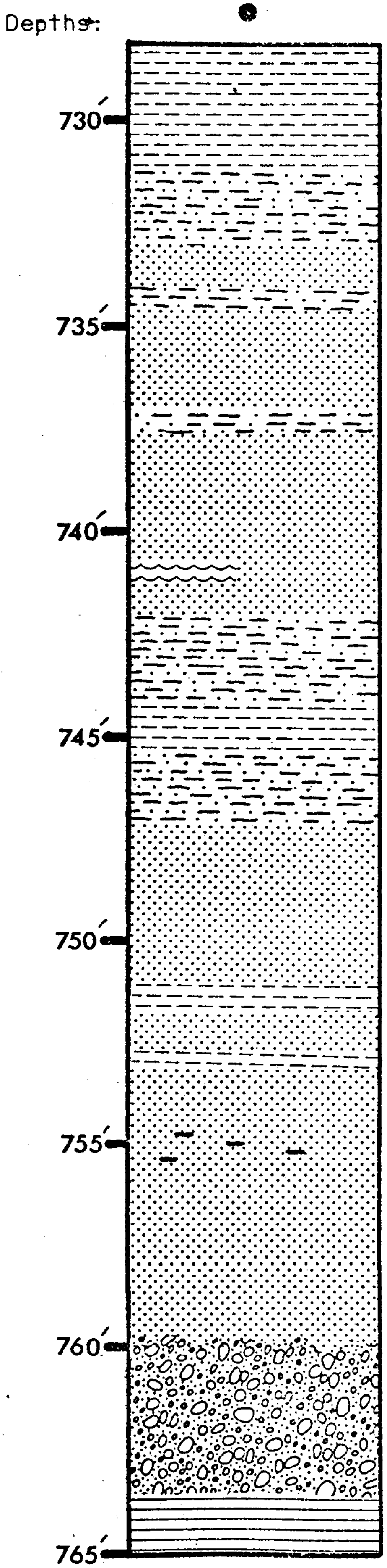
Richard Eng. W-12-Miller "B"
SW SE SW 29-22-21 E
elev. 1032'



Richard Eng. C-2-Van Buskirk

SW SW NW 4-23-21 E

elev. 1055' (est.)



Mas. gy. sh. w/thin sid. layers throughout

Par.-lam. sltst. & sh. w/few carb. ptgs.

Mas. brn. oily fn.-gr. ss.

Interbed. gy. sh. & brn. sltst.

Mas. brn. ss.

Par.-lam. sltst. & sh.

Mas. brn. oily ss. w/some rip. x-bed. & carb. mat.

Interbed. gy. sltst. & sh.

Mas. gy. sh.

Interbed. sltst., ss. & sh.

Carb. brn. ss. w/scattered plant frag's.

Gy. sh. w/few sid. nod's.

Carb. ss.

Mas. brn. oily ss. w/carb. mat. & some hi-ang. x-bed. (30°)

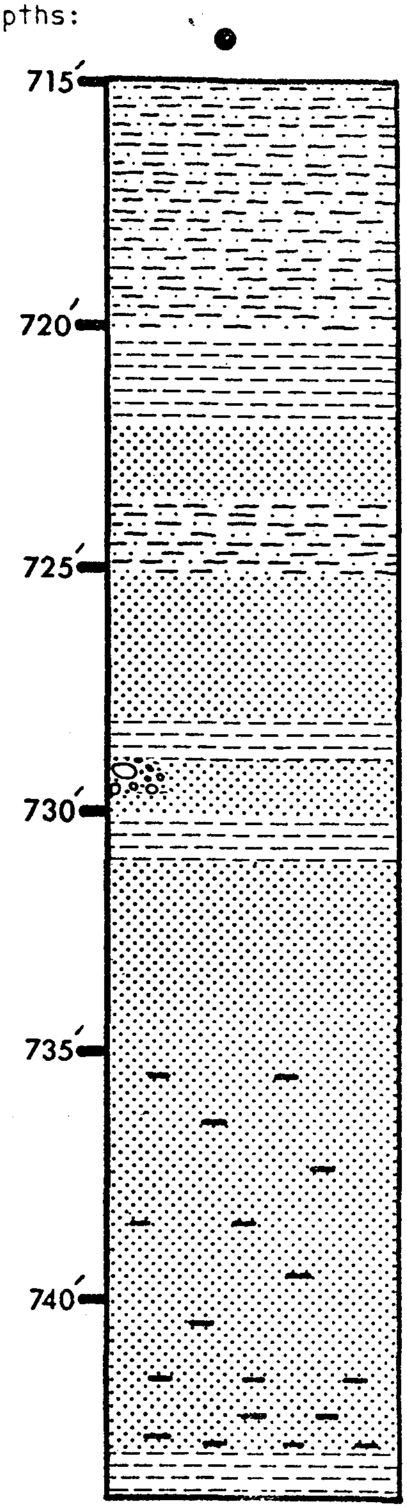
Carb. crs.-gr. ss.

Carb. congl. w/sh., coal & sid. peb's.

Blk. fis. foss. sh.; contains orbiculoid brach's.

Richard Eng. W-2-Gaddis
SW SE SW 4-23-21 E
elev. 1060' (est.)

Depths:



Gy. sltst. w/par. sh. lam's.

Gy. slty. sh.

Mica. brn. ss. w/oily blk. ptgs.

Lt.-brn. shy. sltst.

Mas. brn. ss. w/few sh. ptgs.; oily in places

Dk. gy. sh. w/few thin sid. layers

Brn. ss. w/few sh. peb's.

Gy. sh.

Mas. dk.-brn. oily mica. fn.-gr. ss.

Ss. inc. in carb. ptgs.

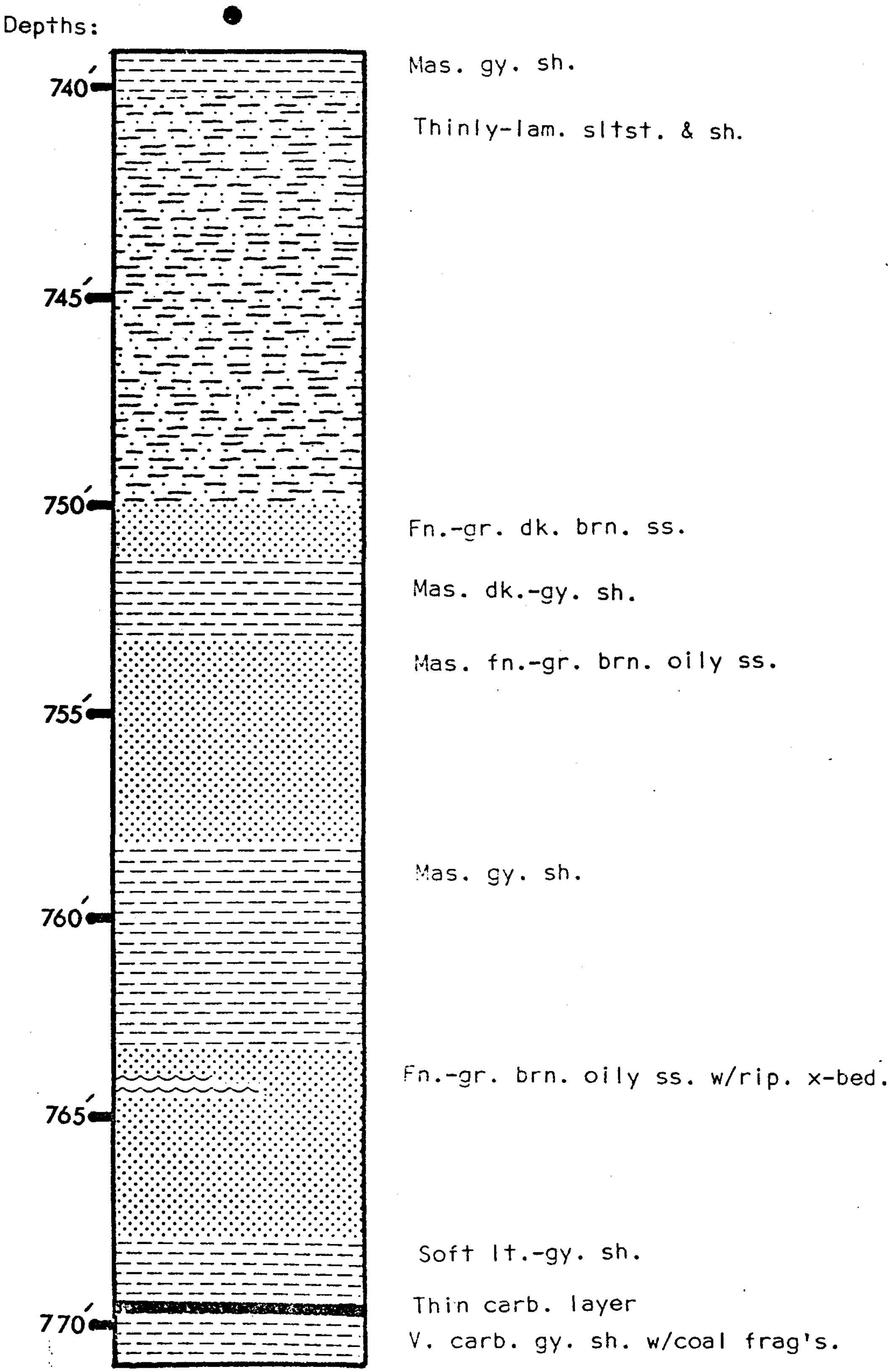
V. mica. carb. blk. ss.

Gy. sh.

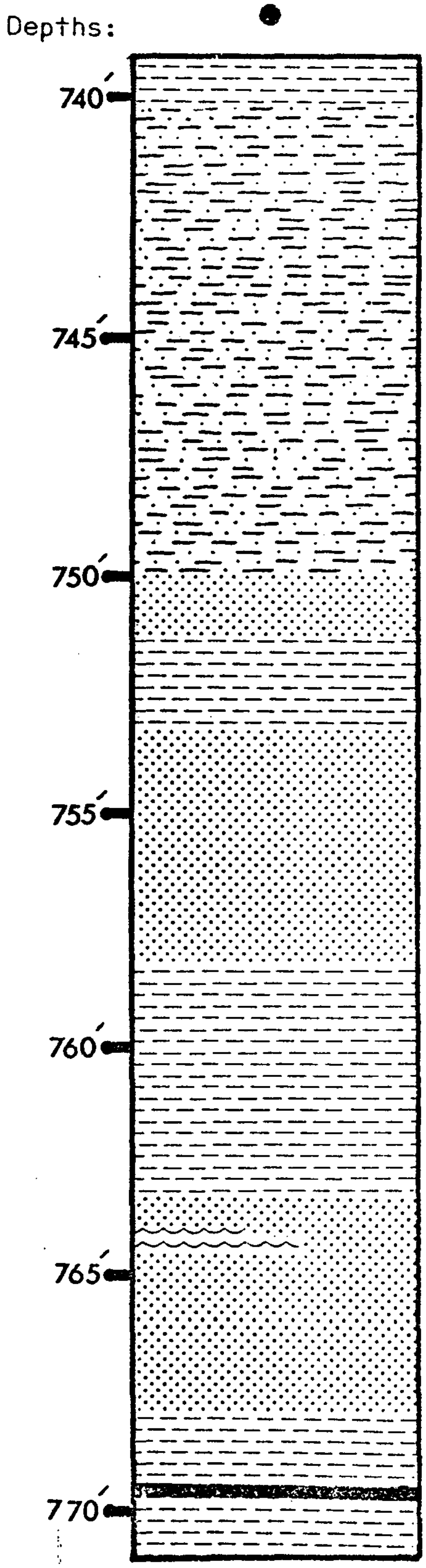
Richard Eng. E-1-Van Buskirk

SE SW NW 4-23-21 E

elev. 1065' (est.)



Richard Eng. E-1-Van Buskirk
SE SW NW 4-23-21 E
elev. 1065' (est.)



Mas. gy. sh.

Thinly-lam. sltst. & sh.

Fn.-gr. dk. brn. ss.

Mas. dk.-gy. sh.

Mas. fn.-gr. brn. oily ss.

Mas. gy. sh.

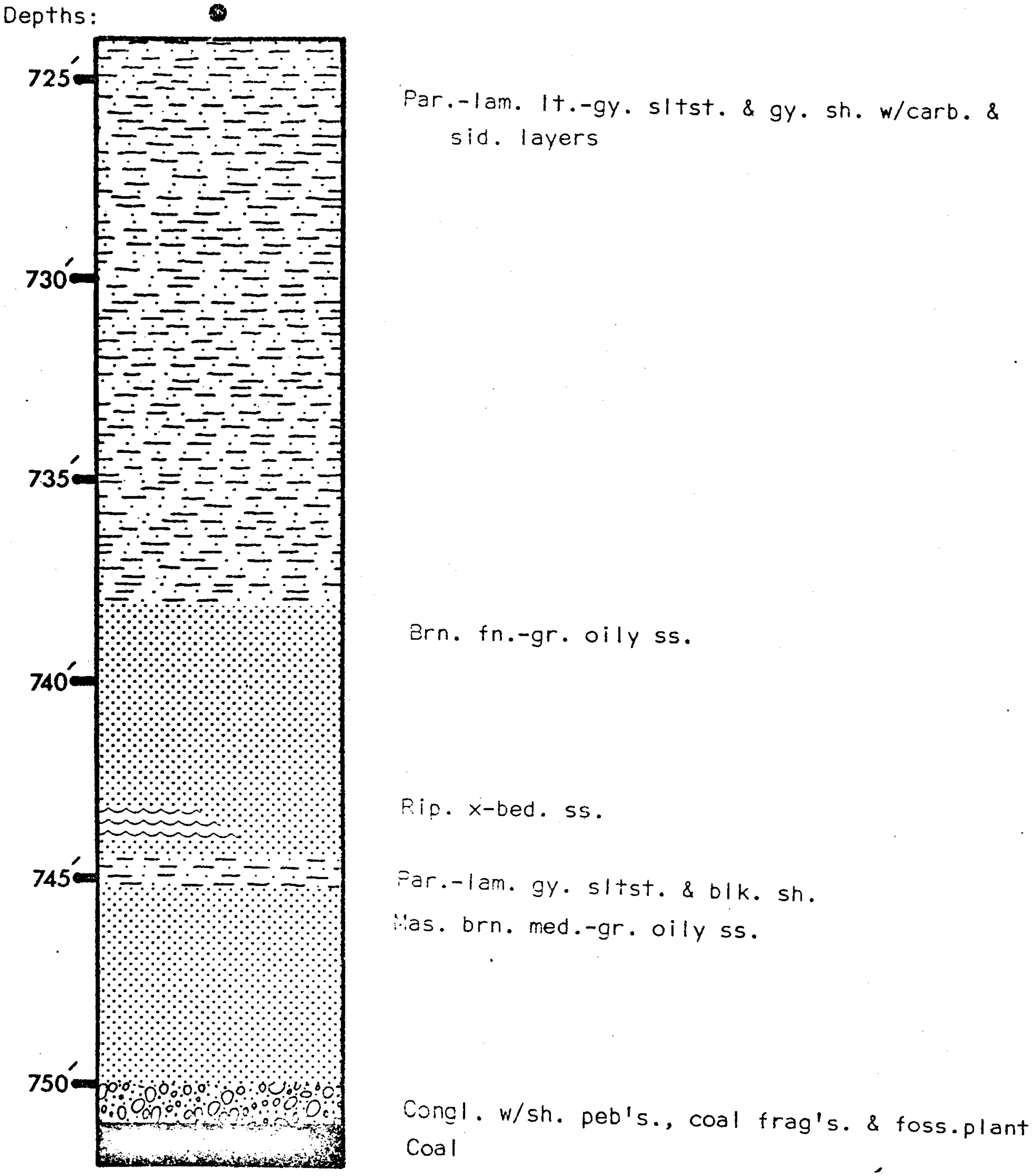
Fn.-gr. brn. oily ss. w/rip. x-bed.

Soft lt.-gy. sh.

Thin carb. layer

V. carb. gy. sh. w/coal frag's.

Richard Eng. C-8-Lockwood
SW SE SE 32-22-21 E
elev. 1039' (est.)

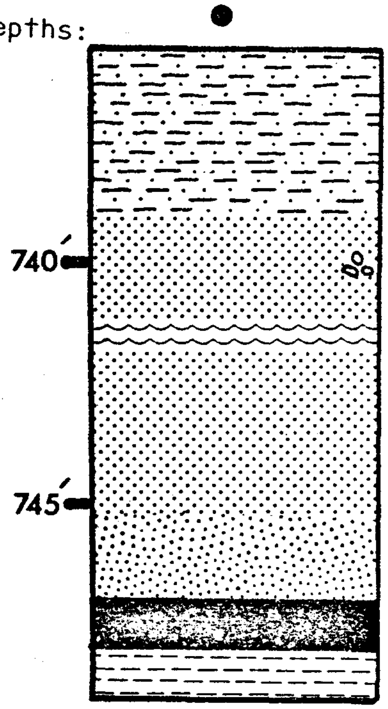


Richard Eng. W-4-Lockwood

SE SW SE 32-22-21 E

elev. 1031'

Depths:



Gy. & brn. sltst. w/mica. lams., few rip. x-bed., gy. sh. ptgs. & thin sid. layers.

Mas. brn. oily ss. w/few sid. peb's.

Rip. x-bed. ss.

X-bed. ss.

Fis., blk. coal

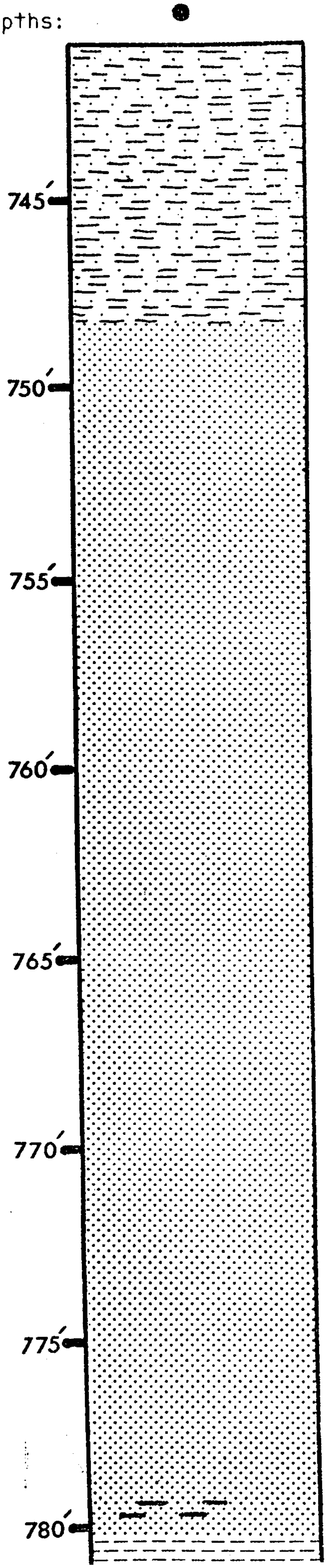
Dk. gy. carb. fis. mica. sh.

Richard Eng. C-10-Van Buskirk

SW SW NW 4-23-21 E

elev. 1062 (est.)

Depths:



Par.-lam. lt.-gy. sltst. & gy. sh.

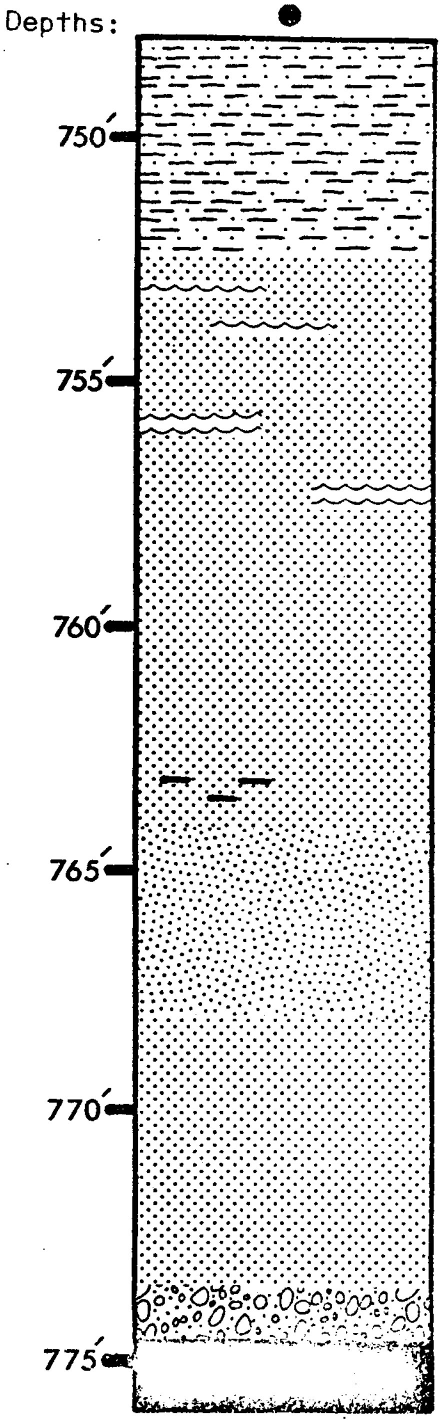
Mas. brn. fn.-gr. oily ss.; ss. gradually becomes dkr. & more mica., carb., & oily near base.

Mas. dk. gy. sh.

Richard Eng. C-6-Cooper-Richart-Frost

SE NE NW 32-22-21 E

elev. 1033'



Gy. par.-lam. shy. sltst.

Brn. fn.-gr. oily ss. w/rip. x-bed.; mica. & carb. along bed. planes

Carb. brn. ss.

Lo-ang. (10-15°) x-bed. oily ss.

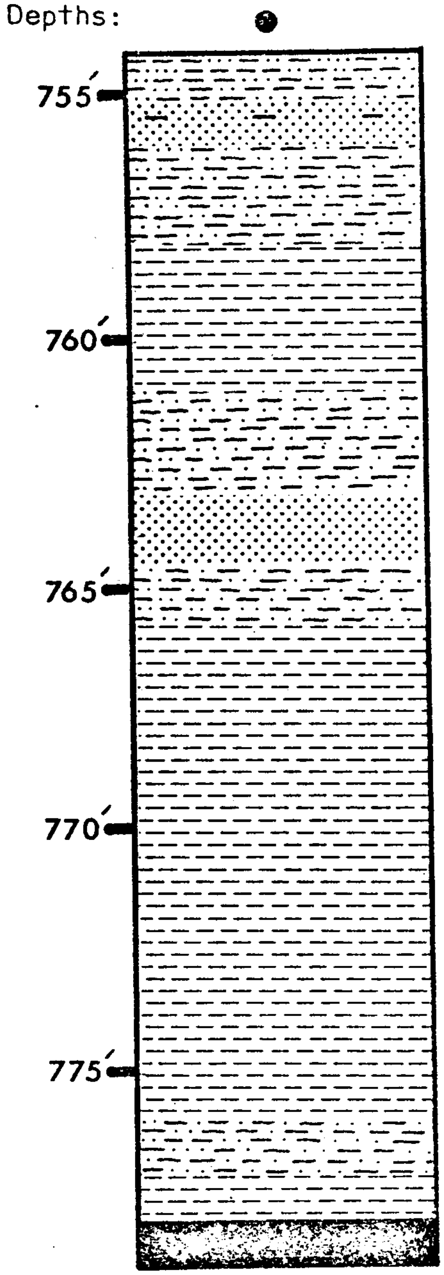
Ss. becomes v. mica. & carb.

V. dk. brn. oily ss.; becomes a crsr. blk. tar sd. near base.

Sh.-peb. congl.

Coal

Richard Eng. W-10-Cooper-Richart-Frost
NW SE NW 32-22-21E
elev. 1022'



Shy. gy. sltst.

V. fn.-Gr. brn. ss. w/sh. ptgs.

Interbed. sh. & sltst. w/thin sid. layers & some sh. pebs.

Mas. gy. sh. w/few sid. layers

Slty. sh. w/few sid. layers

Brn. fn.-gr. carb. ss.

Slty. sh. w/few carb. plant frag's.

Mas. gy. sh.

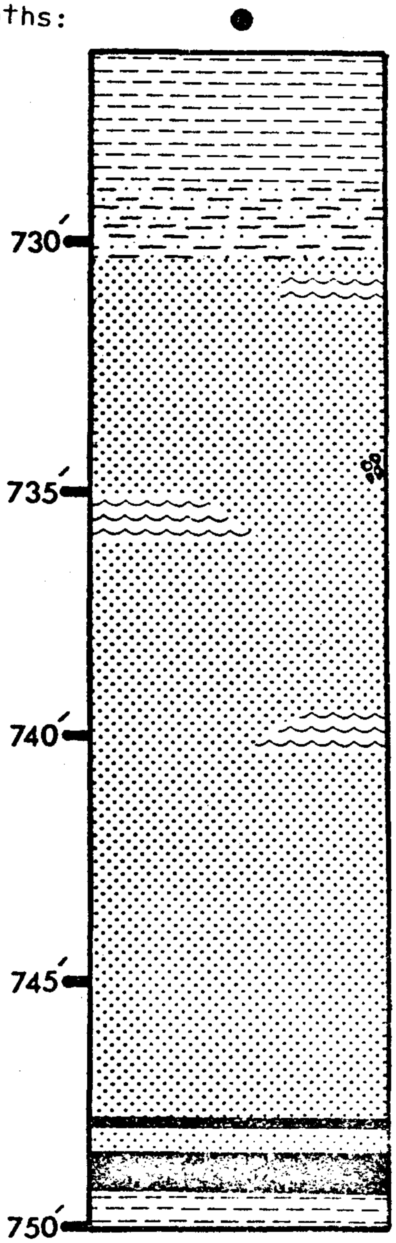
Slty. gy. sh. w/much carb. plant mat.

Mas. hard foss. sh. w/orbiculoid brach's. & conodont

Coal

Richard Eng. C-3-McCaslin
NW NE NE 5-23-21 E
elev. 1036'

Depths:



Mas. dk.-gy. sh.

Brn. sltst. w/gy. sh. lam's.

Brn. fn.-gr. ss. w/rip. x-bed & few sh. peb's.

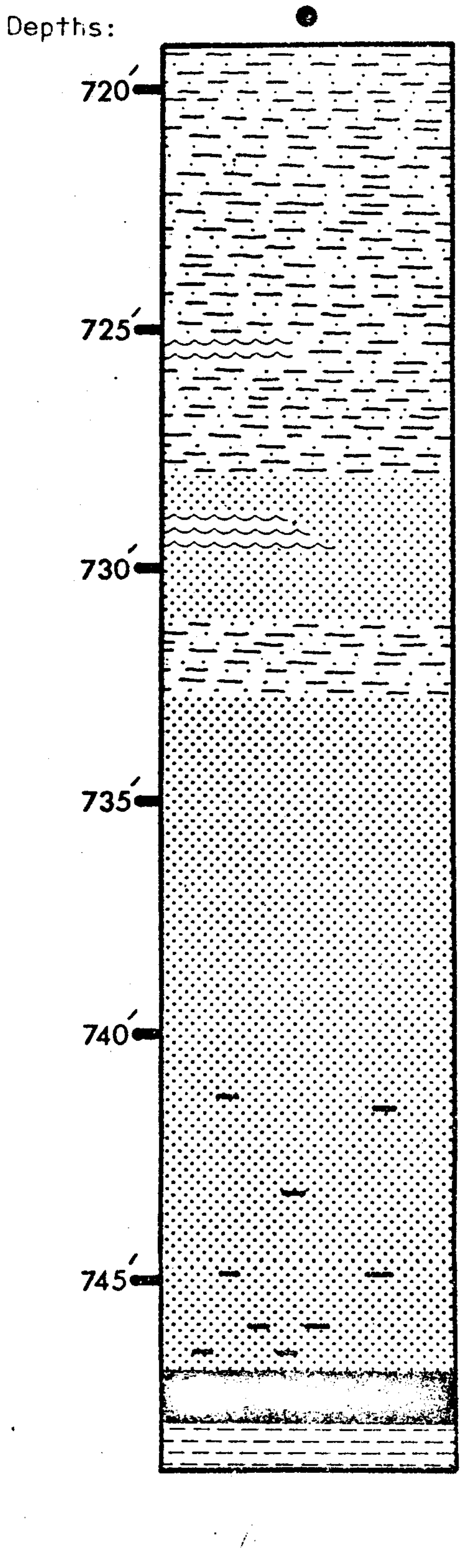
Ss. becomes crsr., dkr. & oily near base w/some lo-ang. (10°) x-bed.

Thin fri. coal

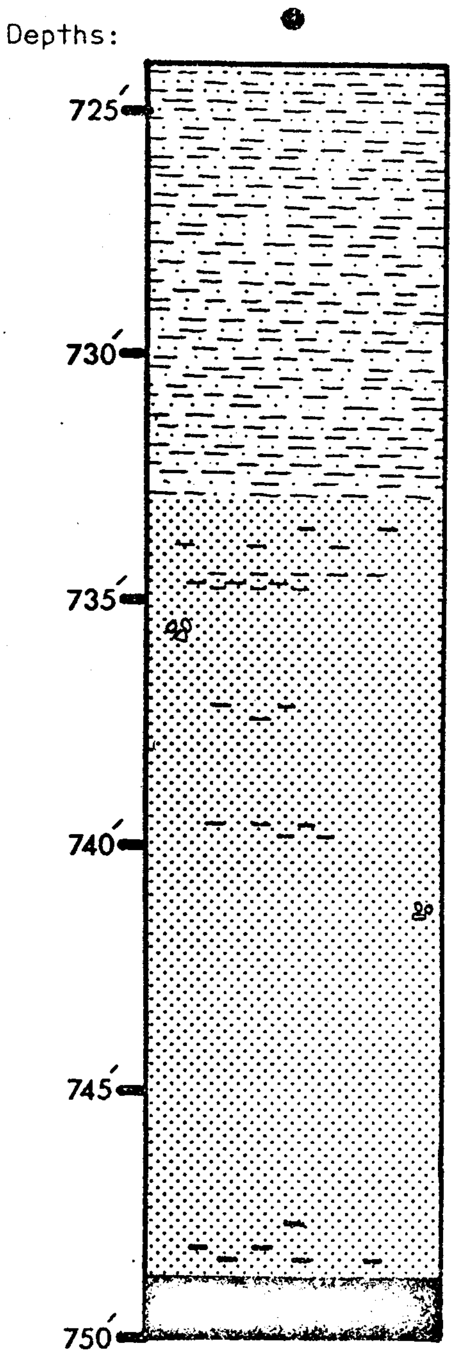
Coal

Soft gy.-gn. sh. (underclay)

Richard Eng. C-9-Lockwood
SE SE SE 32-22-21 E
elev. 1045' (est.)



Richard Eng. E-4-McCaslin
NE NE NE 5-23-21 E
elev. 1048' (est.)



Gy. to brn. par.-bed. sltst. w/thin sh. & sid. layers

Brn. v. fn.-gr. ss. w/sh. & sid. ptgs. & sid. nod's.

Ss. becomes v. oily & blk.

Coal

APPENDIX II

Laboratory Procedures

Samples of the cores, used for the making of thin sections, were chosen in intervals of "clean" sand (sand with very little clay matrix or shale partings). Five samples were taken from one well at evenly spaced intervals throughout the sand unit, perpendicular to bedding (vertically). These samples were used only for estimating mineralogical percentages of the coarse fraction, and were not meant to be representative of the entire sandstone body. Oil was extracted from the rock samples with an apparatus provided by the Department of Petroleum and Chemical Engineering which is essentially a distillation unit, using vaporized toluene to remove the oil from the pore spaces of the rock. The rock samples were impregnated with a red epoxy. Point-counts were made on each of the five samples. Two hundred counts were made on each slide in an imaginary rectangular grid pattern.

A technique described by Chilingar, Bissell, and Fairbridge (1967) was used to stain for dolomite. Equal volumes of alizarin red S and 30% NaOH solutions were combined and boiled. The sample was then inserted, and dolomite changed color from pink to purple. Siderite also changed color from red-brown to dark brown-black. A technique for staining feldspar was suggested by Dr. E. F. McBride (personal communication, 1975). The thin section was first etched in HF fumes for 10 seconds, then dipped in a saturated solution of sodium cobaltinitrite for 3 minutes. The feldspar was changed in color from clear to yellow. Gray shale samples were disaggregated by soaking in a stodard solution and then in water.