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**Heavy-Crude Oil Bearing Sandstones of the
Cherokee Group in Southeastern Kansas**

by

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HEAVY-CRUDE OIL BEARING SANDSTONES OF THE
CHEROKEE GROUP (DESMOINESIAN) IN
SOUTHEASTERN KANSAS

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INTRODUCTION

The Cherokee Basin area of southeast Kansas, northeast Oklahoma, and western Missouri has been an oil producing province, since the discovery of shallow production in Kansas in the latter 1800's. This region is thought of these days as mainly an area of "stripper-wells." That is, one in which daily production in many fields amounts to only a few barrels a day.

There is another side to the story of southeast Kansas, however, which we feel may be increasingly important with time--its resource of heavy-oil. This resource is interesting because of the geology of the reservoir rocks, the variable geochemistry of the heavy-crude oils and associated higher gravity oils, and the possible role of these oils as a future energy resource.

Although more than one-half billion barrels of oil have been produced from a large number of shallow fields (Goebel, 1971, p.1089), many of these fields gave up only a fraction of their in-place oil during primary and secondary phases of operation and experienced rather rapid decline of reservoir pressure. Because much of the very shallow, unrecovered oil, in many cases 70-80%, is too viscous and of too low-gravity to recover by conventional means, this area and adjoining western Missouri have been the testing ground for numerous in-situ tertiary-recovery schemes (Goebel, 1966).

GEOLOGY

Cherokee Basin

Geologically, this part of the Midcontinent petroleum province (Fig. 1) is a shelf-like extension of the Arkoma Basin of Oklahoma. The Ozark Uplift, a famous lead-zinc mining district, forms the eastern flank of the basin, and, on the west, is the prominent Nemaha Uplift. Northward the Cherokee Basin is only partially separated from the deeper Forest City Basin by subtle relief on the pre-Pennsylvanian surface.

The Pennsylvanian sediments which occupy the Cherokee Basin province crop out in a northeastward trending belt and dip westward beneath the study area (Fig.2). Heavy, viscous oil or solid bitumen impregnates these rocks in numerous surface localities in easternmost Kansas and western Missouri (Jewett, 1940; Searight, 1957; Wells and Anderson, 1968).

The heavy-oil bearing sediments discussed here comprise the Cherokee Group, lower part of the Desmoinesian Stage, of Middle Pennsylvanian age, in a 13-county area of southeast Kansas. Figure 3 illustrates the northward thinning of the Pennsylvanian section and transgressive onlap of younger sediments over the eroded Mississippian surface (Weirich, 1953; Visher, et al., 1971). The overlapping of earlier Pennsylvanian sediments during the Desmoinesian is also apparent. Figure 4 shows the present structural attitude of the Desmoinesian section, which varies from 350 to

900 feet in thickness and dips slightly north of west at a rate of approximately 20 to 30 feet per mile, from western Missouri to the eastern flank of the Nemaha Uplift (Lee and Merriam, 1954).

The present northwestward dip of the sediment section in southeast Kansas is inherited from several episodes of tilting which began in Middle Ordovician time and continued intermittently through the Mississippian Period. General southward subsidence of the area beginning in the Pennsylvanian, after uplift of the Nemaha Anticline, was followed, in Late Permian time, by renewed northwestward tilting. The effects of this Permian tilting were not nullified by later events (Merriam, 1963, p.223).

It is important to point out here that the Cherokee sediments in southeastern Kansas probably have never been buried by more than 3500' of younger sediments. There is presently as much as 2000 feet of sediment section above the Cherokee west of the area of main interest here, and, of course, no cover in the extreme eastern portion of the area. Even allowing for as much as 800 to 1000 feet of Lower Permian strata (McKee, et al., 1967, pl. 9) and 500 to 800 feet of Cretaceous beds (Hattin, 1973), all of which has subsequently been removed by erosion from eastern Kansas, this estimate of 3500' of maximum cover since deposition seems reasonable. Moreover, the hydrocarbons accumulating in these rocks probably were generated in the enclosing shales. Evidence for this is found in the high organic-

matter content of some of these shales and in the discontinuity of the sandstone reservoir rocks, which precludes migration from some distant source more near the basin (Weirich, *ibid.*, p. 2031). Thus, whatever chemical changes have been effected in these crude oils have occurred in virtually the same structural environment in which we find the rocks today, that is, only weakly deformed shallow burial; and, more importantly, the heavy-oils have probably not remigrated from one habitat to another.

Sediment Petrology

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). Cherokee sediments (Fig. 5) are mainly terrigenous clastic sandstones and shales, interbedded with thin coal deposits and underclays and a few thin limestone beds. Later cyclic sequences, such as the Upper Desmoinesian Marmaton Group, include far more limestone and almost no coal, supporting the concept of increasingly widespread marine invasion of this area throughout middle and later Pennsylvanian time, with variation of environmental conditions as the interplay of sediment supply and basin subsidence changed. In this setting, the Cherokee Basin has been depicted as the site of shifting and prograding alluvial and deltaic plains, estuaries, tidal delta complexes, beaches, and shallow marine shelf environments (Bass, 1936; Baker, 1962; Hayes,

1963; Visher, et al., 1971). Individual sand bodies in the Cherokee section have been described variously as ancient nearshore bars (Dillard, et al., 1941), barrier islands (Bass, *ibid.*), tidal flat-tidal channel deposits (Hayes, *ibid.*), and alluvial valley-fill sediments (Rich 1923; Charles, 1941; McQuillan, 1968). Probably each of these interpretations is correct in some area.

Petroleum Geology

For a proper evaluation of potential volumes of crude oil to be found in an area, some knowledge of geometry of potential reservoir rocks is necessary. On one hand, fortunately, the long history of exploratory drilling in southeastern Kansas has made much shallow subsurface data available. On the other hand, we have learned that most of the oil found there has been located by random drilling and then following any new trends which might be discovered. The oil fields presently producing from Cherokee reservoirs in our study area are shown on Figure 6. Most, if not all, of these fields owe their location to the attitude or nature of the sand body in which they occur. Generally speaking, structure is important in localizing oil and gas accumulations in these fields only to the extent that it may segregate the gas into higher portions of the reservoir, or localize the hydrocarbons in an updip "reach" of a sinuous sand body. Far more important is the actual

stratigraphic extent of porous, permeable sandstone.

An example of a field displaying these features is the Davis-Bronson Pool, in Allen and Bourbon counties (Fig.6). This pool produces oil whose gravity is in the range of 24°-29°A.P.I. The producing sandstone in this case is in the upper-middle Cherokee section, as shown on Figure 7. The sandstone varies in thickness from zero to almost 100 feet, averaging about 40 feet. A subsurface structure map of a prominent radioactive black shale above the sand body demonstrates the lack of structural closure on the reservoir (Fig.8). The producing area of this pool, is 2-1/2 miles long and 1/4 mile wide. Production is limited northward by a lack of clean sand and southward by a structurally high area which is prone to producing gas. The dominant structural attitude is northward-to-northwestward dip. Differential compaction of the overlying shales accounts for the apparent "nosing" of the contours over the sand axis. A map of thickness from the overlying shale-marker to the base of the sandstone Figure 9, indicates the sinuous trace of the central, thicker part of the sandstone body. This thickening occurs at the expense of underlying marker beds, which are present only in areas flanking the sand body.

The cross-section, A-A' (Figure 10), illustrates the sandstone's convex-downward base. This is a stratigraphic, or "restored" section, but even a structure section which

shows dip and draping over the sand confirms this convex-downward attitude.

A core of the reservoir sandstone (Fig. 11) contains structures typical of some fluvial deposits. There may be cyclic repetitions, each 5 to 6 feet thick, of sequences such as this in a single core: at the base is (1), an erosional contact and conglomeratic layer including clasts of locally derived sideritic-siltstone, sandstone, and coal; this is overlain by (2), a ripple cross-laminated sandstone, here heavily oil-stained; next higher in the sequence is (3), wavy-bedded siltstone with lenses, that is, asymmetric ripples, of sandstone, here lightly oil-stained; and finally, at the top, is (4), sets of slightly inclined, parallel-laminated, clay-rich siltstone or silty shale. This sequence is interpreted as the aggradational channel-fill and over-bank deposits of a perennial, low-gradient, meandering stream.

Thus, extent and quality of the reservoir rock determine the productive area of the oil pool. Other Cherokee sand reservoirs in the area, whether fluvial channel deposits or the product of some other environment, exhibit similar lateral discontinuity and usual length in comparison to width. The frequently changing paleogeography of Middle Pennsylvanian time apparently prevented lateral coalescence of sand-depositing environments and, consequently, no sheet-sand bodies were formed. This, of course, is a factor in estimating potential undiscovered reserves in the very shallow subsurface area between the present pro-

ducing trend and the similar tar-impregnated, lenticular sandstones in outcrops to the east.

Another factor of prime importance in evaluating the potential worth of these heavy-oil resources is the chemical and physical properties of the crudes themselves, as this bears directly on their producibility and refinability.

GEOCHEMISTRY

Crude Oil Gravity

Gravity of the oils in the Cherokee ranges widely, varying both geographically and with depth. Figure 12 shows the distribution of some oil-gravities and depths at which they occur in the various producing areas. There is no obvious pattern to the values. Heavier and lighter crudes, differing by 5 to 8 degrees-A.P.I. may occur in the same pools, and oils contained in different reservoirs at approximately the same depth may vary in gravity by more than 15 degrees.

Heavy oils (10 to 25° API) occur at depths ranging from near-surface to about 1250 feet. Medium gravity oils (25 to 35° API) also occur in this relatively shallow depth range. Lighter oils (35 to 42° API) are produced from deeper reservoirs, with present depths of burial of 1400 to over 2200 feet.

Crude Oil Composition

Some of the chemical and physical properties of the Cherokee crude oils are shown in Tables 1 and 2. As noted, the API gravities of these crudes range from about 10° to over 40°. Despite their gravity range, almost all of the Cherokee crudes are considered naphthenic oils, based on interpretation of U.S. Bureau of Mines Routine Distillation Analysis. The sulfur contents of the heavier oils are about double or triple that of the medium and light oils, but even so, the heavier crudes contain less than 1% sulfur and must be considered low sulfur oils. The heavier oils are highly

resistant to flow, and only those in the upper limit of the low gravity range (22-25°) are somewhat recoverable by conventional secondary methods.

Table 2 illustrates the hydrocarbon composition of some high, medium, and low gravity oils, and of a highly weathered outcrop sample of a tar-impregnated sand. The heavy Bartlett oil, which appears to be typical of "dead-oil" sands, is actually a fairly good low-sulfur crude oil in that it contains about 80% saturated and aromatic hydrocarbons, and about 20% non-hydrocarbon material. For comparison, a rich Athabasca Tar sample, (16% bitumen, by weight) contains approximately 50% hydrocarbons and 50% non-hydrocarbon organic material. Lighter crudes commonly contain well over 90% hydrocarbons and have only minor amounts of non-hydrocarbon material. Although the heavy Cherokee crudes contain only small amounts of low and medium molecular-weight hydrocarbons, modern refineries should be able to produce substantial amounts of both gasoline-range hydrocarbons and fuel oils from heavy crudes like the Bartlett.

The heavier crudes differ in quality from lighter oils primarily in that they have less light ends, less total hydrocarbons, and slightly higher sulfur contents. There are also some differences in the types of hydrocarbon compounds present in the heavier crudes. In the gas chromatographic analysis of the heavy saturated-hydrocarbon fraction of a medium gravity (32°) Cherokee crude-oil from Ft. Scott, Kansas (Fig. 13), the series of peaks represent normal paraffins; these compounds are virtually absent from heavy Cherokee crudes like the 15° Bartlett oil as well from Athabasca Tar.

Alteration of Crude Oils

Some of the variables which could have affected the chemistry of the Cherokee crude oils are shown in Figures 14 and 15, which were modified from Evans, Rogers, and Bailey (1971).

As most of the Cherokee oil pools occur in stratigraphic traps consisting of porous sands encased in impermeable mudstones and claystones, the generation of petroleum was probably from organic material present in the Cherokee sediments. In most cases, migration pathways from older or younger source beds do not appear to exist. Although various types of kerogen present in different lithologies could have generated either gaseous hydrocarbons or different types of crude oils, the basic naphthenic character of most of the Cherokee crudes suggests derivation from similar types of source material. This suggests that variations in the Cherokee crude oil quality are primarily due to differences in maturation and alteration history, rather than to original differences in the crude oil source material.

The lighter Cherokee oils are present only in reservoirs with present depths of burial of 1400 feet or more, suggesting that they have been beneficially altered by only slightly elevated reservoir temperatures over a long period of geologic time. Gas deasphalting, which leads to higher gravity crudes by precipitation of asphaltenes, could have, and probably has, taken place in Cherokee reservoirs at all depths.

The fact that both heavy and medium gravity oils occur throughout the shallow zones of the Cherokee province, the

heavier oils being heavy by virtue of loss of both light ends and heavy normal paraffins, suggests that many of the oils present in these reservoirs have been altered by water-washing and biodegradation, as opposed to representing a more immature stage of oil generation. Unfortunately, extensive water flooding in these reservoirs has made studies of formation-water chemistry almost useless for supporting these concepts.

Obvious pathways of fresh-water influx to some of these reservoirs are difficult to detect, but possibilities include vertical tension cracks, lateral connection of reservoir sands to the surface, and avenues of flow from the subjacent basal Pennsylvanian-Mississippian unconformity. In contrast, the isolation of some reservoirs from such sources of "outside" waters is evidenced by a few occurrences of unaltered medium gravity crude oils at depths of only a couple of hundred feet.

RESERVES

In 1966, the U.S. Bureau of Mines estimated there were, in this Southeast area, 350 million barrels of crude-oil, in the range 20°-25° A.P.I., unrecovered from sandstones thicker than 10 feet and at depths less than 3000 feet. At that time, only about 12% of that amount was considered recoverable by available tertiary-recovery techniques. At least 16 fields were identified in which heavy oil was present, usually associated with higher-gravity crude.

If we assume the same types of sand bodies exist in the shallow subsurface between lenticular producing fields on the west and lenticular tar-impregnated sands on outcrops to the east, and that only 5% of the more-than-a-million acres of land is underlain by heavy-oil bearing sandstones which are 20 feet thick, on the average, we may estimate about one-million acre-feet of in-place reservoir rock. If further, we assign a figure for oil content of 400 B/AF, which is rather low for this area, we arrive at an estimate of three-quarters-of-a-billion barrels of known plus to-be-discovered heavy-oil resources in the southeast Kansas area.

While this figure is speculative at the present, it indicates optimism is appropriate in considering these oil-sands as a potential local fuel-for-the-future. How much of this resource is recovered, of course, will depend on efficiency of the in-situ recovery techniques employed.

CONCLUSIONS

While the occurrence of shallow, heavy crude oils in the southeast Kansas area has been known for a long time, little actual production has taken place. With increasing demand for crude oil, and probable price increases, the economics of various experimental in-situ recovery techniques tried here in the past should be more attractive.

The individual oil-sand reservoirs, most of which occur in the Middle Pennsylvanian Cherokee Group, are lenticular and discontinuous and vary greatly in extent. They comprise sand bodies deposited in coastal plain and near-shore marine environments. The nature and geometry of the sand bodies is more important in localizing oil accumulations than is structure of the rocks.

Geochemically, the heavy-oils are low-sulfur naphthenic crudes whose gravity ranges from less than 10° to 25°API. These crude oils have been altered by water-washing, gas deasphalting, and bacterial biodegradation.

The total resources of heavy-crude oil present in southeast Kansas is estimated to be three-quarters of a billion barrels, including known-but-unproduced resources of 350 million barrels, plus 400 million barrels of to-be-discovered resources east of the area of present production.

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APPENDIX

Analytical Techniques

The organic-geochemical methods of analysis employed in this study of crude oils and oil-impregnated sands are modifications of techniques described in a compilation by Davis and Bray, 1969 (Analyses of oil and cap rock from Challenger (Sigsbee) Knoll, in Initial reports of the deep sea drilling project, v. 1, Ch. 22: Washington, D.C., U.S. Gov't. Print. Off., p. 415-500).

The crude oils were characterized by API gravity, sulfur content, and hydrocarbon-type group analysis of the heavy "C₁₅₊" fraction (boiling point above 270°). The C₁₅₊ fractions of the crude oils were obtained by topping the oil in an oven for 19 hours at 45° C. The asphaltenes were precipitated from the topped crude oil with n-pentane, and the deasphalted oil (n-pentane soluble) fraction was separated into saturated hydrocarbon, aromatic hydrocarbon, and NSO heterocyclic fractions by elution chromatography on silica gel (Davison 950) and alumina (Alcoa F-20) columns by successive elutions with n-pentane, benzene, and 1:1 benzenes methanol. The C₁₅₊ saturated hydrocarbon fraction was further characterized by gas-chromatography utilizing a eutectic salt column packing (Hunneman et al., 1960, Anal. Chem. 32, 1386).

TABLE CAPTIONS

Table 1. Characteristics of some Cherokee crude oils and their depths of occurrence. (data from U.S. Bureau of Mines).

Table 2. Comparison of chemistry of Cherokee crude oils of differing gravity (data from U.S. Bureau of Mines and this study).

FIGURE CAPTIONS

- Fig. 1. Location of the Cherokee Basin.
- Fig. 2. Surface geology of the study area in southeastern Kansas.
- Fig. 3. Cross-section showing northward onlap of Desmoinesian and Lower Pennsylvanian sediments in the northeastern Oklahoma-southeastern Kansas area.
- Fig. 4. Structural cross-section in southeastern Kansas (data from Lee and Merriam, 1954).
- Fig. 5. Simplified surface stratigraphy of the Middle Pennsylvanian section in southeastern Kansas (simplified from Zeller, 1968).
- Fig. 6. Distribution of oil and gas fields in the southeastern Kansas study area which produce from Cherokee sandstone reservoirs (from data in Beene, 1967; Beene, 1967; Beene, 1973; Dilts, 1973; Jewett, 1964).
- Fig. 7. Type-log for the Davis-Bronson Pool, Allen and Bourbon Counties, Kansas (modified from McQuillan, 1968).
- Fig. 8. Subsurface structure map of a marker bed above the producing reservoir, Davis-Bronson Pool. (modified from McQuillan, 1968).
- Fig. 9. Subsurface isopachous map of the thickness from the top of the Cherokee Group to the base of the producing sandstone in the Davis-Bronson Pool (modified from McQuillan, 1968).

- Fig. 10 Stratigraphic section of the producing sandstone, Davis-Bronson Pool (modified from McQuillan, 1968).
- Fig. 11 Core segments from the reservoir sandstone, Colt 2-A Gillaspie, Sec. 10-T24S-R21E, Davis-Bronson Pool, Allen County, Kansas. See text for discussion.
- Fig. 12 Map of the southeastern Kansas study area showing the gravity of some Cherokee oils and the depths at which they occur (data from Dietzman, et al, 1965, Dilts, 1973; Grandone, 1944; Heath, et al, 1972; Powell, 1956; Powell and Eakin, 1953).
- Fig. 13 Gas-chromatographic analyses of two Cherokee crude oils which differ in quality. See text for discussion.
- Fig. 14 Factors in the generation of hydrocarbons which may affect the quality of crude oil (modified from Evans, Rogers, and Bailey, 1971).
- Fig. 15 Factors tending to alter the quality of crude oil after its generation (modified from Evans, Rogers, and Bailey, 1971).

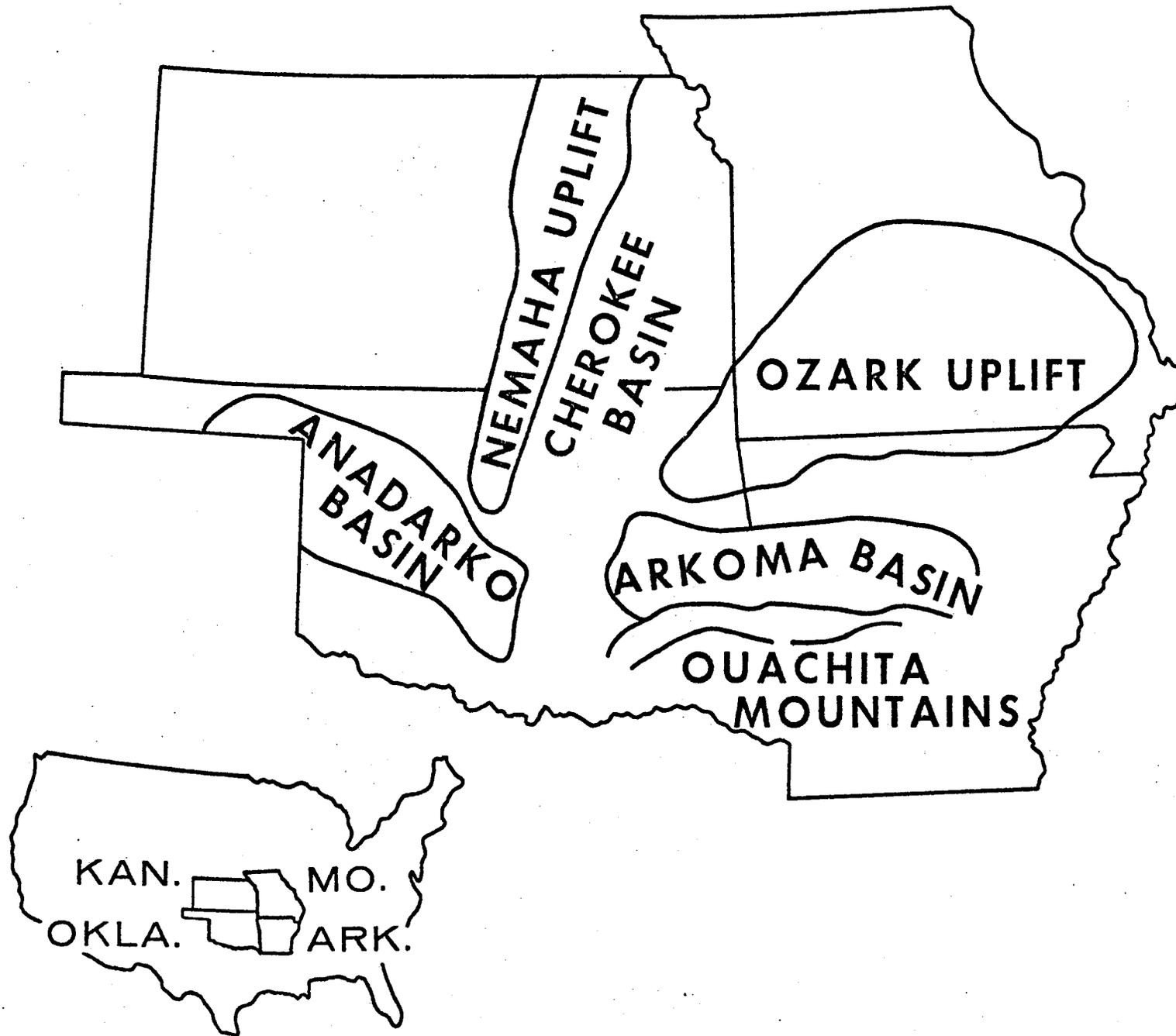
C H E R O K E E O I L Q U A L I T Y

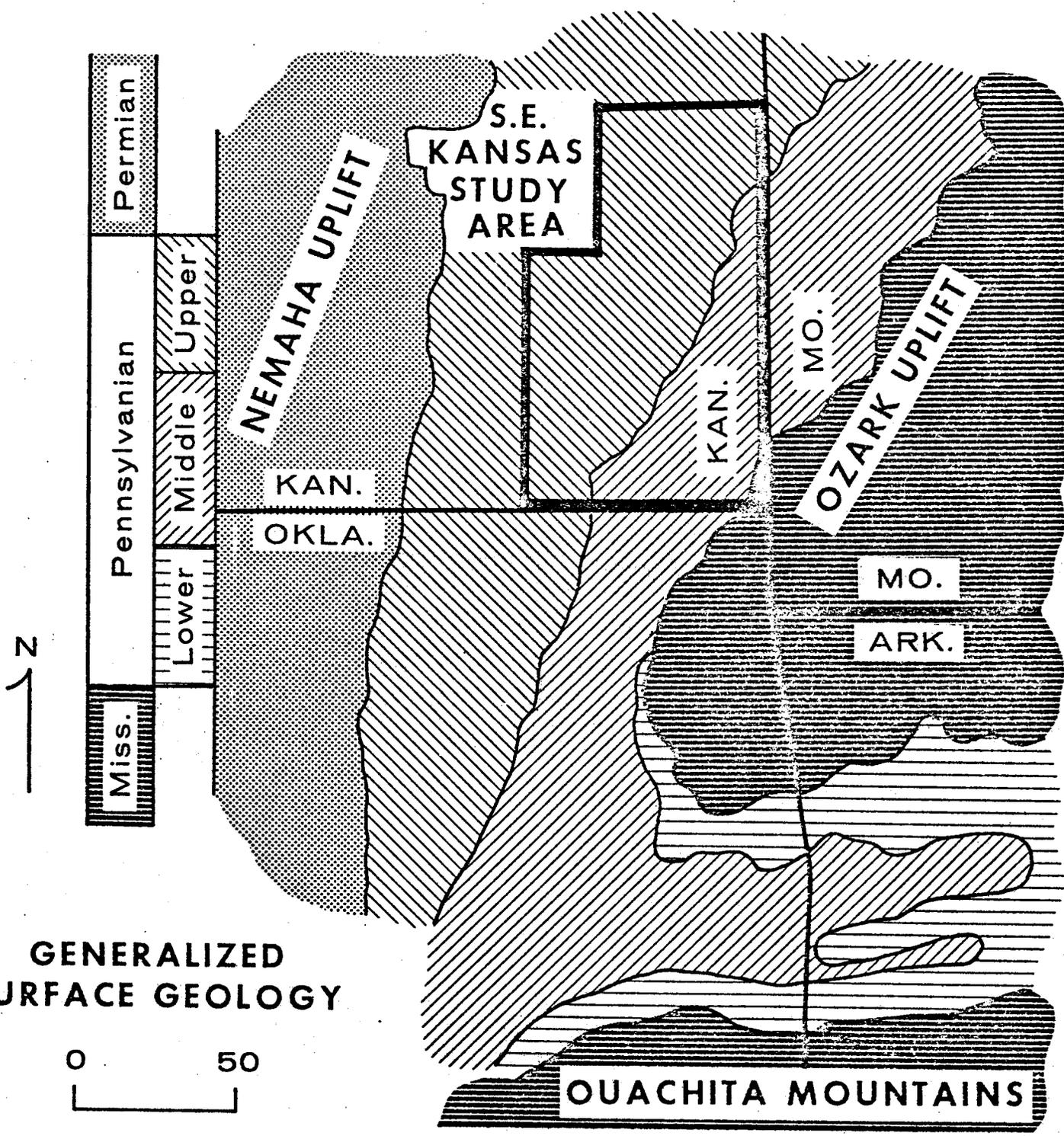
	HEAVY OIL		MEDIUM	LIGHT
API Gravity	15 ^o	23 ^o	30 ^o	39 ^o
% Sulfur	.7	.6	.3	.2
Viscosity*	13,466	420	68	39
Depth of Burial	300'	1,230'	725'	1400'

*Saybolt seconds @ 100^o F.

C H E R O K E E O I L Q U A L I T Y

	Quincy	Ft. Scott	Bartlett	Cherokee ⌘
API Gravity	40 ^o	32 ^o	15 ^o	<10 ^o
% Light HC's	36	25	10	0
% C 15+	64	75	90	100
% SAT HC	62	58	42	17
% ARO HC	31	30	33	10
% NSO's	5	8	10	21
% ASPHALTENES	2	4	15	52
SAT / ARO	2.00	1.93	1.27	1.70
% HC	96	92	78	27
% Non-HC	4	8	22	73



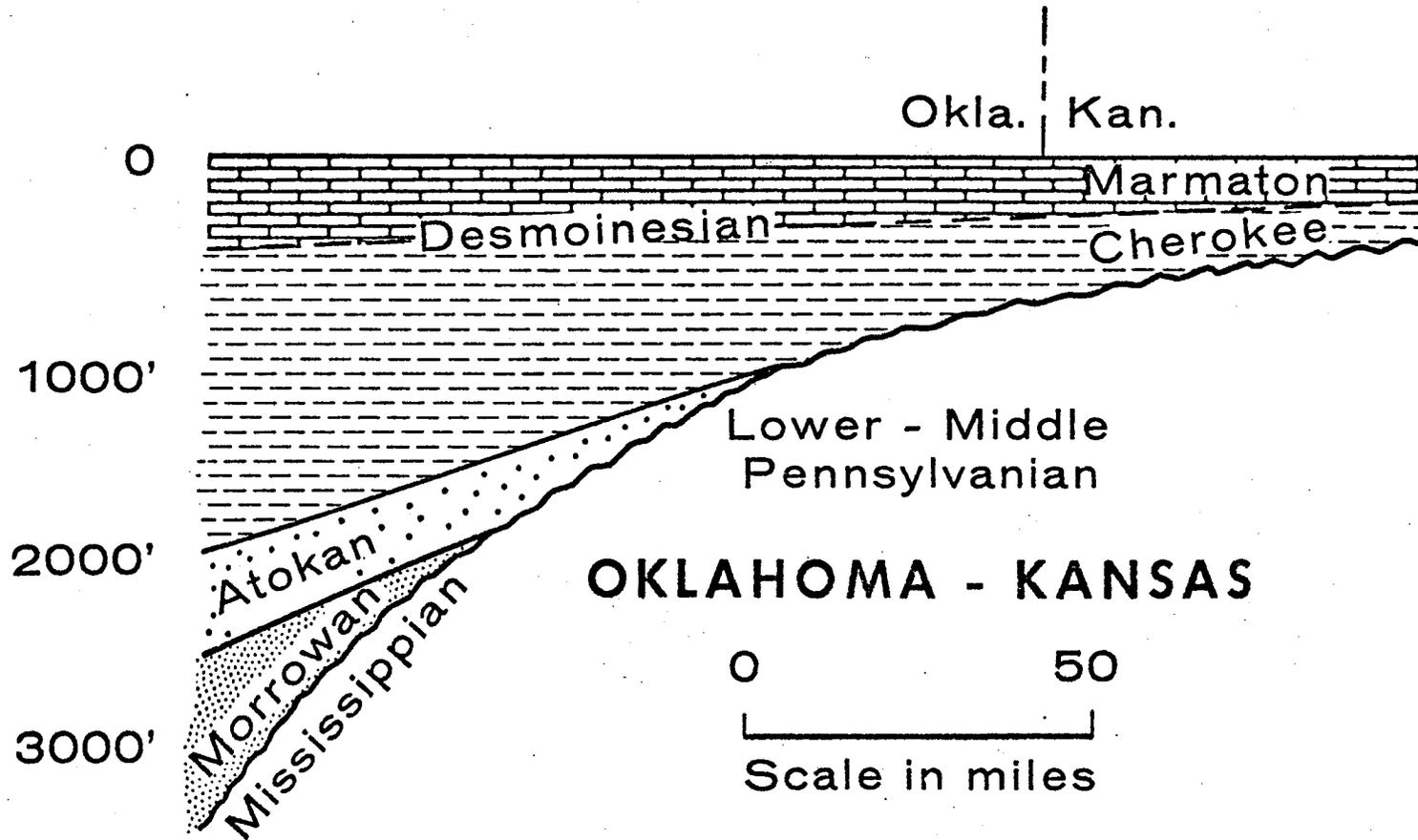


**GENERALIZED
SURFACE GEOLOGY**

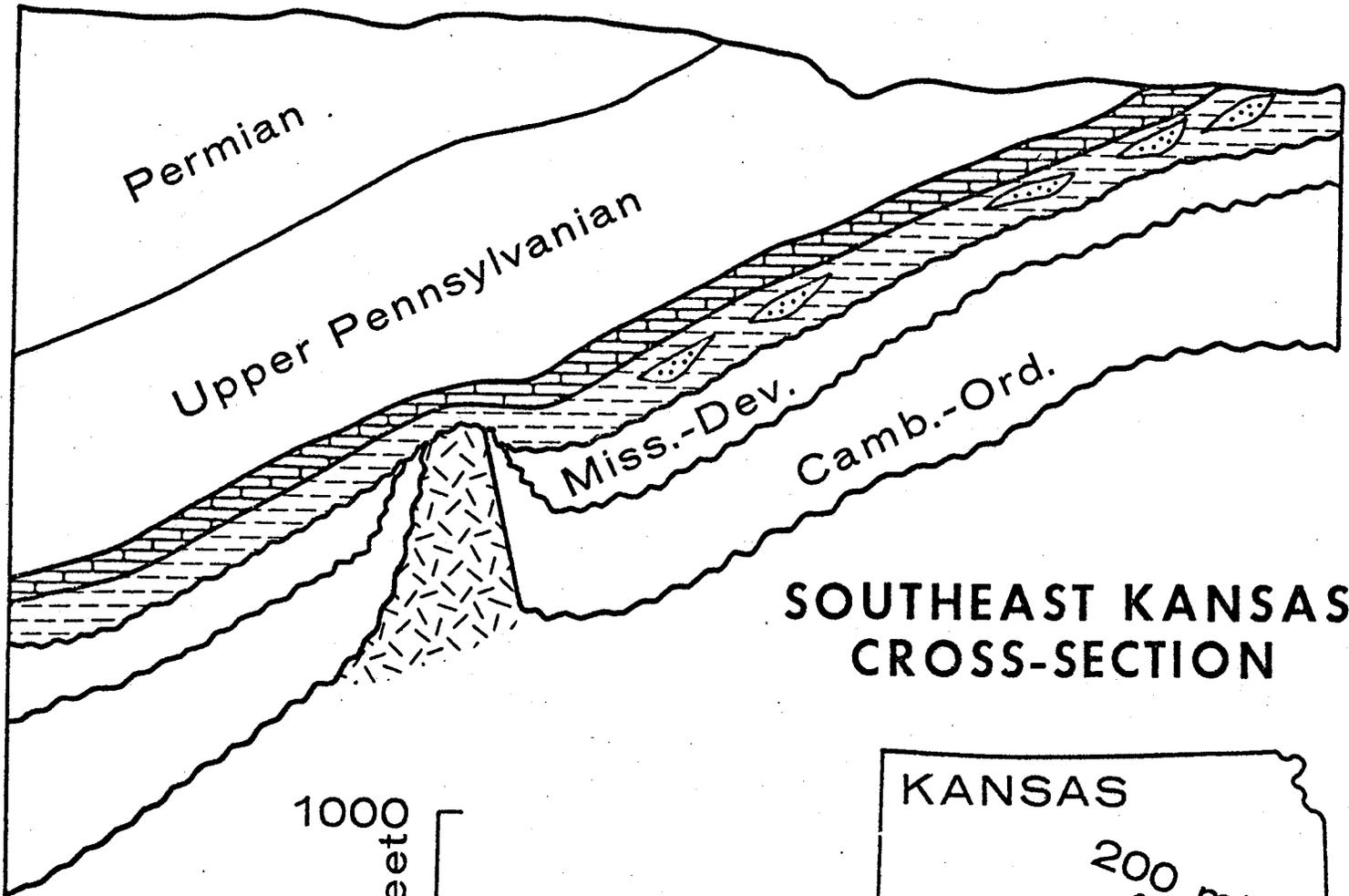
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 Scale in miles

ARKOMA BASIN

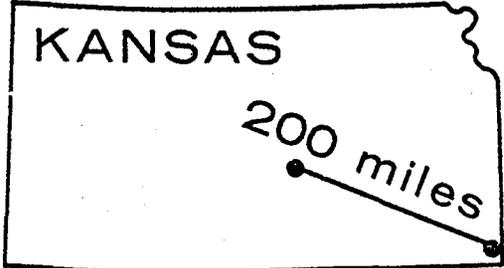
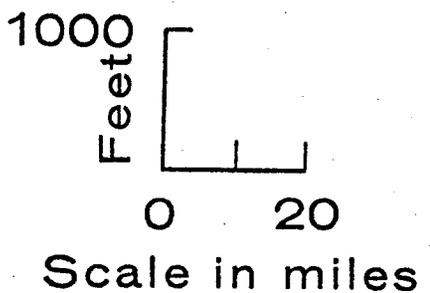
CHEROKEE BASIN

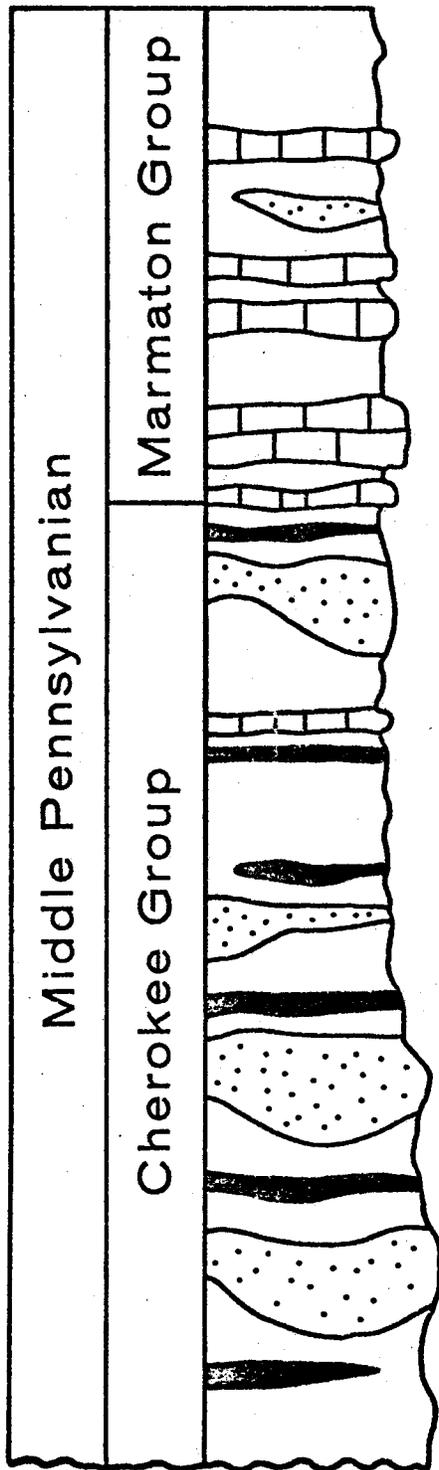


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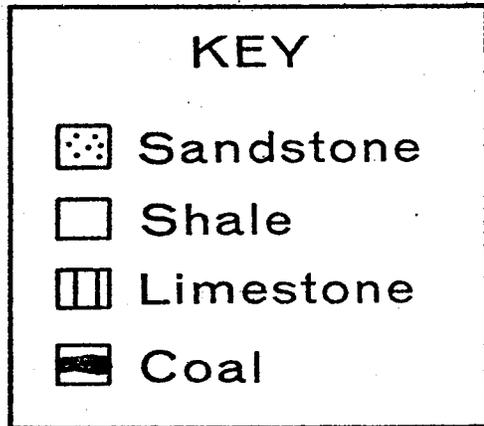
SOUTHEAST KANSAS CROSS-SECTION





Shallow Marine
Limestones
Shales

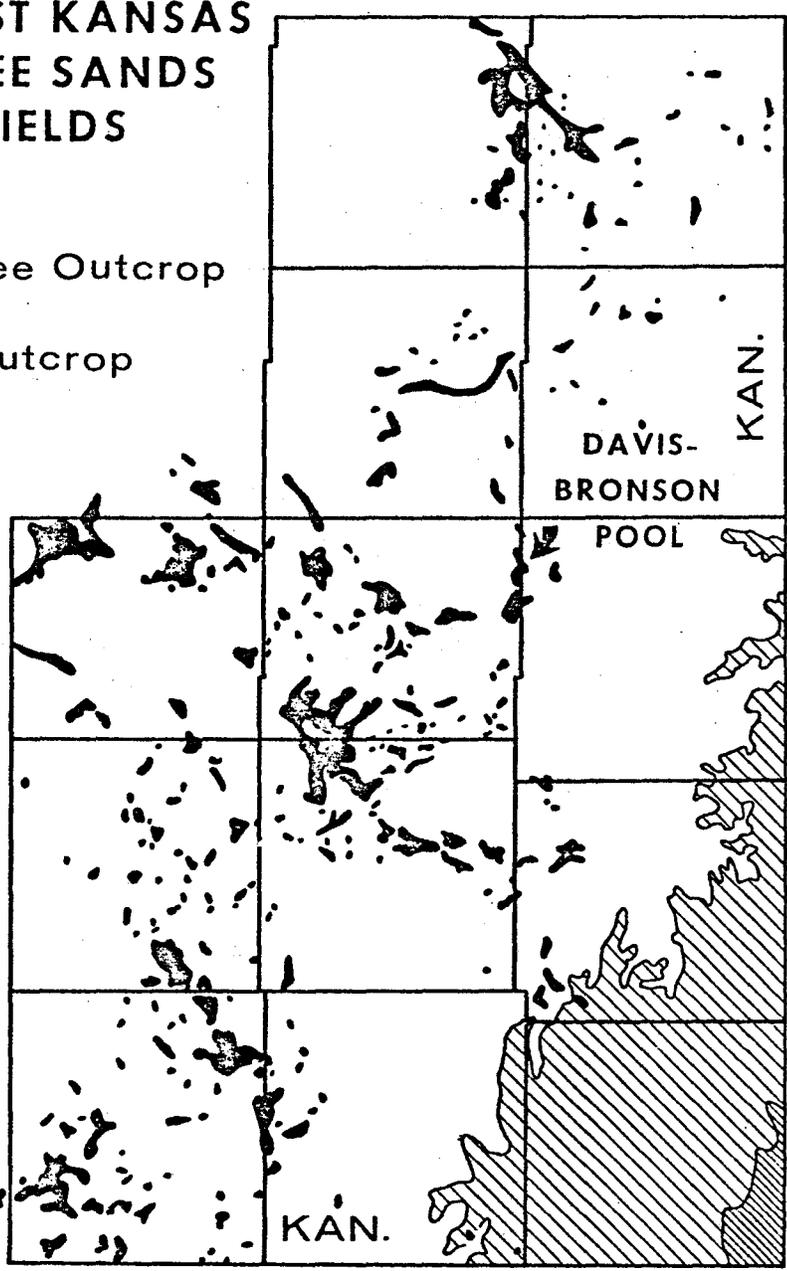
Coastal Complex
Sandstones
Shales
Coals



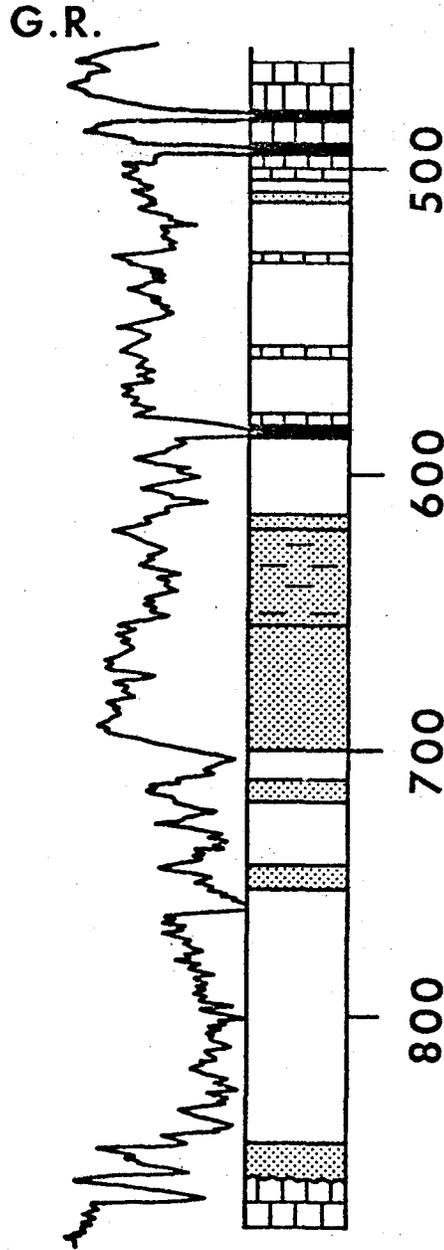
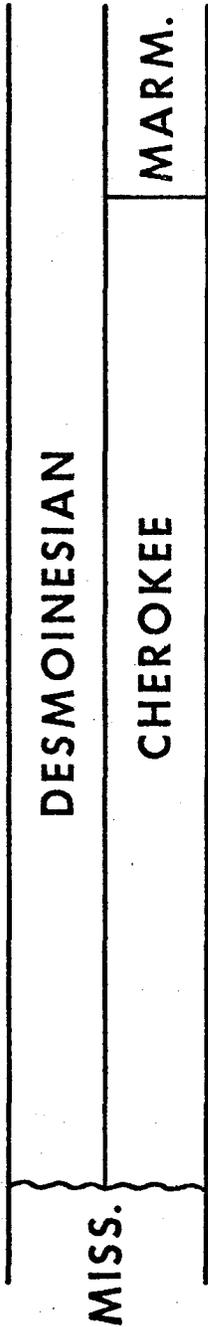
SOUTHEAST KANSAS CHEROKEE SANDS OIL FIELDS

-  Cherokee Outcrop
-  Miss. Outcrop

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Scale in miles



OKLA.

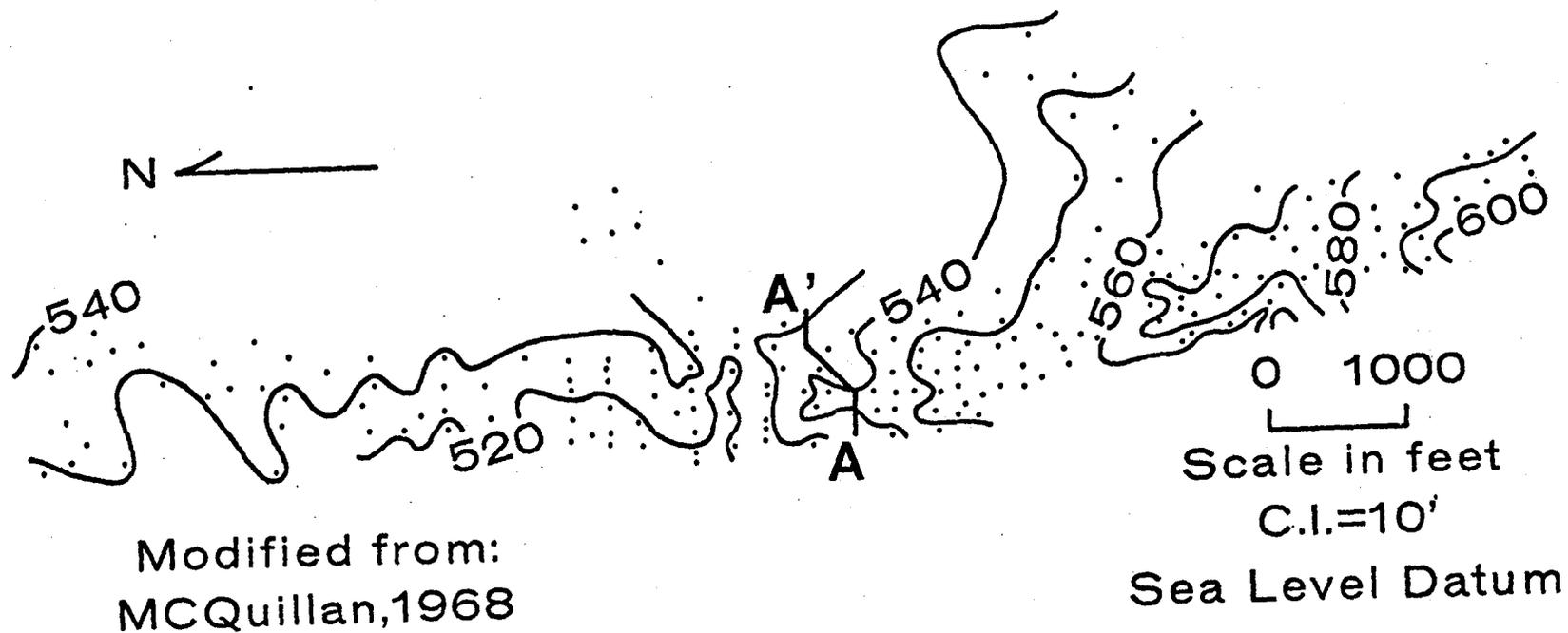


-  Ls.
-  Blk. Sh.
-  SS.
-  Ss.-Sh.
-  Sh.-Sl.-Coal

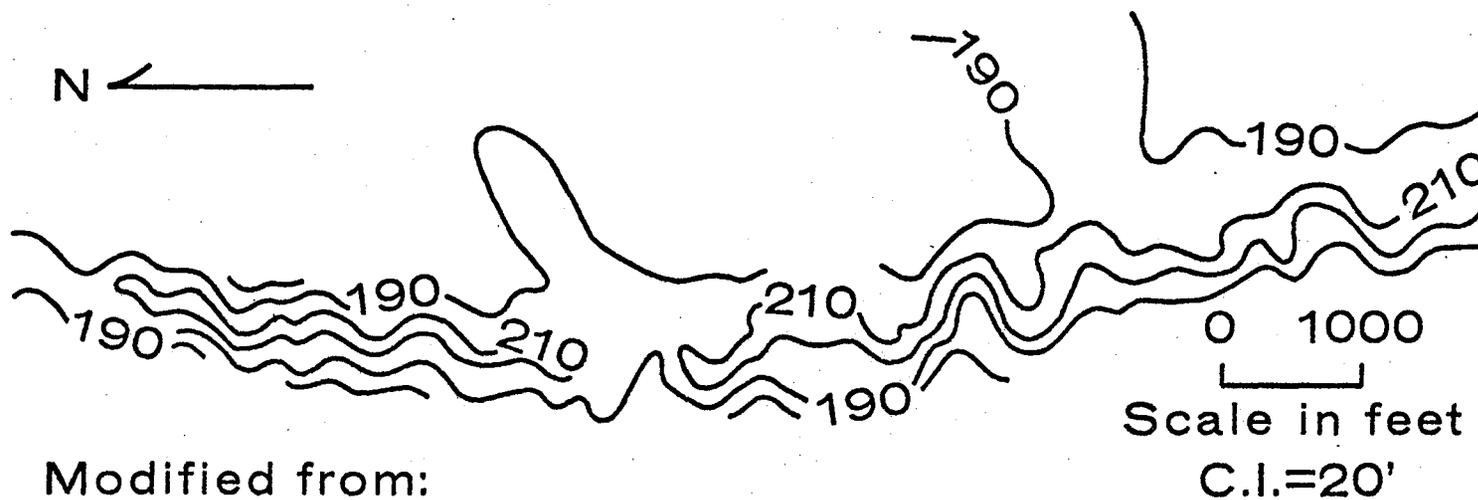
TYPE LOG DAVIS-BRONSON POOL

Modified From
Mc Quillan, 1968

DAVIS-BRONSON POOL STRUCTURE MAP TOP OF CHEROKEE

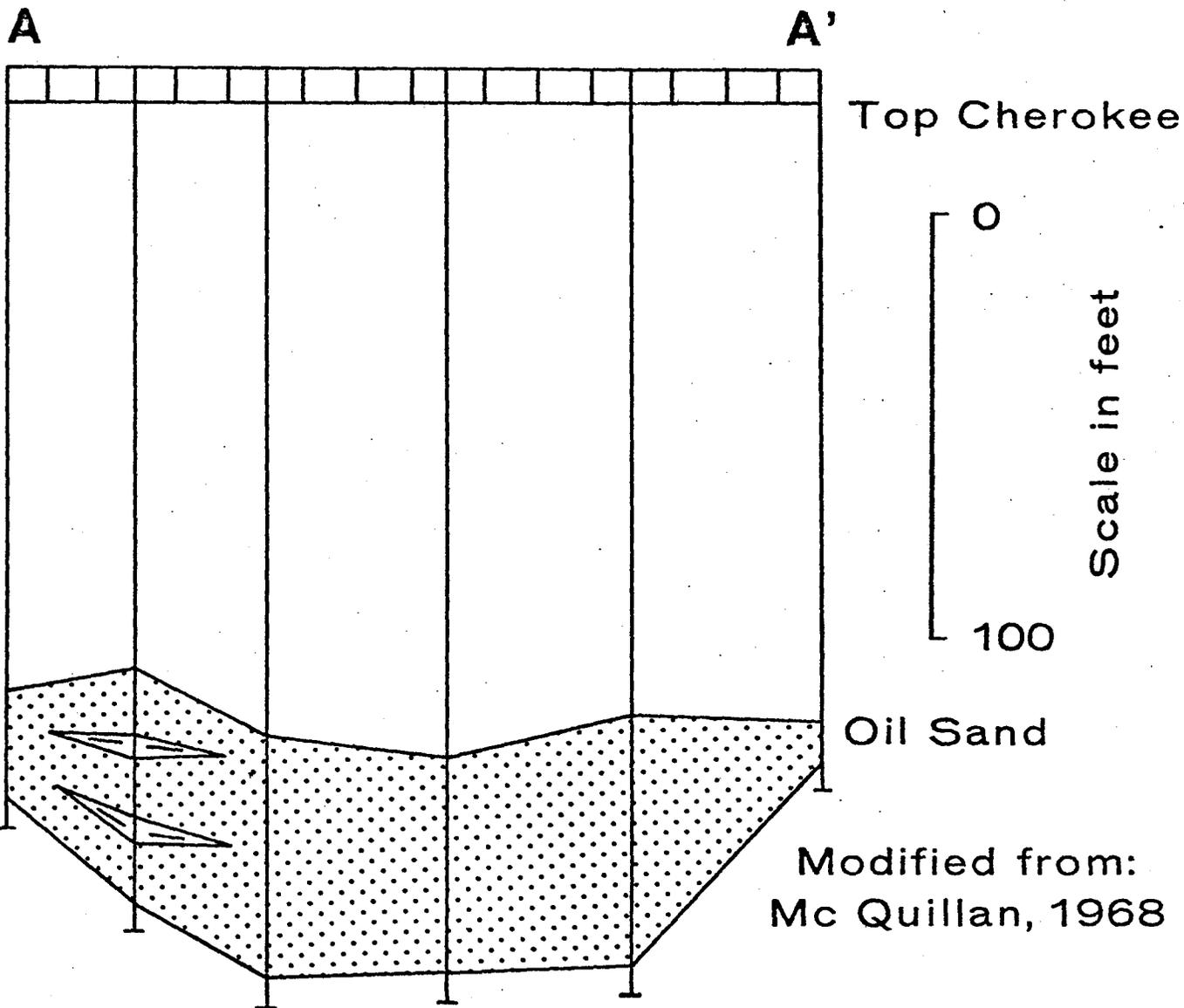


**DAVIS-BRONSON POOL
ISOPACH MAP
TOP OF CHEROKEE
TO BASE OF OIL SAND**

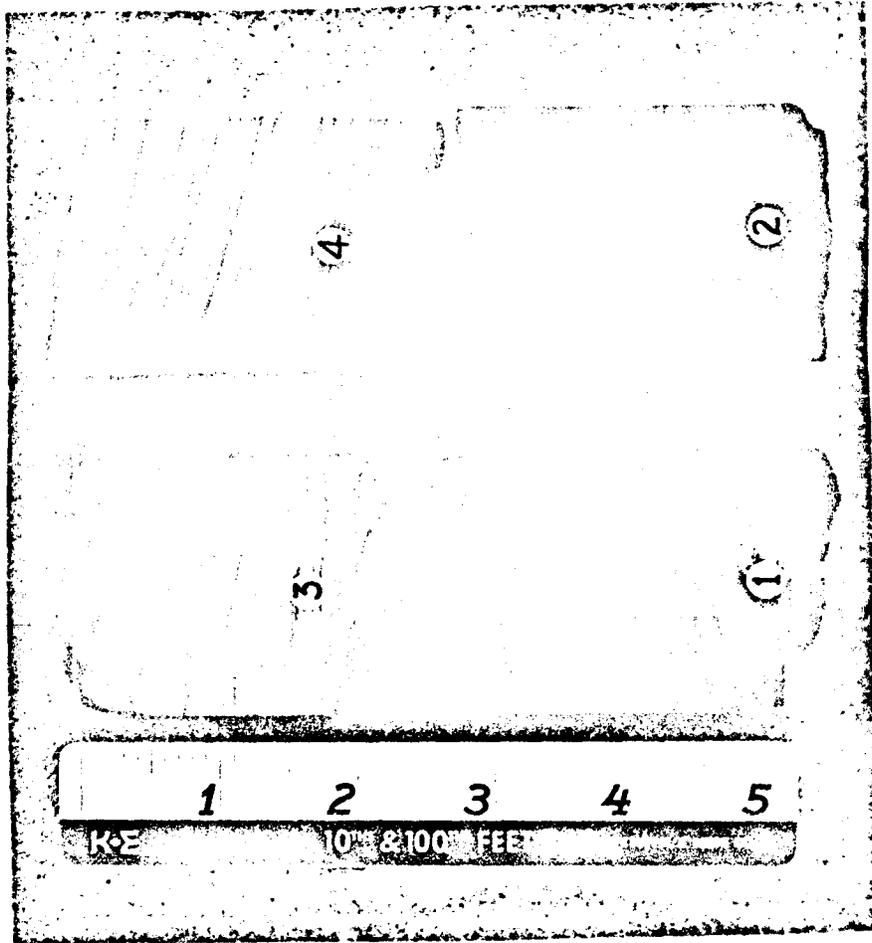


Modified from:
MCQuillan, 1968

DAVIS-BRONSON POOL STRATIGRAPHIC SECTION



Modified from:
Mc Quillan, 1968



SOUTHEAST KANSAS CHEROKEE SANDS OIL FIELDS

 Cherokee Outcrop

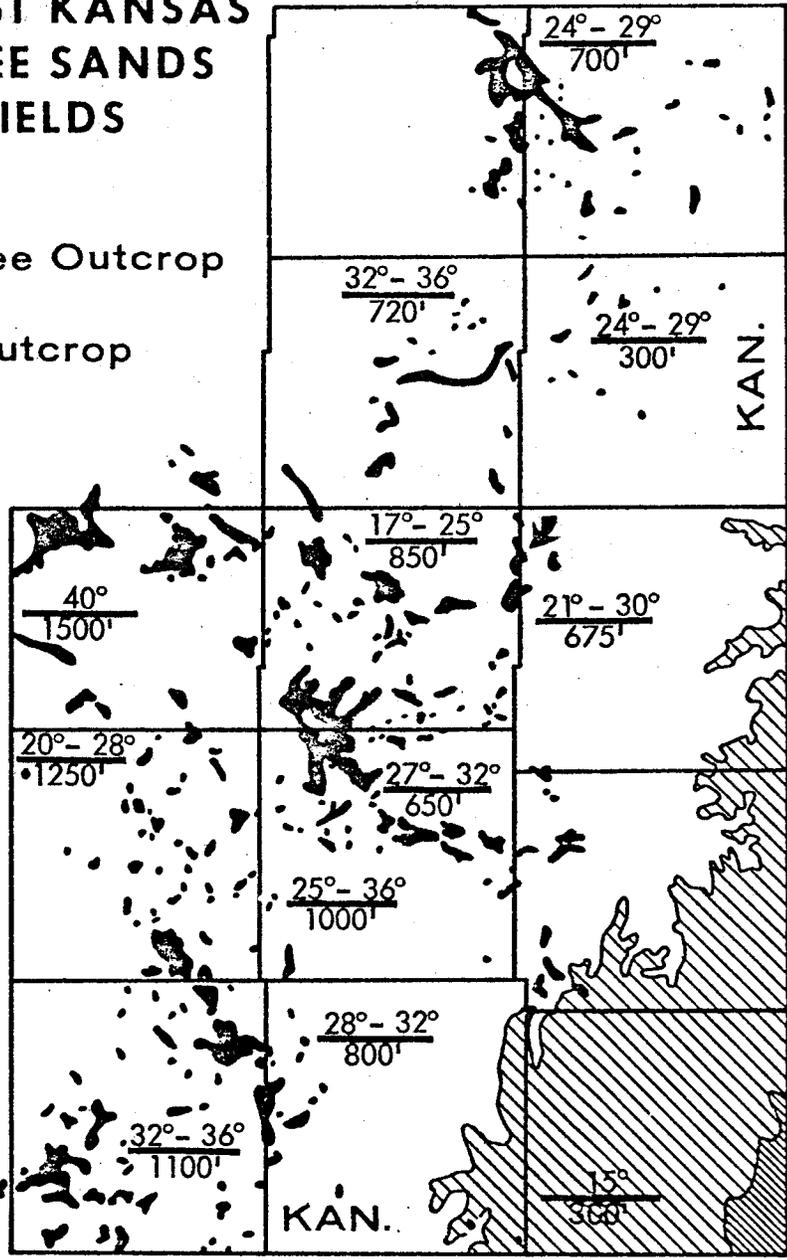
 Miss. Outcrop

GRAVITY
DEPTH

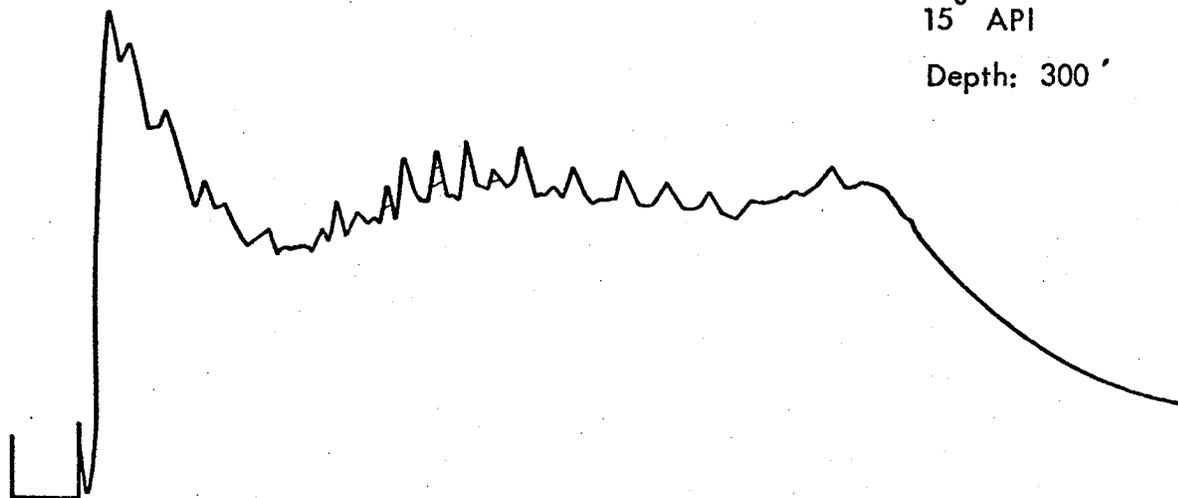


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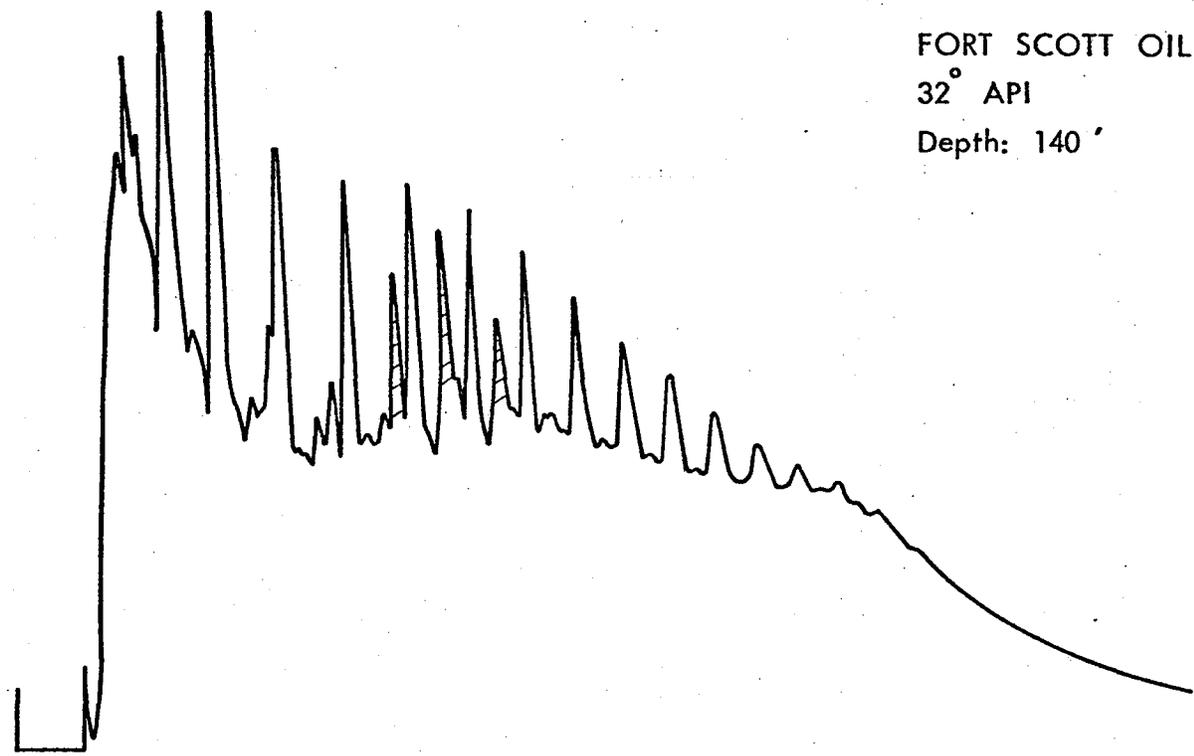
Scale in miles



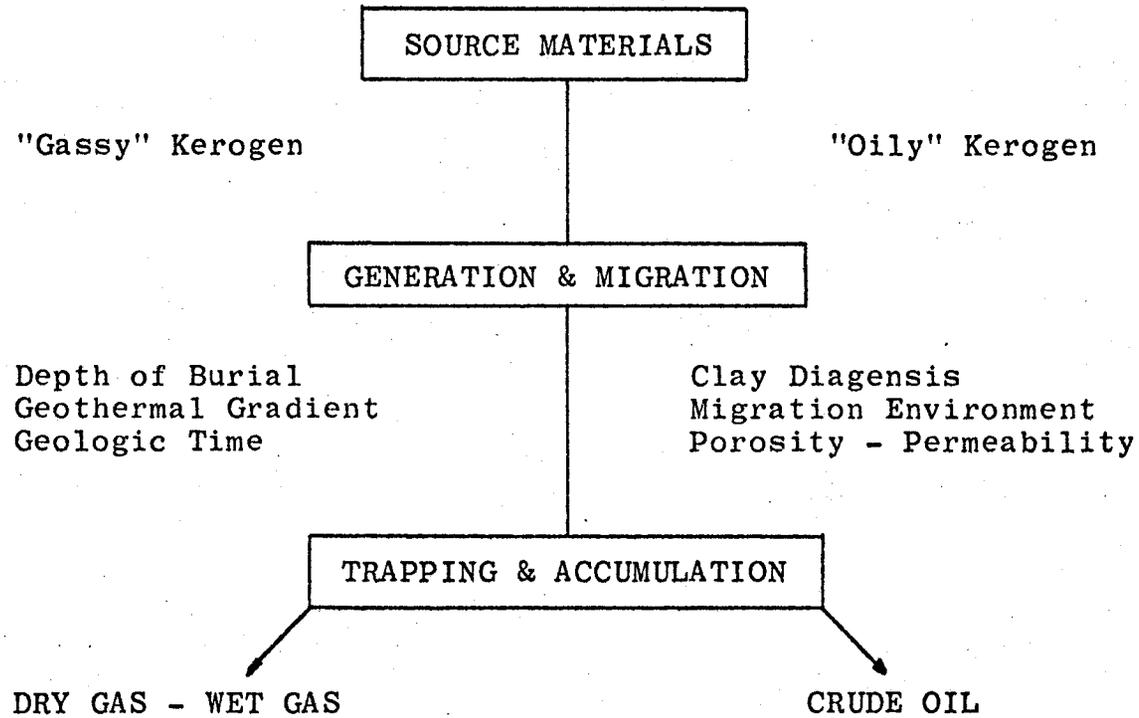
BARTLETT OIL
15° API
Depth: 300'



FORT SCOTT OIL
32° API
Depth: 140'

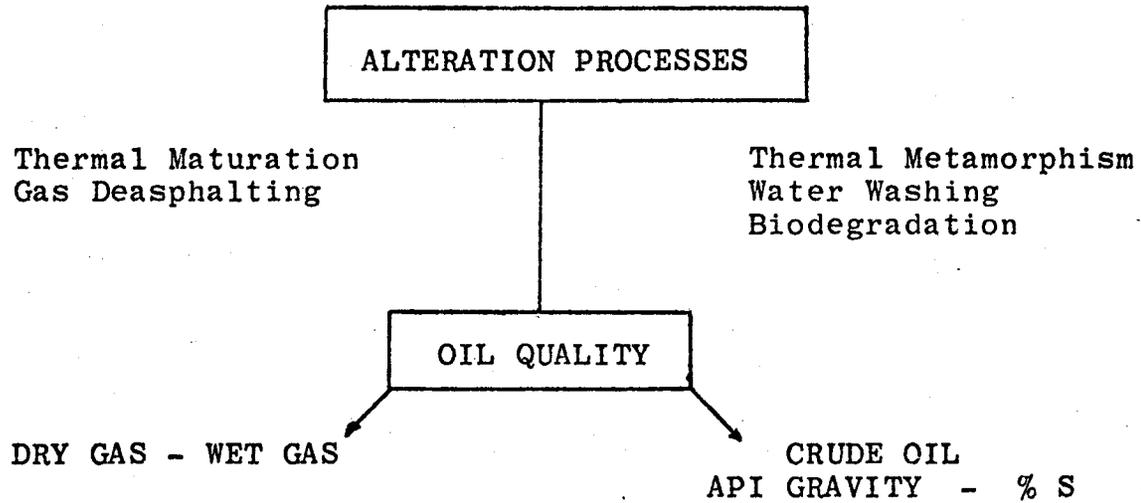


GENERATION OF PETROLEUM



After: Evans, Rogers, & Bailey, 1971

ALTERATION OF PETROLEUM



After: Evans, Rogers, & Bailey, 1971