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HYDROCARBON POTENTIAL IN THE FOREST CITY BASIN

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The Forest City basin is a shallow Late Paleozoic interior cratonic basin occupying the northeastern portion of Kansas and parts of adjoining Missouri, Iowa, and Nebraska. It is an asymmetric structural depression with a broad eastern flank and an axis that is situated very close to the Humboldt fault that separates the basin from the Nemaha uplift to the west. Its northern boundary is defined by the Thurman-Redfield fault zone in southwestern Iowa. The low-lying Bourbon arch forms its southern boundary with the adjacent Cherokee basin. Maximum depth to the Precambrian surface is about 5200 feet in Page County, Iowa (Figure 1).

PRODUCTION TRENDS

Two production trends dominate the Forest City basin (Figure 1). On the eastern flank of the basin a broad belt of oil and gas fields extends south-southwestward from the Kansas City region and continues into the Cherokee basin in southeastern Kansas and northeastern Oklahoma. This trend is characterized by stratigraphic and combination structural-stratigraphic traps developed in lenticular Middle and Upper Pennsylvanian sandstones of the Cherokee, Marmaton, and Pleasanton groups (Jewett, 1954). Most fields in the eastern production trend were

discovered before 1940. Early production records are not accurate but fields in the eastern production trend within the Forest City basin have probably produced in excess of 74 million barrels of oil and 6.6 billion cubic feet of gas. Stripper production now dominates this trend.

The second production trend is defined by a series of fields that occur in anticlines present along the north-northeast--south-southwest-trending axis of the basin (Figure 1). Most production in this western trend comes from Lower Paleozoic reservoirs including Middle Ordovician Simpson sandstones and Middle Ordovician Viola and Silurian-Devonian "Hunton" dolomites. Pennsylvanian Cherokee sandstone production occurs in the Tarkio field in northwestern Missouri, the northeasternmost field of the western production trend. Approximately 32 million barrels of oil have been produced from the western trend since the initial discovery of oil at the Falls City field in 1939 in Richardson County, Nebraska.

In the sparsely explored area between the production trends the drilling density averages below 2 wells per township (Burchett and others, 1983a). Many of these wells do not penetrate below the top of Mississippian strata. Only one small field, the Worner field, lies approximately halfway between the eastern and western production trends (Figure 1). This field was found in 1964 and produced oil from "Hunton" carbonates.

RECENT DEVELOPMENTS

A new round of exploration was spurred along the western production trend with the 1982 discovery of the McClain field in Nemaha County, Kansas (Figure 1). Thirty-eight successful oil wells in 8 new fields

have been completed in the region around the McClain field since 1982 (Figure 2), not including a new Viola discovery in Atchison County in northwestern Missouri this year. Cumulative oil production from new fields in the western production trend is in excess of 850,000 barrels. Initial production from Simpson and Viola reservoirs ranged from 6 to 183 barrels of oil per day (BOPD) while average daily production per well spanned from less than 5 to 39 BOPD.

Another flurry of discoveries has occurred since 1981 on the eastern side of the basin (Figures 1, 2). Most of this activity has been in Jefferson, Atchison, and Leavenworth counties, Kansas where 110 new oil wells and 181 new gas wells in 28 new fields have produced in excess of 284,000 barrels of oil and 1.7 billion cubic feet of commercially purchased gas. Initial production has ranged from 2 to 156 BOPD and 50 to 4900 thousand cubic feet per day from McClouth and Burgess sandstones developed near the base of the Cherokee Group, the lowest Pennsylvanian strata in the area.

GEOCHEMISTRY OF CRUDE OILS

An important factor linking the different pay zones along the western production trend is the geochemical similarity of the oils. Oils from Simpson, Viola, "Hunton", and even the relatively shallow Cherokee sandstone reservoir of the Tarkio field in northwestern Missouri have nearly identical chemical signatures as revealed by gas chromatography (Figure 3a). These oils are very similar to bitumen extracted from shales in the Middle Ordovician Simpson Group (Figure 3c). Chemical characteristics of Ordovician oils such as these include a relatively high abundance of n-alkanes with carbon numbers less than

20, a strong predominance of odd-numbered n-alkanes between C₁₀ and C₂₀, and relatively small amounts of branched and cyclic alkanes (Hatch and others, in press).

Gas chromatography indicates oils in the eastern production trend are distinctively different from oils in the western production trend (Figure 3d). The ultimate origin of the petroleum in the eastern trend is subject to speculation in that some researchers (Rich, 1933; Price, 1980) favor a scenario in which these hydrocarbons were generated in the Anadarko and Arkoma basins in Oklahoma and underwent long-distance migration into Kansas. Evaluation of this hypothesis is beyond the scope of this paper. However, Ordovician oils in the axis of the Forest City basin reside in a relatively deep, isolated structural position as compared to other Kansas production trends that extend into Oklahoma. Structure and isopach mapping (Anderson and Wells, 1968) indicates this structural isolation was maintained at least since Ordovician time, suggesting shales of the Simpson Group probably serve as an indigenous source of oil in the Forest City basin.

Geochemical sampling has revealed at least three fields on the eastern flank of the basin contain Ordovician oil similar to the fields in the axis of the basin. These fields, the Easton field (Mississippian limestone and Burgess sandstone pays; Figure 3b) and the nearby Corral Creek field (Burgess sandstone pay) in Leavenworth County, Kansas, and the Vassar field in Osage County, Kansas (Mississippian limestone pay), are on the westernmost fringe of the eastern production trend (Figure 1). Pay zones in these fields are approximately 200 to 400 feet structurally deeper than the closest production in the eastern trend. The presence of Ordovician oil in relatively shallow reservoirs on the

eastern side of the basin is very important because it indicates that this oil has been generated or migrated significantly away from the axis of the basin and that under certain conditions it can accumulate in younger, shallower reservoirs. The volume of Ordovician oil generated from shales in the Simpson Group and pathways of its migration are significant to defining probable locations of new oil accumulations.

POTENTIAL SOURCE ROCKS

Terrigenous clastics in the Middle Ordovician Simpson Group were deposited in a broad, shallow basin that encompassed most of northeastern Kansas, eastern Nebraska, and western Iowa. In Late-Mississippian--Early Pennsylvanian time movement of the Nemaha uplift effectively separated this basin into the Salina and Forest City basins and correspondingly removed Simpson and younger strata from the crest of the uplift (Lee, 1956; Figure 4a). Elongated thick areas of Simpson and overlying Decorah formation on the eastern side of the uplift nearly coincide in shape and trend to the present axis of the Forest City basin. However, these areas are not due to Late Paleozoic erosion but instead appear to represent differential subsidence during Simpson and Decorah deposition.

The distribution of net shale which contains the oil-prone organic matter in the Simpson and Decorah closely parallels trends of the overall thickness of these units (Figure 4b). The proportion of sandstones and carbonates that comprise the balance of the Simpson Group increases from 60% along the axis of the basin to 90% near the Kansas-Missouri state line. Samples of Simpson and Decorah shales are not available from all parts of the Forest City basin, consequently

there is presently poor control for detailed understanding of the spatial and stratigraphic distribution of organic matter and maturation in these rocks. However, analyses of over 60 samples of Simpson and Decorah shale from axial regions of the Salina and Forest City basin yield oil-prone (type-1) organic matter that varies between near zero to over 15 weight-percent total organic carbon. Wells (1971) also reports asphaltic residues and oil shows are commonly encountered in Simpson rocks in the Forest City basin. If the inferred volume of kerogen available for petroleum generation is roughly proportional to the volume of shale, then the probability of finding Ordovician-derived oil may be greater where substantial thicknesses of shale occur. According to Figure 4b, relatively thick sections of shale extend eastward considerable distances away from the axis of the Forest City basin, hence substantial source rock potential may be indicated for the vast sparsely drilled area between the two production trends. Other source-rock intervals may also be present but present discussion is limited to Ordovician shales.

Rock-Eval pyrolysis indicates Ordovician shales are in initial stages of maturity with respect to oil generation along the axis of the Forest City basin and the comparably buried axis of the adjacent Salina basin (Newell and others, 1986). Maturation modeling utilizing Lopatin's Time-Temperature Index (TTI) (Waples, 1985) was also utilized to calculate theoretical thermal maturity along the axis of the Forest City basin (Figure 5a). The modeling further indicates the Simpson should be in initial stages of oil generation along the axis of the basin. Maturation levels adequate for petroleum generation were reached

well past the Late Mississippian -- Early Pennsylvanian deformational event responsible for most structural traps within the basin.

Inasmuch as Simpson shales should be in initial stages of oil generation in the axis of the Forest City basin, it is of interest here whether they could be mature enough to generate oil on the relatively shallow eastern flank of the basin such as at the Easton and Vassar fields. The Simpson at these localities is approximately 1500 feet shallower than at the McClain field in Nemaha County, hence considerably less maturation would be expected. Regional studies (Rascoe 1962; Kauffman, 1977) also indicate paleoburial, particularly in Permian and Cretaceous time, was probably less on the eastern flank of the basin than along the basin axis. However, geothermal gradients are considerably higher in eastern Kansas than they are farther west and may offset effects of lesser burial (Figure 6). Present geothermal gradients in the Forest City basin vary from as low as 25 degrees C/km (2.3 degrees F/100 ft.) to over 50 degrees C/km (3.7 degrees F/100 ft.) (Stavnes and Steeples, 1982). Local temperature anomalies could conceivably cause isolated sites of thermally mature organic matter to be present in shallower portions of the basin provided the anomalies existed for a sufficiently long period of time. A temperature anomaly present in the vicinity of the Easton and Corral Creek fields may have resulted in local generation of Ordovician-derived oil produced from these fields and other fields nearby (Figure 6).

Maturation modeling indicates high geothermal gradients can easily compensate for lesser paleoburial. A thermal modeling scenario for the axis of the basin in the vicinity of the McClain field in Nemaha County yields a TTI indicating initial stages of oil generation for the Simpson

Group (TTI = 21; Figure 5a). Assumptions for the McClain maturation model include a constant 30 degrees C/km (2.6 degrees F/100 ft.) geothermal gradient and a hypothetical burial by 2000 feet of subsequently eroded Cretaceous strata. A maturation model for the Easton field on the eastern flank of the basin for which a 40-degrees-C/km (3.2 degrees/100 ft.) constant gradient is assumed with no Cretaceous burial yields roughly comparable maturation for the Simpson group (TTI=18; Figure 5b). Maturation would be even greater if some Cretaceous burial was assumed to have occurred. Regional thermal events or temporary local thermal anomalies associated with faults and crustal discontinuities could also possibly contribute to petroleum generation in the Forest City basin (Steeple, 1982).

EXPLORATION STRATEGY

Knowledge of source rock occurrence and maturation when integrated with distribution of carrier systems and potential reservoir rocks establishes a logical exploration strategy for the area and aids in putting the present accumulations into perspective. Potential migration pathways for hydrocarbons generated from Ordovician shales include: 1) Simpson sandstones that are intimately interbedded with petroleum-generating shales; 2) fractures permitting vertical migration through brittle carbonate strata (Viola, "Hunton", Mississippian) which dominate the overlying interval up to the basal Pennsylvanian unconformity; 3) porous and permeable zones developed along unconformities including the unconformities at the base of the Pennsylvanian and base of Devonian-Mississippian Chattanooga Shale; and 4) widespread porous zones developed within carbonate units.

Obvious locations of oil migration and accumulation would be along north-northeast--south-southwest trending anticlines present in the axis of the basin. Berendsen and Blair (1986) have suggested some of these features are mechanically related to oblique left-lateral slip along the Humboldt fault zone, hence the relief of structural features related to deformation along the fault may decrease eastward away from the axis of the basin. Northwest-southeast structural trends dominate the eastern flank of the basin (Burchett and others, 1983b). Wells (1971) suggests intersections between cross-cutting structural trends would be optimal places to search for petroleum.

Structural features found in proximity to thermal anomalies may have a good chance for being productive. Key exploration wells should be drilled to at least the base of the Simpson in order to test all possible reservoir rocks that may accept oil generated from Ordovician source rocks. It may be possible to define some deeper prospects by shallow well tops but westward tilting has dominated the basin since Cretaceous time and structural culminations will likely migrate with increasing depth (Lee and Payne, 1944).

Possible stratigraphic traps that may develop into viable exploration plays include pinchouts of various "Hunton", Viola, and Simpson reservoirs beneath the sub-Chattanooga unconformity in the southeastern flank of the basin. Differentiation and mapping of individual sand bodies is very important in both exploring for and outposting hydrocarbon accumulations in the shallower Pennsylvanian sandstones. Environmental interpretation of Pennsylvanian strata using well logs and cores will be necessary for predicting reservoir trends and performance, particularly in the eastern production trend and in

areas where Ordovician oil has leaked upward into shallow Cherokee, Marmaton, or Pleasanton reservoirs.

Lastly, it is evident that geochemical analyses of oil and source rocks can be extremely valuable even in basins with long-established production trends. Analysis of potential source rocks for maturation and organic richness may help determine if large areas of the basin may be prospective. Chemical analysis of oils in producing fields would be very beneficial to determining both the source rocks of the oil and the likely migration route the oil has taken on its way to the reservoir.

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FIGURE CAPTIONS

Figure 1. Precambrian structure, oil and gas fields, and discoveries since 1981 in the Forest City basin (contour interval = 500 ft.; modified from Burchett and others, 1983a,b).

Figure 2. Discoveries since 1981 in the eastern and western production trends.

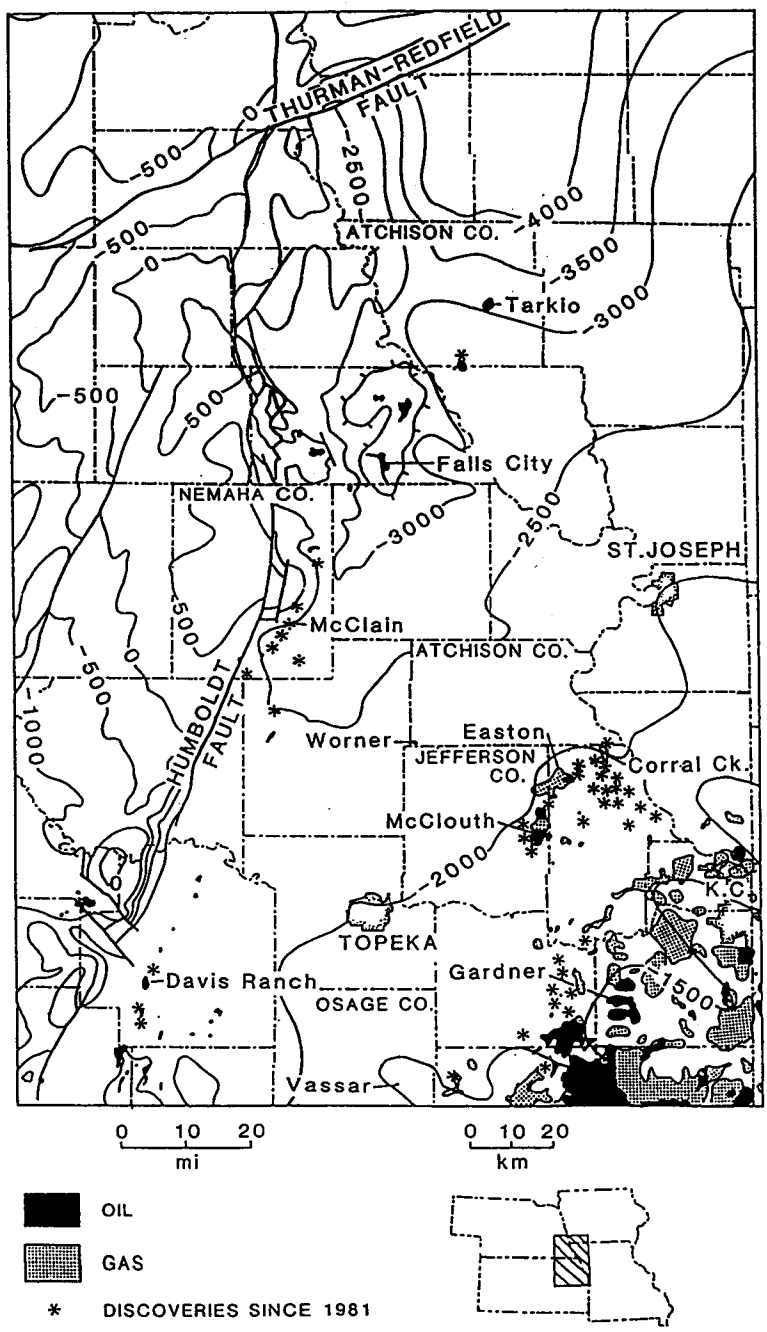
Figure 3. Gas Chromatograms.

Figure 4. a) Isopach of Simpson and Decorah in northeastern Kansas (contour interval = 10 ft.) and b) isopach of net shale in Simpson and Decorah (contour interval = 5 ft.).

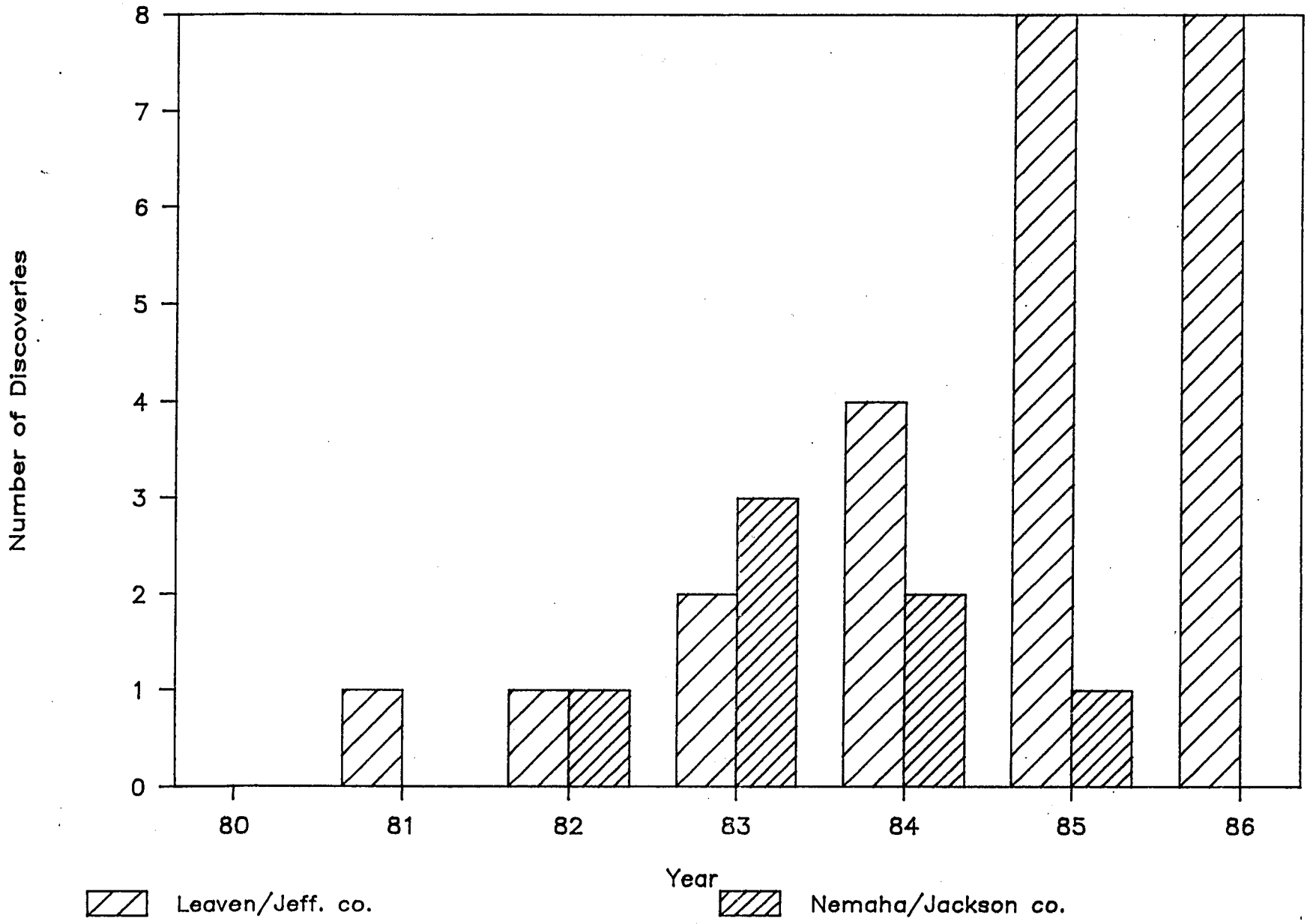
Figure 5. TTI maturation diagrams for a) near axis and b) eastern flank of Forest City basin.

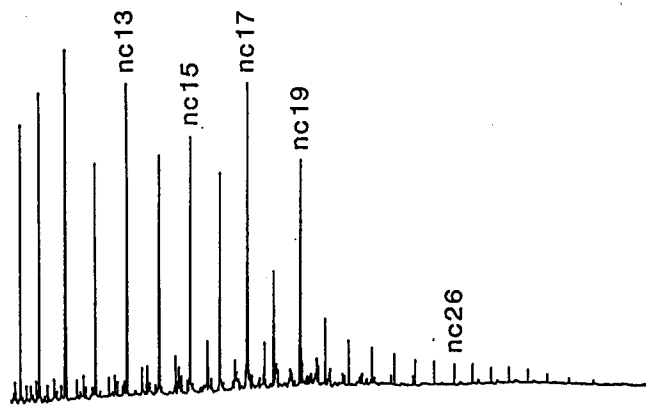
Figure 6. Geothermal gradients in Kansas (in degrees C/km) from 42,348 bottom-hole temperature from wireline logs (modified from Stavnes and Steeples, 1982). Humboldt fault and Bourbon arch indicated by heavy solid and dashed lines, respectively.

Figure 1

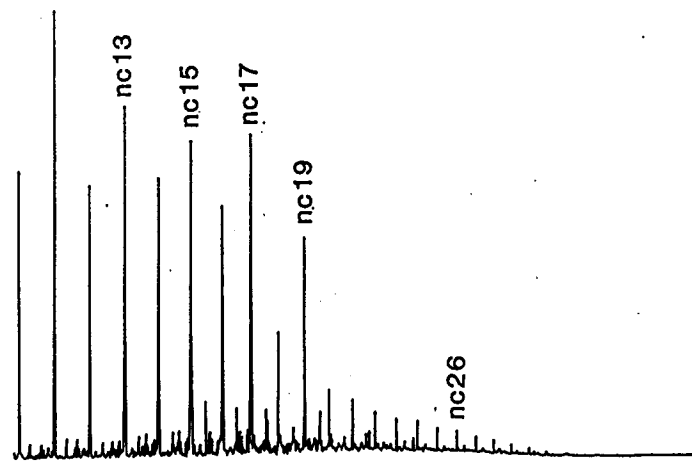


Discoveries Between 1980 and 1986

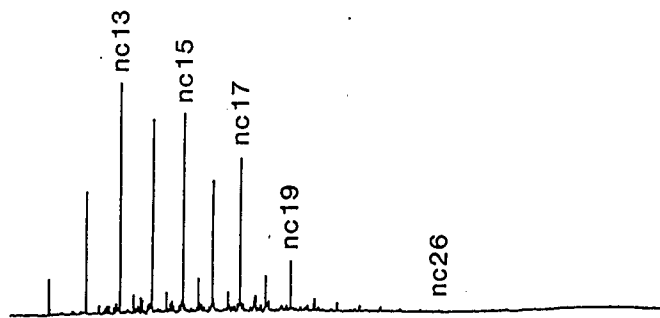




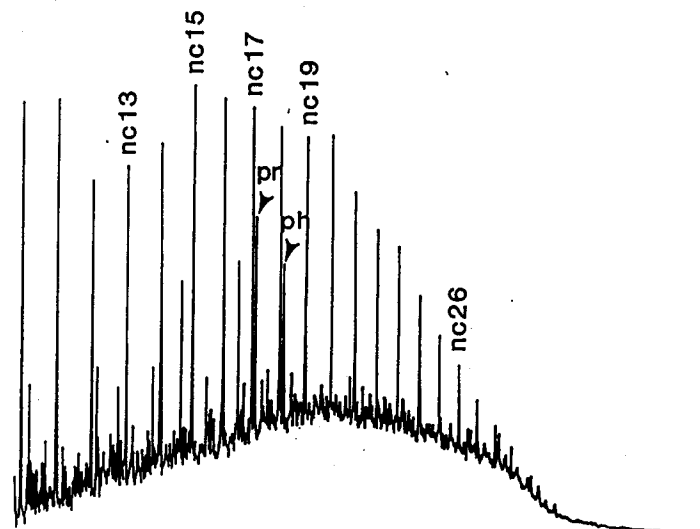
A Hunton oil, Falls City field, Richardson Co., NB



B Cherokee oil, Easton field, Leavenworth Co., KS



C Simpson shale extract, Wabaunsee Co., KS



D Cherokee oil, Gardner field, Johnson Co., KS

