Reproduction Copy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SOURCE BEDS OF PETROLEUM IN THE DENVER BASIN

by

Paul J. Swetland and Jerry L. Clayton

Open-File Report 76-572
1976

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

ABSTRACT

Crude oil and shale samples from the Denver basin of Colorado, Wyoming, and Nebraska were analyzed by organic geochemical techniques to determine the stratigraphic occurrence and regional distribution of petroleum source beds.

The study demonstrates that the oils produced from Cretaceous Sussex, Shannon, "D," and "J" sandstone reservoirs are genetically related and have probably been derived from Cretaceous source beds in the Carlile, Greenhorn, Graneros, and Mowry interval. Oils produced from fractured Niobrara and Lower Pierre formations are geochemically dissimilar to other Cretaceous oils and may have been generated in place. The Permian Lyons oil is distinctly different from all of the Cretaceous oils and its source has not been identified.

Samples of the Cretaceous Carlile-Greenhorn-Graneros-Mowry interval that contain hydrocarbon distributions similar to the Cretaceous oils examined are restricted to the basin axis area between Denver and Fort Collins, Colo. This limited geographic distribution of effective source beds and the occurrence of petroleum in thermally immature areas of the basin suggest that extensive lateral migration has occurred.

Organic geochemical studies can identify oil source-bed relationships and areas of favorable source-bed potential and can, therefore, provide valuable input to oil exploration decisions.

INTRODUCTION

The purpose of this study is to gain a better understanding of the processes of oil generation and migration in Cretaceous rocks of the Denver basin through the use of organic geochemical techniques. Groups, or "families," of genetically related oils have been identified and correlated with their source beds. The crude oil-source rock correlation and implications for future exploration are developed within the stratigraphic and regional geological framework.

The Denver basin is an asymmetric basin with its axis adjacent to the Front Range (fig. 1). On the east flank of the basin, oil is produced almost exclusively from the Cretaceous "D" and "J" sandstones. The "D" and "J" account for more than 90 percent of the total Denver basin production. Production from other reservoirs is generally limited to the basin axis and the west flank. These reservoirs include the Permian Lyons Sandstone and a number of Cretaceous reservoirs shown in figure 2. Crude oils were analyzed from each of the reservoirs indicated in figure 2. Oil from the Permian Lyons Formation was also analyzed for comparison with Cretaceous oils.

Cretaceous shales were obtained from outcrops, canned cuttings, and cores to provide the regional coverage shown in figure 1. To determine which units are potential source beds, the entire section of Cretaceous shales from above the Sussex* (Terry) down to the Skull Creek Shale has been analyzed although not at each sample locality.

*In this paper the names Sussex and Shannon are used instead of the Terry and Hygiene nomenclature.

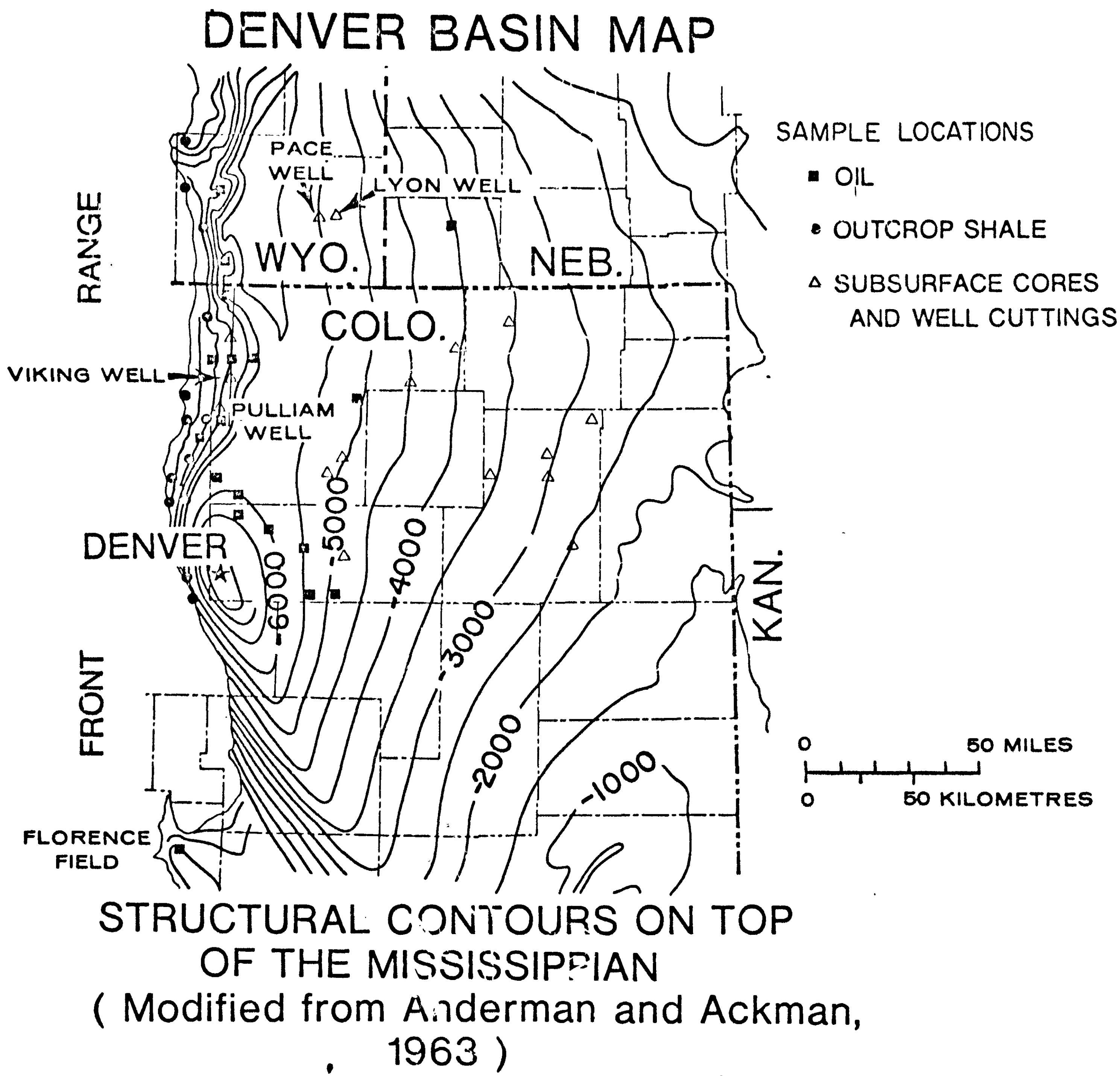


Figure 1.--Structural contour map of the Denver basin showing sample locations.

3

GENERALIZED CRETACEOUS SECTION FRONT RANGE

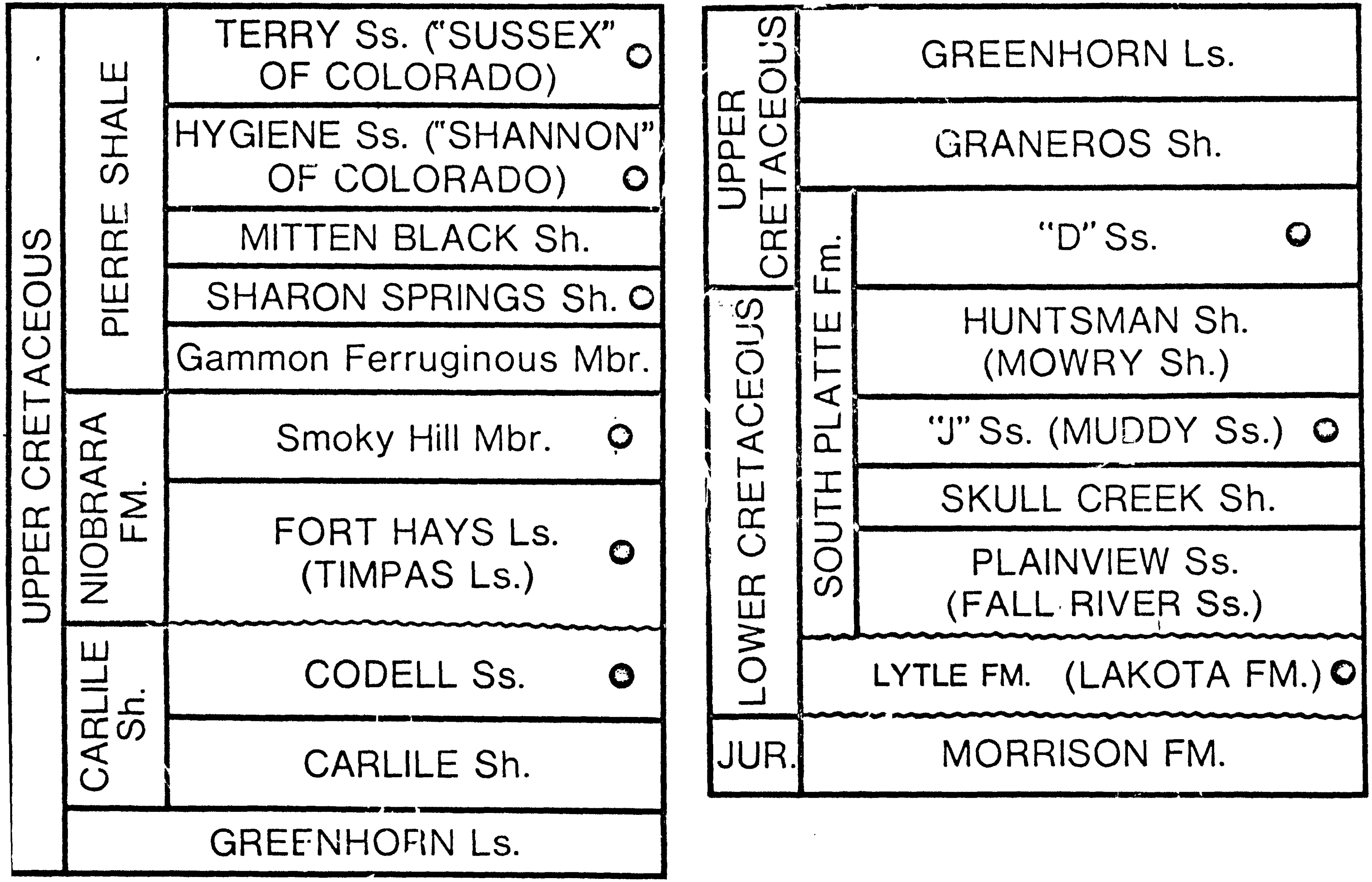


Figure 2.--Cretaceous stratigraphic section of central Front Range area, Colorado. Section shown in two columns for convenience with the Greenhorn limestone as the overlapping unit. Black dots indicate Cretaceous oil reservoirs sampled.

The source-bed potential of Cretaceous shales is evaluated by the geochemical measurements shown in table 1. To be considered a potential source bed, the shale must be both organically rich and thermally mature. In this study thermally mature means that the shale has generated hydrocarbons with a distribution similar to the Cretaceous oils examined.

Geochemical data are presented as follows: first, crude oils from different reservoirs are compared to determine which oils are genetically related, that is, which may have been derived from a common source; second, potential source beds for the oils are identified; and finally, the regional extent of effective source beds is shown.

COMPARISON OF CRUDE OILS

Analysis of the C_{15+} saturated hydrocarbon distribution indicates that all Cretaceous oils are similar and that the Permian Lyons oil is distinctly different from Cretaceous oils. Figure 3 compares the C_{15+} paraffin distribution of typical Cretaceous oils with Permian Lyons oil from the Black Hollow field (sec. 26, T. 8 N., R. 67 W.; Weld Co., Colo.).

A more detailed comparison of oils can be made by examining their gasoline range (C_4-C_7) hydrocarbon composition. Different oil types can be identified by the relative amounts of different hydrocarbon structural types they contain. Figure 4 shows a three-component plot of normalized percentages of straight-chain, branched, and cyclic C_7 saturated hydrocarbons. By this compositional comparison, the Cretaceous oils appear as one oil type and the Lyons oil as a distinctly different oil type.

Table 1.--GEOCHEMICAL MEASUREMENTS USED TO DETERMINE ORGANIC RICHNESS AND THERMAL "MATURITY"

S O U R C E   R O C K   E V A L U A T I O N

ORGANIC RICHNESS

- % organic carbon
- extractable hydrocarbons

THERMAL "MATURITY"

- GLC C_{15+} saturated hydrocarbons
- hydrocarbon/organic carbon

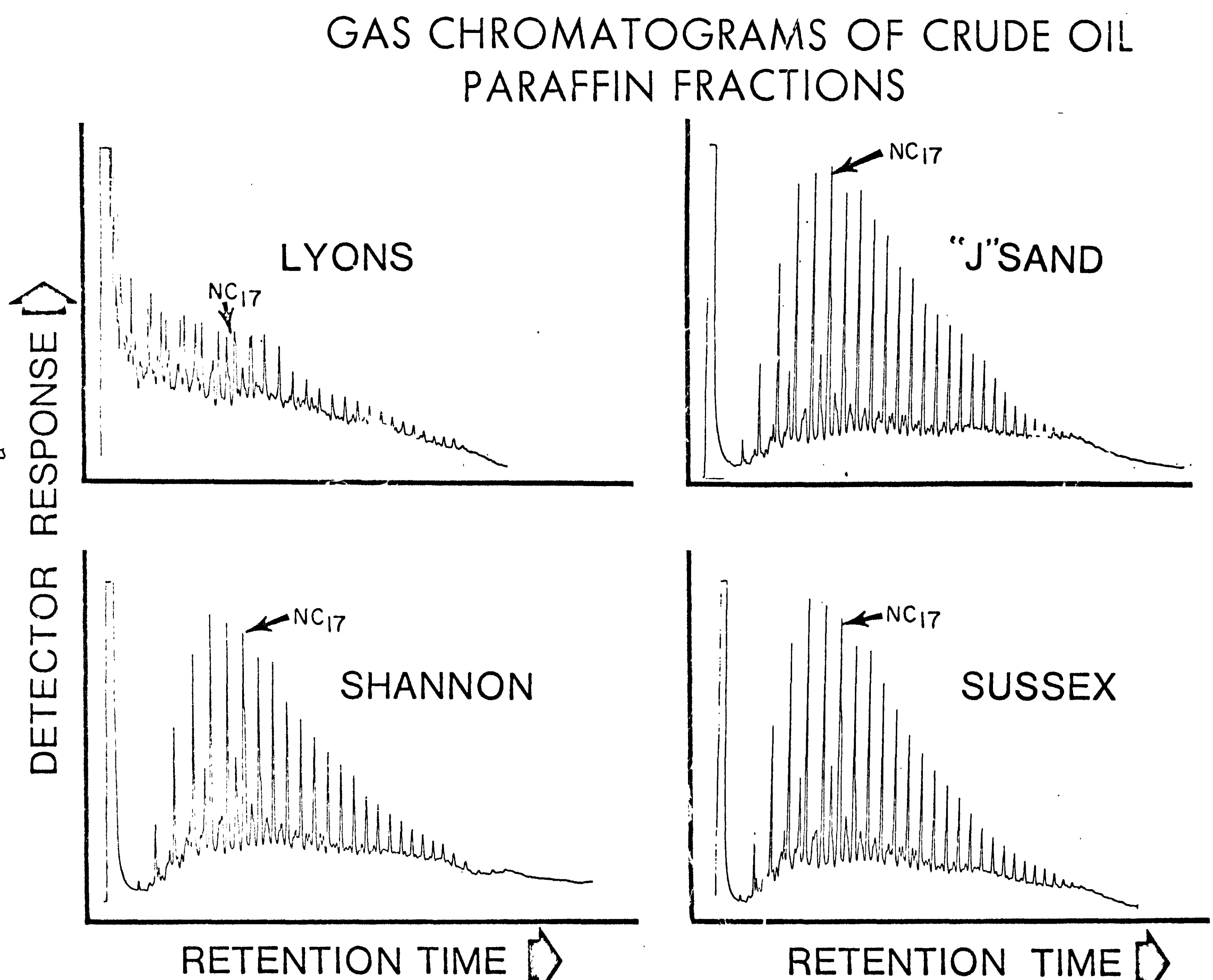


Figure 3.--Gas chromatograms of crude oil paraffin fractions. The location of normal heptadecane ($n\text{-}C_{17}$) is shown on each chromatogram.

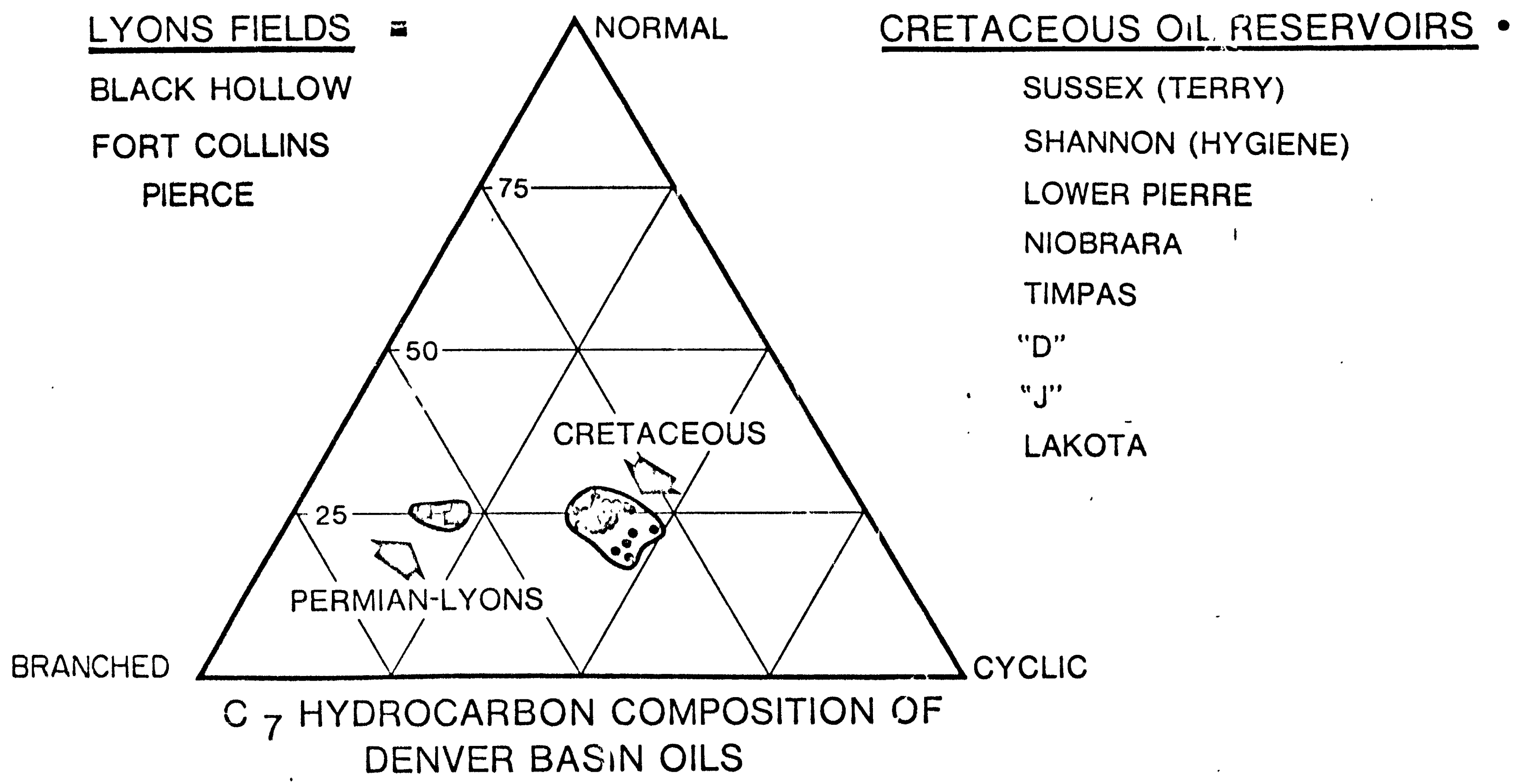


Figure 4.--Compositional comparison of oils from Cretaceous reservoirs with Permian Lyons oil. Dots indicate Cretaceous oil samples and squares indicate Permian Lyons oil samples.

To distinguish differences among Cretaceous oils, a compound by compound comparison was made using the nine gasoline range hydrocarbon ratios shown in table 2. Each ratio compares compounds with similar boiling points so that the physical-chemical effects of secondary processes such as migration and sampling procedure are not confused with primary differences due to the chemical nature of the source material.

The results of this compound by compound comparison of gasoline range hydrocarbons for Cretaceous oils are shown in figures 5a-g. The x-axis numbered from one to nine corresponds to the nine component pairs described in table 2. The value calculated for the ratio of each of the nine pairs is plotted on the y-axis. Figure 5a compares four Sussex oils (Spindle field - T. 1 N., R. 67 W.; Weld Co., Colo.) and shows that there is little compositional variation between oils from the same reservoir. The average composition of oils from each reservoir is plotted in all other comparisons.

The average Sussex oil cannot be distinguished from average Shannon oil (fig. 5b) implying that oils in both Sussex and Shannon reservoirs were derived from similar source beds. "D" and "J" oils are also compositionally similar (except for "J" sandstone oil at Horse Creek and Borie fields in Wyoming) and cannot be distinguished from average Sussex-Shannon oils (figs. 5e and 5f). Based on this compound-by-compound comparison and other geochemical similarities, the Sussex, Shannon, "D" and "J" oils are considered the same oil type. One oil from Timpas-Codell reservoirs (sec. 19, T. 1 S., R. 67 W., Adams Co., Colo.) was analyzed and it was also identified as this same oil type.

Table 2

C_4-C_7 HYDROCARBON RATIOS USED FOR CORRELATION

	COMPOUNDS	BOILING POINTS °C
1.	ISO-BUTANE/n-BUTANE	-11.7/-0.5
2.	ISO-PENTANE/n-PENTANE	27.9/36.1
3.	CYCLOPENTANE/2,3-DIMETHYLBUTANE	49.3/58.0
4.	2-METHYLPENTANE/3-METHYLPENTANE	60.3/63.3
5.	n-HEXANE/METHYLCYCLOPENTANE	68.7/71.8
6.	2-METHYLHEXANE/2,3-DIMETHYLPENTANE	90.1/89.8
7.	3-METHYLHEXANE/1-cis-3-DIMETHYLCYCLOPENTANE+ 1,1-DIMETHYLCYCLOPENTANE	91.9/90.8 + 87.9
8.	1-TRANS-3-DIMETHYLCYCLOPENTANE/1-TRANS-2-DIMETHYLCYCLOPENTANE.	91.7/91.8
9.	n-HEPTANE/METHYLCYCLOHEXANE	98.4/100.9

(Modified from Erdman and Morris, 1974)

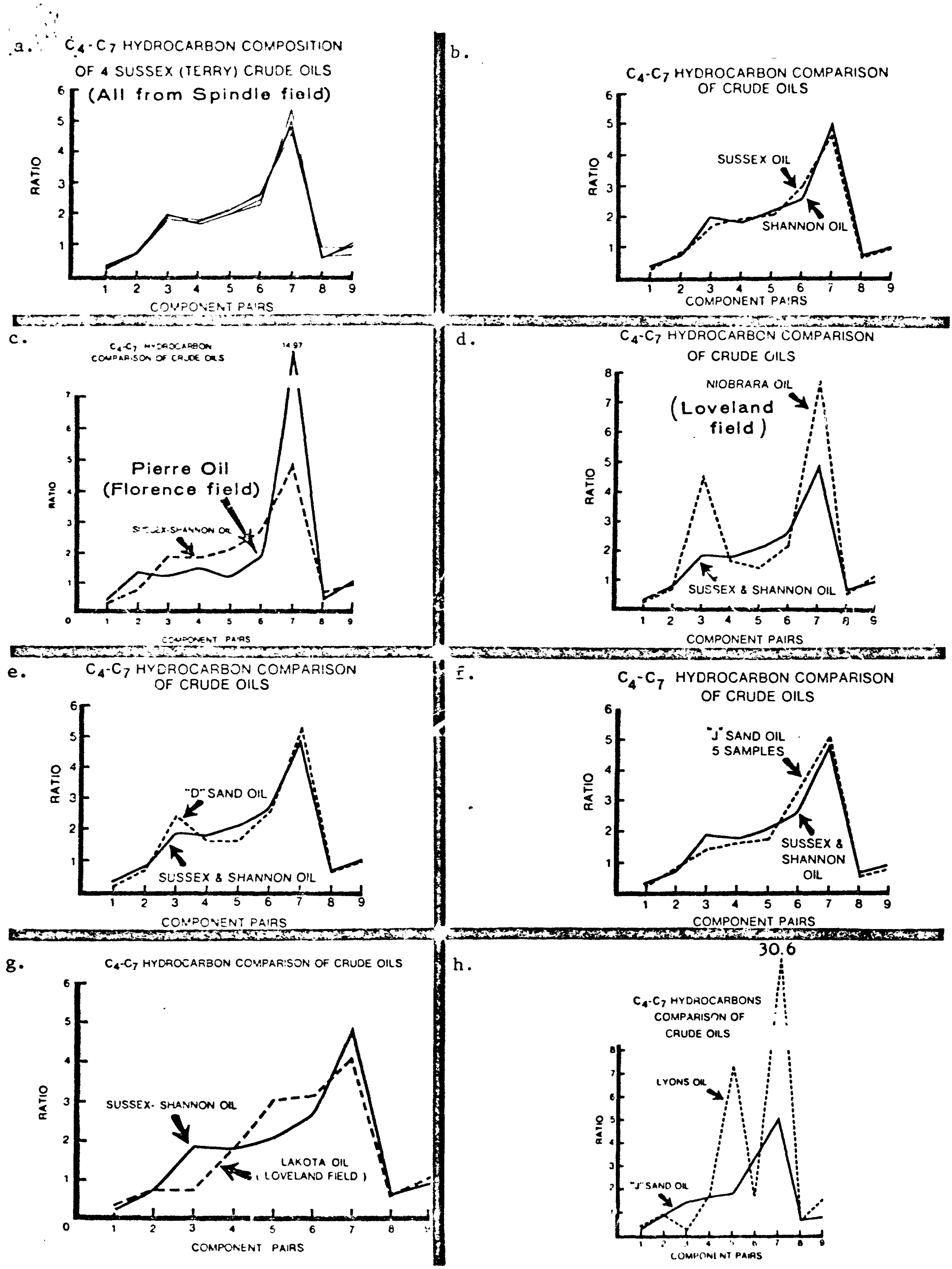


Figure 5.—Compositional comparison of crude oils using nine gasoline range hydrocarbon ratios.

A comparison of oils from fractured shale reservoirs in the Pierre (Florence field) and Niobrara (Loveland field) intervals with average Sussex-Shannon oil, shows differences that may be significant (figs. 5c and 5d). These chemical differences and geological evidence suggesting that the Pierre and Niobrara oils are indigenous may indicate that these oils were generated from different source beds than the Sussex, Shannon, "D", and "J" oils. The C_4-C_7 hydrocarbon composition of the Pierre and Niobrara oils differs from that of the average Sussex-Shannon oil in the same way that thermally immature source rocks differ from their mature equivalents, suggesting that these oils were generated at an earlier stage of thermal maturity than other Cretaceous oils. The Lakota oil (Loveland field) is also somewhat different than the typical Sussex, Shannon, "D," and "J" oils and may have had a different source (fig. 5g).

Comparison of the nine gasoline range hydrocarbon ratios gives further evidence that the Permian Lyons oil is clearly different from all Cretaceous oils (fig. 5h) and that it was not derived from the same source beds as the Cretaceous oils.

Carbon isotope ratios have been used in other basins to identify oil families (Williams, 1974; Koons and others, 1974). However, all Denver basin oils, including the Permian Lyons oil, have similar carbon isotopic compositions* and cannot be distinguished by this technique.

---

*Range for δC^{13}_{PDB}: -27.8 to -29.0% . Analyses of C_{15+} saturated fractions for 30 Cretaceous and 4 Lyons oil samples.

SUMMARY OF OIL COMPARISON

Among Denver basin oils different oil types have been identified, based on comparisons of the composition of the C_{15+} paraffins and the gasoline range (C_4-C_7) hydrocarbons. A detailed comparison of the C_4-C_7 fraction has shown that the oils produced from fractured Pierre and Niobrara Formations may have a different oil-source bed relationship than other Cretaceous oils and that the Sussex, Shannon, "D", and "J" oils analyzed from the area along the basin axis between Denver and Fort Collins, Colo. are all compositionally similar. This suggests that oils of the latter group have been derived from a common source or from different source beds that have generated identical oils.

IDENTIFICATION OF SOURCE BEDS

By comparing the gasoline range hydrocarbon composition of canned well cuttings with those of the oils, the stratigraphic intervals within the Cretaceous section which are the most likely source beds for the major oil accumulations have been identified. The canned cuttings used for this comparison were taken from Amoco's #1-B Pulliam well located near the Front Range (sec. 28, T. 5 N., R. 68 W.; Weld Co., Colorado) in an area where most of the Cretaceous section is thermally mature.

Figures 6a-6e compare the gasoline range hydrocarbon composition of Cretaceous shales from the Pulliam well with Cretaceous oils, using the same nine ratios (table 2) that were used to compare oil types. These comparisons show that both the shale immediately below the Shannon sandstone and the Sharon Springs member of the lower Pierre are unlike the Sussex-Shannon oil (figs. 6a and 6b). Other evidence suggests that the Sharon Springs member of the Pierre Shale may be the source of the Pierre oil produced from the Florence field, but it is not a likely source for oil in Sussex-Shannon reservoirs.

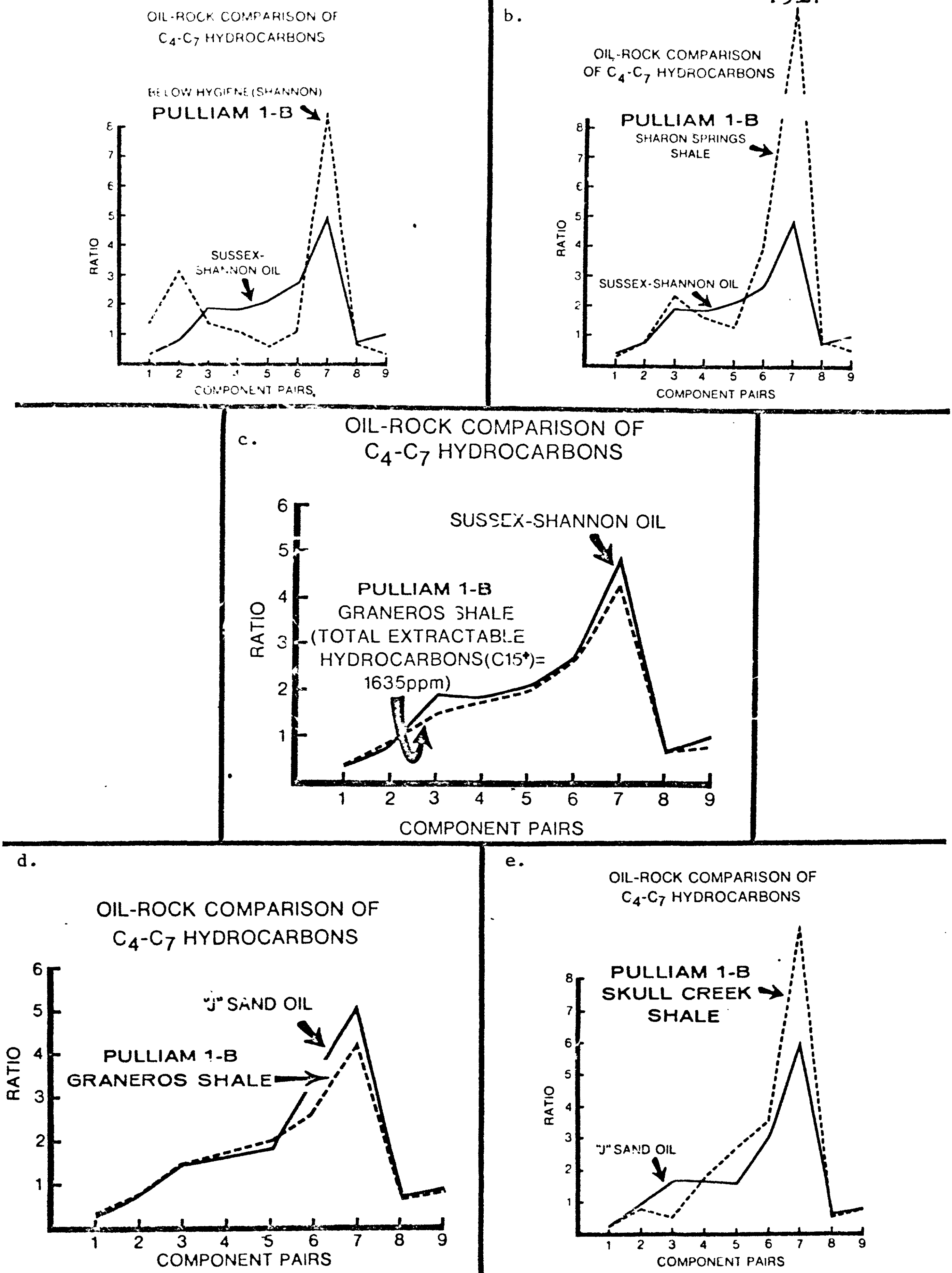


Figure 6.--Compositional comparison of crude oils with canned cuttings from the Amoco #1-B Pulliam well using nine gasoline range hydrocarbon ratios.

The Carlile, Greenhorn, Graneros, and Mowry units also have gasoline-range hydrocarbon distributions that match the "J" sandstone oil distribution (fig. 6d) and could, therefore, be considered potential source beds for the "J" oil.

It should also be noted that the Carlile, Greenhorn, and Graneros are very organic-rich units, containing large quantities of extractable hydrocarbons. The Graneros sample from Pulliam #1-B, for example, contained more than 1,600 ppm hydrocarbons in the C_{15+} range.

It can be concluded, therefore, that the oil type produced from the Sussex, Shannon, "D," and "J" reservoirs was most likely derived from the Carlile, Greenhorn, Graneros, and Mowry interval. This interval containing four formations of varying lithology can be grouped together by similar geochemistry. All of these formations are organically rich and have gasoline-range and C_{15+} saturated hydrocarbon compositions similar to the oil.

From a geological standpoint the Skull Creek Shale directly underlying the "J" sandstone could also be considered a probable source for the "J" oil. The gasoline-range hydrocarbon composition of the Skull Creek in the Pulliam well, however, differs from the "J" oil (fig. 6e) much more than the C_4-C_7 composition of the Graneros Shale overlying the "J" sandstone (fig. 6d). Additional canned well samples of the Skull Creek Shale from other areas will be analyzed to better evaluate its role as a source bed for the "J" oil.

Figure 7 compares the C_7 hydrocarbon composition of cuttings from two wells on the west flank of the basin with the C_7 composition of all Cretaceous oils analyzed. This comparison shows that only the hydrocarbon distributions from the lower part of the Cretaceous section, including the Carlile, Greenhorn, Graneros, Mowry, and Skull Creek, fall within the composition range of the crude oils.

REGIONAL LOCATION OF SOURCE BEDS

Only in areas where Cretaceous shales have reached a certain stage of thermal maturity are their hydrocarbon compositions similar to those of Cretaceous crude oils. The assumption is made that if the distributions of hydrocarbons in shales are unlike crude oils then they probably are not effective source beds. Using this assumption, areas of favorable and unfavorabl source bed potential were defined.

Figure 8 compares the C_7 hydrocarbon composition of Cretaceous shales from two wells in southeastern Wyoming (T. 15 N.; R. 63 and 64 W.; Laramie Co.) with the general Cretaceous oil composition including oils from the nearby fields of Horse Creek and Borie. The entire Cretaceous shale section falls outside of the range for Cretaceous oil composition. At this particular location in Wyoming, the C_7 hydrocarbon composition of the shales and oils are different. Also, the distributions of the $C_{15}+$ paraffins are dissimilar. Therefore, it is unlikely that Cretaceous shales in this area were source beds for any of the Cretaceous oils analyzed in this study.

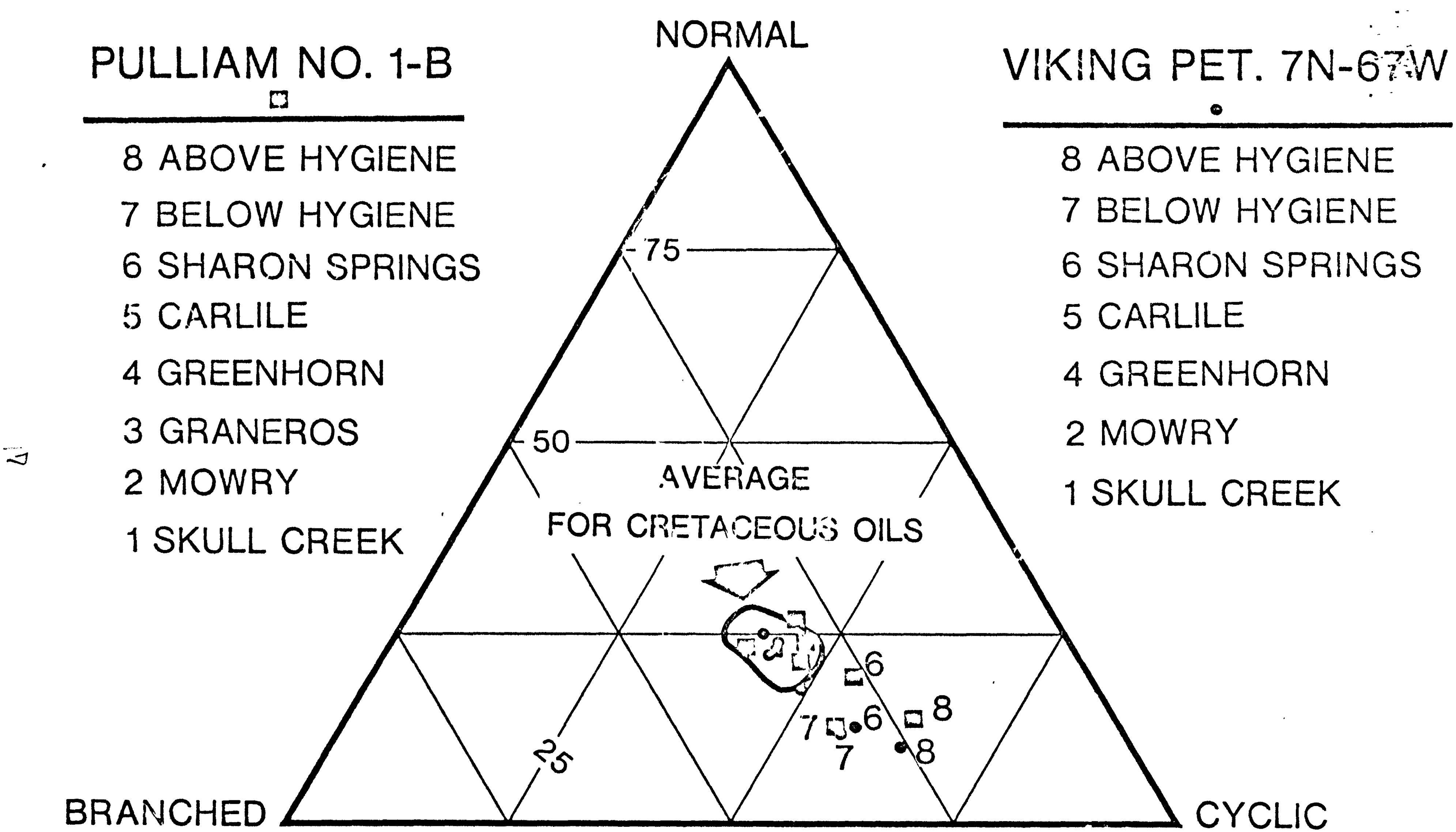
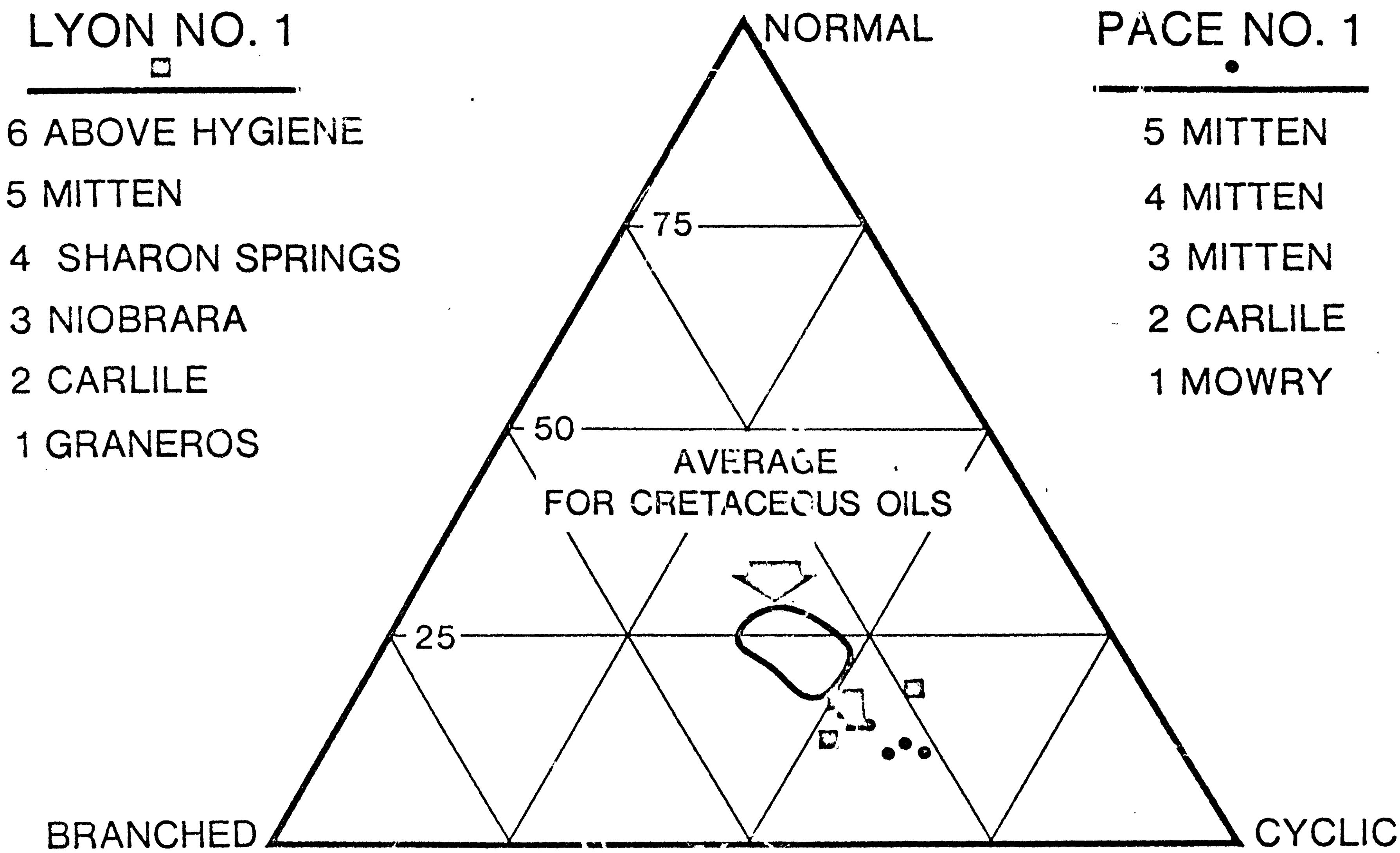


Figure 7.--
C_7 HYDROCARBON COMPOSITION OF WELL CUTTINGS COMPARED TO CRETACEOUS OILS



gure 8.--

C_7 HYDROCARBON COMPOSITION OF WELL CUTTINGS FROM TWO WELLS IN SOUTHEASTERN WYOMING COMPARED WITH CRETACEOUS OILS FROM THE DENVER BASIN

This interpretation does not imply that areas such as southeastern Wyoming and eastern Colorado should be barren of oil. Lateral migration of oil from thermally more mature parts of the Denver basin may have occurred. It is also possible that oil has been generated locally and expelled at an earlier stage of maturity, especially in southeastern Wyoming. The oils from Borie and Horse Creek fields (fig. 9) contain more cyclic gasoline-range hydrocarbons than other Cretaceous oils and are considered examples of oil expelled from source beds at an earlier stage of maturity.

Based on an evaluation of thermal maturity for samples collected at the locations shown in figure 1, a preliminary regional map has been developed showing where potential source beds in the Carlile-Greenhorn-Graneros-Mowry interval are located (fig. 9). The areas of less favorable source potential are those areas where these Cretaceous units do not contain hydrocarbons similar to the Cretaceous oils analyzed. In the area designated as one of favorable source potential, the Carlile-Greenhorn-Graneros-Mowry interval is characterized by a thermally "mature" distribution of hydrocarbons, i.e., oil-like hydrocarbons. In the area indicated as unknown, insufficient data are available at the present time to evaluate source rock potential. This is an area where the presence or absence of effective source beds should be an important factor in understanding the relationships between oil field distribution and favorable source areas.

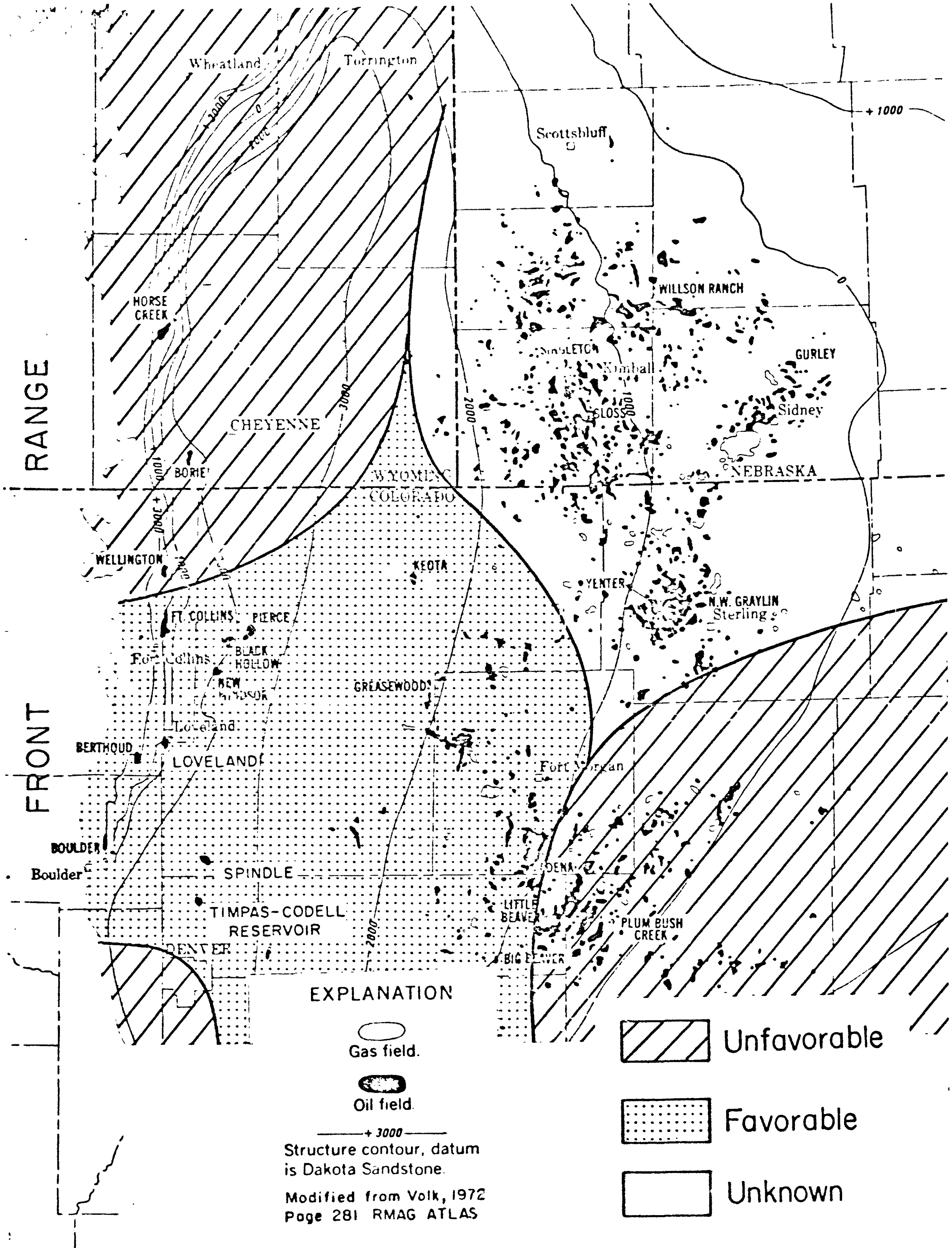


Figure 9.--Preliminary map of Cretaceous source bed potential in the Denver basin.

CONCLUSION

The purpose of this study was to identify the source beds of Denver basin oil and to determine their regional extent. By comparing the organic geochemical characteristics of crude oils with Cretaceous shales, the most probable source beds were identified. On the basis of geochemical evidence, the most likely source of oil produced from Sussex, Shannon, "D," and "J" reservoirs is the Carlile, Greenhorn, Graneros, and Mowry interval. For oil in Sussex-Shannon reservoirs to have been derived from this source interval, as much as 3,000 ft (914 m) of vertical migration is required. Faults common along the west flank of the basin may be possible migration pathways.

Preliminary data suggest that oils in the fractured Pierre and Niobrara reservoirs were generated in place. A knowledge of where these formations are thermally mature can aid in exploration for these reservoirs.

A regional map has been presented showing the geographic distribution of potential source beds in the Carlile-Greenhorn-Graneros-Mowry interval. This preliminary map shows that oil production occurs in areas where these formations are believed to have had unfavorable thermal history, suggesting that lateral migration updip from deeper parts of the basin has occurred. Further work is in progress to better define the areas of thermal maturity and immaturity, and to determine the extent of lateral migration.

ACKNOWLEDGMENTS

We would like to thank Louise W. Kiteley for her help with the Cretaceous stratigraphy and field sampling. The following oil companies provided samples: Amoco, Art Skaer Inc., B & B Resources, Chevron, Sands-American and Viking Petroleum. Analytical assistance provided by Jeff Baysinger (organic carbon) and John Patterson (gas chromatography) of the U. S. Geological Survey is appreciated. We are especially grateful to Jack A. Williams of Amoco Research (Tulsa) for supplying us with carbon isotope data. James G. Palacas offered helpful suggestions during the preparation of this paper. Illustrations were prepared by Tom Kostick of the U.S. Geological Survey.

REFERENCES

Anderman, G. G., and Ackman, E. S., 1963, Structure of the Denver-Julesburg basin and surrounding areas in Geology of the northern Denver basin and adjacent uplifts: Rocky Mountain Association Geologists, p. 170-175.

Erdman, J. G., and Morris, D. A., 1974, Geochemical correlation of petroleum: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 11, p. 2326-2337.

Koons, C. B., Bond, J. G., and Peirce, F. L., 1974, Effects of depositional environment and post depositional history on chemical composition of Lower Tuscaloosa oils: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 7, p. 1272-1280.

Volk, R. W., 1972, The Denver basin and Las Animas arch, in RMAG Geologic Atlas of the Rocky Mountain Region, p. 281-282.

Williams, J. A., 1974, Characterization of oil types in Williston basin: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 7, p. 1243-1252.