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TWO OIL TYPES ON THE NORTH SLOPE OF ALASKA--IMPLICATIONS FOR FUTURE EXPLORATION

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ABSTRACT

Forty oil samples from across the North Slope of Alaska have been analyzed by the U.S. Bureau of Mines and the U.S. Geological Survey. Results of these analyses suggest two separate genetic oil types. The first type, the Simpson-Umiat oil type, occurs in reservoir rocks of Cretaceous and Quaternary age and includes oils from seeps in the Skull Cliff, Cape Simpson, Manning Point, and Ungoon Point areas; the Wolf Creek test well 3, and the Umiat oil field. These are higher gravity, low-sulfur oils with no, or slight, odd-numbered n-alkane predominance and pristane to phytane ratios greater than 1.5. The second type, the Barrow-Prudhoe oil type, occurs in reservoir rocks of Carboniferous to Cretaceous age and includes oils from South Barrow gas field, Prudhoe Bay oil field, and the Fish Creek test well 1. Physical properties of Barrow-Prudhoe oils are variable, but in general the oils are medium-gravity, high-sulfur oils with a slight even-numbered n-alkane predominance and pristane to phytane ratios of less than 1.5. The two types are believed to originate from different source rocks; the Barrow-Prudhoe type may have originated from a carbonate or other iron-deficient source rock, and the Simpson-Umiat type from a siliciclastic source rock. Occurrences of the two oil types, when outlined on a map, indicate at least two exploration fairways. The fairway for the Barrow-Prudhoe type is along the Barrow arch, and the fairway for the

Simpson-Umiat type is the area of the best reservoir development for the Nanushuk Group.

INTRODUCTION

The North Slope of Alaska is a proven petroleum province with numerous seeps, many small undeveloped oil fields, and the largest oil field on the North American continent, Prudhoe Bay. Genetic relations among oils from across the entire North Slope have important implications for future exploration in this petroleum province.

Exploratory drilling for oil has been pursued by government and industry since 1944 (Carter and others, 1977). From 1944 to 1953 the U.S. Navy explored NPR-4 (Naval Petroleum Reserve No. 4) and found only small oil and gas fields such as Umiat, Cape Simpson, and South Barrow. From 1963 to the present, exploration by industry of the area between NPR-4 and Arctic National Wildlife Range culminated in 1968 with the discovery of the Prudhoe Bay oil field (Morgridge and Smith, 1972). A second exploration effort by the U.S. Navy in NPR-4 commenced in 1974 and continued to June 1, 1977, at which time jurisdiction of NPR-4 by the Department of the Navy was turned over to the Department of Interior and renamed the National Petroleum Reserve in Alaska (NPRA). The continuing exploration effort in NPRA is now managed by the U.S. Geological Survey (USGS). The locations of NPRA, Prudhoe Bay oil field, and the Arctic National Wildlife Range are shown on figure 1.

Throughout all phases of exploration by government and industry, oils were acquired from across the North Slope. Oil samples were analyzed by the U.S. Bureau of Mines (USBM), the USGS, and commercial laboratories (Geochem Research, Inc. and Global Geochem Corp.) under contract to the

USGS. Geochem determined API gravity and isolated the C_{15+} hydrocarbon fractions; Global performed elemental (N,S) and gas chromatographic analyses and measured light-stable isotopic ratios (C,N,S) of the whole oil and selected fractions.

This paper describes the results of these analyses and presents our preliminary interpretation. Additional information from the continuing program of collection and analysis of oil samples may require us to modify this interpretation.

Except for the Prudhoe Bay oil field, little has been published concerning the origin of North Slope oils. After the discovery of Prudhoe Bay oil field in 1968, Morgridge and Smith (1972) and Jones and Speers (1976) suggested that the source of Prudhoe Bay oil is Cretaceous marine shale. Young, Monaghan, and Schweisberger (1977) assigned different ages to Prudhoe Bay oil; in Late Cretaceous reservoirs the oil is 87 m.y. old, in Early Triassic reservoirs the oil is 218 m.y.; and in the Pennsylvanian carbonate the oil is 220 m.y. These ages imply at least two source beds of different ages (87 m.y. and 218-220 m.y.). The identification of source beds for North Slope oils is beyond the scope of this paper. Rock analyses and oil-rock correlations are in progress on samples from outcrops and wells from across the entire North Slope. However, even the oil analyses reported here suggest interesting alternate interpretations for the origin of Prudhoe Bay and other North Slope oil.

API gravity and percent sulfur values are available for all crude oils analyzed from the North Slope by the USBM. A few of these oil samples, such as those from Wolf Creek and Skull Cliff areas, cannot be located for more detailed analyses. API and sulfur data provide a means of comparison

of analyses between areas and between the two organizations. More detailed analyses, especially the isotopic studies, permit characterization of biodegraded oils and enable their matching with "normal" oils that are less weathered and not biodegraded. Gas chromatographic n-paraffin profiles are used to determine if an oil is "normal" or biodegraded, and the analyses of the normal oil provide the basis for an oil type.

OIL SAMPLES

The forty oil samples used in this study were collected with permission from industry and government by the USBM and the USGS from surface seeps and wells (fig. 1). The stratigraphic position of the reservoirs is shown on figure 2. The first six oil samples are from seeps and the remainder of the samples were recovered from wells. For convenience, the same oil sample is labeled using the same symbol and number in all figures.

Many of the oil samples and analyses are duplicates: either the same oil was analyzed twice--once by the USBM and once by the USGS, each organization doing different analyses except for API gravity and percent sulfur--or each organization collected oil from the same well or seep at different times. To determine which situation is applicable, figures 1 and 2 must be compared. For comparison, all the API gravity and percent sulfur analyses from both organizations are shown on figure 3.

Oil samples from four different wells in the Prudhoe Bay field are from three separate oil pools (State of Alaska, 1978); the Lisburne pool (#37 and 38), the Prudhoe pool (#32-36), and the Kuparuk River pool (#30 and 31). Oil from the Prudhoe pool is assumed to be representative of the oil from the Ivishak Formation of the Sadlerochit Group, the Shublik Formation, and the Sag River Sandstone as these three reservoir rocks all

have a common oil-water contact (McIntosh, 1977). The oil from the Colville Group is not included in this paper, but it is presumed to be similar to the oils from the three separate pools.

RESULTS

API gravity and sulfur content.--API gravity plotted against percent sulfur on figure 3 shows two groups of oils. One group, shown by open symbols, includes those oils with sulfur content of less than 0.5% and API gravities that range from 18° to 38°. Normal, nonbiodegraded oils from the Umiat and Wolf Creek areas have API gravities of approximately 35° with sulfur content less than 0.15%. Samples with API gravities of about 20° and sulfur contents that range from 0.2 to 0.5% include biodegraded oils from the Cape Simpson area and one oil (#12) from the Umiat area. The Manning Point oil has an intermediate API gravity of 27° and sulfur content of 0.15%. The API gravity of Ungoon Point oil has not been determined, but with a sulfur content of 0.22%, it is judged to be part of this low-sulfur group. Because most of the oil samples come from the Cape Simpson and Umiat areas, this group of samples is referred to as the Simpson-Umiat oil type.

The second group, shown by solid circles, includes oils with sulfur content ranging from 0.8 to 2.0% and API gravities from 13° to 28°. Normal, nonbiodegraded, high-sulfur oils with API gravities of approximately 25° characterize the oils from the three oil pools in the Prudhoe Bay area and the Sag River Sandstone in the South Barrow area. Because of the large volume of oil at Prudhoe and because these oils are toward the extremities of the Barrow arch, this group is referred to as the Barrow-Prudhoe oil type.

C_{15+} saturated hydrocarbons.--Chromatograms of the C_{15+} saturated hydrocarbons for the two oil types are shown on figures 4 and 5. Two samples (#15 and 18) from the Umiat area are normal, nonbiodegraded oils; whereas one oil (#12) from Umiat is biodegraded. The chromatograms of the normal oils show a small odd-to-even predominance in the normal paraffins, or carbon preference index (CPI) slightly greater than 1. The pristane to phytane ratio for normal Umiat oil is slightly above 1.5. The biodegraded oil (#12) is characterized by lack of normal paraffin peaks, higher sulfur content and lower API gravity compared with the nonbiodegraded oil. Also, the biodegraded Umiat oil contains pristane and phytane (inferred from gas chromatographic retention times) in about the same relative proportions as the normal Umiat oil.

Chromatograms of oils from the Cape Simpson and Manning Point areas resemble the biodegraded Umiat oil, as shown on figure 4. The Ungoon Point oil (#2) is an extensively biodegraded sample with no compounds recognizable by gas chromatographic analysis of the C_{15+} saturated hydrocarbons. With the exception of the Ungoon Point oil seep, the similarity of the chromatograms for these biodegraded oils and their low sulfur contents are consistent with the proposed genetic relation to the low-sulfur, high-gravity normal oils in the Umiat area. Unfortunately, samples of the oils from the Wolf Creek and Skull Cliff areas were not available for our study, but the sulfur contents and oil gravities are similar to the normal oil at Umiat.

The oils of the Barrow-Prudhoe type are normal except for the Fish Creek oil, which has high-sulfur (1-2%), low gravity (13°-16° API), and is biograded as shown on figures 3 and 5. The chromatograms of the normal

oils from both South Barrow and Prudhoe Bay areas show slight even-to-odd predominance or a CPI of less than 1, and pristane to phytane ratios of less than 1.5. The apparent low pristane to phytane ratio and the high sulfur content suggest that the Fish Creek oil belongs to the Barrow-Prudhoe type. In the Fish Creek area, this oil occurs in a stratigraphic unit (Nanushuk Group) that dips east toward Prudhoe Bay area, providing a possible mechanism for lateral migration into the Fish Creek area.

Carbon isotope ratios.--Carbon isotope ratios (presented in the δ-notation) were determined for the whole oil, and the saturated and aromatic hydrocarbon fractions for 16 oils. The whole oil analyses are shown on figure 6 and the analyses for hydrocarbon fractions are shown on figure 7. Carbon isotope ratios of the whole oils show two groupings. The Simpson-Umiat oils have values that range from -29.1 to -27.8 permil, whereas the Barrow-Prudhoe oils range from -30.3 to -29.8 permil.

Carbon isotope ratios for the C_{15+} saturated and aromatic hydrocarbon fractions appear to show three oil groups. However, a more likely interpretation is only two groups, and two subgroups of the Simspon-Umiat type: the normal, nonbiodegraded oils and the biodegraded oils, as shown by the chromatograms on figure 4. In addition, the oils in each subgroup from the Umiat area were recovered from closely spaced well (<0.5 km apart) and from the same reservoir rock--facts, which argue for genetically related oils.

The carbon isotope ratios of the oils at South Barrow (#39 and 40) are similar to those measured for the Prudhoe Bay oil. Carbon isotope ratios indicate that Fish Creek oil (#28 and 29) is a member of the Barrow-Prudhoe family. The sulfur content of Fish Creek oil is very high (1.15-1.9%). It is unlikely that secondary alteration processes (weathering, biodegrada-

tion) can account for the increased sulfur content and lowered ^{13}C content of Fish Creek oil. For example, the Ungoon Point oil (#2) is one of the most intensely weathered and biodegraded oils (fig. 4), but the sulfur content is only 0.33% or about twice the sulfur content of the normal-gravity, low-sulfur oil.

Content and isotope ratios of sulfur and nitrogen.--The ratio of sulfur-to-nitrogen compared to sulfur isotope data are shown on figure 8. Though there is a broad range of values within each oil type, the two oil types are split by the sulfur isotope values. Values lighter than -4.5 permil are characteristic of the Simpson-Umiat oil type, whereas values heavier than -3 permil are characteristic of the Barrow-Prudhoe oil type. The similarity of sulfur to nitrogen ratio for both oil types indicates a direct relation between sulfur and nitrogen content--high sulfur oils are higher in nitrogen and vice versa, as shown on figure 9. The nitrogen isotope values, as shown on figure 10, overlap, ranging from 1 to 11 permil for the Simpson-Umiat type and from 1 to 5.5 permil for the Barrow-Prudhoe type. These data seem to suggest that little secondary sulfur has been added either from maturation or biodegradation.

DISCUSSION

Results of analyses of 40 oil samples suggest two separate oil types as summarized on table 1. The Simpson-Umiat oil type occurs in reservoir rocks of Cretaceous and Quaternary age and includes oils from the Skull Cliff, Cape Simpson, Manning Point, and Ungoon Point areas, the Wolf Creek test well 3, and the Umiat oil field. These are high-gravity, low-sulfur oils with no, or slight, odd-numbered n-alkane predominance and pristane to phytane ratios greater than 1.5.

Table 1. Characteristics of the two oil-types on the North Slope, Alaska.

	Oil Family	
	Barrow-Prudhoe	Simpson-Umiat
API gravity*	25	35
Sulfur, percent*	0.9	0.1
CPI*	<1	≥1
Pristane/phytane*	<1.5	>1.5
$\delta^{34}S$, permil	<-4	>-3
$\delta^{13}C_{sat}$, permil	-30	-29
$\delta^{13}C_{arom}$, permil	-29.5	-28
$\delta^{13}C$ whole oil, permil	-30	-28.5

*for the normal oil

The Barrow-Prudhoe oil type occurs in reservoir rocks of Carboniferous to Cretaceous age and includes oils from South Barrow gas field, Prudhoe Bay oil field, and the Fish Creek test well 1. The Barrow-Prudhoe oils vary in physical properties, but in general they are medium-gravity, high-sulfur oils with a slight even-numbered n-alkane predominance and pristane to phytane ratios of less than 1.5.

The two oil types may originate from different source rocks. The low sulfur content and the detailed hydrocarbon distribution of the Simpson-Umiat family suggest that this oil originated from a siliciclastic source rock (Gransch and Posthuma, 1974). Analogous properties of the Barrow-Prudhoe type suggest derivation from a carbonate or other iron-deficient source rock.

The presence of oil in the subsurface or as a seep at a specific location indicates that the proper conditions for petroleum generation, migration, and accumulation existed. Oils from the North Slope can be groupe

into two types. Outlined on a map, these two types indicate at least two exploration fairways. The fairway for the Barrow-Prudhoe oil family is along the Barrow arch, and that for the Simpson-Umiat family is the area of the best reservoir development for the Nanushuk Group between the Simpson and Umiat areas.

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FIGURE CAPTIONS

Figure 1.--Map of the North Slope of Alaska showing the geographic distribution of the oil samples. Compare to figure 2 for the age of the reservoir.

Figure 2.--Generalized stratigraphic chart for the North Slope of Alaska showing the age of the reservoir rock from which the oil samples were acquired (geologic names used after Fackler and others, 1970). Symbols are explained on figure 1.

Figure 3.--API gravity is compared to percent sulfur for the Simpson-Umiat (open symbols) and the Barrow-Prudhoe (solid symbols) oil types. The API gravity for sample numbers 2 and 5 are not available owing to insuppicient sampling and heavy (tar-like) oil.

Figure 4.--Chromatograms of the C_{15+} n-paraffin distribution for the normal (#15 and 18) and biodegraded oils (#1, 2, 5, 6, 10, and 12) are shown for the Simpson-Umiat oil type.

Figure 5.--Chromatograms of the C_{15+} n-paraffin distribution for the normal (#31, 32, 38, 39 and 40) and biodegraded oils (#28) are shown for the Barrow-Prudhoe oil type.

Figure 6--Carbon isotope ratios from the whole oil for the Simpson-Umiat (open symbols) and Barrow-Prudhoe (solid symbols) oil types.

Figure 7--Carbon isotope ratios from the saturated and aromatic hydrocarbon fractions are compared for the Simpson-Umiat (open symbols) and Barrow-Prudhoe (solid symbols) oil types.

Figure 8.--Sulfur isotope and sulfur to nitrogen ratios are compared for the Simpson-Umiat (open symbols) and Barrow-Prudhoe (solid symbols) oil types.

Figure 9.--Sulfur and nitrogen content, in percent, vary directly, or as sulfur content increases so does the nitrogen content.

Figure 10.--Sulfur isotope and nitrogen isotope ratios are compared for the Simpson-Umiat (open symbols) and the Barrow-Prudhoe (solid symbols) oil types.

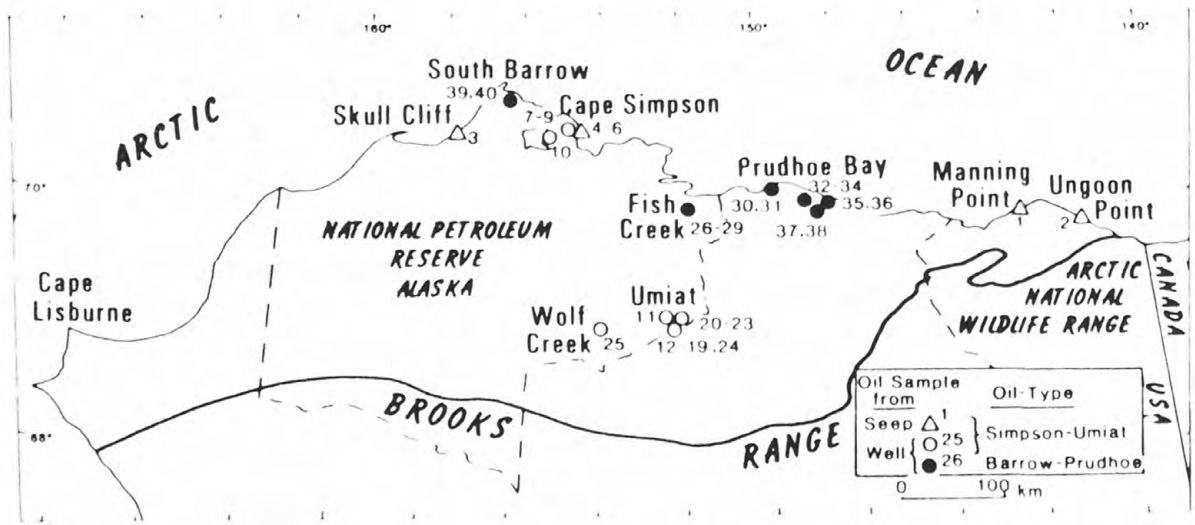
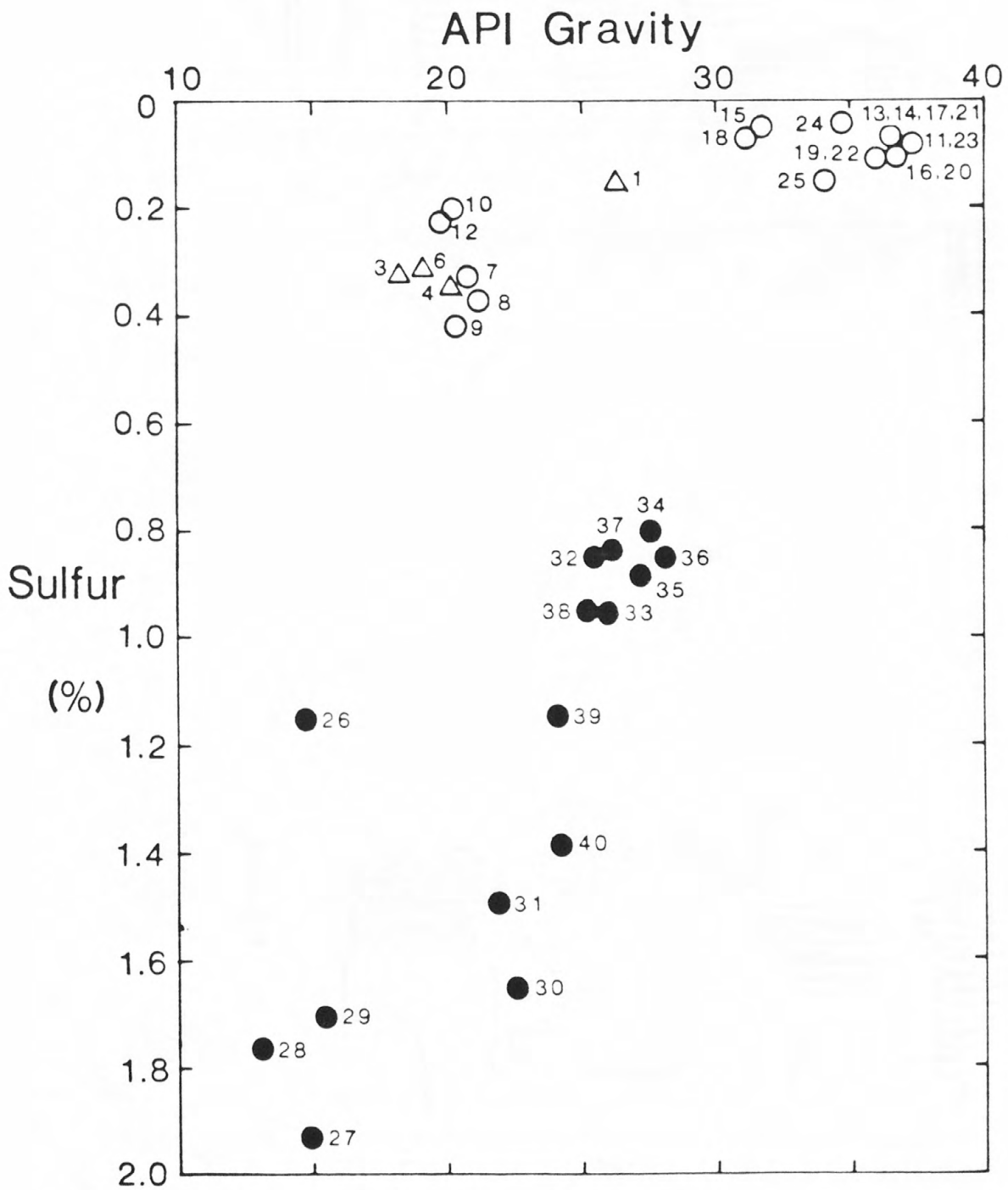

160°
150°
140°
70°
68°
ARCTIC
OCEAN
South Barrow
39,40
Skull Cliff
3
7-9
Cape Simpson
4 6
10
Prudhoe Bay
32 34
30,31
35,36
37,38
Fish Creek
26-29
Manning Point
1
Ungoon Point
2
NATIONAL PETROLEUM RESERVE ALASKA
Cape Lisburne
Umiat
11
20-23
12 19,24
Wolf Creek
25
ARCTIC NATIONAL WILDLIFE RANGE
CANADA
USA
BROOKS
RANGE
Oil Sample from
Oil-Type
Seep
1
Well
25
26
Simpson-Umiat
Barrow-Prudhoe
0
100 km

Figure 1

System	Rock Units	Oil Type: Simpson-Umiat	Oil Type: Barrow-Prudhoe
QUATERNARY	gravel	△ 1,2	
TERTIARY	Sagavanirktok Formation		
CRETACEOUS	Colville Group		
	Nanushuk Group	△ 3-6 ○ 7-25	26-29 ●
	Torok Formation		
	Pebble shale unit		
JURASSIC	Kuparuk River sands		30,31 ●
	Kingak Shale		
TRIASSIC	Sag River Sandstone		39,40 ●
	Shublik Formation		32-36 ●
TRIASSIC AND PERMIAN	Sadlerochit Group		
PERMIAN TO MISSISSIPPIAN	Lisburne Group		37,38 ●
MISSISSIPPIAN AND DEVONIAN	Endicott Group		
PRE-DEVONIAN	Basement complex		

Figure 2


API Gravity
10
20
30
40
Sulfur
(%)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
15
18
24
13,14,17,21
11,23
19,22
16,20
25
1
10
12
3
6
7
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39
40
31
30
29
28
27

Figure 3

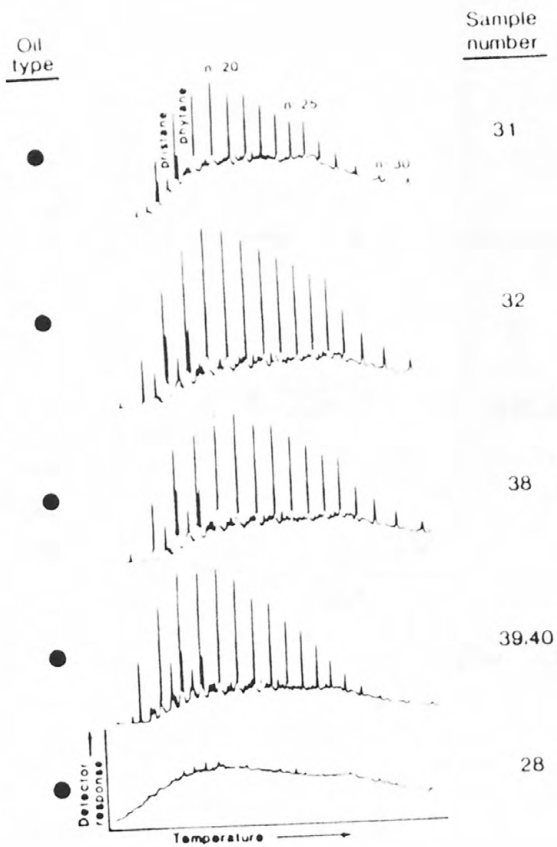

Figure 5

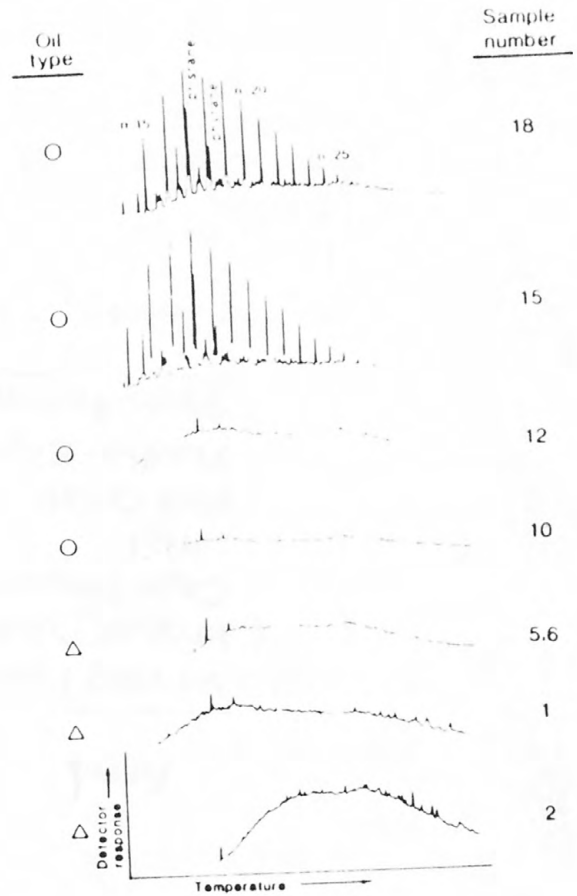

Figure 4

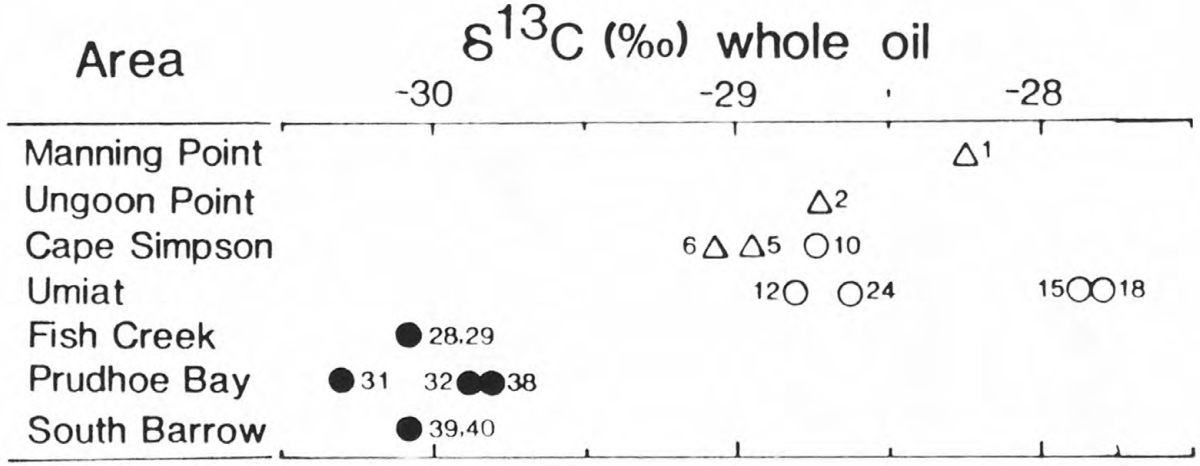
Area
δ13C (‰) whole oil
-30
-29
-28
Manning Point
Ungoon Point
Cape Simpson
Umiat
Fish Creek
Prudhoe Bay
South Barrow
1
2
6
5
10
12
24
15
18
28,29
31
32
38
39,40

Figure 6

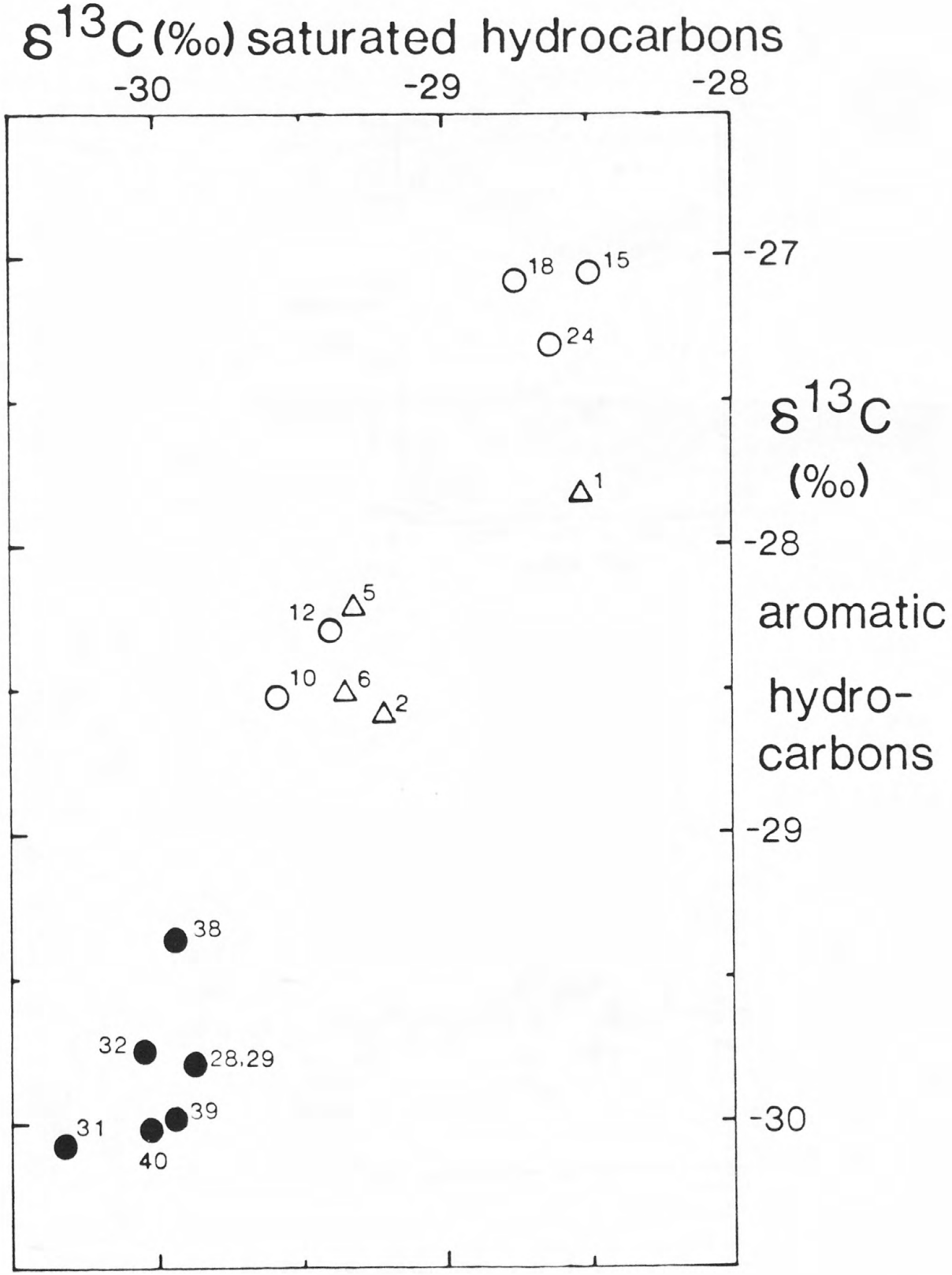
δ13C (‰) saturated hydrocarbons
-30
-29
-28
-27
-28
-29
-30
δ13C
(‰)
aromatic
hydro-
carbons
18
15
24
1
12
5
10
6
2
38
32
28,29
39
31
40

Figure 7

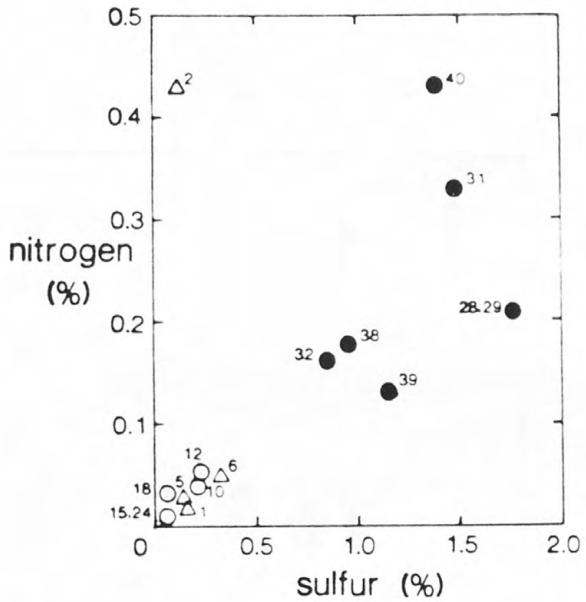

Figure 9

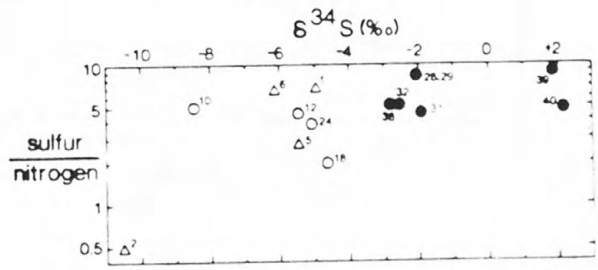

Figure 8

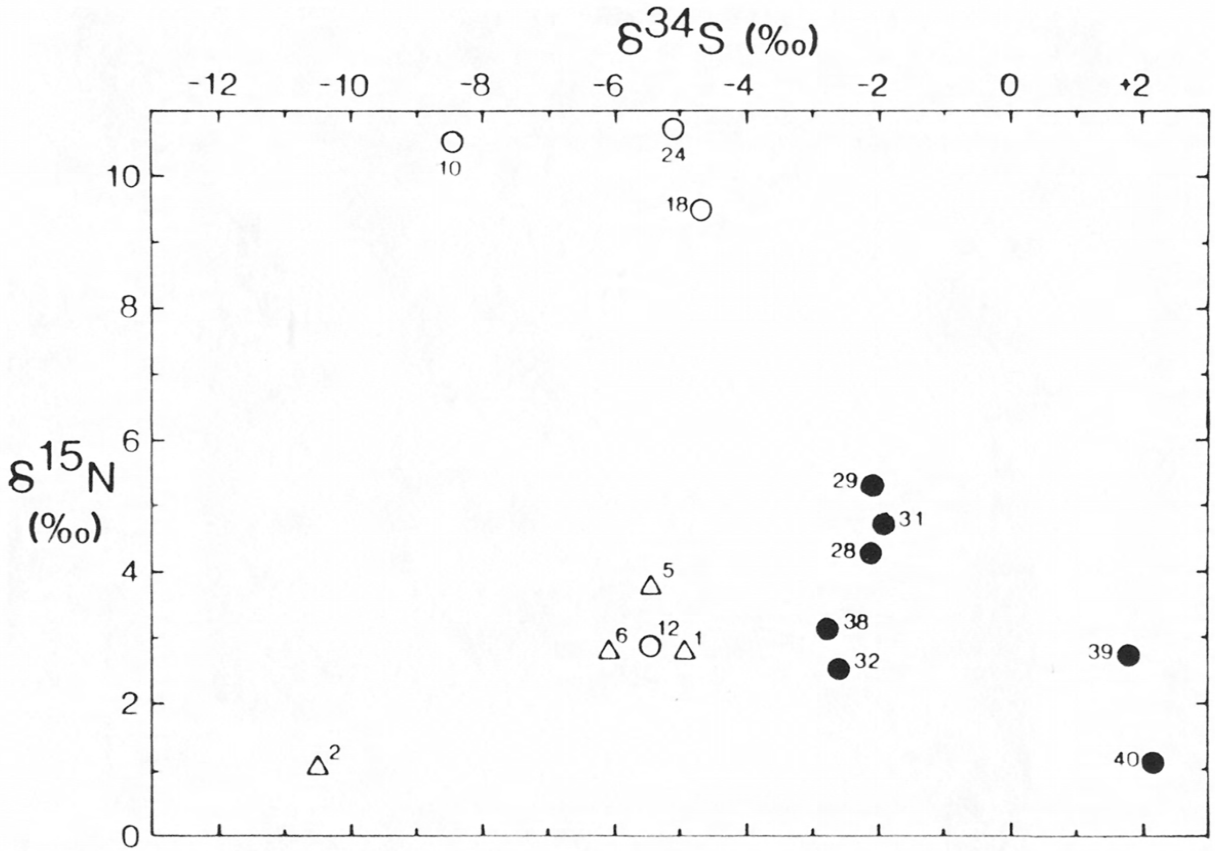
δ34S (‰)
-12
-10
-8
-6
-4
-2
0
+2
δ15N (‰)
0
2
4
6
8
10
10
24
18
29
31
28
5
38
6
12
1
32
39
2
40

Figure 10