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A GEOCHEMICAL PROFILE OF TUNALIK NO. 1 WELL, NATIONAL PETROLEUM RESERVE IN ALASKA

By

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A Geochemical Profile of Tunalik No. 1 Well, National Petroleum Reserve in Alaska (NPRA)

ABSTRACT

Plotting recently released organic geochemical data against depth shows that the sedimentary section penetrated at the Tunalik No. 1 well is prone to generate gas. Treatment of fifteen geochemical parameters illustrates the organic quality, quantity, and thermal maturity of well cuttings and core samples. Major maturity indicators suggest that the section is thermally mature for oil from approximately 3,300 feet to 10,500 feet (1,006 to 3,200 m). Kerogen types are predominantly herbaceous and humic and, consequently, yield mainly gas. Additional gas is generated from the thermal degradation of hydrocarbons buried beyond maturity.

INTRODUCTION

The purpose of this investigation is to provide timely geochemical information for use in supporting the NPRA leasing program. This geochemical profile was constructed from data on the Tunalik No. 1 well, which is one of 21 wells drilled in the NPRA by Husky Oil Company under contract for the U.S. Geological Survey (USGS) (Contract #14-08-001-16474). All the geochemical analyses presented in this report were performed for the USGS by Geochem Research Inc., and Global Geochemistry Corporation (Contract #14-08-001-19188). Tunalik well is located in sec. 20, T. 10 N., R. 36 W., Umiat Meridian, in the NPRA on Alaska's North Slope. Drilling operations started on October 18, 1978, and terminated January 7, 1980, after reaching a total depth (TD) of 20,335 feet (6,198 m) (20,211 feet [6,160 m] true vertical depth). No oil-producing horizons were found. Strong mud-log gas shows were encountered in several intervals, but no successful tests of these intervals were made.

Cuttings, cores, and sidewall cores were taken, sealed in cans at the drill site, and analyzed by Geochem Research Inc., and Global Geochemistry Corporation. Analytical procedures are described in Magoon and Claypool (1980 and 1983). The results of the analyses were released to the public in May 1982 through the National Oceanic and Atmospheric Administration (NOAA).

This report describes the lithology, organic carbon (% C_{org}), total carbon, vitrinite, blended gas (C_1 - C_7), pristane/phytane, visual kerogen, pyrolysis, and elemental hydrogen, carbon, and oxygen (table 1, pl. 1), and the changes of these parameters as a function of depth. Fifty samples with complete or nearly complete data suites were chosen to represent the main lithologic units; to provide a fairly continuous and even distribution of data; and to compare cuttings analyses versus core analyses. My formation picks accompany the geophysical logs on plate 2.

STRATIGRAPHY

At the Tunalik No. 1 well, a sedimentary section of the following stratigraphic order, oldest to youngest, was drilled and logged: Lisburne Group (Mississippian), Sadlerochit Group (Permo-Triassic), Shublik Formation (Triassic), Sag River Formation (Triassic), Kingak Shale (Jurassic-Cretaceous), Pebble Shale (Cretaceous), Torok Formation (Cretaceous), and Nanushuk Group (Cretaceous). Core and cuttings descriptions and gas shows are from the Tunalik lithologic well log. Rocks are described "youngest to oldest" to facilitate comparison with the geochemistry. All depths are measured from Kelly Bushings.

Gubik Formation and Alluvium

The surficial sediments are tundra-covered alluvium derived from the unconsolidated sands and gravels of the Gubik Formation. No geophysical logs

Table 1.--Geochemical parameters versus depth and lithology

(sa=sandstone, sh=shale, sd=siderite, si=siltstone, do=dolomite, lm=limestone, mu=mudstone, sish=siliceous shale
Multiply depth by 0.3048 m/ft for conversion)

Depth (ft)	Lithology	%C_{org}	Total C	%R_o	TAI	Light Hydrocarbons (ppm): C_5-C_7	Light Hydrocarbons (ppm): C_2-C_4/C_1-C_4	Light Hydrocarbons (ppm): wetness (%)	Light Hydrocarbons (ppm): rock extracts i-C_4/n-C_4	Light Hydrocarbons (ppm): rock extracts ratio	Pristane/Phytane (ppm)	ratio	Visual relative Kerogen percent: Am	He	Ro	In	Pyrolysis: hydrocarbons wt%	Pyrolysis: Volatiles ppm	Pyrolysis: T_{max}	Elemental Ratios: H/C wt%	H/C atomic	O/C wt%	O/C atomic
720- 750	sd_{60}, co_{40}	4.36	8.90	0.47	2.0	4	385/ 48,140	00.01	7.8/ 7.1	1.09	-------	---	0	56	33	11	0.40	168	432	4.13/67.20	0.74	----------	----
1,320- 1,350	sd_{40}, co_{40}	5.62	10.90	.49	2.1	26	17,171/150,599	9.00	36.7/10.6	3.60	-------	---	0	36	36	27	.73	259	427	3.69/68.58	.65	----------	----
1,920- 1,950	co_{90}	43.02	44.24	.56	2.1	40	22,444/187,227	12.00	46.0/10.8	4.30	-------	---	0	44	33	22	8.09	4714	411	4.78/73.67	.78	----------	----
2,580- 2,610	$co_{40}, si_{31}, sa_{20}$	.73	-----	.57	---	76	13,819/126,399	10.90	---------	----	-------	---	-	--	--	--	----	---	---	----------	---	----------	----
3,280 core	sh_{100}	13.23	13.80	.62	2.4	--	-------------	-----	---------	----	-------	---	10	50	30	10	7.68	1012	416	4.64/67.33	.83	----------	----
3,300- 3,320	sh_{50}, si_{50}	1.05	2.44	.51	2.3	101	15,189/139,775	10.90	49.5/13.5	3.70	0/1.8	---	0	40	40	20	.15	1714	416	4.51/72.38	.75	----------	----
3,829 core	sh_{100}	1.13	1.27	.62	2.4	---	-------------	-----	26.0/28.1	.62	-------	---	0	36	36	27	.21	619	410	4.21/73.52	.69	----------	----
3,840- 3,860	sh_{80}, sa_{20}	1.27	2.41	.50	2.3	213	4,821/ 11,140	43.00	---------	---	8.9/3.2	2.8	0	63	25	13	.22	379	430	4.64/74.89	.74	9.42/74.89	0.09
4,200- 4,220	sh_{75}, sa_{25}	1.02	1.84	.53	2.3	178	2,235/ 3,897	57.00	27.6/16.0	1.70	-------	---	0	36	36	27	.12	160	429	4.36/53.16	.98	5.68/53.16	.08
4,790- 4,820	sh_{90}, sa_{5}	1.67	2.50	.56	2.3	110	1,522/ 3,273	46.00	30.6/16.4	1.90	-------	---	0	45	27	27	.19	218	435	4.21/68.06	.74	6.64/68.06	.07
5,450- 5,480	sh_{100}	1.02	1.87	.60	2.3	284	3,471/ 6,254	55.00	---------	----	5.1/2.0	2.6	0	50	30	20	.18	422	429	4.85/82.49	.70	7.32/82.49	.07
5,990- 6,020	sh_{80}, sa_{20}	1.18	2.06	.60	2.4	138	3,253/ 7,310	44.00	21.8/13.6	1.60	------	---	0	50	13	38	.12	185	426	4.74/72.06	.79	2.33/72.06	.02
6,504 core	sh_{100}	1.37	1.90	.74	2.7	---	-------------	-----	11.4/14.4	.80	4.7/1.6	2.9	0	38	31	31	.29	896	420	4.45/79.47	.67	4.46/79.47	.04
6,590- 6,620	sh_{70}, sa_{20}	1.14	1.85	.63	2.4	358	1,881/ 3,510	54.00	20.8/14.7	1.40	-------	---	0	27	36	36	.12	212	432	4.65/77.14	.72	6.72/77.14	.06
7,190- 7,220	sh_{90}	1.38	1.99	.61	2.4	265	2,243/ 3,908	57.00	17.2/13.1	1.30	-------	---	0	27	36	36	.16	294	421	4.57/59.69	.92	6.64/59.69	.08
7,790- 7,820	sh_{90}	1.36	1.91	.58	2.4	233	1,943/ 6,197	31.00	13.2/12.6	1.20	-------	---	0	36	36	27	.15	292	433	4.46/76.49	.70	6.18/76.49	.06
7,875 core	sh_{100}	1.38	1.97	1.03	2.7	---	-------------	-----	15.9/19.2	.80	2.7/1.4	1.9	17	33	25	25	.28	846	452	4.15/83.62	.60	2.92/83.62	.03
8,300- 8,330	do_{75}, sh_{20}, co_{5}	3.63	5.25	.56	2.1	2246	3,461/ 4,323	80.00	15.7/10.0	1.60	------	---	8	42	33	17	.84	1620	418	5.83/65.09	1.10	----------	----
8,792 core	sh_{100}	1.25	1.78	1.27	2.7	---	-------------	-----	---------	----	------	---	8	33	25	33	.36	1431	422	4.69/79.50	.68	----------	----
9,010- 9,040	sh_{100}	.95	1.59	----	2.3	1952	9,965/ 12,509	80.00	19.8/13.8	1.40	-------	---	0	42	33	25	.12	370	442	4.42/58.46	.91	7.08/58.40	.09

Table 1.--Geochemical parameters versus depth and lithology

(ss=sandstone, sh=shale, sd=siderite, si=siltstone, do=dolomite, lm=limestone, mu=mudstone, sish=siliceous shale
Multiply depth by 0.3048 m/ft for conversion.

Depth (ft)	Lithology	$\%C_{org}$	Total C	$\%R_0$	TAI	Light Hydrocarbons (ppm) C_5-C_7	C_2-C_4/ C_1-C_4	wetness (%)	rock extracts i-C_4/n-C_4	ratio
9,610- 9,640	sh_{100}	1.25	1.90	---	2.3	707	12,191/ 19,185	63.00	22.0/ 8.9	2.50
9,910- 9,940	sh_{100}	1.62	1.90	1.24	2.4	640	11,440/ 19,471	59.00	27.6/10.4	2.60
10,472 core	sh_{100}	1.35	1.77	1.86	2.9	---	---	---	---	---
10,510-10,540	sh_{95},si_5	1.25	1.84	1.62	2.7	566	3,177/ 7,197	44.00	20.1/18.4	1.10
10,810-10,840	sh_{100}	2.47	3.56	1.82	2.7	23	3,982/ 12,331	32.00	40.1/18.5	2.20
10,925-10,930	si_{100}	.21	1.01	2.11	3.1	---	---	---	16.4/15.4	1.10
11,050-11,080	si_{80},sh_5	.70	1.25	---	---	192	980/ 3,581	27.00	---	---
11,410-11,440	sh_{40},ss_{40},si_{20}	.81	1.42	1.90	2.7	35	274/ 6,147	4.00	36.1/18.7	1.93
11,677 core	sh_{100}	1.99	2.73	2.41	3.2	---	---	---	28.8/15.4	1.87
11,710-11,740	sh_{70},mu_{30}	1.45	2.38	2.17	2.7	1	2,641/ 16,063	16.00	43.4/14.4	3.01
12,070-12,100	sh_{90}	1.21	2.23	1.86	3.4	3.	340/ 6,638	5.00	---	---
12,572 core	si_{100}	.93	1.48	2.48	3.5	---	---	---	17.8/16.3	1.09
12,910-12,940	do_{60},sh_{40}	1.01	1.72	2.54	3.3	25	1,071/ 8,110	13.00	42.0/12.2	3.40
13,540-13,570	sh_{100}	.92	1.18	2.86	3.3	2	277/ 20,045	1.00	18.4/14.8	1.24
13,840-13,870	sh_{80}	1.17	1.62	2.91	3.3	6	1,578/ 15,706	10.00	52.6/29.5	1.78
14,200-14,230	sh_{100}	2.22	2.49	2.59	---	0	---	---	---	---
14,500-14,530	sh_{100}	1.34	2.42	2.56	3.6	0	1,247/ 17,403	7.00	---	---
14,518 core	sh_{100}	.60	.68	3.42	3.9	---	---	---	4.1/ 2.5	1.64
15,070-15,100	sh_{60}	1.68	2.66	---	3.7	1869	283/ 6,387	4.00	---	---
15,550-15,580	$sish_{90}$	.30	1.16	---	---	1387	59/ 2,901	2.00	---	---

Depth (ft)	Pristane/ Phytane (ppm)	ratio	Visual Kerogen relative percent Am	Be	Hu	In	Pyrolysis hydrocarbons wt%	Volatiles ppm	Tmax	Elemental Ratios H/C wt%	H/C atomic	O/C wt%	O/C atomic
9,610- 9,640	---	---	0	42	33	25	0.11	336	456	3.87/61.99	0.75	6.71/61.99	0.0
9,910- 9,940	4.6/2.8	1.6	0	40	40	20	.13	429	424	4.45/75.30	.71	8.02/75.30	.0
10,472 core	---	---	0	27	36	36	.23	909	408	3.36/81.21	.50	2.82/81.23	.0
10,510-10,540	---	---	0	27	36	36	.11	365	426	3.67/78.48	.56	---	---
10,810-10,840	---	---	33	33	17	17	.10	321	416	---	---	---	---
10,925-10,930	---	---	0	40	20	40	.02	117	360	---	---	---	---
11,050-11,080	---	---	-	---	---	---	.10	642	384	---	---	---	---
11,410-11,440	---	---	8	25	33	33	.50	162	404	3.43/67.70	.61	---	---
11,677 core	---	---	0	27	36	36	.10	197	504	3.49/86.54	.48	2.52/86.54	.02
11,710-11,740	---	---	0	36	27	36	.10	220	412	3.58/68.98	.62	---	---
12,070-12,100	6.2/2.8	2.2	15	23	31	31	.09	158	447	4.81/61.09	.94	---	---
12,572 core	---	---	0	20	40	40	.06	202	531	3.40/76.98	.53	---	---
12,910-12,940	---	---	23	31	31	15	.05	111	443	6.74/67.84	.84	14.21/67.84	.1
13,540-13,570	---	---	0	20	40	40	.02	76	422	3.10/63.84	.60	11.84/63.84	.14
13,840-13,870	---	---	37	25	33	25	.02	50	433	3.82/69.01	.66	---	---
14,200-14,230	---	---	---	---	---	---	.10	362	424	---	---	---	---
14,500-14,530	---	---	8	25	33	33	.09	352	408	---	---	---	---
14,518 core	---	---	0	20	40	40	.02	89	390	---	---	---	---
15,070-15,100	---	---	---	---	---	---	.15	853	412	---	---	---	---
15,550-15,580	---	---	---	---	---	---	.06	267	405	---	---	---	---

Table 1.--Geochemical parameters versus depth and lithology

(ss=sandstone, sh=shale, sd=siderite, si=siltstone, do=dolomite, lm=limestone, mu=mudstone, sish=siliceous shale
Multiply depth by 0.3048 m/ft for conversion)

Depth (ft)	Lithology	%C_{org}	Total C	TR_0	TAI	Light Hydrocarbons (ppm): C_5–C_7	Light Hydrocarbons (ppm): C_2–C_4/C_1–C_4	Light Hydrocarbons (ppm): wetness (%)	Light Hydrocarbons (ppm): rock extracts i-C_4/n-C_4	Light Hydrocarbons (ppm): rock extracts ratio
15,970-16,000	sish$_{95}$	0.51	1.26	3.70	3.6	71	93/ 2,037	4.00	3.2/ 6.7	0.48
16,256 core	sh$_{100}$	.27	----	4.04	4.1	---	-------------	-----	4.6/ 6.4	.71
16,570-16,600	sh$_{100}$	.41	.80	4.00	3.7	532	171/ 2,510	7.00	5.3/12.0	.44
17,145 core	sh$_{100}$	.31	1.47	4.30	6.1	---	-------------	-----	2.6/ 7.4	.35
17,230-17,260	sish	.37	2.77	4.28	4.1	495	41/ 1,822	2.00	6.3/19.3	.32
17,800-17,830	sish	.26	4.42	4.27	3.7	246	65/ 1,077	6.00	10.2/13.1	.78
18,520 core	lm$_{90}$,sh$_{10}$	.35	8.79	4.67	4.1	339	66/ 2,233	3.00	.9/ 2.4	.38
18,820-18,850	lm$_{80}$,sh$_{20}$	.42	7.58	4.65	4.1	86	90/ 3,870	1.00	3.3/ 9.7	.34
19,420-19,450	lm$_{95}$,sh$_{5}$	.33	7.37	5.02	4.0	62	27/ 912	3.00	1.3/ 7.1	.18
20,260-20,290	lm$_{70}$,sh$_{10}$	.35	7.67	----	4.2	57	181/ 1,366	13.00	---------	----

Depth (ft)	Pristane/Phytane (ppm)	ratio	Visual relative Kerogen percent: Am	He	Hu	In	Pyrolysis: hydrocarbons wt%	Pyrolysis: Volatiles ppm	Pyrolysis: T_{max}	Elemental Ratios: H/C wt%	H/C atomic	O/C wt%	O/C atomic
15,970-16,000	-------	---	0	40	20	40	0.06	334	400	4.42/53.82	0.99	----------	----
16,256 core	-------	---	0	22	33	44	.15	640	416	----------	----	----------	----
16,570-16,600	-------	---	0	36	27	36	.06	270	417	3.47/59.51	.70	----------	----
17,145 core	-------	---	0	22	33	44	.08	412	411	----------	----	----------	----
17,230-17,260	-------	---	0	0	50	50	.05	235	435	----------	----	----------	----
17,800-17,830	-------	---	0	11	44	44	.04	159	421	3.65/58.78	.74	----------	----
18,520 core	-------	---	11	22	22	44	.05	218	426	4.90/52.24	1.10	----------	----
18,820-18,850	-------	---	0	25	25	50	.04	187	429	----------	----	----------	----
19,420-19,450	-------	---	0	20	40	40	.08	322	420	5.58/52.02	1.30	36.02/52.02	0.52
20,260-20,290	8.2/6.5	1.3	0	20	40	40	.06	209	422	----------	----	----------	----

recorded the top 106 feet (32 m) of the well, but gamma ray logs of nearby shot holes show the combined thickness of alluvium and Gubik to be 20 to 40 feet (6 to 12 m) (G. Martin, personal communication, 1982).

Nanushuk Group

The Nanushuk Group is divided into the nonmarine Corwin Formation and the underlying Kukpowruk Formation. The Corwin Formation is approximately 3,650 feet (1,112 m) thick at the well. The upper contact is erosional (Molenaar, 1981), and the base of the coal-bearing section is picked at 3,708 feet (1,130 m) (pl. 2). The lithology is subbituminous coal, claystone, mudstone, siltstone with siderite nodules, carbonaceous shale, and very fine grained to medium-grained sandstone. Porosity of the sands ranges from 8 to 17 percent.

The Kukpowruk Formation, 3,708 to 6,280 feet (1,130 to 1,914 m), consists of shale, siltstone, claystone, and very fine grained to medium-grained sandstone. Porosities are less than in the Corwin Formation, ranging from 4 to 6 percent. Minor gas shows, 198-1,300 units, were reported in this interval.

Torok Formation

The Torok Formation, 6,280 to 10,633 feet (1,914 to 3,241 m), is predominantly a monotonous sequence of gray shale with minor thin beds of siltstones and very fine grained to fine-grained sandstone. It is conformable beneath the Nanushuk Group, and the contact is picked at the onset of the uneventful log response (pl. 2). Minor gas shows, 132-3,000 units, were recorded.

Pebble Shale

The Pebble Shale, 10,622 to 10,903 feet (3,241 to 3,323 m), is conformable beneath the Torok Formation. The unit is easily recognized on logs by the higher interval transit time compared to the surrounding rocks and by the gamma ray zone at the top of the unit (pl. 2). The gamma ray zone is a widespread organic-rich shale ($\%C_{org}$= 2.47%) (table 1) that is also mildly radioactive and is easily picked on gamma ray logs. It is a useful marker over much of the North Slope. The lithology is predominantly fissile, splintery shale with minor sandstone beds and the rare quartzite or chert pebble characteristic of this unit. A regional unconformity, the Lower Cretaceous unconformity (LCU) is the base of the Pebble Shale.

Kingak Shale

The Kingak Shale, 10,903 to 14,352 feet (3,323 to 4,374 m), is eroded at the LCU. It is divided into an upper and lower unit at a Cretaceous-Jurrasic unconformity at approximately 12,507 feet (3,812 m). The Cretaceous unit consists of black platy shale and very fine grained to fine-grained gas-bearing sands (150-560 units). The Jurassic unit also consists primarily of black marine shale with minor amounts of siltstone and very fine grained sandstone.

Sag River Formation

The Sag River Formation, 14,352 to 14,640 feet (3,323 to 4,462 m), is conformable beneath the Kingak Shale. The top is picked at an abrupt decrease in the interval transit time, and the base is picked at another velocity increase (pl. 2). The lithology is mostly gray to dark-gray shale with minor amounts of siltstone.

Shublik Formation

One hundred eighty feet of Shublik Formation, 14,640 to 14,820 feet, (3,323 to 4,517 m) underlie the Sag River. The unit consists of black, silty, fissile shale interfingers with siltstone and limestone at the top and becomes less silty and more calcareous with depth. The base of the unit reverts to a black shale lithology, easily picked from the logs.

Sadlerochit Group

The Sadlerochit Group includes the Ivishak and Echooka Formations. The Ivishak Formation, 14,820 to 16,884 feet (4,517 to 5,146 m), consists of very fine grained to medium-grained sandstones interbedded with black platy to subfissile shale at the top of the unit. Below 15,562 feet (4,743 m), the unit is a uniform argillaceous gray siltstone with black shale lamina. No gas shows were recorded through this interval.

Siltstones of the Echooka Formation, 16,884 to 17,100 feet (4,517 to 5,212 m), are the basal unit of the Sadlerochit Group. These siltstones are dark gray to black and sandy. The upper contact is conformable and distinct on the logs, as is the lower unconformable basal contact with the Lisburne Group carbonates (pl. 2).

Lisburne Group

The predominantly carbonate Lisburne Group, 17,100 to 20,335 feet (5,215 to 6,198 m) (TD), is the deepest sequence penetrated. The top of the unit, 17,100 to 17,560 feet (5,215 to 5,352 m), consists of interbedded silty limestone, siltstone, and minor fine-grained sandstone. This overlies a thick section of volcanic rocks, 17,580 to 18,304 feet (5,352 to 5,579 m), consisting of andesite (?) with minor accessory chlorite, feldspar, and calcite vein fill. Approximately 20 feet (6 m) of black shale underlies the volcanics. The rest of the sequence to TD is the limestone and silty limestone of the Wahoo Formation

GEOCHEMISTRY

Fifteen geochemical parameters are listed in table 1 to illustrate changes as a function of depth. The lithologies described in the stratigraphy are listed as percentages of each sample. Some samples only list the dominant lithology (e.g., Sh $_{80}$) and no minor lithologies as per the data released by NOAA.

Organic Carbon

The percent of organic carbon is listed for each sample. It is especially high in the Corwin Formation because of the numerous coals. In fact, the entire section to a depth of approximately 15,000 feet (4,572 m) is rich in organic material (i.e., > 1 percent). This amount is considered to be good source-rock potential (table 2) for siliciclastic rocks. The section is lean in organics between 15,000 and 18,304 feet (4,572 to 5,579 m) (sloughing of upsection cuttings make the volcanic rocks incorrectly appear to have organic carbon). Carbonate rocks below 18,500 feet (5,639 m) have 0.35 to 0.42 percent organic carbon, but this richness (table 2) may also be misleading because of sloughing of upsection material.

Also, the use of only organic carbon as a source-rock indicator may be misleading because it does not differentiate between kinds of organic material or maturity. Inertinite and recycled organic material present in most rocks will not generate hydrocarbons. In addition, the generation of hydrocarbons from organic matter is very inefficient, i.e., only about 3 percent is converted into C_{15}+ hydrocarbons (Hunt, 1979, p. 204). These facts are illustrated by the Tunalik Well data. Samples deeper than 10,500 feet (3,200 m) with greater than 1 percent C_{org} have no hydrocarbon potential.

Table 2.--Comparison of organic richness

(Source-Rock Evaluation Manual, Geochem Laboratories)

Percentage Organic Carbon Clastics	Percentage Organic Carbon Carbonates	Source-Rock Potential
0-0.50	0-0.12	Poor
0.50-1.00	0.12-0.25	Fair
1.00-2.00	0.25-0.50	Good
2.00-4.00	0.50-1.00	Very Good
4.00-8.00+	1.00-2.00	Excellent

Total Carbon

An estimate of carbonate carbon is available from the difference between total carbon and organic carbon; both measurements are direct measurements. However, erroneous data may be generated from the analyses of carbonate rocks because the percent error in the method of measuring organic carbon is often of the same order as the actual amount of organic carbon (Waples, 1980). Consequently, the carbonate section of the Tunalik well may have suspect organic carbon values (table 1). Claypool (1983, written commumication) adds that estimates of carbonate carbon contents in coaly sections are also suspect because of the uncertainty associated with the difference between large numbers.

Vitrinite Reflectance

Mean values of $\%R_o$ (over 30 measurements/sample) are listed and plotted (table 1, pl. 1). Good, single-mode reflectance data of primary vitrinite is probably the best indicator of organic maturity through the oil-generating range. $\%R_o$ values between 0.6 and 1.2 (Dow, 1977), 0.6 and 1.5 (Tissot and Welte, 1978), and 0.6 and 1.35 (Hunt, 1979) are generally accepted as limits for generating and preserving oil. Gas may be generated to $\%R_o$ values of 3 percent or more owing to the thermal degradation of kerogen and already generated hydrocarbons. Variations in the $\%R_o$ limits reflect the uniqueness of the kerogen, sedimentary basins, and investigators.

Vitrinite reflectance values for even the shallowest samples (table 1) show that considerable burial and diagenesis has already occurred. Note the subbituminous coals in the Corwin Formation. The oil-generating window is from approximately 3,300 feet (1,006 m) (core sample) to approximately 10,000 feet, (3,048 m) and the gas-generating window extends to approximately 14,000 feet (4,267 m). This shows that thermal maturity has been reached in the section above the LCU (pl. 2).

Dow (1977) has used $\%R_o$ plots to estimate the amount of erosion at unconformities. By extrapolating the $\%R_o$ from the Nanushuk Group to a value of .20 percent, as is found in peat, approximately 4,500 feet of section appears to have been eroded, assuming no dramatic change in geothermal gradient. There is no noticeable change in $\%R_o$ across the LCU; this suggests that the upper Kingak shale was not too deeply buried, and there were no major changes in the geothermal gradient during the Lower Cretaceous erosion.

The slope of the $\%R_o$ line is steep in the Sadlerochit and Lisburne Groups. Although information from over mature $\%R_o$ values (greater than 3 percent) may be dubious, the steep slope may reflect a lower geothermal gradient or slow sedimentation during Lisburne deposition.

Thermal Alteration Index (TAI)

The TAI values range from 2.0 to 4.2 in the Tunalik samples. The TAI is less sensitive than $\%R_o$ values as a maturity indicator because it involves considerable subjectivity in picking the kerogen color changes; and variables such as color, light transmission, and reflectivity are interrelated. The oil-generating window, as defined by TAI = 2.0-3.0, would be from the surface to approximately 11,710 feet, which is less definitive than the $\%R_o$.

Light Hydrocarbons

The C_1-C_7 light hydrocarbons (i.e., blended cuttings and headspace gas) are also important direct indicators of hydrocarbon generation, thermal maturity, and kerogen quality. Significant amounts of the C_2-C_7 fraction are found in oils and thermally mature sediments, but not in plants, animals, and thermally immature sediments (Tissot and Welte, 1978, p. 459 and Hunt, 1979, p. 153). This evidence indicates that these hydrocarbons are products of catagenesis.

Generation of the gasoline range, total C_5-C_7, increases steadily to a depth of 9,500 feet (2,896 m) from thermal degradation of kerogen. Below 10,000 feet (3,048 m), the kerogen ceases to generate this fraction (pl. 1), and below 15,000 feet (4,572 m), the C_5-C_7 fraction represents the thermal breakdown (cracking) of previously formed hydrocarbons that are unstable at higher temperatures. Note the alkane distributions (pl. 2) becoming skewed toward increasing amounts of shorter chain n-alkanes at the expense of the longer chain n-alkanes.

The total C_1-C_4 and C_2-C_4 fractions and the wetness ratio (C_2-C_4/C_1-C_4) are plotted on plate 1. The concentration of methane (C_1) is especially high, approximately 80,000 ppm, in the coal-bearing Corwin Formation. The data are so dramatic that the Corwin Formation could be picked from either the total C_1-C_4 plot or the wetness plot (pl. 1). Through the mature section the total C_1-C_4 and total C_2-C_4 concentrations are fairly constant. Wetness increases to 80 percent at the base of the oil-generating zone, but decreases to less than 20 percent in the over mature section where total C_2-C_4 is depleted (pl. 1).

Butane

Both butanes from rock extracts, n-C_4 and i-C_4, are plotted as a ratio (i-C_4/n-C_4) to demonstrate isomeric equilibrium as a function of maturity (Reznikof, 1969). Thermodynamically, immature sediments should have a higher percentage of i-C_4 because the tertiary carbon of i-C_4 should cleave more easily from the kerogen than the n-C_4 at lower temperatures. At higher temperaatures equilibrium tends towards unity. As observed from samples in the Tunalik well, this is generally true. However, it appears that the enriched i-C_4 may be a function of the Corwin Formation lithology rather than strictly owing to thermodynamics.

C_{15}+ Alkanes

Values for extracted C_{15}+ alkanes are presented on plate 2 for samples where data are available. Carbon preference indices (CPI) and pristane/phytane ratios are calculated where data are sufficient. The shallowest sample, at 3,300 feet, shows a n-alkane distribution common to sediments rich in land plant material. The deeper samples show a more normal distribution of n-alkanes extracted from marine sediments. Also demonstrated is the loss of the longer alkanes (greater than C_{24}) with increasing thermal degradation (pl.2). CPI values show no distinct trends, which may be because the sedimentary section is already mature.

Eight pristane/phytane ratios are available. Values are high in the Kukpowruk and Torok Formations, indicating that there is a significant contribution of land plant material to the kerogen (Connan and Cassou, 1980). The ratios are too sparse in the deeper rocks, and the rocks are too mature in the deeper part of the section to show any significant changes with depth.

Kerogen

Kerogen isolated from the cuttings and cores is divided into four categories based on visual description: 1) amorphous, presumably derived from algal materials which are oil prone upon maturity; 2) herbaceous, consisting of spores, pollen, grains, cuticles, and leaf epidermis of terrestrial origin and largely gas prone; 3) humic, woody material with recognizable microscopic cellular structure, gas prone; 4) inertinite, consisting of recycled, carbonized material, probably not capable of generating hydrocarbons.

Herbaceous kerogen is a major constituent to approximately 10,000 feet (3,048 m). Deeper than 10,000 feet (3,048 m), the humic kerogen and inertinite are the dominant kerogen species. Amorphous kerogen is rare and a minor constituent when found.

The Tunalik well drilling record reported only gas shows. This fact is consistent with the kerogen analyses. The only appreciable amorphous material was recorded from 10,810 to 10,840 feet (3,295 to 3,304 m) in the Pebble Shale unit, which is beyond the oil-generating window and into the beginning of the thermal degradation phase.

Other investigators (Brosge', Reiser, Dutro, and Detterman, 1981; Molenaar, Egbert, and Krystinik, 1981; Magoon and Claypool, 1979) have also reported that the Nanushuk Group and Torok Formation are gas-prone source rocks. Snowden and Powell (1982), however, that suggest land-plant-derived humic and herbaceous kerogens rich in resinite can generate waxy oil. Consequently, there may be potential for the Nanushuk and Torok elsewhere on the North Slope.

Pyrolysis

Pyrolysis-flame ionization detection (FID) involves heating crushed rock samples in the absence of free oxygen to yield hydrocarbons. As temperature increases, hydrocarbons are driven out and detected as two peaks, P_I and P_{II}. The first detector peak is the volatile hydrocarbons in ppm (table 1) which are proportional to the solvent-extracted bitumens (Claypool and Reed, 1976), i.e., those hydrocarbons which have already been generated. Thus, both immature and overmature samples will give low amounts of hydrocarbons.

The second detector peak (P_{II}) is a measure of the remaining hydrocarbon potential that will be released upon the breakdown of the kerogen during maturation. Claypool and others (1976) suggested that the T_2 max (the temperature of maximum hydrocarbon generation under controlled conditions) reflects maturity: the T_2 max for immature rocks is in the range 450-490°C, mature rocks 510-530°C, and overmature rocks above 600°C. Because the generation of hydrocarbons is governed by normal kinetics, heating time and rates will vary the T_2 max, but the trends should not be affected.

Total hydrocarbon yield ($P_I + P_{II}$) (table I) is a semiquantative measure of the genetic potential of a source rock. Tissot and Welte (1978) suggest the following classification: less than 2,000 ppm (.2 wt percent) = no oil potential, 2,000-6,000 ppm (.2-.4 wt percent) = moderate potential, and greater than 6,000 ppm (.6 wt percent) = good source potential. Table 1 lists total hydrocarbons as weight percent, as per the format released by NOAA.

Thermal analyses of the Tunalik well samples show that the coal-bearing Corwin Formation yields the highest amounts of total hydrocarbons and volatiles even though it is immature. In comparison, the underlying marine Kukpowruk and Torok Formations are mature, but yield hydrocarbons in the no- to- moderate potential range of Tissot and Welte (1978). The Pebble Shale and deeper units, although fairly rich in organic carbon, yield low amounts of hydrocarbons because they are overmature and have no more potential. Units that are lean in organic carbon yield very little hydrocarbon no matter how deeply buried.

The pyrolysis maturity data T_2 max shown in table I, show no distinct regular increase as a function of depth/maturity. Core T_2 max data for the immature section is 416°C. the mature section is 400°-452°C, and the detector response is too low to be meaningful in overmature sections.

H/C and O/C Ratios

Tissot, Durand, and others (1974) used H/C and O/C ratios to characterize kerogen type. Low H/C and high O/C ratios are diagnostic of polycyclic unsaturates and aromatics of immature woody and coaly material. Only a sample from the Lisburne Group carbonates was plotted as immature and oil generating types with a high H/C ratio (pl. 2).

CONCLUSION

The geochemical profile of the Tunalik No. 1 well shows that the quality and quantity of indigenous kerogen and the burial history of the sediments overwhelmingly favor the generation of gas. Major maturity indicators show that the oil-generating window is from approximately 3,300 feet (1,000 m) to approximately 10,500 feet (3,200 m), and above the Late Cretaceous unconformity.

Both the Nanushuk Group and Torok Formation are rich in organic material that is predominantly herbaceous and humic and, consequently, gas prone. The Pebble Shale kerogen is partly amorphous, but too deeply buried to produce liquid hydrocarbons.

Cuttings and core samples are in close agreement where comparisons are possibe. Also, all the thermal maturity indicators are in agreement, with the exception of the T_2 max data which is irregular. However, a fairly complete geochemical profile has been constructed from the available data and explains why only gas was found at Tunalik No. 1.

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