GeoChem Laboratories (U.K.) Limited

GEOCHEMICAL SERVICE REPORT

Prepared for

BP PETROLEUM DEVELOPMENT OF NORWAY A.S.

INTERIM GEOCHEMICAL EVALUATION OF THE INTERVAL 1375 - 2345 METRES OF BP NORWAY'S 30/4 - 1 WELL, NORWEGIAN NORTH SEA

PetroData as

February 1979

CHESTER STREET · CHESTER CH4 8RD · ENGLAND

INTERIM GEOCHEMICAL EVALUATION OF THE INTERVAL 1375-2345 METRES OF BP NORWAY'S 30/4-1 WELL, NORWEGIAN NORTH SEA

SUMMARY

Three (3) geochemical zones are recognised between 1375 metres and 2345 metres.

The Zone A^1 (1375-1780$\pm$ metres) shales are fair (with good interbeds above 1690$\pm$ metres) source rocks for oil and gas. They are however immature on-structure and, therefore, unable to realise this potential.

Zones A^2 and B (1780-2170$\pm$ metres and 2170-2345$\pm$ metres) are, with the exception of a fair interval at 1950-2050$\pm$ metres, poor, immature hydrocarbon sources.

No evidence of migrated hydrocarbons was observed in the analysed samples.

M J Sauer
GEOCHEM LABORATORIES (UK) LIMITED

INTRODUCTION

This report is an interim geochemical evaluation of the section between 1375 metres and 2345 metres in BP's 30/4-1 well, Norwegian North Sea.

The study was designed to be compatible with the previous studies performed for BP and to have the following primary objectives:

- to determine the hydrocarbon source potential of the section in terms of richness, maturity and hydrocarbon type
- to recognise and characterise migrated hydrocarbons

The results and conclusions from this study will be incorporated into a final report including the section below 2345 metres.

This study was authorised by Mr D South, BP Petroleum Development of Norway A.S.

A. ANALYTICAL

Twenty-nine (29) canned cuttings samples were received from the interval 1375-2345 metres in 30/4-1. They were generally composited over a 30 metre interval below 1500 metres (10 metre composite at 1590-1600 metres and spot sample at 1560 metres). Thirteen (13) sidewall cores were also submitted for analysis in addition to a mud sample from 2345 metres. The samples were assigned the Geochem job number 313 and numbered sequentially from -001 to -044.

Only scattered minor contamination was observed in washing the canned samples.

The samples were screened with the light hydrocarbon (C_1-C_7) and organic carbon analyses and samples for further analysis were selected on the basis of the screen results. A total of thirty light hydrocarbon analyses, twenty-four visual kerogen analyses, eleven vitrinite reflectance determinations, eleven extractions with chromatography, eleven paraffin-naphthene analyses and ten pyrolysis analyses were performed.

The data are presented in tables 1 to 8 and graphically in figures 1 to 5.

B. GENERAL INFORMATION

Twelve copies of this report have been forwarded to Mr D South, BP Petroleum Development of Norway A.S., Stavanger. A copy of the data has been retained by Geochem for future consultation

with authorised BP personnel.

The kerogen slides and vitrinite reflectance worksheets will be forwarded with the final report. The remaining sample material will be handled as directed.

All of the results and interpretations related to this study are regarded as highly confidential and are proprietary to BP Petroleum Development of Norway A.S.

RESULTS AND INTERPRETATION

Each of the parameters relevant to the evaluation of the interval 1375-2345 metres will be discussed individually and then combined to form the "Conclusions".

A. ORGANIC GEOCHEMICAL ZONATION

This zonation is based upon the light (C_1-C_7) hydrocarbon and organic carbon data. Three (3) Zones are recognised.

Zone A^1 (1375-1780± metres), apparently consists of olive grey and greenish grey shales with minor sandstones (notably at 1660-1720± metres). However, the sidewall cores at 1573 metres and 1647 metres (± 1541.5 metres) are dominantly sandy suggesting that the sands may be under represented in the cuttings - possibly due to losses on the shale shaker. Cuttings samples from between 1560± metres and 1690± metres contain minor to significant proportions of caved shales.

The sand at 1541.5 metres yielded a minor blue cut.

C_1-C_4 hydrocarbon abundances exceed 1000 ppm above 1600± metres (1560-4941 ppm) but are generally less than 200 ppm (765 ppm at 1720-1750± metres) below this depth. These gases are dry (less than 10% C_{2+} hydrocarbons) and are accompanied by traces (less than 100 ppm) of the C_5-C_7 hydrocarbons fraction.

Organic carbon contents are generally above average in this Zone ranging from (0.63) 0.85-1.65% .

Zone A^2 (1780-2170± metres) is largely shaly, with minor limestones, although the lowermost 50± metres consists mainly of sandstones. The shales are dominantly greenish grey and less frequently olive grey, in colour.

No fluorescence was observed in the sandstones. Gaseous hydrocarbons vary irregularly between 363 ppm and 3806 ppm (generally above 1000 ppm) and are dry (3.6-15.2% metres). This dryness is reflected in the heavier C_5-C_7 hydrocarbon fraction which is relatively sparse (36-374 ppm).

Unlike the Zone A^1 shales, the Zone A^2 shales rarely contain more than 0.7% organic carbon (0.9% at 1950± metres).

Zone B (2170-2345± metres). The dominantly medium grey to greenish grey shales are interbedded with minor to

significant sandstones. The cuttings generally contain minimal amounts of caved greenish grey shale (except at 2320-2345± metres where they are significant).

The carbonate present in the core at 2318± metres did not fluoresce.

Gaseous hydrocarbons are less abundant (101-904 ppm, 1801 ppm at 2200-2230± metres) but wetter (21-37% C_{2+} hydrocarbons) than those in the overlying sediments. The isobutane to normal butane ratio is less than unity (0.37-0.85) whilst the C_5-C_7 hydrocarbon abundances are generally poor at 182-421 ppm (1193 ppm at 2200-2230± metres).

The Zone B shales, like their Zone A^1 counterparts, have poor to fair organic carbon contents ranging from 0.26% up to 0.61%.

B. AMOUNT AND TYPE OF ORGANIC MATTER

The amount of organic matter within a sediment is measured by its organic carbon content. Average shales contain approximately one percent organic carbon and this is the standard to which these samples will be compared.

Organic matter type influences not only source richness but also the character (oil/gas) of the hydrocarbon product and the response to thermal maturation. Richness and oiliness decrease in the order: amorphous-herbaceous-stem-woody. Wood has a primary (but not exclusive) potential for gas, whilst coaly (oxidised) material has only a limited hydrocarbon potential.

Down to 1560± metres the olive grey and greenish grey shales have average ((0.63), 0.85-1.12% organic carbon) contents of mainly woody, herbaceous and stem kerogen in varying proportions. Amorphous and coaly debris are generally minor to significant fractions in this interval. The underlying greenish grey shales (within Zone A^1) are of similar richness (0.96-1.43% organic carbon) but contain woody and coaly organic matter with only minor to significant proportions of herbaceous and stem material. The medium olive grey shales (believed caved at 1590-1690± metres) have good (1.36-1.65%) organic carbon contents and contain organic matter which resembles that in the shales above 1560± metres.

Grey, greenish grey and olive grey shales occur throughout Zone A^2. They are, however, lean with organic carbon contents of less than 0.5% except at 1950-2050± metres where the values reach 0.90%. Woody and herbaceous organic matter is dominant (stem and coaly kerogens minor) in the olive grey and medium dark grey shales. The more abundant, but slightly leaner, greenish grey shales contain mainly woody and coaly debris and only minor to significant amounts of herbaceous and stem material.

Organic carbon values range from 0.26% to 0.61% (average 0.4%) in the greenish grey and grey Zone B shales. Woody and coaly organic matter is dominant in this Zone although a slight improvement (woody and herbaceous, possible contamination) is noted in the olive grey shale at 2240± metres. The limestone at 2318± metres contains sparse (0.28% organic carbon) woody and coaly debris. Herbaceous and stem organic matter is generally minor in the Zone B sediments.

The analysed sediments were mainly deposited under oxidising conditions. A slightly more reducing environment apparently prevailed for the shales above 1560± metres.

C. LEVEL OF THERMAL MATURATION

Thermal maturity has been evaluated using the organic matter colouration and vitrinite reflectance methods.

A maturation index (based upon organic matter colouration) of 2- is achieved at approximately 1800± metres, whilst a level of 2 is not reached by the bottom of the analysed section.

Above 1800± metres the sediments are totally immature. Below this depth the dominant woody and coaly material is also immature, although the generally minor (to significant) herbaceous and stem fractions are marginally mature. The section is, for practical purposes, immature throughout. These conclusions are supported by the characteristics of the extracted C_{15+} paraffin-naphthene chromatograms which show marked signs of immaturity.

If vitrinite reflectance values of greater than 0.7% Ro (due to reworked material) are eliminated, the remaining data points closely define a linear trend which passes through 0.4% Ro at 1700± metres and reaches a maximum value of 0.45% Ro at 2300± metres.

Although the vitrinite reflectance scale is relatively insensitive to changes in maturation at this level, the trend is in good agreement with that established from the spore fluorescence colours. Furthermore, if the vitrinite reflectance and organic matter colouration scales are related by the equivalence of 0.45% Ro and a maturation index of 2-/2- to 2, all three methods correlate.

D. HYDROCARBON SOURCE RICHNESS

Preliminary assessments of present and potential source richness can be obtained from the light hydrocarbon and organic carbon abundances respectively.

Light hydrocarbon data suggest that the Zone A^1 shales above 1600± metres are fair source rocks. The interval 1800± metres to 2230±

metres is similarly rated as fair with poor interbeds whilst the remaining sediments in the analysed section are poor.

The Zone A^1 shales, from the organic carbon values, are rated as fair to good or good source rocks and the underlying shales, with the exception of a fair interval at 1950-2050± metres, as poor.

The abundance of C_{15+} hydrocarbons can provide a definitive assessment of source richness. They vary from 139 ppm up to 1098 ppm indicating that these sediments are apparently variously fair to rich source rocks. However, the hydrocarbon to total extract and hydrocarbon to organic carbon ratios (31-56% and 2.2-19.3% respectively) are higher than anticipated for these largely immature sediments. The data indicate that non indigenous hydrocarbons have augmented those sourced by the sediment (see Section E). Thus, the C_{15+} hydrocarbon abundances are not an accurate measure of source richness for the analysed shales. The indigenous hydrocarbons probably approximate 100-200 ppm, which would suggest poor and fair source rocks.

The pyrolysis analysis simulates, in the laboratory, the maturation process and measures source richness under optimum conditions. Generally fair ratings are assigned by this method to the Zone A^1 shales although better intervals of greenish grey (1660-1690± metres) and olive grey (1375± metres and 1471± metres) shales with good ratings also occur. The richer shales of Zones A^2 and B are, likewise, rated as fair source rocks but otherwise, these intervals are poor.

To summarise:

- the olive grey shale interbeds above 1690± metres are good source rocks whilst the remaining shales within Zone A^1 are fair
- Zone A^2 is generally a poor hydrocarbon source although the interval 1950-2050± metres is rated as fair.
- the Zone B shales are also poor, or at best poor to fair, source rocks.

E. MIGRATED HYDROCARBONS

Sandstone (limestone at 2320± metres) interbeds occur throughout the analysed section. A minor blue cut was observed in the sandstone core at 1541.5± metres but the C_1-C_4 gas abundance and wetness data do not suggest migrated hydrocarbons anywhere within the section.

This suggests that the C_{15+} hydrocarbon abundances (139-1098 ppm) referred to in Section D are not due to migrated crude oil. Their paraffin-naphthene chromatograms all display the same characteristics - namely a high background hump and a low proportion of normal paraffins. The hump, which is believed to be due to

contamination, is frequently most pronounced in those samples which have high hydrocarbon to total extract ratios. The strong odd carbon preference shown by the normal paraffins is indicative of immature organic matter. Hence the chromatograms indicate the presence of both source-indigenous and contaminant hydrocarbons, but not migrated species.

F. CONCLUSIONS

Three (3) geochemical zones are recognised between 1375 metres and 2345 metres in the 30/4-1 well.

Zone A^1 (1375-1780$\pm$ metres) consists of mixed shale lithologies but is dominated by olive grey and greenish grey shales which have, in general, above average ((0.63), 0.85-1.65%) organic carbon contents. The medium olive grey shales (possibly caved) at 1590-1690$\pm$ metres are the richest and their organic matter is dominantly woody in type, although with significant proportions of herbaceous and stem kerogen. A similar type of organic matter is present in the shales above 1560$\pm$ metres whilst those below this depth contain mainly woody and coaly debris. The shales have a fair to good potential for gas and oil (chiefly for gas below 1560$\pm$ metres) but are immature on structure and, therefore, unable to realise this potential.

Zone A^2 (1780-2170$\pm$ metres). The dominant (greenish grey) shales are interbedded with minor limestones, although the basal 50 metres is sandy. In contrast to the overlying sediments these shales are lean (less than 0.5% organic carbon), although the values improve to 0.5-0.9% at 1950-2050$\pm$ metres. Their organic matter is dominantly woody and coaly in character but improves in type, to a herbaceous-woody assemblage in the less abundant grey shales.

The "richest" interval (1950-2050$\pm$ metres) is characterised by this improved type of organic matter. The herbaceous and stem fraction of the organic matter is marginally mature but the dominant woody (and coaly) debris, which determines for practical purposes the maturity of these sediments, is immature. The Zone A^2 shales are both lean and immature and, therefore, have a negligible hydrocarbon potential.

Zone B lies between 2170$\pm$ metres and 2345$\pm$ metres and is composed of shales and minor sandstones (limestone at 2320$\pm$ metres). The shales are lean (0.26-0.61%, average 0.4% organic carbon) and contain mainly woody and coaly organic matter (woody and herbaceous in the minor grey shale at 2240$\pm$ metres). Minor proportions of stem and herbaceous ($\pm$ amorphous) kerogen also occur in these sediments. The woody-coaly fraction of the organic matter is immature and the marginally mature herbaceous and stem debris is only capable of generating minor volumes of liquids. Hence, this is a poor and effectively immature source interval which is of minimal exploration interest.

The analytical data do not indicate the presence of migrated hydrocarbons within the analysed section.

TABLE 1A

CONCENTRATION (VOL. PPM OF ROCK) OF C_1 - C_7 HYDROCARBONS IN AIR SPACE GAS

GEOCHEM SAMPLE NUMBER	DEPTH	C_1 Methane	C_2 Ethane	C_3 Propane	iC_4 Isobutane	nC_4 Butane	TOTAL C_1 - C_4	TOTAL C_2 - C_4	% GAS WETNESS	TOTAL C_5 - C_7	$\frac{iC_4}{nC_4}$
313-003	1500-530m	3461	29	7.1	-	-	3497	36	1.0	1.7	-
313-005	1560m	1367	14.3	3.2	-	-	1384	17.5	1.3	1.3	-
313-006	1560-590m	1020	104	1.9	-	-	1126	106	9.4	0.2	-
313-008	1590-600m	4809	81	10.6	-	-	4901	92	1.9	86	-
313-009	1600-630m	120	1.6	0.2	-	-	122	1.9	1.5	0.4	-
313-010	1630-660m	164	3.0	0.3	-	-	167	3.3	1.9	4.4	-
313-012	1660-690m	69	1.6	0.3	-	-	71	1.9	2.7	-	-
313-013	1690-720m	54	1.8	0.5	-	-	56	2.3	4.1	8.7	-
313-014	1720-750m	337	5.8	1.7	-	-	344	7.5	2.2	-	-
313-015	1750-780m	66	3.7	1.1	-	-	71	4.9	6.9	19.9	-
313-017	1780-810m	60	4.8	1.7	-	-	66	6.5	9.9	9.8	-
313-018	1810-840m	2540	71	11.3	7.4	3.4	2633	93	3.5	61	2.19
313-019	1840-870m	293	25	3.4	-	-	321	28	8.7	59	-
313-020	1870-900m	3080	96	19.7	7.8	3.2	3207	126	3.9	5.6	2.41
313-022	1900-930m	1075	44	8.4	3.8	1.8	1132	58	5.1	11.7	2.12
313-023	1930-960m	310	43	7.2	-	-	360	51	14.0	62	-
313-025	1960-990m	3426	187	28	17.3	5.9	3665	239	6.5	64	2.91
313-026	1990-2020m	2039	94	13.9	10.3	3.2	2161	122	5.6	24	3.18
313-027	2020-050m	1047	57	7.5	9.3	1.6	1122	75	6.7	25	5.99
313-029	2050-080m	427	45	21	6.2	1.0	500	74	14.7	32	6.37
313-030	2080-110m	1422	147	20	30	5.3	1624	203	12.5	285	5.58
313-032	2110-140m	2691	178	15.3	18.0	3.1	2906	215	7.4	44	5.86
313-033	2140-170m	1182	75	8.3	13.9	3.2	1282	100	7.8	48	4.35
313-034	2170-200m	184	30	12.1	8.7	9.0	244	59	24.4	79	0.96
313-035	2200-230m	1295	157	75	37	36	1599	304	19.0	1053	1.05
313-036	2230-260m	562	55	32	16.5	15.7	681	119	17.5	62	1.05
313-039	2260-290m	108	15.9	13.6	9.1	13.5	160	52	32.5	293	0.67
313-040	2290-320m	229	32	28	14.1	15.6	318	89	28.1	92	0.91
313-042	2320-345m	31	7.5	2.4	-	-	40	9.8	24.4	83	-
313-043	2345m	225	23	8.6	-	-	256	31	12.3	51	-

TABLE 1B

CONCENTRATION (VOL. PPM OF ROCK) OF C_1 - C_7 HYDROCARBONS IN CUTTINGS GAS

GEOCHEM SAMPLE NUMBER	DEPTH	C_1 Methane	C_2 Ethane	C_3 Propane	iC_4 Isobutane	nC_4 Butane	TOTAL C_1 - C_4	TOTAL C_2 - C_4	% GAS WETNESS	TOTAL C_5 - C_7	$\frac{iC_4}{nC_4}$
313-003	1500-530m	366	7.0	1.9	-	-	375	8.9	2.4	15.3	-
313-005	1560m	245	5.0	0.9	-	-	251	5.9	2.4	20	-
313-006	1560-590m	426	7.0	1.1	-	-	434	9.1	2.1	14.0	-
313-008	1590-600m	37	3.2	-	-	-	40	3.2	8.0	15.2	-
313-009	1600-630m	64	1.6	-	-	-	66	1.6	2.4	11.8	-
313-010	1630-660m	27	3.5	1.0	-	-	32	4.5	14.1	-	-
313-012	1660-690m	28	3.5	1.9	-	-	33	5.4	16.4	7.7	-
313-013	1690-720m	23	3.3	-	-	-	26	3.3	12.7	0.5	-
313-014	1720-750m	388	14	9.6	-	-	412	24	5.7	-	-
313-015	1750-780m	23	3.2	-	-	-	26	3.2	12.3	46	-
313-017	1780-810m	55	3.2	-	-	-	58	3.2	5.5	36	-
313-018	1810-840m	70	4.8	-	-	-	75	4.8	6.4	25	-
313-019	1840-870m	37	5.0	-	-	-	42	5.0	11.9	5.5	-
313-020	1870-900m	218	14.4	4.2	2.6	1.3	241	23	9.3	30	2.00
313-022	1900-930m	110	6.9	1.1	-	-	118	8.0	6.8	37	-
313-023	1930-960m	18.6	5.2	3.0	-	-	27	8.2	30.4	59	-
313-025	1960-990m	92	26	9.7	8.5	5.0	141	49	34.9	73	1.70
313-026	1990-2020m	408	21	4.2	3.8	1.5	439	31	6.9	71	2.53
313-027	2020-050m	557	45	9.5	9.0	3.7	624	67	10.8	145	2.43
313-029	2050-080m	60	6.9	2.2	3.8	1.3	74	14.2	19.2	131	2.92
313-030	2080-110m	60	8.6	3.2	5.6	2.1	80	19.5	24.3	89	2.66
313-032	2110-140m	232	24	3.2	3.8	1.2	264	32	12.2	41	3.16
313-033	2140-170m	408	45	8.4	10.3	3.0	475	67	14.0	76	3.43
313-034	2170-200m	97	30	22	15.8	21	186	89	47.7	160	0.75
313-035	2200-230m	129	25	20	11.6	21	207	78	37.5	140	0.55
313-036	2230-260m	147	23	22	11.6	19.1	223	76	33.9	133	0.61
313-039	2260-290m	36	8.0	9.1	5.8	10.7	70	34	48.0	128	0.54
313-040	2290-320m	58	10.0	14.0	6.6	14.0	103	45	43.3	162	0.47
313-042	2320-345m	44	3.3	4.0	2.3	6.2	60	15.8	26.3	99	0.37
313-043	2345m	4.5	1.5	-	-	-	6.0	1.5	25.0	36	-

TABLE 1C

TOTAL CONCENTRATION (VOL. PPM OF ROCK) OF C_1 - C_7 HYDROCARBONS (1A + 1B)

GEOCHEM SAMPLE NUMBER	DEPTH	C_1 Methane	C_2 Ethane	C_3 Propane	iC_4 Isobutane	nC_4 Butane	TOTAL C_1 - C_4	TOTAL C_2 - C_4	% GAS WETNESS	TOTAL C_5 - C_7	$\frac{iC_4}{nC_4}$
313-003	1500-530m	3827	36	9.0	-	-	3872	45	1.2	17.0	-
313-005	1560m	1612	19.3	4.1	-	-	1635	23	1.4	21	-
313-006	1560-590m	1446	111	3.0	-	-	1560	114	7.3	14.2	-
313-008	1590-600m	4846	84	10.6	-	-	4941	95	1.9	101	-
313-009	1600-630m	184	3.2	0.2	-	-	187	3.4	1.8	12.2	-
313-010	1630-660m	191	6.5	1.3	-	-	199	7.8	3.9	4.4	-
313-012	1660-690m	97	5.1	2.2	-	-	104	7.3	7.0	7.7	-
313-013	1690-720m	77	5.1	0.5	-	-	83	5.6	6.7	9.2	-
313-014	1720-750m	725	19.8	11.3	-	-	756	31	4.1	-	-
313-015	1750-780m	89	6.9	1.1	-	-	97	8.0	8.2	66	-
313-017	1780-810m	115	8.0	1.7	-	-	125	9.7	7.8	46	-
313-018	1810-840m	2610	76	11.3	7.4	3.4	2708	98	3.6	86	2.18
313-019	1840-870m	330	30	3.4	-	-	363	33	9.2	65	-
313-020	1870-900m	3298	110	24	10.4	4.5	3447	150	4.3	36	2.31
313-022	1900-930m	1185	51	9.5	3.8	1.8	1251	66	5.3	49	2.11
313-023	1930-960m	329	48	10.2	-	-	387	58	15.0	121	-
313-025	1960-990m	3518	213	38	26	10.9	3806	288	7.6	137	2.39
313-026	1990-2020m	2447	115	18.1	14.1	7.4	2602	155	5.9	95	1.91
313-027	2020-050m	1604	102	17.0	18.3	5.3	1747	143	8.2	170	3.45
313-029	2050-080m	487	52	23	10.0	2.3	574	87	15.2	163	4.35
313-030	2080-110m	1482	156	23	36	7.4	1704	222	13.0	374	4.86
313-032	2110-140m	2923	202	18.5	22	4.3	3170	247	7.8	85	5.12
313-033	2140-170m	1590	120	16.7	24	6.2	1757	167	9.5	124	3.87
313-034	2170-200m	281	60	34	24	30	430	149	34.6	239	0.82
313-035	2200-230m	1424	182	95	49	57	1807	383	21.2	1193	0.85
313-036	2230-260m	709	78	54	28	35	904	195	21.6	195	0.81
313-039	2260-290m	144	24	23	14.9	24	230	86	37.3	421	0.62
313-040	2290-320m	287	42	42	21	30	421	134	31.9	254	0.70
313-042	2320-345m	75	10.8	6.4	2.3	6.2	101	26	25.5	182	0.37
313-043	2345m	230	25	8.6	-	-	263	33	12.6	87	-

TABLE 2
ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH		GROSS LITHOLOGIC DESCRIPTION	G S A Colour Code	TOTAL ORGANIC CARBON (% of Rock)
313-001 S.W.C. No.87	1375m		Shale, fissile, non calcareous, olive grey	5Y3/2	1.01
313-002 S.W.C. No.84	1471m		Shale, fissile, non calcareous, olive grey	5Y3/2	0.98,0.95
313-003	1500-1530m	A 85%	Shale, fissile, non calcareous, medium grey to medium greenish grey	N5-5GY5/1	1.12
		B 15%	Silty shale, fissile to blocky, non calcareous, cavings, medium olive grey Minor sandstone	5Y5/1	0.85
313-004 S.W.C. No.81	1541.5m		Shale, fissile, non calcareous, dark greenish greyish black Sandstone, very fine grained, non calcareous, minor blue cut, very light grey	5GY3/1 N8	0.63
313-005	1560m	A 98%	Shale, as 313-003A Minor siltstone and other shale	N5-5GY5/1	1.05
313-006	1560-1590m	A 70%	Shale, fissile, non calcareous, significant cavings, medium grey to medium olive grey	N5-5Y5/1	1.46
		B 30%	Shale, fissile, non calcareous, greenish grey to greenish grey Minor other shale and sandstone cavings	5GY6/1-5G6/1	1.19,1.19
313-007 S.W.C. No.79	1573m	A	Silty sandstone, very fine, angular grained, no fluorescence, medium greenish grey	5Y7/1	
		B	Silty sandstone, fine grained, non calcareous, no fluorescence, medium olive grey Minor shale, olive grey	5Y4/2 5Y3/2	
313-008	1590-1600m	A 60%	Shale, as 313-006B	5GY6/1-5G6/1	1.11
		B 40%	Shale, as 313-006A, significant cavings Minor sandstone	N5-5Y5/1	1.65

TABLE 2
ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	G S A Colour Code	TOTAL ORGANIC CARBON (% of Rock)
313-009	1600-1630m	A 60% Shale, fissile, non calcareous, greenish grey to greenish grey, cavings	5GY6/1-5G6/1	1.43
		B 40% Shale, fissile, non calcareous, medium grey to medium olive grey, cavings Minor sandstone	N5-5Y5/1	1.48
313-010	1630-1660m	A 55% Shale, as 313-009A, minor cavings	5GY6/1-5G6/1	1.21,1.21
		B 45% Shale, as 313-009B, minor cavings Minor sandstone	N5-5Y5/1	1.36
313-011 S.W.C. No.78	1647m	Sandstone, very fine angular grained, non calcareous, no fluorescence, light olive grey	5Y6/1	
313-012	1660-1690m	A 95% Shale, fissile, non calcareous, medium grey to greenish grey, minor cavings	N5-5GY6/1	1.34
		B 5% Quartz grains, coarse to medium, subangular clear to opaque Minor other shale		
313-013	1690-1720m	A 85% Shale, as 313-012A	N5-5GY6/1	0.96
		B 15% Quartz grains, as 313-012B Minor other shale		
313-014	1720-1750m	A 98% Shale, fissile, non calcareous, medium greenish grey Minor limestone	5G5/1	1.05
313-015	1750-1780m	A 98% Shale, as 313-012A Minor limestone	N5-5GY6/1	1.07,1.07
313-016 S.W.C. No.74	1780m	Shale, fissile, non calcareous, dark greenish grey	5GY4/1	1.10
313-017	1780-1810m	A 98% Shale, fissile, non calcareous, medium greenish grey, minor cavings Minor limestone and other shale	5GY4/2	0.19

TABLE 2
ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	GSA Colour Code	TOTAL ORGANIC CARBON (% of Rock)
313-018	1810-1840m	A 99% Shale, fissile, non calcareous, medium yellow greenish grey	10GY6/2	0.17
313-019	1840-1870m	A 98% Shale, fissile, non calcareous, medium greenish grey Minor limestone and other shale	5G5/1	0.29
313-020	1870-1900m	A 65% Shale, as 313-019A, cavings	5G5/1	0.17
		B 30% Shale, fissile, non calcareous, dark greenish grey	5G4/1	0.37,0.37
		C 5% Shale, fissile, non calcareous, brownish grey Minor other shale and limestone	5YR4/1	
313-021 S.W.C. No.72	1878m	Shale, fissile, non calcareous, olive grey	5Y3/2	0.22
313-022	1900-1930m	A 98% Shale, fissile, non calcareous, medium grey to greenish grey Minor limestone	N5-5GY6/1	0.16
313-023	1930-1960m	A 98% Shale, fissile, non calcareous, medium grey to medium greenish grey, cavings Minor other caved shale	N5-5GY5/1	0.25
313-024 S.W.C. No.70	1950m	Shale, fissile, non calcareous, olive grey	5Y4/1	0.90
313-025	1960-1990m	A 98% Shale, as 313-023A, significant cavings Minor limestone and other caved shales	N5-5GY5/1	0.47
313-026	1990-2020m	A 98% Shale, as 313-023A, cavings Minor other shale	N5-5GY5/1	0.68
313-027	2020-2050m	A 70% Shale, as 313-023A	N5-5GY5/1	0.34,0.34
		B 30% Shale, fissile, non calcareous, medium dark grey to dark greenish grey Minor other shale	N4-5GY4/1	0.78

TABLE 2
ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH		GROSS LITHOLOGIC DESCRIPTION	G S A Colour Code	TOTAL ORGANIC CARBON (% of Rock)
313-028 S.W.C. No.39	2024m		Silty shale, fissile to blocky, slightly calcareous, olive grey	5Y3/2	0.46,0.46
			Shale inclusions - fissile, non calcareous, greenish grey	5G6/1	
313-029	2050-2080m	A 98%	Shale, fissile, non calcareous, medium light grey to greenish grey	N6-5GY6/1	0.13
			Minor other shale		
313-030	2080-2110m	A 98%	Shale, as 313-029A, minor cavings	N6-5GY6/1	0.28
			Minor quartz grains		
313-031 S.W.C. No.67	2102m	A	Silty shale, fissile to blocky, non calcareous, dark greenish grey	5GY4/1	0.33
		B	Shale, fissile, non calcareous, medium greenish grey	5GY5/1	0.06
313-032	2110-2140m	A 85%	Shale, fissile, non calcareous, medium dark to medium grey	N4-5	0.52
		B 10%	Quartz grains, fine angular clear		
		C 5%	Limestone, blocky, no fluorescence, very light grey to pinkish grey	N8-5YR8/1	
			Minor other shale		
			Minor coal		
			Poor sample		
313-033	2140-2170m	A 70%	Quartz grains, coarse to medium, subangular to subrounded, opaque		
		B 30%	Shale, fissile, non calcareous, cavings, medium grey	N5	0.36,0.37
			Minor limestone		
313-034	2170-2200m	A 80%	Shale, fissile, non calcareous, medium grey to medium greenish grey, cavings	N5-5GY5/1	0.49
		B 20%	Quartz grains, as 313-033A		
			Minor sandstone		

TABLE 2

ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	G S A Colour Code	TOTAL ORGANIC CARBON (% of Rock)
313-035	2200-2230m	A 95% Shale, fissile, non calcareous, medium grey to medium greenish grey, cavings B 5% Quartz grains, coarse to medium, subangular to subrounded, opaque	N5-5GY5/1	0.40
313-036	2230-2260m	A 98% Shale, as 313-035A, cavings Minor quartz grains	N5-5GY5/1	0.26
313-037 S.W.C. No.64	2240m	Silty shale, fissile, calcareous, olive grey	5Y4/1	0.42
313-038 S.W.C. No.63	2259m	Shale, fissile, calcareous, medium grey	N5	0.36
313-039	2260-2290m	A 95% Shale, as 313-035A, cavings B 5% Quartz grains, as 313-035B Minor coal and limestone	N5-5GY5/1	0.48
313-040	2290-2320m	A 95% Shale, as 313-035A, minor cavings B 5% Limestone, blocky, no fluorescence, very light grey to pinkish grey Minor coal and quartz grains	N5-5GY5/1 N8-5YR8/1	0.34,0.34
313-041 S.W.C. No.61	2318	Limestone, fissile to blocky, no fluorescence, light grey Minor shale inclusions - poor sample	N7	0.28,0.28
313-042	2320-2345	A 65% Shale, as 313-035A, significant cavings B 35% Quartz grains, as 313-035B Minor limestone	N5-5GY5/1	0.61
313-043	2345m	Mud sample		

TABLE 3

VISUAL KEROGEN DATA

GEOCHEM SAMPLE NUMBER	DEPTH	ORGANIC MATTER DESCRIPTION				THERMAL MATURATION INDEX
		TYPES	REMARKS	PARTICLE SIZE	PRESERV-ATION	
313-001	1375m	W;Am*-H*;S-C	* includes H passing to Am.	M	F-G	1+ to 2-/2-
313-002	1471m	W-S;H-Am;C	some H at 2-	F-M	G	1+ to 2-/2-
313-004	1541.5m	H-S-W;-;C-Am		F-M	F-G	2-max.
313-005	1560m	H;W-S-C;Am		M	G	2-max.
313-006B	1560-590m	W;C-H;S		F-M	F	1+ to 2-/2-
313-010A	1630-660m	W-C;-;S-H	lean	F	F	2-(?)
313-010B	1630-660m	W;H*-S;C	* scattered minor sapropel-isation	M	F	1+ to 2-/2-
313-012A	1660-690m	W-C;H-S;-	lean	F-M	F	1+ to 2-
313-014A	1720-750m	W;C-S;H		F-M	F	2-(?)
313-016	1780m	W;C-H;S	lean, contamination. Rework-ing	F	F	2-
313-018A	1810-840m	W;C-H;S	lean	F	F-G	1+ to 2-
313-021	1878m	H;W;S-C	algae. Significant H at 1+ to 2-	F	G	2-
313-022A	1900-930m	W;C;S-(H)	fine contaminant, lean	F	F	2-
313-024	1950m	H;W;S-C		F	G	2-
313-027B	2020-050m	W-H;-;S-C		F-M	F-G	2-
313-028	2024m	W;C-S;H	reworking	F-M	F	2-
313-029A	2050-080m	W-C;H;S	lean, contamination	F	F	2- to 2
313-031A	2102m	W;C;H-S		M	G	2- to 2
313-031B	2102m	W-C;-;H-S	lean	F-M	P	
313-032A	2110-140m	W;H-C;S-Am	reworking (2).	M	F-G	2- to 2

Algal, Amorphous, Coaly, Herbaceous, Stem, Woody.

TABLE 3

VISUAL KEROGEN DATA

GEOCHEM SAMPLE NUMBER	DEPTH	ORGANIC MATTER DESCRIPTION				THERMAL MATURATION INDEX
		TYPES	REMARKS	PARTICLE SIZE	PRESERV-ATION	
313-034A	2170-200m	C-W;H;S	reworking (2)	M-C	F	2- to 2
313-037	2240m	W;H;S-C	contamination	F-M	F-G	
313-038	2259m	W;C;H-S		F-C	F	2- to 2
313-041	2318m	W;C;H	lean	F	F	2- to 2(?)

Algal, Amorphous, Coaly, Herbaceous, Stem, Woody.

TABLE 4
VITRINITE REFLECTANCE DATA

GEOCHEM SAMPLE NUMBER	DEPTH	SAMPLE TYPE	AVERAGE REFLECTIVITY Ro (%)			NUMBER OF PARTICLES			REMARKS
			1	2	3	1	2	3	
313-001	1375m	S.W.C.	0.39	-	-	20	-	-	Green-yellow fluorescence
313-002	1471m	S.W.C.	0.36	-	-	20	-	-	yellow fluorescence
313-004	1541.5m	S.W.C.	0.43	-	-	18	-	-	yellow-mid orange fluorescence
313-016	1780m	S.W.C.	0.50	1.09*	-	3	4	-	yellow/orange fluorescence
313-021	1878m	S.W.C.	0.74	1.05*	-	1	2	-	lt-mid orange fluorescence
313-024	1950m	S.W.C.	0.38	-	-	12	-	-	yellow+orange fluorescence
313-028	2024m	S.W.C.	0.42	-	-	20	-	-	yellow/orange fluorescence
313-031B	2102m	S.W.C.	0.87	1.18*	-	1	1	-	barren
313-037	2240m	S.W.C.	0.78	1.11*	-	3	17	-	mid-deep orange fluorescence
313-038	2259m	S.W.C.	0.65	1.16*	-	3	11	-	
313-041	2318m	S.W.C.	0.47	0.80	1.04*	4	3	11	lt-mid orange fluorescence

*reworked

TABLE 5A

WEIGHT (GRAMMES) OF C_{15+} EXTRACTS AND CHROMATOGRAPHIC FRACTIONS

GEOCHEM SAMPLE NUMBER	INTERVAL	ROCK EXTRACTED	TOTAL EXTRACT OBTAINED	TOTAL EXTRACT		nC_5 SOLUBLE FRACTION				
				Preciptd. Asphaltenes	nC_5 soluble	Paraffin – Naphthenes	Aromatics	Eluted NSO's	Non-eluted NSO's	Sulphur
313-001	1375m	8.43000	0.02323	0.01147	0.01176	0.00556	0.00361	0.00226	0.00033	–
313-005A	1560m	35.83000	0.01725	0.00481	0.01244	0.00569	0.00212	0.00343	0.00122	–
313-008A	1590-600m	7.04000	0.01505	0.00537	0.00968	0.00497	0.00276	0.00182	0.00013	–
313-012	1660-690m	51.91000	0.01951	0.00830	0.01121	0.00594	0.00346	0.00167	0.00014	–
313-014	1720-750m	49.84000	0.01753	0.00984	0.00769	0.00488	0.00204	0.00047	0.00030	–
313-016	1780m	8.56000	0.01705	0.00686	0.00389	0.00235	0.00102	0.00030	0.00022	–
313-024	1950m	8.55000	0.01303	0.00747	0.00556	0.00410	0.00107	0.00032	–	–
313-030	2080-110m	31.58000	0.01820	0.00914	0.00906	0.00593	0.00274	0.00039	–	–
313-034A	2170-200m	11.12000	0.00982	0.00327	0.00655	0.00329	0.00223	0.00073	0.00030	–
313-038	2259m	11.37000	0.01449	0.00691	0.00758	0.00474	0.00226	0.00039	0.00019	–
313-043	2345m	28.00000	0.11417	0.02050	0.09367	0.04737	0.01533	0.03097	–	–

TABLE 5B

CONCENTRATION (PPM) OF EXTRACTED C_{15+} MATERIAL IN ROCK

GEOCHEM SAMPLE NUMBER	INTERVAL	TOTAL EXTRACT	HYDROCARBONS			NON HYDROCARBONS				
			Paraffin – *Naphthenes*	*Aromatics*	TOTAL	Preciptd. *Asphaltenes*	Eluted NSO's	Non-eluted NSO's	Sulphur	TOTAL
313-001	1375m	2756	660	428	1088	1361	268	39	–	1668
313-005A	1560m	481	159	59	218	134	96	34	–	264
313-008A	1590-600m	2138	706	392	1098	763	259	18	–	1040
313-012	1660-690m	376	114	67	181	160	32	3	–	195
313-014	1720-750m	352	98	41	139	197	9	6	–	213
313-016	1780m	1256	275	119	394	801	35	26	–	862
313-024	1950m	1524	480	125	605	874	46	–	–	919
313-030	2080-110m	576	188	87	275	289	12	–	–	302
313-034A	2170-200m	883	296	201	496	294	66	27	–	387
313-038	2259m	1274	417	199	616	608	34	17	–	659
313-043	2345m	4078	1692	548	2239	732	1106	–	–	1838

TABLE 5C

COMPOSITION (NORMALISED %) OF C_{15+} MATERIAL EXTRACTED FROM ROCK

GEOCHEM SAMPLE NUMBER	INTERVAL	HYDROCARBONS			NON HYDROCARBONS					HC / NON HC
		Paraffin – Naphthenes	Aromatics	P – N / AROM	Preciptd. Asphaltenes	Eluted NSO's	Non eluted NSO's	Sulphur	ASPH / NSO	
313-001	1375m	23.93	15.54	1.54	49.38	9.73	1.42	-	4.43	0.65
313-005A	1560m	32.98	12.29	2.68	27.89	19.88	7.07	-	1.03	0.83
313-008A	1590-600m	33.02	18.34	1.80	35.68	12.09	0.86	-	2.75	1.06
313-012	1660-690m	30.45	17.73	1.72	42.54	8.56	0.72	-	4.59	0.93
313-014	1720-750m	27.84	11.64	2.39	56.13	2.68	1.71	-	12.78	0.65
313-016	1780m	21.86	9.49	2.30	63.81	2.79	2.05	-	13.19	0.46
313-024	1950m	31.47	8.21	3.83	57.33	2.99	-	-	19.15	0.66
313-030	2080-110m	32.58	15.05	2.16	50.22	2.14	-	-	23.44	0.91
313-034A	2170-200m	33.50	22.71	1.48	33.30	7.40	3.05	-	3.17	1.28
313-038	2259m	32.71	15.60	2.10	47.69	2.69	1.31	-	11.91	0.93
313-043	2345m	41.49	13.43	3.09	17.96	27.13	-	-	0.66	1.22

TABLE 6

SIGNIFICANT RATIOS (%) OF C_{15+} FRACTIONS AND ORGANIC CARBON

GEOCHEM SAMPLE NUMBER	DEPTH	ORGANIC CARBON	HYDROCARBONS / TOTAL EXTRACT	HYDROCARBONS / ORGANIC CARBON	TOTAL EXTRACT / ORGANIC CARBON
313-001X	1375m	0.82	39.48	13.27	33.61
313-005AX	1560m	0.66	45.32	3.30	7.29
313-008AX	1590-600m	0.60	51.36	18.30	35.63
313-012X	1660-690m	0.73	48.14	2.48	5.15
313-014X	1720-750m	0.64	39.49	2.17	5.50
313-016X	1780m	0.61	31.37	6.46	20.59
313-024X	1950m	0.63	39.69	9.60	24.19
313-030X	2080-110m	0.56	47.74	4.91	10.29
313-034AX	2170-200m	0.56	56.17	8.85	15.77
313-038	2259m	0.32	48.35	19.25	39.81

TABLE 7

PYROLYSIS ANALYSIS

SAMPLE NUMBER	DEPTH	ORGANIC CARBON	PPM BITUMEN*	PPM PYROLYSATE+	PYROLYSATE / ORGANIC CARBON	BITUMEN / PYROLYSATE	PEAK PYROL. TEMP. (°C)
313-001X	1375m	0.82	42	2594	0.32	0.02	540
313-005X	1560m	0.66	63	1296	0.20	0.05	510
313-008AX	1590-600m	0.60	53	865	0.14	0.06	510
313-012X	1660-690m	0.73	86	1755	0.24	0.05	510
313-014X	1720-750m	0.64	56	1106	0.17	0.05	490(540)
313-016X	1780m	0.61	39	891	0.15	0.04	470
313-024X	1950m	0.63	68	986	0.16	0.07	490
313-030X	2080-110m	0.56	86	928	0.17	0.09	500
313-034X	2170-200m	0.56	29	964	0.17	0.03	480(540)
313-038X	2259m	0.32	36	662	0.21	0.05	470(540)

*300°C

+550°C

TABLE 8

COMPOSITION (NORMALISED %) OF C_{15+} PARAFFIN – NAPHTHENE HYDROCARBONS

GEOCHEM SAMPLE NUMBER	-001	-005A	-008A	-012	-014	-016	-024
DEPTH	1375m	1560m	1590-600m	1660-690m	1720-750m	1780m	1950m
SAMPLE TYPE							
nC_{15}	5.1	8.9	6.1	8.8	7.9	3.8	3.4
nC_{16}	7.3	10.0	7.8	10.2	9.3	6.9	6.3
nC_{17}	8.8	9.1	10.4	11.6	9.6	10.0	9.9
nC_{18}	9.5	7.9	8.7	8.8	8.2	9.6	9.1
nC_{19}	8.1	6.6	6.5	5.7	5.9	6.7	6.9
nC_{20}	9.4	7.0	7.6	5.8	5.1	6.8	6.7
nC_{21}	7.3	5.1	6.1	4.0	3.8	5.4	5.7
nC_{22}	7.4	4.4	6.1	3.8	3.8	5.8	5.7
nC_{23}	6.7	4.6	5.8	4.4	5.0	6.3	6.7
nC_{24}	6.1	3.7	5.1	3.7	5.2	6.1	6.5
nC_{25}	4.7	4.9	4.6	5.0	6.4	6.4	6.3
nC_{26}	4.0	3.3	3.7	3.5	4.9	5.1	5.3
nC_{27}	3.4	5.4	4.1	5.5	6.0	5.8	4.6
nC_{28}	2.9	3.1	3.7	3.7	3.6	3.8	3.9
nC_{29}	3.4	5.9	4.6	5.7	5.6	4.9	3.8
nC_{30}	1.9	2.1	2.7	3.0	3.6	2.6	2.8
nC_{31}	2.3	4.2	3.1	3.8	3.2	2.8	2.9
nC_{32}	0.8	1.4	1.7	1.4	1.0	0.8	1.3
nC_{33}	0.6	1.3	1.0	1.0	0.8	0.3	1.1
nC_{34}	0.1	0.6	0.5	0.3	0.8	0.2	0.7
nC_{35}	0.1	0.3	0.2	0.3	0.4	0.2	0.4
PARAFFIN	8.3	17.7	13.4	11.1	18.9	16.4	18.6
ISOPRENOID	1.0	1.7	1.9	1.5	2.6	2.2	2.0
NAPHTHENE	90.7	80.6	84.7	87.4	78.5	81.4	79.4
CPI INDEX A	0.96	1.23	1.00	1.20	1.16	1.08	1.03
CPI INDEX B	1.19	1.84	1.22	1.58	1.43	1.38	1.14
PRISTANE/PHYTANE	0.81	1.02	0.91	1.33	1.27	0.95	1.17
PRISTANE/nC_{17}	0.59	0.53	0.64	0.68	0.81	0.66	0.58

TABLE 8

COMPOSITION (NORMALISED %) OF C_{15+} PARAFFIN – NAPHTHENE HYDROCARBONS

GEOCHEM SAMPLE NUMBER	-030	-034A	-038	-043
DEPTH	2080-110m	2170-200m	2259m	2345m
SAMPLE TYPE				
nC_{15}	6.8	3.5	3.0	8.0
nC_{16}	9.0	5.6	5.5	10.8
nC_{17}	12.5	8.5	9.5	14.3
nC_{18}	13.6	8.8	9.6	14.0
nC_{19}	7.0	6.4	5.1	9.3
nC_{20}	6.0	6.4	5.3	7.5
nC_{21}	4.2	5.7	4.2	5.1
nC_{22}	4.6	5.7	5.5	4.2
nC_{23}	5.3	6.3	6.6	3.3
nC_{24}	5.3	6.2	7.7	3.1
nC_{25}	5.7	6.1	7.7	3.5
nC_{26}	4.2	5.3	6.4	2.9
nC_{27}	4.2	5.1	5.8	2.5
nC_{28}	2.7	4.7	4.2	3.1
nC_{29}	2.9	4.8	4.5	1.8
nC_{30}	2.2	3.2	3.7	1.4
nC_{31}	2.0	3.5	2.9	0.9
nC_{32}	0.7	1.3	1.4	1.2
nC_{33}	0.5	1.3	0.6	1.2
nC_{34}	0.4	1.5	0.5	0.9
nC_{35}	0.2	0.3	0.3	0.8
PARAFFIN	10.0	14.3	13.8	9.7
ISOPRENOID	3.0	1.4	1.4	1.5
NAPHTHENE	87.0	84.3	84.8	88.8
CPI INDEX A	1.06	1.02	1.00	0.95
CPI INDEX B	1.26	1.18	1.14	0.92
PRISTANE/PHYTANE	1.40	1.02	0.91	1.11
PRISTANE/nC_{17}	1.40	0.58	0.53	0.57

BRIEF DESCRIPTION OF THE ANALYSES PERFORMED BY GEOCHEM

"Screen Analyses" are described in sections A and C, "Sample Preparation" in section B, "Follow-up Analyses" in sections C through J and "Correlation Studies" in section K. The analyses can be run on either core or cuttings material with the proviso that samples must be canned for the C_1-C_7 analysis and should be canned (or at least wet) for the C_4-C_7 analysis. The other analyses can be run on both canned and bagged samples.

A) C_1-C_7 LIGHT HYDROCARBON ANALYSIS

The abundance and composition of the C_1-C_7 hydrocarbons in sediments reflects their source richness, maturity and the character of the hydrocarbons they can yield. This analysis provides a very sensitive means for detecting migrated hydrocarbons. As it provides information on most of the critical parameters and is also economical, this analysis is excellent for screening samples to decide which of them merit further analysis.

During the time which elapses between the collection of the sample at the wellsite and its analysis in the laboratory, a fraction of the total gas passes from the rock to the air space at the top of the can. For this reason, both the air space and the cuttings are analysed.

The analysis involves the gas chromatographic separation of the individual C_1-C_4 gaseous hydrocarbons (methane, ethane, propane, isobutane and normal butane) and a partial resolution of the C_5-C_7 gasoline-range hydrocarbons (for their complete resolution see Section D). The ppm abundance of the five gases and of the total C_5-C_7 hydrocarbons are calculated from their electronically integrated peak areas (not from peak height) by comparison with a standard.

In the report, the following data are tabulated: the abundance and composition of the air space gas, of the cuttings gas and of the combined air space and cuttings gases. The combined results are also presented graphically.

B) SAMPLE WASHING AND HAND PICKING

All of the analyses described in subsequent sections are run on washed and hand picked samples.

Cuttings are washed to remove the drilling mud, care being taken not to remove soft clays and fine sand during the washing procedure. Using the C_1-C_7 hydrocarbon data profile of the well, or the organic carbon profile (if this analysis is used for screening), electric logs (if supplied) and the appearance of the cuttings under the binocular microscope, samples are selected to represent the lithological and geochemical zones penetrated by the well. These samples are then carefully hand picked and the lithology of the uncaved material is described. It is these samples which are submitted for further analysis.

The remaining and unused samples (also washed) are dried and packaged in labelled plastic bags for return to the client. Any hand picked sample remaining after analysis can also be returned together with the extracted rock material.

Our reports incorporate a gross lithological description of all the samples which have been analysed and litho percentage logs are featured on all of the figures. As screen analyses are recommended at narrow intervals, a complete lithological profile is obtained.

C) ORGANIC CARBON ANALYSIS

The organic carbon content of a rock is a measure of its total organic richness. Combined with the visual kerogen, C_1-C_7, C_4-C_7 and C_{15+} analyses, the organic carbon content is used to evaluate the potential (not necessarily actual) hydrocarbon source richness of the sediment. This analysis is an integral part of a total evaluation and it can also be used as an economical screen analysis for dry samples (when the C_1-C_7 analysis cannot be used).

Hand picked samples are dried, crushed and then acidised to remove the inorganic calcium and magnesium carbonates. The actual analysis involves combustion in a Leco carbon analyser. Blanks, standards and duplicates are run routinely for purposes of quality control at no extra cost to the client.

The data are tabulated and presented diagramatically in our reports in a manner which facilitates comparison with the gross lithology (see Section B) of the samples.

D) DETAILED C_4-C_7 HYDROCARBON ANALYSIS

The abundance and composition of the C_4-C_7 gasoline-range hydrocarbons in sediments reflects their source quality, level of thermal maturation and organic facies. In addition, the data also reveal the presence of migrated hydrocarbons and can be used for crude oil-parent source rock correlation studies.

This powerful analysis, performed upon hand picked lithologies, is employed as a follow-up to confirm the potential of samples which have been selected using the initial screen analysis. It is used in conjunction with the organic carbon, visual kerogen and C_{15+} analyses.

The individual normal paraffins, isoparaffins, naphthenes and aromatics with between four and seven carbon atoms in the molecule (but also including toluene) are resolved gas chromatographically and their peak areas electronically integrated.

Tabulation of the composition and ppm abundance of the total gasoline-range fraction is achieved by comparison with a standard. In the report, the data are also presented graphically

E) KEROGEN TYPE AND MATURATION

Kerogen is the insoluble organic matter in rocks. Visual examination of the kerogen gives a direct measure of thermal maturity and of the composition of the organic matter (organic facies) and indicates the source quality of the sediment - which is confirmed using the organic carbon, light hydrocarbon and C_{15+} analyses.

The type of hydrocarbon (oil or gas) generated by a source rock is a function of the types and level of thermal maturation of the organic matter which are present. Both of these parameters are measured directly by this method.

Kerogen is separated from the inorganic rock matrix by methods which avoid oxidation of the organic matter. It is then mounted on a glass slide and examined under a high power microscope.

This examination gives the following data: the composition of the organic matter by type (amorphous, algal, herbaceous, stem, woody, oxidised etc.), the proportions of these fractions, the colour and hence level of thermal maturation of the organic matter, and its state of preservation.

Upon completion of the study, the glass slides are sent to the client.

F) VITRINITE REFLECTANCE

Vitrinite reflectance is an alternative/confirmatory method for evaluating thermal maturation which is used in conjunction with the visual kerogen , light and heavy hydrocarbon analyses. The reflectivity of vitrinite macerals increases in response to thermal alteration and is used to define maturation levels and, by projection, to predict maturity at depth.

Measurements are made upon polished whole rock samples in polarised light. The technique is only valid for vitrinite (not the other macerals) which is indigenous to the sediment and hence the experience of the operator is critical. Geochem employs Dr J M Jones for this work.

If possible, twenty measurements are taken per sample and plotted in a histogram. This distinguishes the indigenous vitrinite from possible reworked or caved material. Averages are calculated for each population. Comments upon exinite fluorescence and upon the character of the phyto-clasts are noted on the histograms. The reports contain the tabulated data and the reflectivities plotted against depth; the histograms are included with the reports.

G) C_{15+} EXTRACTION, DEASPHALTENING AND CHROMATOGRAPHIC SEPARATION

Sections "A" and "D" dealt with analyses covering the light end of the hydrocarbon spectrum. This section is concerned with the solvent extractable organic material in the rock with more than fourteen carbon atoms in the molecule (i.e. the heavy end). The amount and composition of this extract indicates source richness and type, the level of thermal maturation and the possible presence of migrated hydrocarbons.

These results are integrated with those derived from the pyrolysis, visual kerogen, organic carbon and light hydrocarbon analyses.

The techniques involved in this analysis have been designed to give very reproducible results. Hand picked samples are ground and then solvent extracted in a soxhlet apparatus with benzene-methanol or methylene chloride (the solvent system can be adapted to client's specifications). The total extract obtained is then separated by column chromatography into the following fractions: paraffin-naphthene hydrocarbons, aromatic hydrocarbons, eluted NSO's (nitrogen-, sulphur-, and oxygen- containing non-hydrocarbons), non-eluted NSO's and precipitated asphaltenes. Note that the non-hydrocarbons are split into three fractions instead of being reported as a gross value. These fractions can be submitted for further analyses (carbon isotopes, gas chromatography, high mass spectroscopy) which are primarily designed to correlate crude oils to their parent source rocks (but also see section "H").

For convenience and thoroughness, the data are reported in three formats: the weights of the fractions, ppm abundances and normalised percentage compositions. The data are also presented diagramatically.

Upon completion of the study, the extracts and extracted powders are available, if required, for further analysis.

H) GC ANALYSIS OF C_{15+} PARAFFIN-NAPHTHENE HYDROCARBONS

The gas chromatographic configurations of the heavy C_{15+} paraffin-naphthene hydrocarbons reflect source type, the degree of thermal maturation and the presence and character of migrated hydrocarbons or contamination.

Not only is this analysis an integral part of any source rock study but it also provides a fingerprint for correlation purposes and helps to define the geochemical/palynological environmental character of the source rocks from which crude oils were derived.

The paraffin-naphthene hydrocarbons obtained by column chromatography are introduced into the gas chromatograph. Excellent resolution of the individual normal paraffins and of the significant isoprenoids and other isoparaffins is achieved.

The normal paraffin carbon preference indices (C.P.I.) indicate if odd (values in excess of 1) or even (values less than 1) normal paraffins are dominant. Strong odd preferences (± strong pristane peaks) are characteristic of immature land plant organic matter whilst even preferences (± strong phytane peaks) suggest a reducing environment of deposition. With increasing maturity, values approach 1.0 and oils are typically close to 1.0. The indices are calculated using the following formulae:

$$C.P.I_A = \frac{\frac{C_{21} + C_{23} + C_{25} + C_{27}}{C_{20} + C_{22} + C_{24} + C_{26}} + \frac{C_{21} + C_{23} + C_{25} + C_{27}}{C_{22} + C_{24} + C_{26} + C_{28}}}{2}$$

$$C.P.I_B = \frac{\frac{C_{25} + C_{27} + C_{29} + C_{31}}{C_{24} + C_{26} + C_{28} + C_{30}} + \frac{C_{25} + C_{27} + C_{29} + C_{31}}{C_{26} + C_{28} + C_{30} + C_{32}}}{2}$$

Chromatograms are reproduced in the report for use as visual fingerprints and in addition, the following data are tabulated: normalised normal paraffin distributions; proportions of paraffins, isoprenoids and naphthenes in the total paraffin-naphthene fraction; $C.P.I_A$ and $C.P.I_B$; pristane to phytane ratio; pristane to nC_{17} ratio.

Very high resolution of the C_{15+} paraffin-naphthenes (and aromatics) can be achieved with capillary columns. These chromatograms are used for correlation purposes.

J) PYROLYSIS

The process of thermal maturation can be simulated in the laboratory by pyrolysis, which involves heating the sample under specified conditions and measuring the oil-like material which is freed/generated from the rock. With this analysis, the potential richness of immature sediments can be determined and, by coupling the pyrolysis unit to a gas chromatograph, the liberated material can be characterised. These results are correlated with those obtained from the organic carbon and C_{15+} analyses.

Small amounts of powdered sample are heated to release the thermal bitumen (up to 300°C) and pyrolysate (over 300°C). The abundance (ppm of rock) of each fraction and of the generated carbon dioxide is measured. Pyrolysate yields provide a definitive measure of potential source richness which avoids the ambiguities of the organic carbon data and the problem of contamination. The data also evaluate the quality and character of the organic material and the degree to which it has realised its hydrocarbon potential.

The data are reported and presented graphically as ppm thermal bitumen and pyrolysate, the ratio of the two fractions, the ratio of pyrolysate to organic carbon and as the abundance of carbon dioxide and its ratio to organic carbon. The temperature at which peak pyrolysate evolution occurs is also reported.

K) CORRELATION STUDY ANALYSES

Oil to oil and oil to parent source rock correlation studies require high resolution analytical techniques. This requirement is satisfied by some of the analyses discussed above but others have been selected specifically for correlation work. Many of these analyses also provide information upon the character of the environment of deposition of the parent source rocks.

- detailed C_4-C_7 hydrocarbon (gasoline range) analysis. See section D. Although these hydrocarbons can be affected by migrational/alteration processes, they commonly provide a very useful correlation parameter.
- capillary gas chromatography of the C_{15+} paraffin-naphthenes. See section H. The branched$^{\pm}$normal paraffin distributions are used to "fingerprint" the samples.
- capillary gas chromatography of whole oils and of C_{15+} aromatic hydrocarbons. The detailed resolution achieved in these analyses makes them an ideal fingerprinting tool. Chromatograms are reproduced in our reports.
- mass spectrometric carbon isotope analyses of the C_{15+} paraffin-naphthene and aromatic hydrocarbons of oils and sediments, and of kerogen separations. A powerful tool for comparing hydrocarbons and correlating hydrocarbons to organic matter. With this technique the problem of source rock contamination can be avoided. The data are recorded on x-y plots.
- mass fragmentograms (mass chromatograms) of fragment ions characteristic of selected hydrocarbon groups such as the steranes and terpanes. The fragmentograms provide a convenient and simple means of presenting detailed mass spectrometric data and are used as a sophisticated fingerprinting technique. This provides the ultimate resolution for correlating hydrocarbons and facilitates the examination of hydrocarbon classes (Masspec).

Suites of (rather than single) analyses are employed in correlation studies, the actual selection depending upon the complexity of the problem.

L) ANALYSES FOR SPECIAL CASES

L-1) ELEMENTAL KEROGEN ANALYSIS

This analysis evaluates source quality, whether the sediments are oil or gas prone, the character of the organic matter and its level of thermal maturation. It is the chemical equivalent of the visual kerogen analysis and the data are also integrated with the light hydrocarbon and C_{15+} results.

The separated kerogen is combusted and the resulting gases converted into molecules which are measured to give the elemental carbon, hydrogen, nitrogen, oxygen and sulphur contents of the organic matter. The data are reported as percentages and ratios.

As a general rule, the pyrolysis analysis is preferred to this technique, both methods providing similar information.

L-2) NORMAL PARAFFIN ANALYSIS

Following the removal of the branched paraffins and naphthenes from the total paraffin-naphthene fraction, a chromatogram of the normal paraffins is obtained. The resulting less complicated chromatogram facilitates the examination of the normal paraffin distribution.

L-3) CARBONATE CONTENT

The mineral carbonate content of sediments is determined by acid treatment. These data are particularly useful when used in conjunction with organic carbon contents as a screening technique.

L-4) SOLID BITUMEN EVALUATION

Residual solid bitumen after crude oil is generated by three prime processes: the action of waters, gas deasphalting, thermal alteration. Thus it provides a means of determing the reservoir history of a crude and of evaluating whether adjacent traps will or will not be prospective for oil. In carbonate sections, where organic matter is sometimes sparse, this technique is also used to evaluate thermal maturation levels.

The analysis involves the determination of the solubility (in CS_2) of the solid bitumen and of the atomic hydrogen to carbon ratio of the insoluble fraction.

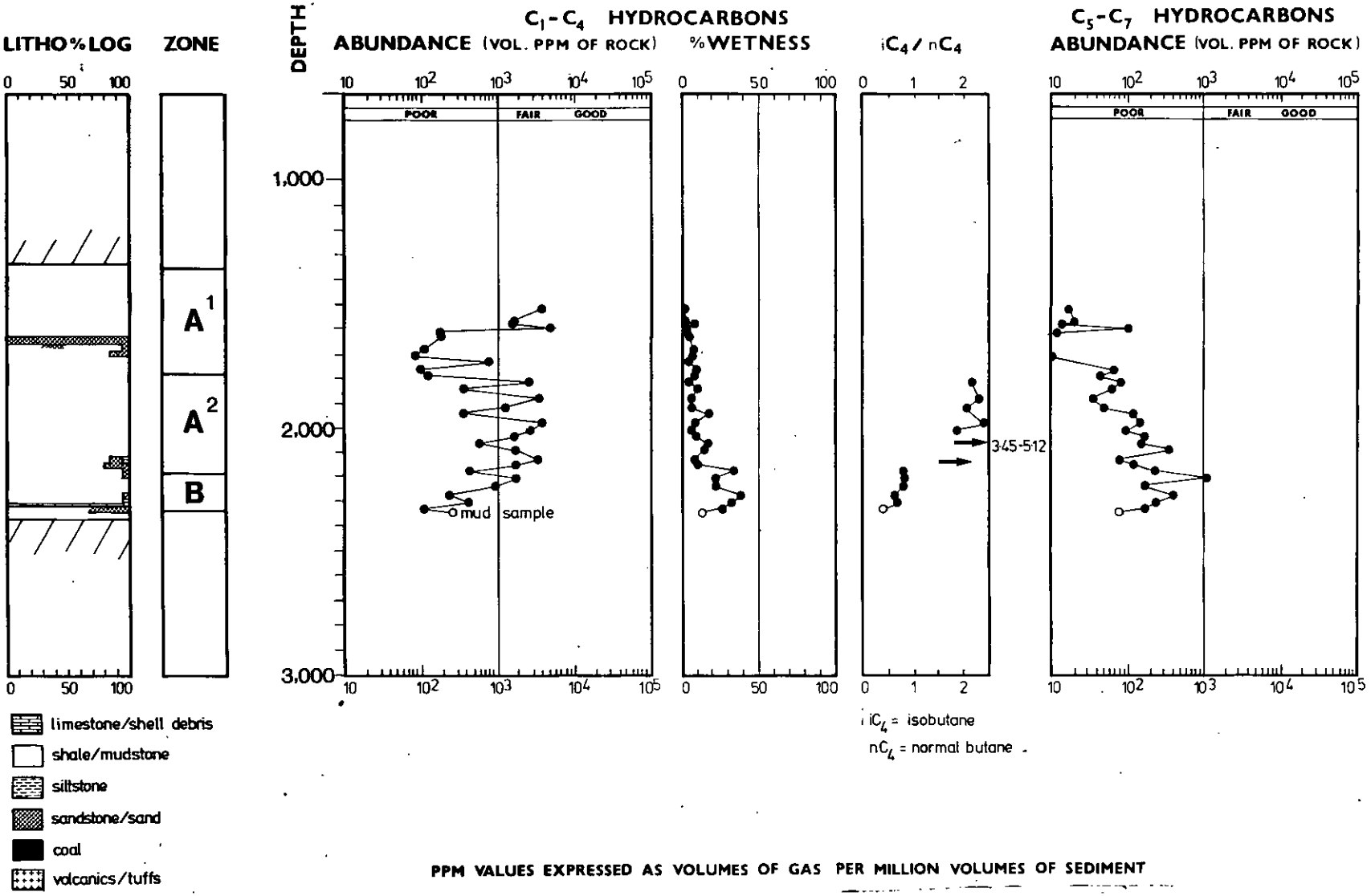
L-5) EXTRACTION WITHOUT CHROMATOGRAPHY

The removal of the soluble C_{15+} material either to measure its abundance or to prepare the sediment for further analysis.

FIGURE 1

C_1-C_7 HYDROCARBONS

PRESENTATION OF ANALYTICAL DATA



PPM VALUES EXPRESSED AS VOLUMES OF GAS PER MILLION VOLUMES OF SEDIMENT

FIGURE 2

PYROLYSIS

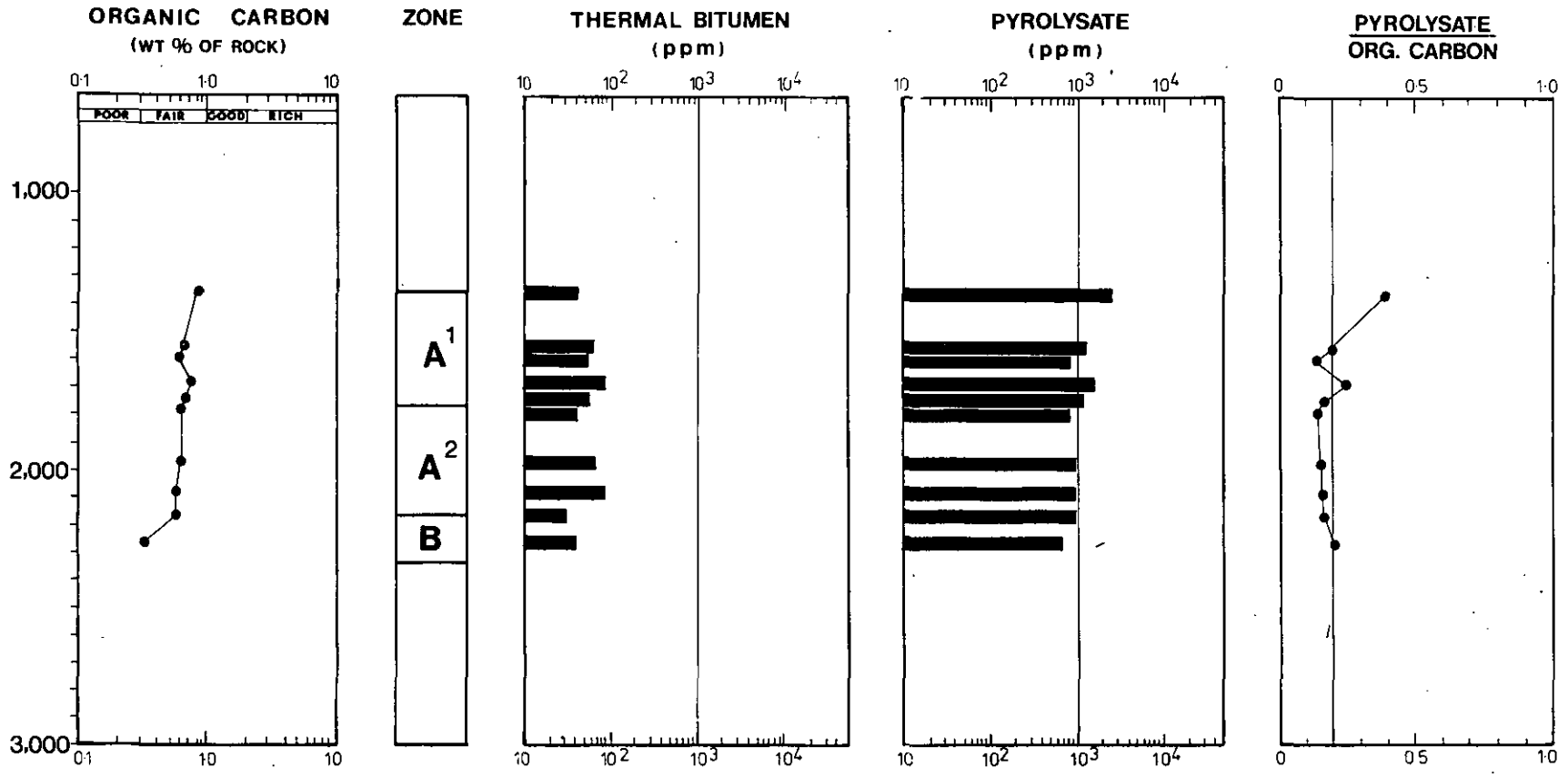


FIGURE 3

C_{15+} HYDROCARBONS — RICHNESS

PRESENTATION OF ANALYTICAL DATA

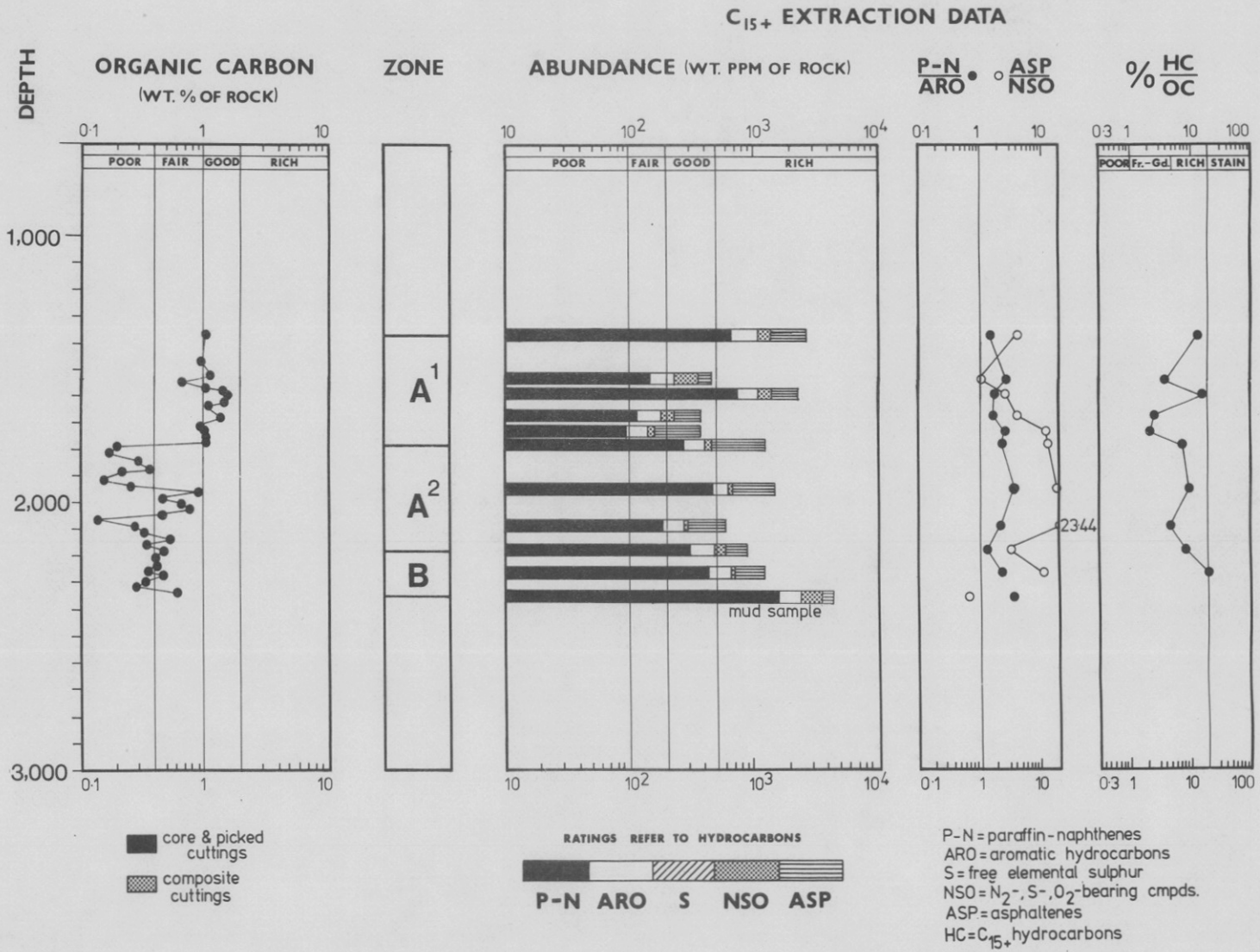
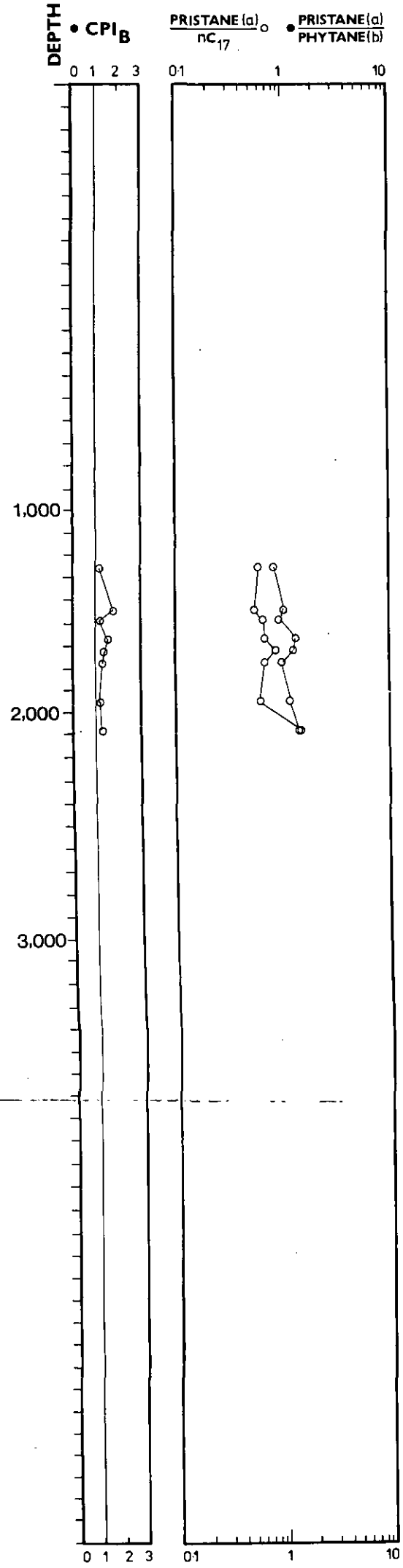
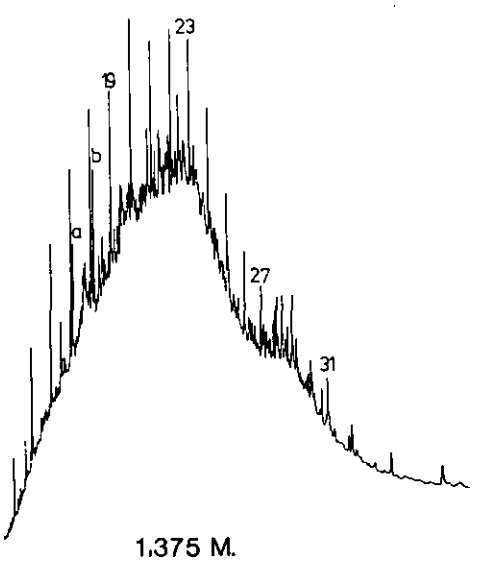


FIGURE 4a

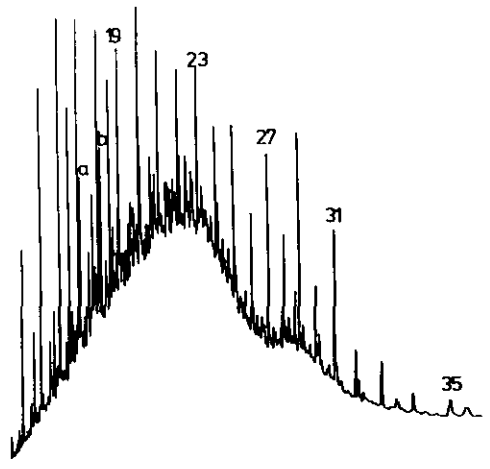
C_{15+} PARAFFIN – NAPHTHENE HYDROCARBONS

PRESENTATION OF ANALYTICAL DATA

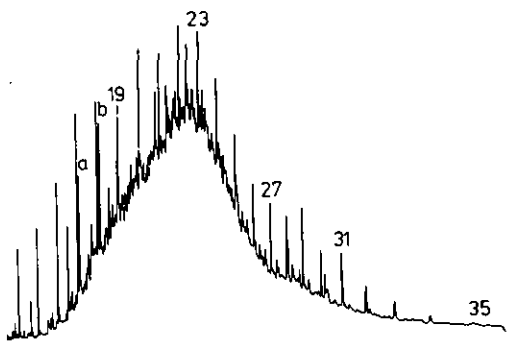




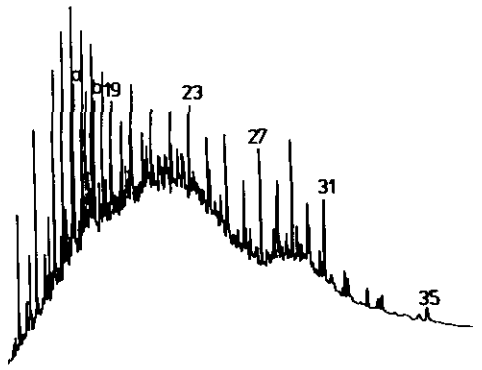
1,375 M.



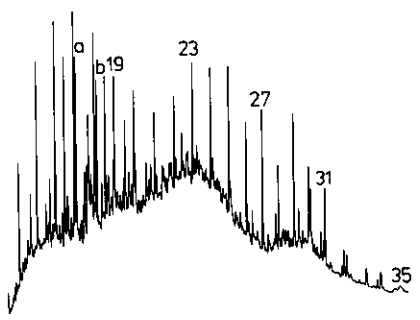
1,560 M.
SHALE



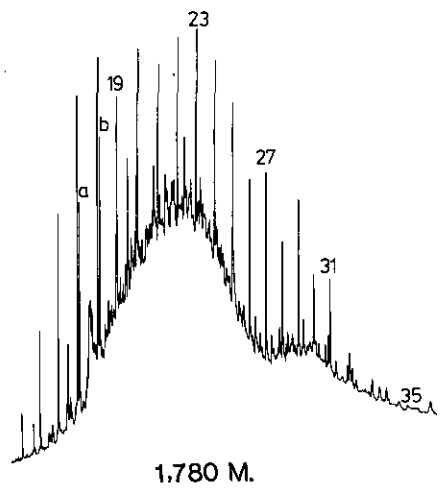
1,590 - 1,600 M.
SHALE



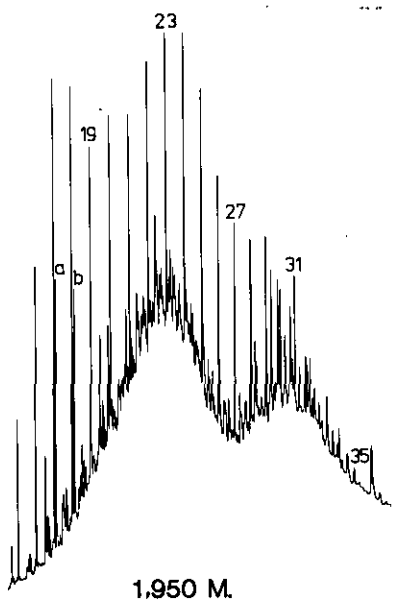
1,660 - 1,690 M.



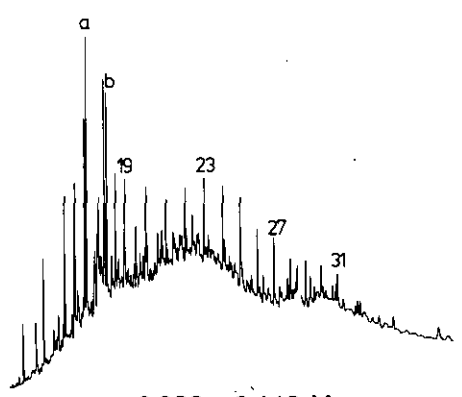
1,720 - 1,750 M.



1,780 M.



1,950 M.



2,080 - 2,110 M.

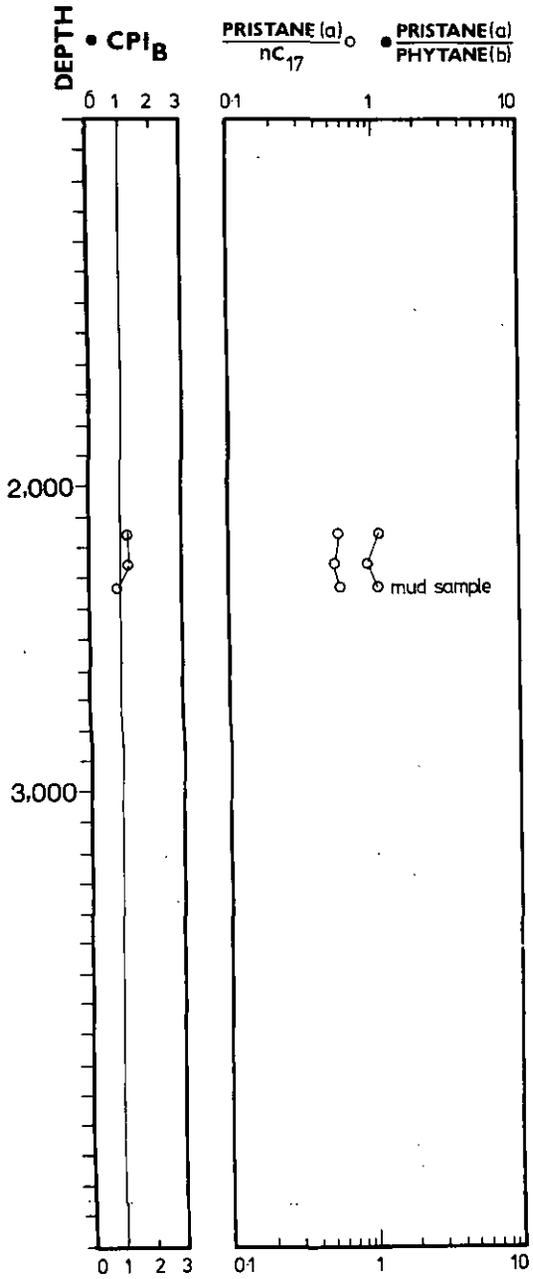
a = pristane
b = phytane

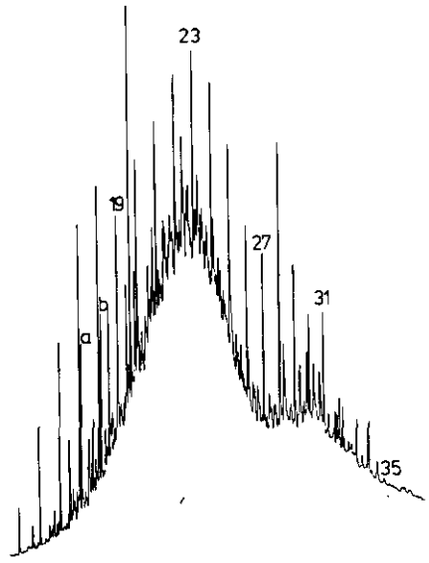
carbon numbers of normal paraffins indicated (19 = nC_{19})

FIGURE 4b

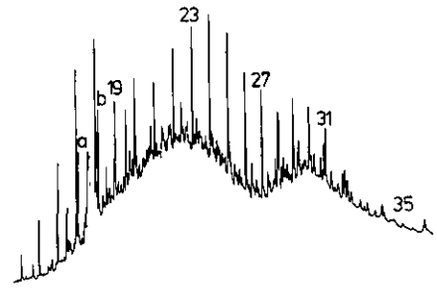
C_{15+} PARAFFIN — NAPHTHENE HYDROCARBONS

PRESENTATION OF ANALYTICAL DATA

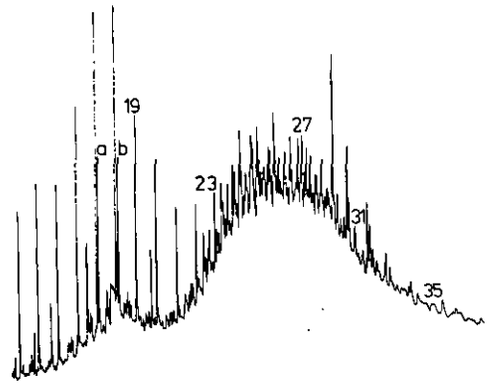




2,170 - 2,200 M.
SHALE



2,259 M.



2,345 M.
MUD SAMPLE

a = pristane
b = phytane

carbon numbers of normal paraffins indicated (19 = nC_{19})

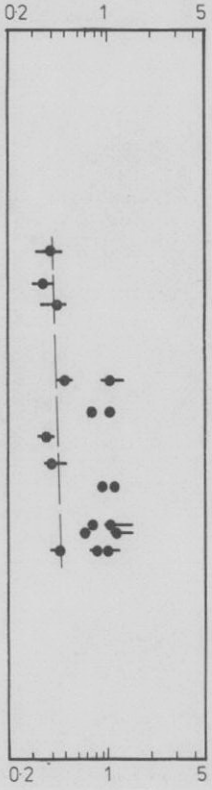
FIGURE 5

INTERPRETATION DIAGRAM

SOURCE TYPE

VITRINITE REFLECTANCE

0·2 1 5



0·2 1 5

BAR SHOWS RANGE OF VALUES

VISUAL KEROGEN

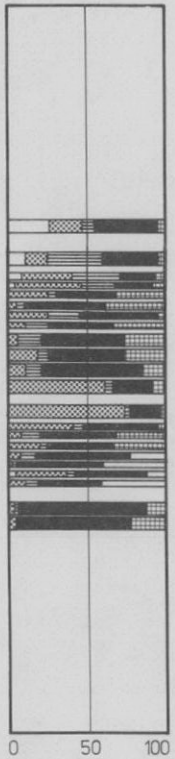
MATURATION INDEX

0 1 2 3 4 5

0 1 2 3 4 5

TYPE OF ORGANIC MATTER

0 50 100



0 50 100

Al = algal

Am = amorphous

H = herbaceous-spore, pollen, cuticle

C = black fusain-related material (C/H hi)

S = stem

W = woody

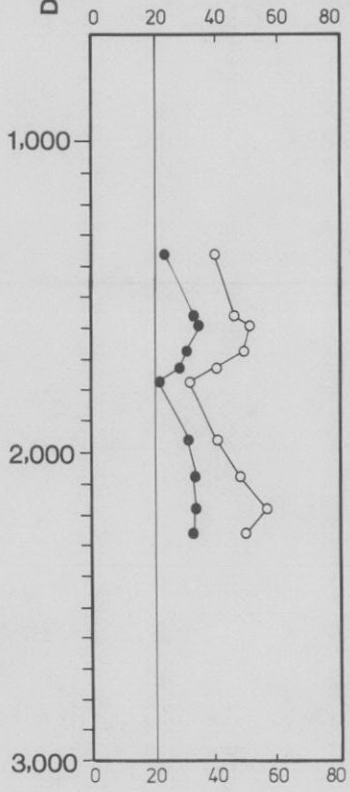
MATURATION

C_{15+} FRACTION

DEPTH

$\%\frac{P-N}{TE}$ ● ○ $\%\frac{HC}{TE}$

0 20 40 60 80



1,000

2,000

3,000

0 20 40 60 80

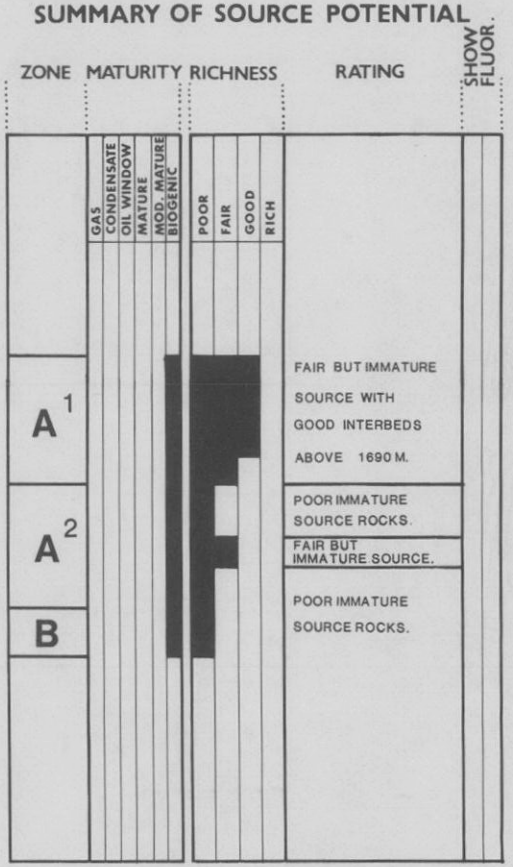
P–N = paraffin-napthenes

TE = total extract

HC = hydrocarbons

RATING

SUMMARY OF SOURCE POTENTIAL



INTERPRETATION BASED UPON BOTH THIS DIAGRAM & THE PREVIOUS FIGURES

"SHOW" BASED UPON GEOCHEMICAL DATA

○ Core

● Cutting