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GeoChem Laboratories

GEOCHEMICAL SERVICE REPORT

Prepared for

NORSKE GULF PRODUCTION COMPANY A.S.

MIGRATED CRUDE OIL DETECTION IN NORSKE GULF'S 3/5-1 WELL

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CHESTER STREET · CHESTER CH4 8RD · ENGLAND

MIGRATED CRUDE OIL DETECTION IN NORSKE GULF'S 3/5-1 WELL

SUMMARY

Migrated crude oil has been sought in the section between 10100 feet and 11233 feet. The heavy (C_{15+}) hydrocarbons are masked by drilling-introduced contamination and hence the study is primarily based upon the gasoline-range fraction.

The best abundance values apply to the carbonates between 10110± feet and 10165± feet, fair levels being achieved within the interval 10110-10130± feet. These largely (at least) reflect the source potential of the sediments and, if trace amounts of free oil are present, it was probably sourced within the carbonates.

There is no evidence to suggest residual migrated oil in the sands below 10225± feet but there is a slight enhancement above this depth. It is <u>not</u> believed however, that this can be interpreted to support the migration of oil through this section.

N J L Bailey
GEOCHEM LABORATORIES (UK) LIMITED

INTRODUCTION

This report presents the results of a geochemical study performed upon the interval between 10100 feet and 11233 feet in Norske Gulf's 3/5-1 well.

The study was designed to determine whether trace (non-economic) amounts of migrated crude oil are present within the Rotliegendes sandstones, which would suggest the possibility that oil may have migrated through the formation en route to an ultimate updip trap.

This project was authorised by Mr N H Dewhirst, Norske Gulf Production Company A.S., Stavanger.

A. ANALYTICAL

A total of one hundred and fourteen (114) damp, bagged samples were received from the interval 10100-11233 feet in 3/5-1. The samples were collected on an interval of ten feet, but that from 11160 feet was missing. In addition, samples of Resinex and Spersene mud additives were included in the study. The samples were assigned the Geochem job number 294 and sequential sample numbers from -001 to -116.

Geochem Laboratories were instructed to screen the section on a thirty foot interval with the cuttings gas (bagged samples, therefore no air space) and detailed gasoline range analyses and to select samples for further analysis on the basis of the screen results. However, the gasoline range programme was amended in view of the data to give additional fill-in results at the top of the section and to omit samples from below 10620± feet. A significant number of samples were so lean in the gasoline-range fraction that a detailed breakdown into individual compounds was not possible.

A total of thirty-eight cuttings gas analyses, forty-two detailed gasoline range analyses, twelve organic carbons, two visual kerogen analyses (additives), ten extractions with chromatography and ten paraffin-naphthene analyses were performed in this study.

The data are presented in tables 1 through 6 and graphically in figures 1 through 4. A brief description of the analytical techniques employed in the study is included in the back of the report.

B. GENERAL INFORMATION

Ten (10) copies of this report have been forwarded to Mr N H Dewhirst, Norske Gulf Production Company A.S., Stavanger. A copy of the data has been retained by Geochem for future consultation with authorised Norske Gulf personnel.

All of the results and interpretations included in this report are regarded as highly confidential and are proprietary to Norske Gulf Production Company A.S.

RESULTS AND INTERPRETATION

With the exception of that from 10100 feet (evaporite), the samples received for analysis consist of dolomites above 10165± feet and of sands below this depth (clear and grossly light brown above and below 10300± feet respectively). A weak blue cut was observed in the carbonates below 10125± feet and in the sands at 10200 feet, 10230-10260± feet (milky blue/green), 10350-10380± feet, 10710 feet, 11010 feet and 11200 feet.

In order to detect (possibly) trace amounts of migrated liquid hydrocarbons, analyses involving the light hydrocarbons were selected. They have two distinct advantages over the heavy hydrocarbon analyses: firstly, they are more sensitive to the presence of oil or condensate and secondly, they are relatively unaffected by sediment contamination from the common mud additives.

The light hydrocarbon data will be discussed first.

A. LIGHT HYDROCARBONS

The air space analysis could not be run on these bagged samples but, as they were still damp, the presence of significant migrated oil should be reflected in the cuttings gas abundances. Gas wetness values however, would not be expected to be reliable.

Few of the analysed samples exceed a very low 50 ppm of the C_1-C_4 cuttings gas. The highest value (113 ppm) is at 10140 feet and the "richest" (but still very lean) samples tend to be above 10330± feet, but no significance can be placed upon this trend. Similarly low abundance levels apply in the case of the heavier C_5-C_7 hydrocarbon fraction (maximum of 27 ppm) below 10400± feet, but there is some improvement at 10110-10200± feet (80-189 ppm) and 10290-10350± feet (100-291 ppm), suggesting a gross correlation with the C_1-C_4 data.

Thus, although the section is lean, hydrocarbon abundances are slightly better above 10350± feet.

Detailed gasoline range analysis of the washed samples tends to divide the section at 10340± feet. Below this depth, few of the analysed samples exceed 30 ppm, giving a maximum of 64 ppm at 10890 feet. Most of the shallower samples (except the evaporite) exceed 70 ppm, but values of greater than 200 ppm are restricted to the interval 10110-10160± feet, which corresponds to the carbonates. The richest samples are at 10110 feet (695 ppm), 10120 feet (1358 ppm) and 10130 feet (1268 ppm), whilst the sands contain a maximum of 150 ppm and are best above 10225± feet.

The samples of Resinex and Spersene yielded 83 ppm and 287 ppm gasoline range hydrocarbons respectively, whilst the mud separated from the sample at 10790 feet gave 62 ppm. Clearly, although contamination from the mud system could influence some of leaner sediments (i.e. below 10340± feet), it cannot explain the better values and particularly those of the carbonates.

In summary:

1. the best light hydrocarbon abundances apply to the carbonates and particularly to the interval 10110-10130± feet.
2. abundances are low throughout the sands but tend to be better above 10225 (10340)± feet than below this depth (where they are nominal).
3. although no diagnostically high values were observed, it is interesting to note that the gases tend to be wettest above 10210± feet and at 10290± feet.
4. It should be noted that the degree of variation in the composition of the gasoline-range fraction, especially in the sands, does not suggest a homogenous "soaking" by oil but this could, in part, be a function of the low abundance levels involved. It would appear likely that the hydrocarbons in the limestones have an amorphous source.
5. the data at the top of the section do not definitively prove the presence of (very minor traces of) migrated liquid hydrocarbons, but they do require explanation.

B. <u>HEAVY HYDROCARBONS</u>

The analysed dolomites have good (for carbonates) contents of 0.75-1.36% organic carbon rising to a very high 4.44% (double-checked) at 10110 feet. Thus the light hydrocarbon results could reflect either source character or the presence of (traces of) migrated liquid hydrocarbons.

In order to check these alternatives, two carbonates and six sand samples were extracted. The sands yielded 493-4811 (14705) ppm and the carbonates 1575-2038 ppm $C_{15}+$ hydrocarbons. These values are far in excess of those which could be attributed to the source character of the sediments and hence, non-indigenous hydrocarbons are indicated. Most of the samples have rather high paraffin-naphthene to aromatic ratios. Their paraffin-naphthene chromatograms are all very naphthenic and all have very similar configurations of both their unresolved background envelopes and of the superimposed peaks. In fact, they indicate drilling-introduced contamination. Hence, no conclusions, can be drawn from the heavy hydrocarbons regarding the possible presence of migrated oil other than to say that, if it does occur, only fairly low abundance levels could be involved.

The contaminant is neither "Resinex" nor "Spersene". These additives yielded only 545-1235 ppm C_{15+} hydrocarbons which constituted less than 18% of the total soluble extract. Their paraffin-naphthene chromatograms have similar background envelopes to those of the samples but Resinex differs in the presence of high non-normal paraffin peaks in the C_{19-21} region and an odd carbon preference index, whilst Spersene has a more pronounced front end bias in the normal paraffins and a lower phytane to nC_{18} ratio.

C. CONCLUSIONS

A weak blue cut was observed below 10125± feet in the carbonates and occasionally, but particularly within the interval 10200-10260± feet, in the underlying sands.

The heavy hydrocarbon data cannot be used to determine whether this fluorescence indicates migrated liquid hydrocarbons, due to the masking effect of drilling-introduced contamination.

Below 10225± feet, the sands contain only background levels of the gasoline range hydrocarbons and there is nothing to suggest the presence of residual oil. Even above this depth, the sands contain a maximum of only 150 ppm. Better values apply to the carbonates and particularly (695-1358 ppm) to the interval 10110-10130± feet. Even so, these abundance levels are only fair and must largely reflect the source potential of the sediments.

In summary therefore, the hydrocarbon abundances within this section do not definitively indicate the presence of crude oil residual to the migrational process. Trace amounts of free oil could be present within the carbonate interval but it is likely that this would have been locally sourced. The slight improvement in the sands above 10225± feet (relative to the underlying section) is more difficult to interpret, but could indicate:

a) insignificantly minor traces of residual migrated oil

b) diffusion from the carbonates

c) contamination from the mud system

The variations in composition exhibited between these samples suggest a random process, although this could be a function of leanness. Nevertheless, in view of both the very low hydrocarbon abundances and the compositional variations, it is not believed that the slight enhancement at the top of the sand body can be interpreted as an indication of residual migrated oil.

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	$\frac{iC_4}{nC_4}$
294-001	10100'	17.8	7.4	8.3	2.9	3.7	40	22	55.6	28	0.79
294-005	10140'	34	12.4	22	15.2	29	113	79	69.7	189	0.52
294-008	10170'	30	8.9	8.7	5.5	9.4	62	32	52.1	80	0.59
294-011	10200'	30	9.9	11.9	9.0	14.7	75	45	60.4	109	0.61
294-014	10230'	31	9.4	7.9	1.4	2.5	52	21	21.2	41	0.56
294-017	10260'	22	4.2	3.5	1.3	2.7	34	11.7	34.2	46	0.49
294-020	10290'	27	5.2	8.0	11.8	23	75	48	63.5	291	0.52
294-023	10320'	29	8.0	3.1	3.2	6.1	49	20	41.6	100	0.52
294-026	10350'	21	3.3	2.9	1.4	4.3	33	12.0	36.5	126	0.32
294-029	10380'	10.1	4.7	2.7	2.4	2.7	23	12.5	55.4	60	0.91
294-032	10410'	5.0	1.1	1.9	-	-	8.0	3.0	37.2	14.1	-
294-035	10440'	17.5	2.0	0.2	-	-	20	2.2	11.0	1.1	-
294-038	10470'	10.1	3.2	1.7	-	-	14.9	4.8	32.5	7.4	-
294-041	10500'	12.2	4.0	0.2	-	-	16.4	4.2	25.8	13.4	-
294-044	10530'	9.4	3.0	2.4	-	-	14.8	5.4	36.5	14.7	-
294-047	10560'	30	17.9	16.7	4.4	12.5	81	52	63.2	26	0.35
294-050	10590'	20	2.8	3.7	1.3	3.4	31	11.2	35.8	10.7	0.39
294-053	10620'	38	6.0	7.7	0.9	2.3	55	16.9	30.8	8.6	0.38
294-056	10650'	20	2.4	3.3	-	-	26	5.7	22.2	27	-
294-059	10680'	27	5.4	3.7	-	-	36	9.1	25.4	8.0	-
294-062	10710'	25	5.2	2.8	-	-	33	8.0	24.2	5.4	-

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	$\frac{iC_4}{nC_4}$
294-065	10740'	27	2.6	2.8	-	-	33	6.4	19.3	14.1	-
294-068	10770'	23	5.0	2.3	0.1	0.2	30	7.6	24.5	16.1	0.50
294-071	10800'	12.6	2.0	1.8	-	-	16.4	3.8	23.1	7.4	-
294-074	10830'	43	5.4	8.8	0.6	1.6	60	16.4	27.3	25	0.38
294-077	10860'	26	2.6	2.7	-	-	31	5.3	16.8	12.0	-
294-080	10890'	24	2.8	3.0	-	-	30	5.8	19.4	18.1	-
294-083	10920'	32	3.0	3.3	-	-	38	6.3	16.6	4.4	-
294-086	10950'	31	2.8	3.2	-	-	37	6.0	16.3	2.1	-
294-089	10980'	28	5.0	3.1	-	-	36	8.1	22.3	23	-
294-092	11010'	21	2.8	3.0	-	-	26	5.7	21.8	8.6	-
294-095	11040'	11.2	3.8	4.1	-	-	19.1	7.9	41.3	5.4	-
294-098	11070'	32	4.8	3.7	-	-	41	8.5	20.8	19.4	-
294-101	11100'	32	4.8	1.9	-	-	39	6.7	17.2	21	-
294-104	11130'	23	2.4	2.8	-	-	28	5.2	18.5	12.7	-
294-107	11170'	21	2.6	3.3	0.4	1.8	29	8.1	27.8	22	0.22
294-111	11210'	41	6.0	9.7	-	-	56	15.6	27.7	4.5	-
294-114	11233'	42	6.2	8.6	-	-	56	14.8	26.2	3.4	-

TABLE 2
ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	GSA Colour Code	TOTAL ORGANIC CARBON (% of Rock)
294-001	10100'	A 80% Evaporite - gypsum, fissile to blocky, non calcareous, insoluble in water, no fluorescence, pinkish grey	5YR8/1	
		B 20% Lost circulation material lignite, finely ground Minor gypsum - colourless/ crystalline		
294-002	10110'	A 98% Dolomite, fissile to blocky, hard, no fluor- escence, light grey to light olive grey	N7-5Y6/1	
294-003	10120'	A 98% Argillaceous dolomite, fissile to blocky, hard, no fluorescence, medium dark grey to olive grey Minor other dolomite	N4-5Y4/1	
294-004	10130'	A 98% Argillaceous dolomite, as 294-003A Minor other dolomite	N4-5Y4/1	
294-005	10140'	A 98% Argillaceous dolomite, as 294-003A Minor limestone and minor shale	N4-5Y4/1	
294-006	10150'	A 98% Argillaceous dolomite, fissile, minor blue cut medium dark grey to olive grey Minor other dolomite	N4-5Y4/1	
294-007	10160'	A 98% Limestone, fissile to to blocky, argillaceous, minor blue cut, medium dark grey to medium dusky yellowish brown Minor dolomite	N4-10YR3/2	
294-008	10170'	A 95% Quartz grains, fine, subrounded, clear and opaque		
		B 5% Limestone, as 294-007A faint blue cut Poor sample	N4-10YR3/2	

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)
294-009	10180'	A 98% Quartz grains, fine, subrounded, clear and opaque no fluorescence Minor shale and mudstone		
294-010	10190'	A 98% Quartz grains, as 294-010A no fluorescence Minor limestone and mudstone		
294-011	10200'	A 98% Quartz grains, as 294-010A faint blue cut Minor shale and limestone		
294-012	10210'	A 98% Quartz grains, fine to medium, subrounded, opaque no fluorescence Very minor shale		
294-013	10220'	A 98% Quartz grains, as 294-012A no fluorescence Minor shale		
294-014	10230'	A 90% Quartz grains, as 294-012A milky blue/green cut		
		B 10% Limestone, blocky, soft, no fluorescence, white Minor shale	N9	
294-015	10240'	A 90% Quartz grains, as 294-012A no fluorescence		
		B 10% Limestone, as 294-014B no fluorescence	N9	
294-016	10250'	A 98% Quartz grains, as 294-012A milky blue/green cut Minor limestone		
294-017	10260'	A 90% Quartz grains, as 294-012A milky blue/green cut		
		B 10% Limestone, as 294-014B	N9	
294-020	10290'	A Mostly fine ground anhydrite and minor sand Very poor sample		

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ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	GSA Colour Code	TOTAL ORGANIC CARBON (% of Rock)
294-023	10320'	A 70% Sandstone, fine grained, calcareous, no fluorescence, pinkish grey	5YR8/1	
		B 20% Anhydrite, blocky, soft, non calcareous, white	N9	
		C 10% Quartz grains, very fine, angular, clear Very poor sample		
294-026	10350'	A 98% Fine sand, subrounded, opaque, faint blue cut pinkish grey Minor limestone	5YR8/1	
294-029	10380'	A 90% Sand, fine, subrounded, and angular, faint blue cut, light brown	5YR6/4	
294-032	10410'	A 98% Sand, fine, subrounded, no fluorescence, light brown Minor lost circulation material and sandstone	5YR5/6	
294-035	10440'	A 98% Sand, as 294-032A no fluorescence Minor sandstone	5YR5/6	
294-038	10470'	A 98% Sand, as 294-032A no fluorescence Minor sandstone	5YR5/6	
294-041	10500'	A 98% Sand, as 294-032A, no fluorescence Minor sandstone	5YR5/6	
294-044	10530'	A 98% Sand, as 294-032A no fluorescence Minor sandstone	5YR5/6	
294-047	10560'	A 99% Sand, as 294-032A no fluorescence	5YR5/6	
294-050	10590'	A 98% Sand, fine to medium grained, subrounded, no fluorescence, light brown Minor sandstone	5YR5/6	

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)
294-053	10620'	A 98% Sand, fine to medium grained, subrounded, no fluorescence, light brown Minor sandstone	5YR5/6	
294-056	10650'	A 98% Sand, as 294-053A no fluorescence Minor anhydrite	5YR5/6	
294-059	10680'	A 98% Sand, as 294-053A no fluorescence Minor anhydrite	5YR5/6	
294-062	10710'	A 98% Sand, fine to medium, subrounded, blue cut light brown Minor sandstone	5YR5/6	
294-065	10740'	A 98% Sand, as 294-062A no fluorescence Minor anhydrite	5YR5/6	
294-068	10770'	A 98% Sand, as 294-062A no fluorescence Minor anhydrite	5YR5/6	
294-071	10800'	A 98% Sand, as 294-062A no fluorescence Minor limestone	5YR5/6	
294-074	10830'	A 99% Sand, as 294-062A no fluorescence	5YR5/6	
294-077	10860'	A 98% Sand, as 294-062A no fluorescence Minor anhydrite	5YR5/6	
294-080	10890'	A 65% Sand, as 294-062A no fluorescence	5YR5/6	
		B 35% Shale, fissile, non calcareous, pale brown Minor anhydrite - poor sample	5YR5/2	0.36
294-083	10920'	A 99% Sand, as 294-062A no fluorescence	5YR5/6	

TABLE 2
ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	GSA Colour Code	TOTAL ORGANIC CARBON (% of Rock)
294-086	10950'	A 98% Sand, fine to medium, subrounded, no fluorescence, light brown Minor shale	5YR5/6	
294-089	10980'	A 98% Sand, as 294-086A no fluorescence Minor sandstone	5YR5/6	
294-092	11010'	A 98% Sand, as 294-086A faint blut cut Minor anhydrite	5YR5/6	
294-095	11040'	A 98% Sand, as 294-086A no fluorescence Minor anhydrite	5YR5/6	
294-098	11070'	A 98% Sand, fine to medium grained, subrounded, no fluorescence, light brown to greyish orange pink Minor anhydrite	5YR6/4 5YR7/2	
294-101	11100'	A 98% Sand, as 294-098A no fluorescence Minor anhydrite	5YR6/4	
294-104	11130'	A 98% Sand, as 294-098A no fluorescence Minor anhydrite	5YR6/4	
294-107	11170'	A 85% Sand, as 294-098A no fluorescence B 15% Shale, fissile to blocky, slightly calcareous, pale brown to medium brown	5YR6/4 5YR7/2 5YR5/2- 5YR6/2	0.19
294-110	11200'	A 98% Sand, as 294-098A faint blue cut Minor shale - poor sample	5YR6/4	
294-113	11230'	A 98% Sand, fine to medium grained, no fluorescence, light brown Minor shale and sandstone	5YR5/6	

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

GEOCHEM SAMPLE NUMBER	001	002	003	004	005	006	007
DEPTH	10100'	10110'	10120'	10130'	10140'	10150'	10160'
NORMALISED COMPOSITION							
isobutane	NO RESULT	3.56	2.70	3.71	4.95	5.82	5.46
n - butane (nB)		9.41	6.31	9.93	10.43	13.17	16.11
isopentane		7.57	8.35	9.97	8.09	10.40	8.36
n - pentane (nP)		10.93	9.51	12.13	9.15	10.03	9.65
2,2 - dimethylB		1.27	0.74	0.87	0.23	0.87	0.51
cyclopentane (CP)		1.45	1.66	1.19	0.70	1.21	1.41
2,3 - dimethylB		0.52	0.10	0.54	0.23	0.41	0.56
2 - methylP		8.86	8.49	8.57	7.51	11.75	8.77
3 - methylP		5.22	6.41	5.65	2.48	5.03	3.60
n - hexane (nH)		9.73	9.93	10.85	7.78	8.56	5.45
methylCP (MCP)		2.52	4.57	3.84	4.14	2.41	2.44
2,2 - dimethylP		1.50	1.17	0.79	0.88	0.37	0.73
benzene		1.50	2.54	1.60	1.52	2.21	3.04
2,4 - dimethylP		0.09	0.04	0.19	0.24	0.22	0.24
2,2,3 - trimethylB		0.38	0.26	0.26	0.79	0.64	0.83
cyclohexane (CH)		9.30	7.07	5.31	6.20	5.02	3.97
3,3 - dimethylP		–	–	–	0.02	0.01	–
1,1 - dimethylCP		0.02	–	0.05	0.11	0.14	0.05
2 - methylH		5.69	4.84	3.60	6.25	6.26	5.53
2,3 - dimethylP		1.15	1.87	1.26	2.44	0.94	1.79
1,c,3 - dimethylCP		–	–	–	–	–	–
3 - methylH		0.86	1.67	1.09	1.82	0.69	1.37
1,t,3 - dimethylCP		–	–	–	–	–	–
1,t,2 - dimethylCP		2.58	4.47	3.12	4.28	2.34	3.03
3 - ethylP		0.01	0.04	0.32	0.02	–	0.51
n - heptane		8.31	8.53	9.11	11.27	6.70	9.51
1,c,2 - dimethylCP		1.38	2.02	1.18	1.43	0.85	0.99
methylCH (MCH)		5.77	6.08	3.92	5.04	2.83	4.59
toluene		0.44	0.62	1.17	1.97	1.10	1.51
ABUNDANCE (ppm)	20	695	1358	1268	156	322	205
MCP/benzene		1.68	1.80	2.40	2.72	1.09	0.80
MCP/MCH		0.44	0.75	0.98	0.82	0.85	0.53
CH/MCP		3.69	1.55	1.38	1.50	2.08	1.63
iP/nP		0.69	0.88	0.82	0.88	1.04	0.87
%n - PARAFFINS		38.37	34.28	42.02	38.63	38.46	40.71
% ISOPARAFFINS		36.67	36.69	36.61	35.97	43.42	38.27
% NAPHTHENES		23.01	25.86	18.61	21.91	14.80	16.47
% AROMATICS		1.94	3.17	2.77	3.49	3.31	4.55

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

GEOCHEM SAMPLE NUMBER	008	011	013	014	017	019	020
DEPTH	10170'	10200'	10220'	10230'	10260'	10280'	10290'
NORMALISED COMPOSITION							
isobutane	5.57	5.14	7.61	11.76	N	7.58	13.24
n - butane (nB)	11.28	19.42	11.62	47.78	O	12.38	42.15
isopentane	8.35	6.57	4.07	11.56		5.19	11.03
n - pentane (nP)	10.74	10.28	4.92	13.06		5.39	12.69
2,2 - dimethylB	0.27	–	0.86	–	R	0.70	0.39
cyclopentane (CP)	0.61	1.31	0.51	1.17	E	1.39	1.19
2,3 - dimethylB	0.37	–	0.31	–	S	0.46	–
2 - methylP	7.87	6.78	2.50	7.15	U	11.51	1.67
3 - methylP	5.48	3.19	2.01	1.62	L	3.55	1.17
n - hexane (nH)	8.61	9.03	4.13	4.22	T	12.09	5.29
methylCP (MCP)	4.73	2.55	2.36	1.62		1.23	1.27
2,2 - dimethylP	–	–	–	–		–	–
benzene	2.68	4.48	8.43	0.06		1.96	0.91
2,4 - dimethylP	–	–	–	–		0.22	–
2,2,3 - trimethylB	1.23	5.45	4.41	–		2.02	0.63
cyclohexane (CH)	7.80	4.69	6.58	–		5.84	1.78
3,3 - dimethylP	–	–	–	–		0.02	–
1,1 - dimethylCP	–	–	0.89	–		0.14	–
2 - methylH	7.80	4.10	5.03	–		4.77	0.91
2,3 - dimethylP	0.78	1.04	1.34	–		0.56	–
1,c,3 - dimethylCP	–	–	–	–		–	–
3 - methylH	0.70	0.73	1.37	–		0.46	–
1,t,3 - dimethylCP	–	–	–	–		–	–
1,t,2 - dimethylCP	3.39	1.16	2.73	–		1.65	–
3 - ethylP	–	–	–	–		–	–
n - heptane	8.16	9.07	11.64	–		12.87	3.98
1,c,2 - dimethylCP	0.47	–	0.84	–		0.85	–
methylCH (MCH)	2.22	2.93	12.77	–		5.46	1.07
toluene	0.89	1.27	3.12	–		1.71	0.66
ABUNDANCE (ppm)	107	135	150	74		87	123
MCP/benzene	1.76	0.57	0.28	27.0		6.16	1.39
MCP/MCH	2.13	0.87	0.18	–		0.22	1.19
CH/MCP	1.65	1.84	2.79	–		4.75	1.40
iP/nP	0.78	0.64	0.82	0.88		0.96	0.87
%n - PARAFFINS	38.80	47.80	32.30	65.05		42.72	64.11
% ISOPARAFFINS	38.42	33.80	29.45	32.09		37.05	29.02
% NAPHTHENES	19.21	12.64	26.70	2.79		16.56	5.30
% AROMATICS	3.57	5.76	11.55	0.06		3.67	1.57

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

GEOCHEM SAMPLE NUMBER	023	026	029	032	035	038	041
DEPTH	10320'	10350'	10380'	10410'	10440'	10470'	10500'
NORMALISED COMPOSITION							
isobutane	6.86						
n - butane (nB)	36.49						
isopentane	11.75						
n - pentane (nP)	16.65						
2,2 - dimethylB	-						
cyclopentane (CP)	1.35						
2,3 - dimethylB	-						
2 - methylP	4.44						
3 - methylP	1.38						
n - hexane (nH)	3.49						
methylCP (MCP)	1.22						
2,2 - dimethylP	-						
benzene	1.65						
2,4 - dimethylP	-	TOO LEAN FOR RESOLUTION					
2,2,3 - trimethylB	1.22						
cyclohexane (CH)	3.44						
3,3 - dimethylP	-						
1,1 - dimethylCP	-						
2 - methylH	1.65						
2,3 - dimethylP	-						
1,c,3 - dimethylCP	-						
3 - methylH	-						
1,t,3 - dimethylCP	-						
1,t,2 - dimethylCP	0.69						
3 - ethylP	-						
n - heptane	6.12						
1,c,2 - dimethylCP	-						
methylCH (MCH)	0.81						
toluene	0.82						
ABUNDANCE (ppm)	71	39	27	20	24	10	36
MCP/benzene	0.74						
MCP/MCH	1.51						
CH/MCP	2.82						
iP/nP	0.70						
%n - PARAFFINS	62.74						
% ISOPARAFFINS	27.29						
% NAPHTHENES	7.50						
% AROMATICS	2.47						

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

GEOCHEM SAMPLE NUMBER		044	047	050	053	056	059	062
DEPTH		10530'	10560'	10590'	10620'	10650'	10680'	10710'
NORMALISED COMPOSITION	isobutane							
	n - butane (nB)							
	isopentane							
	n - pentane (nP)							
	2,2 - dimethylB							
	cyclopentane (CP)							
	2,3 - dimethylB							
	2 - methylP							
	3 - methylP							
	n - hexane (nH)	TOO LEAN FOR RESOLUTION						
	methylCP (MCP)							
	2,2 - dimethylP							
	benzene							
	2,4 - dimethylP							
	2,2,3 - trimethylB							
	cyclohexane (CH)							
	3,3 - dimethylP							
	1,1 - dimethylCP							
	2 - methylH							
	2,3 - dimethylP							
	1,c,3 - dimethylCP							
	3 - methylH							
	1,t,3 - dimethylCP							
	1,t,2 - dimethylCP							
	3 - ethylP							
	n - heptane							
	1,c,2 - dimethylCP							
	methylCH (MCH)							
	toluene							
ABUNDANCE (ppm)		41	40	10	22	-	-	16
	MCP/benzene							
	MCP/MCH							
	CH/MCP							
	iP/nP							
	%n - PARAFFINS							
	% ISOPARAFFINS							
	% NAPHTHENES							
	% AROMATICS							

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

GEOCHEM SAMPLE NUMBER	065	068	071	074	077	080	083
DEPTH	10740'	10770'	10810'	10830'	10860'	10890'	10920'
NORMALISED COMPOSITION							
isobutane						5.49	
n - butane (nB)						5.05	
isopentane						6.62	
n - pentane (nP)						9.05	
2,2 - dimethylB						-	
cyclopentane (CP)						4.81	
2,3 - dimethylB						-	
2 - methylP						9.49	
3 - methylP						2.62	
n - hexane (nH)						8.17	
methylCP (MCP)	TOO LEAN FOR RESOLUTION					6.45	
2,2 - dimethylP						-	
benzene						3.36	
2,4 - dimethylP						1.84	
2,2,3 - trimethylB						4.81	
cyclohexane (CH)						12.02	
3,3 - dimethylP						-	
1,1 - dimethylCP						-	
2 - methylH						6.97	
2,3 - dimethylP						-	
1,c,3 - dimethylCP						-	
3 - methylH						-	
1,t,3 - dimethylCP						-	
1,t,2 - dimethylCP						4.76	
3 - ethylP						-	
n - heptane						3.97	
1,c,2 - dimethylCP						1.23	
methylCH (MCH)						2.53	
toluene						0.78	
ABUNDANCE (ppm)	-	29	18	61	27	64	16
MCP/benzene							
MCP/MCH							
CH/MCP							
iP/nP							
%n - PARAFFINS							
% ISOPARAFFINS							
% NAPHTHENES							
% AROMATICS							

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

	GEOCHEM SAMPLE NUMBER	086	089	092	095	098	101	104
	DEPTH	10950'	10980'	11010'	11040'	11070'	11100'	11130'
NORMALISED COMPOSITION	isobutane							
	n - butane (nB)							
	isopentane							
	n - pentane (nP)							
	2,2 - dimethylB							
	cyclopentane (CP)							
	2,3 - dimethylB							
	2 - methylP							
	3 - methylP							
	n - hexane (nH)							
	methylCP (MCP)							
	2,2 - dimethylP	TOO LEAN FOR RESOLUTION						
	benzene							
	2,4 - dimethylP							
	2,2,3 - trimethylB							
	cyclohexane (CH)							
	3,3 - dimethylP							
	1,1 - dimethylCP							
	2 - methylH							
	2,3 - dimethylP							
	1,c,3 - dimethylCP							
	3 - methylH							
	1,t,3 - dimethylCP							
	1,t,2 - dimethylCP							
	3 - ethylP							
	n - heptane							
	1,c,2 - dimethylCP							
	methylCH (MCH)							
	toluene							
	ABUNDANCE (ppm)	12	27	11	18	25	–	12
	MCP/benzene							
	MCP/MCH							
	CH/MCP							
	iP/nP							
	%n - PARAFFINS							
	% ISOPARAFFINS							
	% NAPHTHENES							
	% AROMATICS							

TABLE 3
DETAILED GASOLINE RANGE ($C_4 - C_7$) ANALYSIS

GEOCHEM SAMPLE NUMBER	107	111	114	115	116
DEPTH	11170'	11210'	11233'	RESINEX	SPERSENE
NORMALISED COMPOSITION					
isobutane	TOO LEAN FOR RESOLUTION			3.49	3.38
n - butane (nB)				31.10	9.18
isopentane				7.94	10.07
n - pentane (nP)				11.25	14.25
2,2 - dimethylB				–	0.25
cyclopentane (CP)				1.50	1.03
2,3 - dimethylB				–	0.92
2 - methylP				5.23	6.10
3 - methylP				1.66	3.52
n - hexane (nH)				10.95	10.75
methylCP (MCP)				5.08	5.56
2,2 - dimethylP				–	0.63
benzene				1.48	5.28
2,4 - dimethylP				–	0.02
2,2,3 - trimethylB				0.68	0.91
cyclohexane (CH)				3.47	4.85
3,3 - dimethylP				–	0.01
1,1 - dimethylCP				–	0.24
2 - methylH				1.30	4.12
2,3 - dimethylP				–	0.95
1,c,3 - dimethylCP				–	–
3 - methylH				–	0.89
1,t,3 - dimethylCP				–	–
1,t,2 - dimethylCP				1.63	1.58
3 - ethylP				–	–
n - heptane				6.52	6.47
1,c,2 - dimethylCP				–	0.75
methylCH (MCH)				6.52	6.07
toluene				0.20	1.50
ABUNDANCE (ppm)	–	–	13	83	287
MCP/benzene				7.40	2.03
MCP/MCH				0.78	0.91
CH/MCP				0.68	0.87
iP/nP				0.70	0.71
%n - PARAFFINS				59.81	41.45
% ISOPARAFFINS				20.31	31.69
% NAPHTHENES				18.20	20.08
% AROMATICS				1.68	6.78

TABLE 4
VISUAL KEROGEN DATA

GEOCHEM SAMPLE NUMBER	DEPTH	ORGANIC MATTER DESCRIPTION				THERMAL MATURATION INDEX
		TYPES	REMARKS	PARTICLE SIZE	PRESERV-ATION	
294-115	RESINEX		particles of dark brown to black woody-like material, commonly well rounded. Matrix of light to mid brown (thinner) angular, woody (?) particles.			
294-116	SPERSENE		essentially barren of recoverable organic matter. Few specks of woody-herbaceous type material.			

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

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
294-005	10140'	4.96000	0.02569	0.01557	0.01012	0.00534	0.00247	0.00207	0.00024	–
294-007	10160'	3.70000	0.02538	0.01623	0.00915	0.00530	0.00224	0.00142	0.00019	–
294-008	10170'	0.29310	0.01653	0.01026	0.00577	0.00375	0.00056	0.00146	–	–
294-011	10200'	1.82020	0.01313	0.00748	0.00565	0.00320	0.00091	0.00154	–	–
294-013	10220'	7.72780	0.01753	0.01224	0.00529	0.00303	0.00078	0.00148	–	–
294-020	10290'	0.94780	0.02054	0.01463	0.00591	0.00362	0.00094	0.00134	–	–
294-023	10320'	1.74850	0.01677	0.01079	0.00598	0.00384	0.00079	0.00135	–	–
294-080	10890'	2.62100	0.04140	0.01446	0.00668	0.00444	0.00070	0.00154	–	–
294-115	RESINEX	14.23000	0.04454	0.02960	0.01494	0.00409	0.00366	0.00711	0.00008	–
294-116	SPERSENE	4.73000	0.07408	0.06668	0.00740	0.00462	0.00122	0.00142	0.00014	–

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
294–005	10140'	5179	1077	498	1575	3139	417	48	–	3605
294–007	10160'	6859	1432	605	2038	4386	384	51	–	4822
294–008	10170'	56397	12794	1911	14705	36711	4981	–	–	41692
294–011	10200'	7213	1758	500	2258	4109	846	–	–	4955
294–013	10220'	2268	392	101	493	1584	192	–	–	1775
294–020	10290'	21671	3819	992	4811	15436	1414	–	–	16850
294–023	10320'	9591	2196	452	2648	6171	772	–	–	6943
294–080	10890'	8066	1694	267	1961	5517	588	–	–	6105
294–115	RESINEX	3130	287	257	545	2080	500	6	–	2585
294–116	SPERSENE	15662	977	258	1235	14097	300	30	–	14427

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	
294-005	10140'	20.79	9.61	2.16	60.61	8.06	0.93	-	6.74	0.44
294-007	10160'	20.88	8.83	2.37	63.95	5.59	0.75	-	10.08	0.42
294-008	10170'	22.69	3.39	6.70	65.09	8.83	-	-	7.37	0.35
294-011	10200'	24.37	6.93	3.52	56.97	11.73	-	-	4.86	0.46
294-013	10220'	17.28	4.45	3.88	69.82	8.44	-	-	8.27	0.28
294-020	10290'	17.62	4.58	3.85	71.23	6.52	-	-	10.92	0.29
294-023	10320'	22.90	4.71	4.86	64.34	8.05	-	-	7.99	0.38
294-080	10890'	21.00	3.31	6.34	68.40	7.28	-	-	9.39	0.32
294-115	RESINEX	9.18	8.22	1.12	66.46	15.96	0.18	-	4.12	0.21
294-116	SPERSENE	6.24	1.65	3.79	90.01	1.92	0.19	-	42.74	0.09

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
294-005 Ext.	10140'	0.75	30.41	21.00	69.05
294-007 Ext.	10160'	0.79	29.71	25.80	86.82
294-008 Ext.	10170'	1.02	26.07	144.17	552.91
294-011 Ext.	10200'	0.39	31.30	57.90	184.95
294-013 Ext.	10220'	0.32	21.74	15.41	70.88
294-020 Ext.	10290'	0.23	22.20	209.17	942.22
294-023 Ext.	10320'	0.23	27.61	115.13	417.00
294-080 Ext.	10890'	0.10	24.31	196.10	806.60
294-002 Ext	10110'	4.44			
294-003 Ext	10120'	1.24			
294-004 Ext	10130'	1.15			
294-006 Ext	10150'	1.36			

TABLE 7

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

GEOCHEM SAMPLE NUMBER	005	007	008	011	013	020	023	080
DEPTH	10140'	10160'	10170'	10200'	10220'	10290'	10320'	10890'
SAMPLE TYPE								
nC_{15}	2.6	2.5	5.1	8.2	5.0	3.4	4.1	6.6
nC_{16}	8.1	7.8	9.5	12.2	9.2	6.2	7.7	9.7
nC_{17}	14.4	15.5	13.1	13.6	13.2	10.1	12.2	13.3
nC_{18}	15.0	15.7	15.3	12.6	12.3	9.8	12.0	12.7
nC_{19}	13.1	13.2	15.6	11.9	11.5	9.4	10.9	11.5
nC_{20}	12.6	12.2	16.7	12.9	11.8	9.8	11.1	11.7
nC_{21}	8.1	8.5	8.4	7.7	8.5	8.1	8.8	7.6
nC_{22}	7.2	7.0	5.5	7.0	6.7	7.7	7.7	6.6
nC_{23}	6.8	6.6	5.1	6.1	5.2	7.1	7.0	5.3
nC_{24}	4.4	4.8	2.5	4.0	5.0	7.1	5.9	4.7
nC_{25}	4.1	3.1	1.8	1.6	3.5	6.0	4.8	3.5
nC_{26}	2.2	1.9	0.7	1.2	2.9	5.1	2.0	2.5
nC_{27}	0.9	0.6	0.4	0.5	2.2	3.8	2.0	1.8
nC_{28}	0.4	0.4	0.4	0.2	1.3	3.0	1.4	1.4
nC_{29}	0.2	0.2	–	0.2	1.3	2.3	1.1	1.0
nC_{30}	–	–	–	–	0.3	0.8	0.9	–
nC_{31}	–	–	–	–	0.1	0.6	0.5	–
nC_{32}	–	–	–	–	0.1	–	–	–
nC_{33}	–	–	–	–	–	–	–	–
nC_{34}	–	–	–	–	–	–	–	–
nC_{35}	–	–	–	–	–	–	–	–
PARAFFIN	13.4	15.4	7.9	12.8	15.9	14.8	12.6	12.6
ISOPRENOID	4.2	3.6	2.5	2.8	2.9	2.1	2.2	3.0
NAPHTHENE	82.3	80.9	89.6	84.4	81.2	83.2	85.3	84.3
CPI INDEX A	1.08	1.03	1.17	0.96	0.99	0.97	1.09	0.96
CPI INDEX B	–	–	–	–	1.17	–	–	–
PRISTANE/PHYTANE	0.67	0.67	0.60	0.77	0.77	0.68	0.67	0.66
PRISTANE/nC_{17}	0.88	0.61	0.89	0.69	0.60	0.56	0.57	0.71

TABLE 7

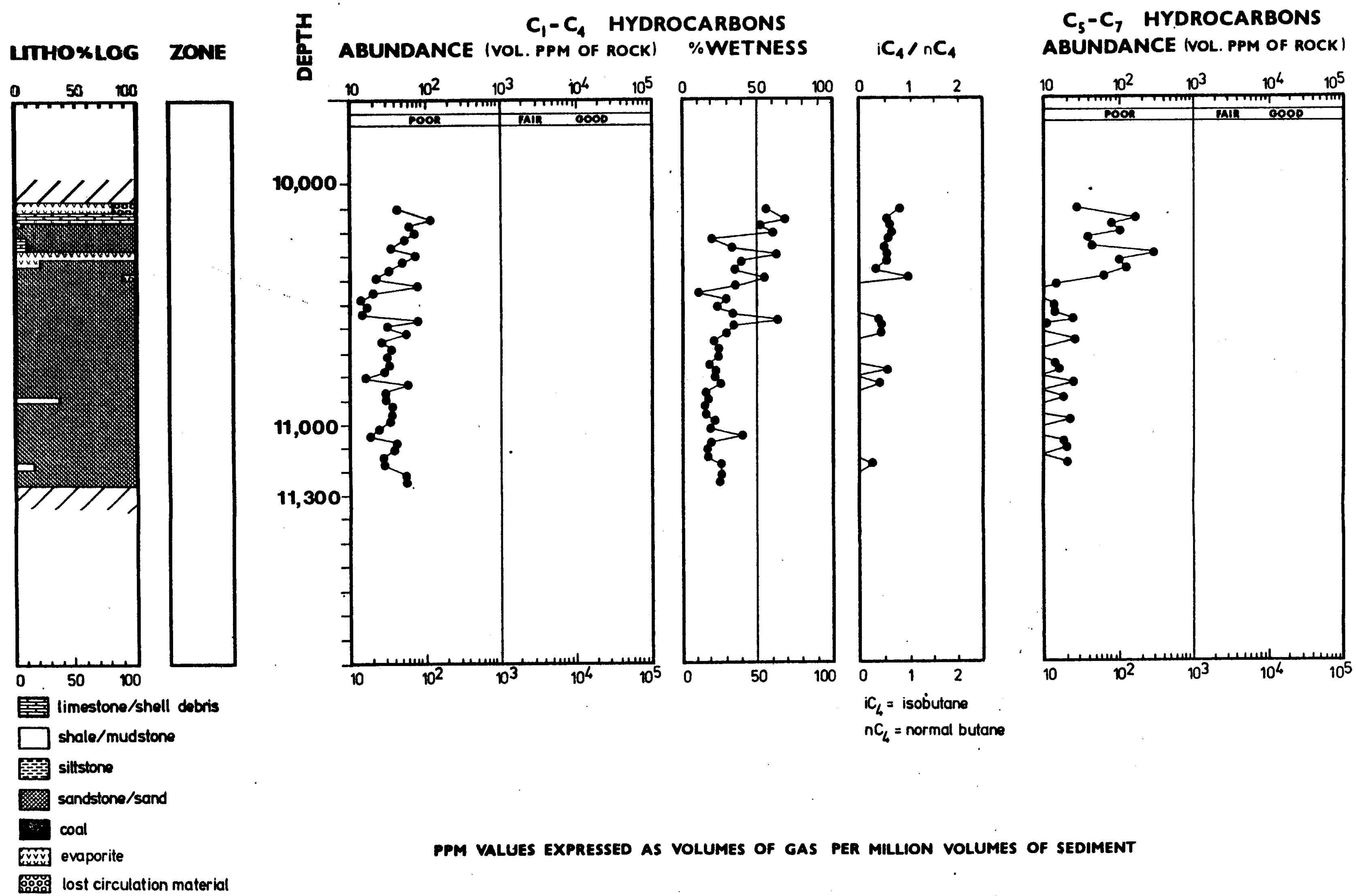
COMPOSITION (NORMALISED %) OF C_{15+} PARAFFIN – NAPHTHENE HYDROCARBONS

GEOCHEM SAMPLE NUMBER	115	116
DEPTH		
SAMPLE TYPE	Resinex additive	Spersene
nC_{15}	7.1	14.7
nC_{16}	2.8	18.8
nC_{17}	10.6	19.0
nC_{18}	9.0	15.7
nC_{19}	9.9	10.5
nC_{20}	20.1	7.0
nC_{21}	8.5	4.1
nC_{22}	7.6	2.9
nC_{23}	7.3	2.2
nC_{24}	6.4	1.7
nC_{25}	7.8	1.4
nC_{26}	1.9	0.9
nC_{27}	0.5	0.7
nC_{28}	0.2	0.3
nC_{29}	0.2	0.2
nC_{30}	-	0.1
nC_{31}	-	-
nC_{32}	-	-
nC_{33}	-	-
nC_{34}	-	-
nC_{35}	-	-
PARAFFIN	19.0	27.5
ISOPRENOID	2.3	4.6
NAPHTHENE	78.7	67.9
CPI INDEX A	1.09	1.06
CPI INDEX B	-	-
PRISTANE/PHYTANE	0.55	1.13
PRISTANE/nC_{17}	0.40	0.47

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

C_4-C_7 HYDROCARBONS

PRESENTATION OF ANALYTICAL DATA

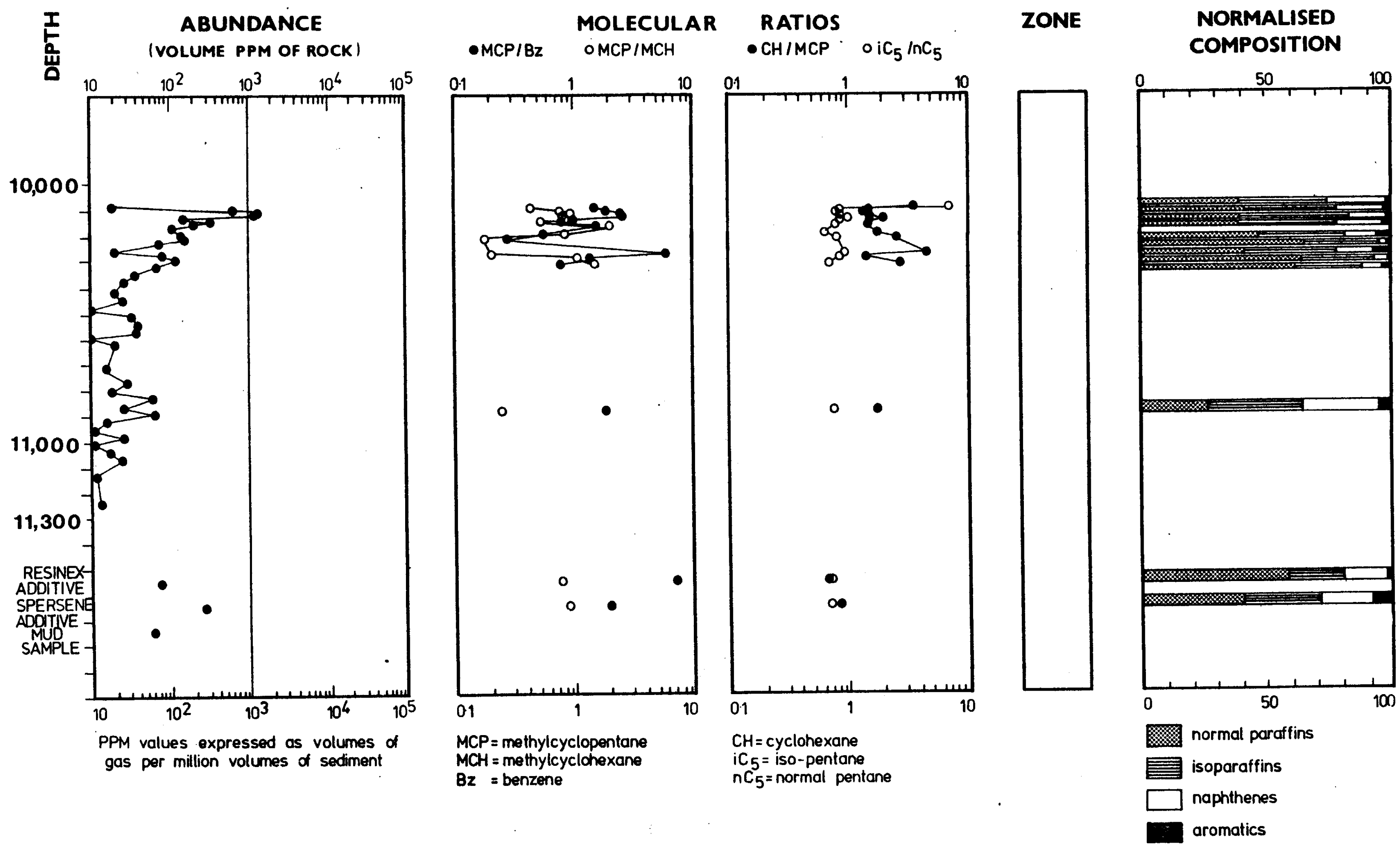


FIGURE 3

C_{15+} HYDROCARBONS — RICHNESS

PRESENTATION OF ANALYTICAL DATA

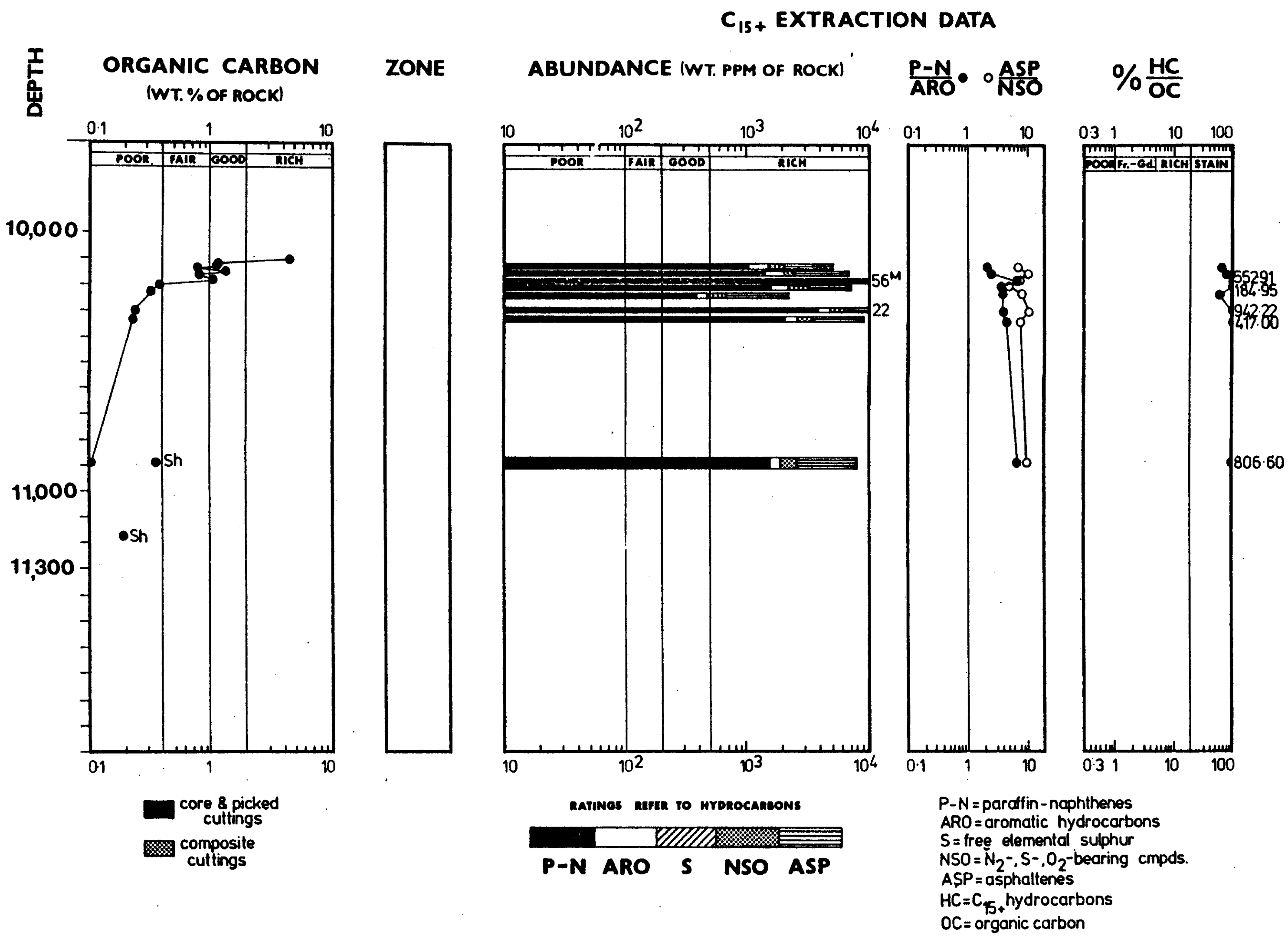
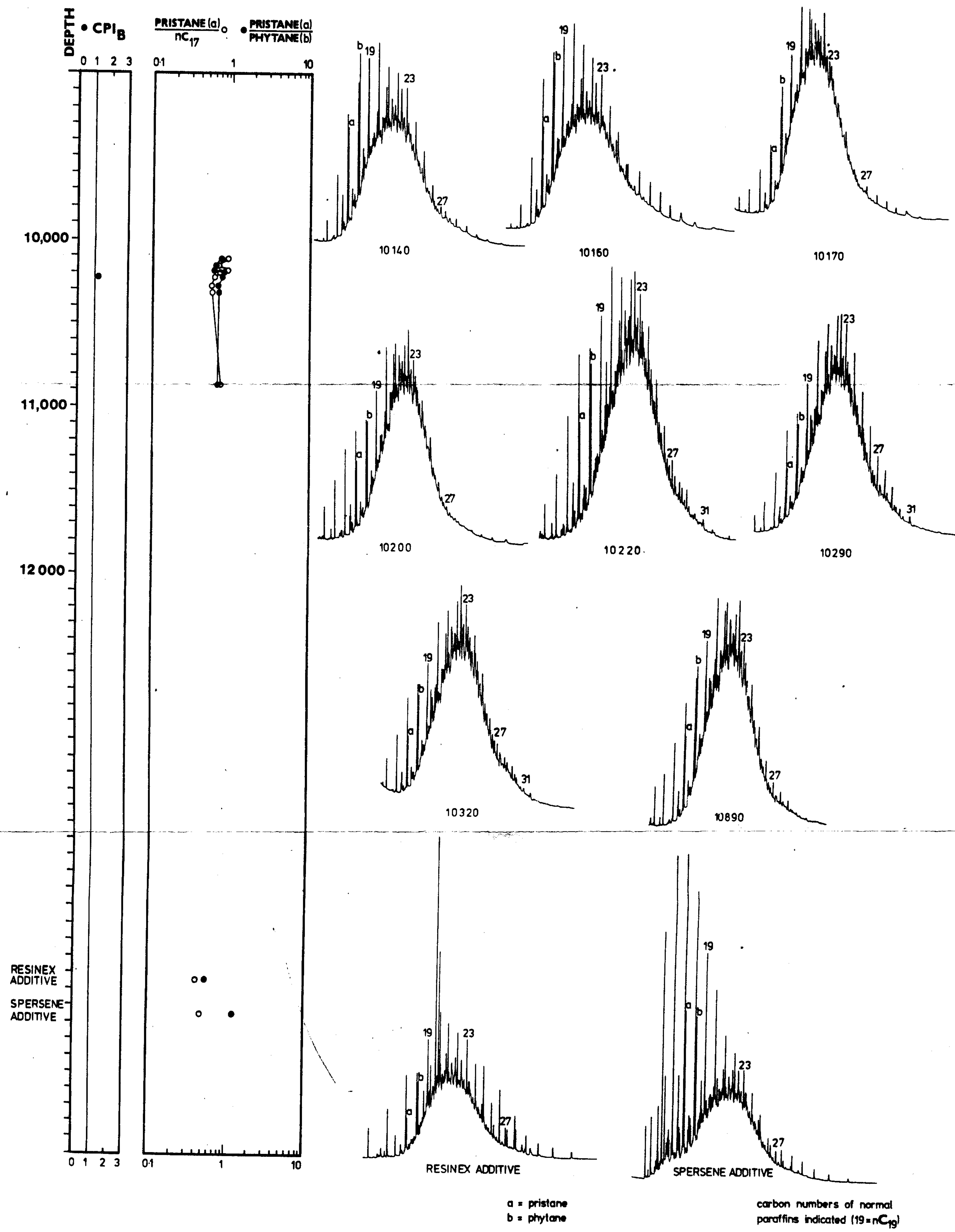


FIGURE 4

C_{15+} PARAFFIN – NAPHTHENE HYDROCARBONS

PRESENTATION OF ANALYTICAL DATA



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 phytoclasts 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:

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

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

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+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.