



# **GEOCHEMICAL SERVICE REPORT**

Prepared for  
STATOIL

CORRELATION STUDY INVOLVING CORED  
SANDSTONES FROM THE STATOIL 6407/6-1  
WELL, HALTENBANKEN, OFFSHORE NORWAY

February 1985

CHESTER STREET · CHESTER CH4 8RD · ENGLAND

COMPANY PROPRIETARY

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CORRELATION STUDY INVOLVING CORED  
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SUMMARY

25 MAF 1985  
REGISTRERT  
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The cored sands from the 1665.5-1883.9 metre interval in 6407/6-1 are essentially clean. Insignificantly minor traces, however, of a suspected crude oil were detected in the Paleocene sands at 1665.5 metres and the Middle Jurassic sands at 1870 metres.



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## INTRODUCTION

This report presents the results of a partial geochemical evaluation of selected sands from the 1665.5-1883.9 metre interval in Statoils 6407/6-1 Haltenbanken Well.

The purpose of this study was to detect and characterise possible shows of liquid hydrocarbons and to correlate them with hydrocarbon shows and potential source rocks observed during the routine geochemical evaluation of the 6407/6-1 well (see Geochem report February, 1985).

This project was authorised by Dr. H. Irwin, Statoil, Stavanger.

### A. ANALYTICAL

A total of six sidewall cores and three core samples from the 1665.5 - 1883.9 metre interval in 6407/6-1 were received and assigned the Geochem job number 1019.

The analytical format was specified by the client (contract T-6192 No. 7). Unfortunately the sidewall cores were extremely small and all of the samples proved to be very lean. As a result it was impossible to perform the majority of the analyses requested by the client. In total, nine chromatographic separations and nine C<sub>15+</sub> paraffin-naphthene analyses were performed in this study.

The data are presented in tables 1 through 4 and graphically in figure 1.

### B. GENERAL INFORMATION

Ten (10) copies of this report have been forwarded to Dr. H. Irwin at Statoil in Stavanger. A copy of the data has been retained by Geochem for future consultation with authorised Statoil personnel.

The remaining sample material will be handled as directed.

All of the results relating to this study are proprietary to Statoil.

## RESULTS AND DISCUSSION

The Paleocene (Alstahaug Formation) sands at 1665.5 metres are light olive grey in colour and are loosely cemented by fine clays. Similarly, the Middle Jurassic (Tomma Formation) sands, sampled between 1856.5 metres and 1883.9 metres, are also loosely cemented, fine to medium grained and moderately well sorted sands, which range in colour from light olive grey to dark yellowish brown.

The sands are non fluorescent.

Upon extraction, and severely hampered by extremely small samples, the sidewall cores from 1665.5-1870 metres yielded 7-51 ppm  $C_{15+}$  hydrocarbons whilst the cored sands from the 1878.6-1883.9 metre interval, despite sufficient sample material, yielded only 4-7 ppm of the  $C_{15+}$  hydrocarbons. With hydrocarbon to total extract ratios of 4.5-17%, migrated crude oil is not immediately suspected. However, the paraffin-naphthene chromatograms corresponding to the sands at 1665.5 metres and 1870 metres exhibit hydrocarbon profiles which are too mature for indigenous hydrocarbons and clearly, traces, although insignificantly minor, of crude oil in the sands at these depths are indicated. Because of extremely low extract weights the remaining chromatograms offer no qualitative support to the above findings as their chromatograms are characterised by large naphthenic humps and paraffin distributions which neither support the presence of migrated crude oil or of immature indigenous hydrocarbons.

### CONCLUSIONS

Six sidewall cores and three core samples from the 1665.5-1883.9 metre interval in 6407/6-1 have been analysed.

Despite the very small size of some of the samples received (sidewall cores), it is apparent from the extremely low abundances (4-51 ppm) of the C<sub>15+</sub> hydrocarbons that the analysed sands are clean. The only exceptions to this are the Paleocene sands at 1665.5 metres and the Middle Jurassic sands at 1870 metres within which, insignificantly minor traces of a suspected migrated crude oil were detected.

**TABLE 1**  
**ORGANIC CARBON RESULTS AND GROSS LITHOLOGIC DESCRIPTIONS**

GEOCHEM SAMPLE NUMBER	DEPTH	GROSS LITHOLOGIC DESCRIPTION	G S A Colour Code	TOTAL ORGANIC CARBON (Wt. % of Rock)
1019-001	1665.5m	SWC A 98% Sandstone, with muddy horizons, loosely consolidated, fine grained, well sorted, sub-rounded, quartz and micas, light olive grey	5Y6/1	
1019-002	1856.5m	SWC A 98% Sandstone, quartz and mica in muddy matrix, pyritic, loosely consolidated, fine grained, well sorted, sub-rounded, olive grey	5Y4/1	
1019-003	1859.5m	SWC A 98% Sandstone, loosely consolidated, fine grained, well sorted, sub-rounded, quartz and micas, light olive grey	5Y6/1	
1019-004	1862.5m	SWC A 98% Sandstone, as 1019-003A	5Y6/1	
1019-005	1868.5m	SWC A 98% Sandstone, muddy in part, loosely consolidated, fine grained, well sorted, sub-rounded, quartz and micas, light olive grey	5Y6/1	
1019-006	1870m	SWC A 98% Sandstone, as 1019-005A	5Y6/1	
1019-007	1878.6m CORE	A 98% Sandstone, with muddy matrix, loosely consolidated, medium to coarse grained, mod. sorted, sub-rounded, quartz and mica, dark yellowish brown	10YR4/2	
1019-008	1883.0m CORE	A 98% Sandstone, with muddy matrix, loosely consolidated, coarse grained, poorly sorted, sub-rounded, quartz, light olive grey	5Y6/1	
1019-009	1883.9m CORE	A 98% Sandstone, as 1019-008A, but with red mud lenses, light olive grey	5Y6/1	

**TABLE 2a**  
**CONCENTRATION (PPM) OF EXTRACTED C<sub>15+</sub> MATERIAL IN ROCK**

GEOCHEM SAMPLE NUMBER	DEPTH	TOTAL EXTRACT	HYDROCARBONS			NON HYDROCARBONS			
			Paraffin - Naphthenes	Aromatics	TOTAL	Precipd. Asphaltenes	Eluted NSO's	Non-eluted NSO's	Sulphur
1019-001A	1665.5 SWC	231	25	8	33	169	12	10	7
1019-002A	1856.5 SWC	301	32	18	51	174	41	26	10
1019-003A	1859.5 SWC	156	4	3	7	131	8	6	4
1019-004A	1862.5 SWC	149	11	5	16	104	18	5	5
1019-005A	1868.5 SWC	270	30	17	46	158	45	15	5
1019-006A	1870 SWC	156	17	10	27	93	27	5	5
1019-007A	1878.6 CORE	54	5	2	7	28	14	3	2
1019-008A	1883.0 CORE	65	3	3	5	49	11	0	0
1019-009A	1883.9 CORE	66	2	2	4	45	11	6	0

**TABLE 2b**  
**COMPOSITION (NORMALISED %) OF C<sub>15</sub>+ MATERIAL EXTRACTED FROM ROCK**

GEOCHEM SAMPLE NUMBER	DEPTH	HYDROCARBONS		NON HYDROCARBONS			
		Paraffin – Naphthenes	Aromatics	Preciptd. Asphaltenes	Eluted NSO's	Non eluted NSO's	Sulphur
1019-001A	1665.5 SWC	10.73	3.41	73.17	5.37	4.39	2.93
1019-002A	1856.5 SWC	10.72	6.09	57.68	13.62	8.70	3.19
1019-003A	1859.5 SWC	2.70	1.80	83.78	5.41	3.60	2.70
1019-004A	1862.5 SWC	7.44	3.31	70.25	12.40	3.31	3.31
1019-005A	1868.5 SWC	11.01	6.17	58.59	16.74	5.73	1.76
1019-006A	1870 SWC	10.94	6.25	59.38	17.19	3.12	3.12
1019-007A	1878.6 CORE	9.87	3.95	52.63	25.00	5.26	3.29
1019-008A	1883.0 CORE	3.88	3.88	75.24	16.50	0.49	0.00
1019-009A	1883.9 CORE	2.79	2.79	68.16	17.32	8.94	0.00



**TABLE 3**  
**SIGNIFICANT RATIOS (%) OF C<sub>15+</sub> FRACTIONS AND ORGANIC CARBON**

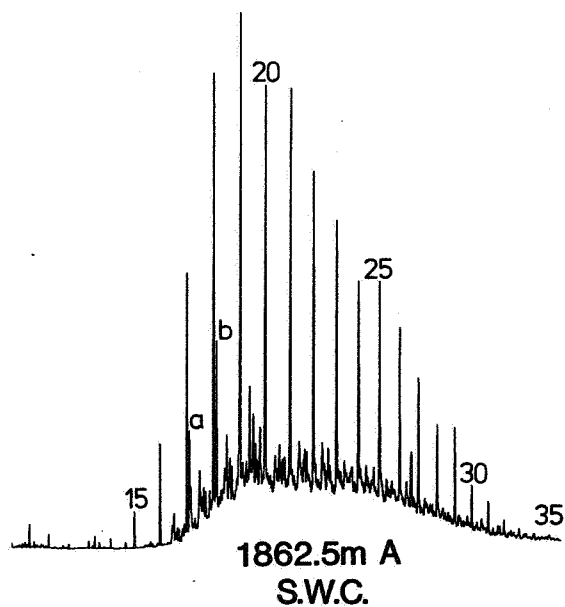
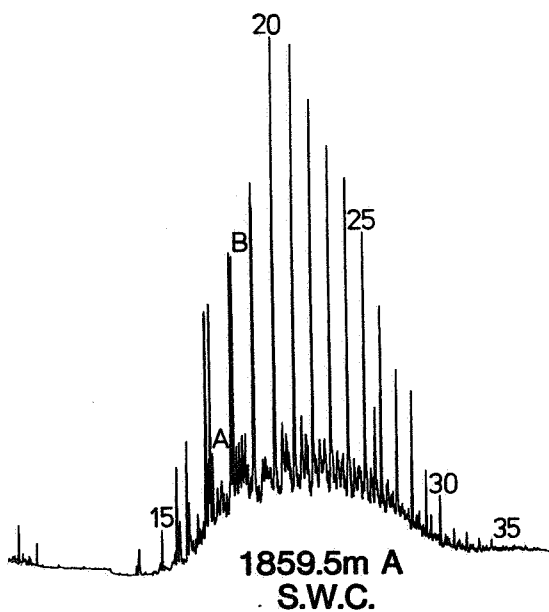
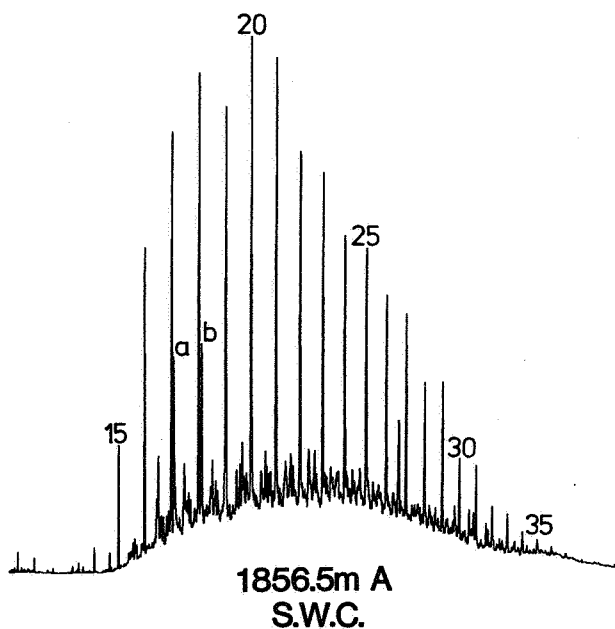
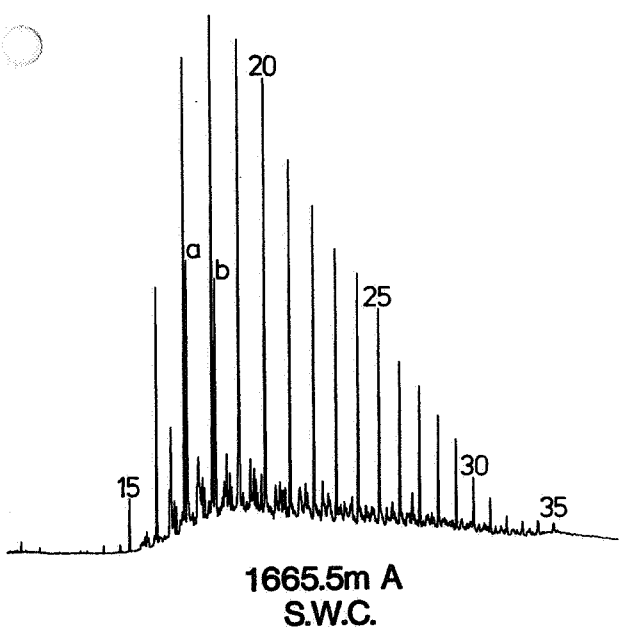
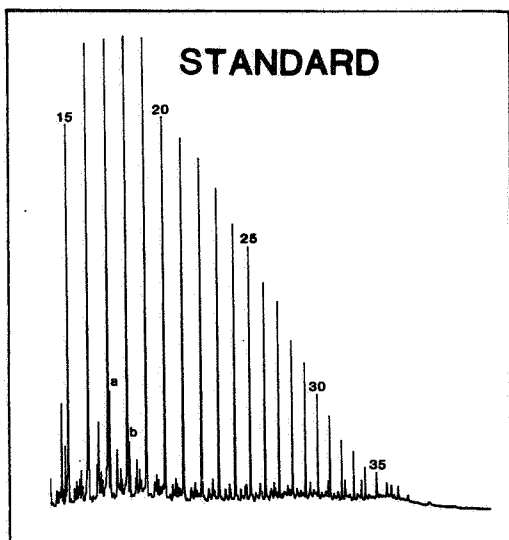
GEOCHEM SAMPLE NUMBER	DEPTH		ORGANIC CARBON (wt. %)	HYDROCARBONS	HYDROCARBONS	TOTAL EXTRACT	P-NAPHTHENES
				TOTAL EXTRACT	ORG. CARBON	ORG. CARBON	AROMATICS
1019-001A	1665.5	SWC	0.12	14.15	2.73	19.28	3.14
1019-002A	1856.5	SWC	0.34	16.81	1.49	8.86	1.76
1019-003A	1859.5	SWC	0.12	4.50	0.59	13.03	1.50
1019-004A	1862.5	SWC	0.10	10.74	1.60	14.86	2.25
1019-005A	1868.5	SWC	1.17	17.18	0.40	2.30	1.79
1019-006A	1870	SWC	0.17	17.19	1.58	9.18	1.75
1019-007A	1878.6	CORE	0.12	13.82	0.62	4.51	2.50
1019-008A	1883.0	CORE	0.06	7.77	0.84	10.75	1.00
1019-009A	1883.9	CORE	0.11	5.59	0.34	6.00	1.00

**TABLE 4**  
**COMPOSITION (NORMALISED %) OF C<sub>15+</sub> PARAFFIN – NAPHTHENE HYDROCARBONS**

GEOCHEM SAMPLE NUMBER	-001A	-002A	-003A	-004A	-005A	-006A	-007A
DEPTH	1665.5m SWC	1856.5m SWC	1859.5m SWC	1862.5m SWC	1868.5m SWC	1870m SWC	1878.6m CORE
SAMPLE TYPE							
nC <sub>15</sub>	1.04	1.83	0.89	0.73	0.61	0.86	0.59
nC <sub>16</sub>	5.12	5.12	2.65	2.18	3.24	5.03	1.16
nC <sub>17</sub>	10.48	7.80	5.08	6.62	9.80	11.11	3.40
nC <sub>18</sub>	12.24	8.27	7.81	12.21	13.28	11.78	8.22
nC <sub>19</sub>	12.75	9.92	7.19	13.01	11.53	11.33	13.55
nC <sub>20</sub>	9.84	10.00	12.48	11.80	10.15	9.62	12.25
nC <sub>21</sub>	8.28	9.33	12.46	9.86	9.23	7.87	9.76
nC <sub>22</sub>	7.16	8.26	10.18	8.90	8.16	7.05	9.36
nC <sub>23</sub>	6.12	6.96	9.54	7.48	6.90	6.02	7.20
nC <sub>24</sub>	5.48	5.59	8.73	5.75	6.38	5.13	7.27
nC <sub>25</sub>	5.20	6.00	5.46	5.19	5.63	5.78	6.33
nC <sub>26</sub>	3.84	4.25	4.85	4.13	5.36	4.60	4.97
nC <sub>27</sub>	3.32	4.18	3.76	3.61	2.98	3.41	4.15
nC <sub>28</sub>	2.76	3.15	3.20	2.78	2.26	2.80	3.22
nC <sub>29</sub>	2.16	3.08	1.52	2.52	1.79	2.50	2.83
nC <sub>30</sub>	1.20	1.48	1.12	1.17	0.88	1.42	1.86
nC <sub>31</sub>	0.84	1.53	0.76	0.98	0.63	1.21	1.51
nC <sub>32</sub>	0.40	1.00	0.69	0.42	0.54	0.80	0.75
nC <sub>33</sub>	0.52	0.99	0.61	0.29	0.36	0.75	0.71
nC <sub>34</sub>	0.72	0.69	0.54	0.22	0.18	0.56	0.55
nC <sub>35</sub>	0.56	0.56	0.46	0.14	0.13	0.37	0.36
PARAFFIN	34.82	26.38	26.87	26.96	29.63	36.09	25.83
ISOPRENOID	4.98	2.10	2.30	2.31	3.81	4.78	1.71
NAPHTHENE	60.19	71.52	70.83	70.73	66.56	59.13	72.46
CPI INDEX A	1.03	1.09	1.01	1.03	0.97	1.03	0.96
CPI INDEX B	1.14	1.26	0.90	1.17	0.98	1.13	1.12
PRISTANE/PHYTANE	1.09	0.83	0.37	0.53	1.05	1.01	0.56
PRISTANE/nC <sub>17</sub>	0.71	0.46	0.45	0.45	0.67	0.60	0.70

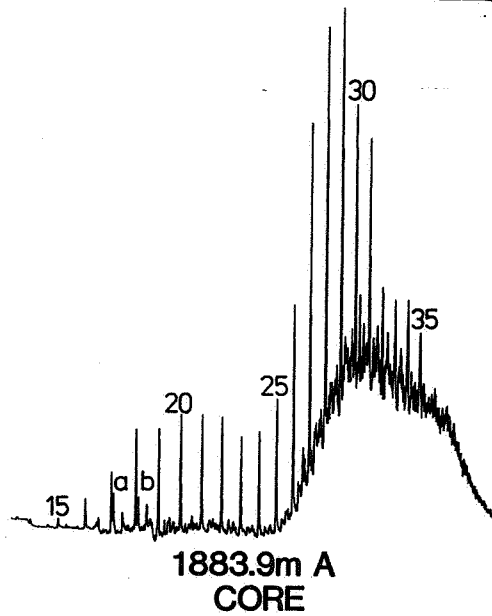
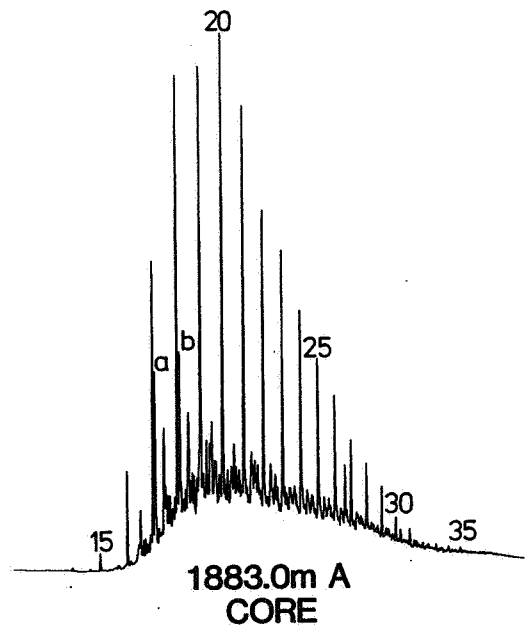
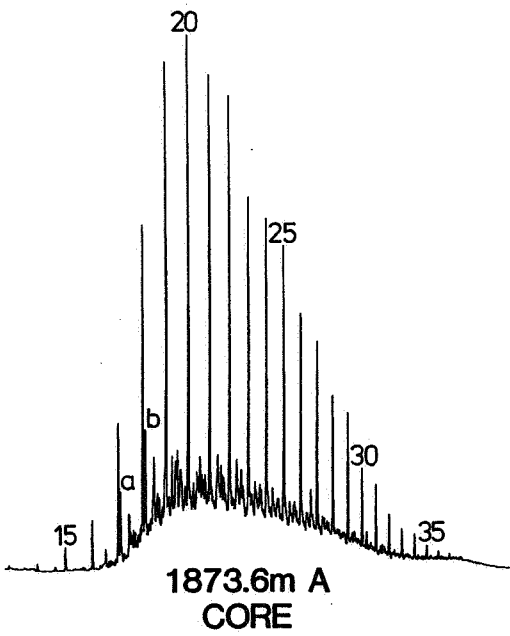
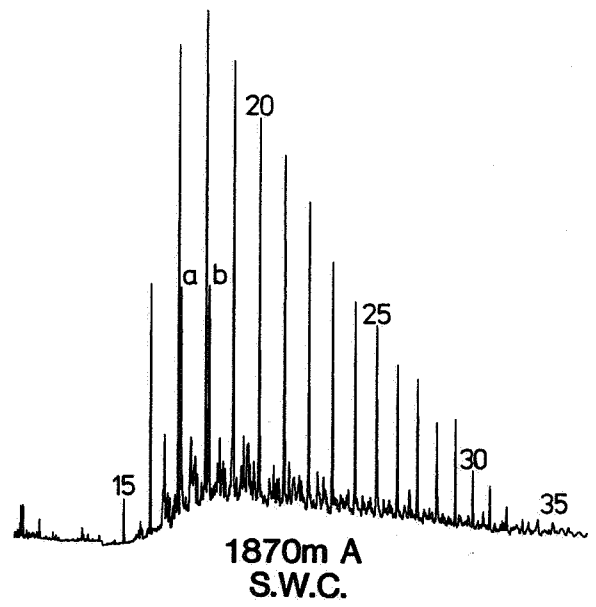
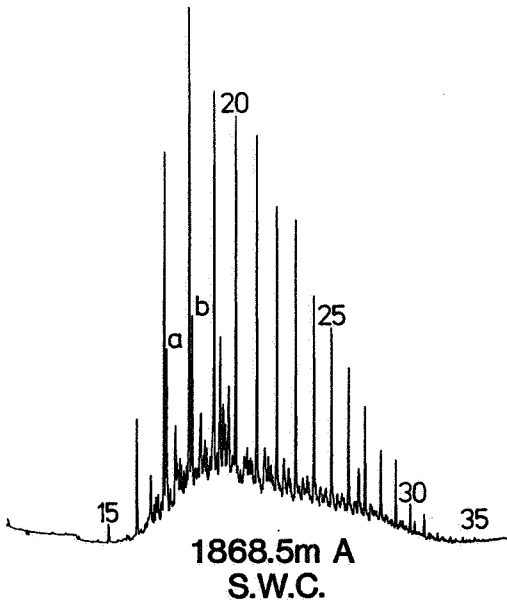
TABLE 4  
COMPOSITION (NORMALISED %) OF C<sub>15+</sub> PARAFFIN – NAPHTHENE HYDROCARBONS

GEOCHEM SAMPLE NUMBER	-008A	-009A
DEPTH	1883.0m CORE	1883.9m CORE
SAMPLE TYPE		
nC <sub>15</sub>	0.49	0.30
nC <sub>16</sub>	2.43	0.90
nC <sub>17</sub>	7.95	1.86
nC <sub>18</sub>	12.75	2.85
nC <sub>19</sub>	15.73	3.36
nC <sub>20</sub>	13.64	3.75
nC <sub>21</sub>	10.29	3.36
nC <sub>22</sub>	9.23	3.42
nC <sub>23</sub>	6.59	3.06
nC <sub>24</sub>	4.71	3.51
nC <sub>25</sub>	4.84	4.23
nC <sub>26</sub>	3.06	5.97
nC <sub>27</sub>	2.53	8.52
nC <sub>28</sub>	1.86	12.64
nC <sub>29</sub>	1.41	12.03
nC <sub>30</sub>	0.72	8.76
nC <sub>31</sub>	0.44	6.18
nC <sub>32</sub>	0.39	3.51
nC <sub>33</sub>	0.35	4.68
nC <sub>34</sub>	0.31	4.38
nC <sub>35</sub>	0.28	2.70
PARAFFIN	23.67	18.41
ISOPRENOID	2.97	0.54
NAPHTHENE	73.36	81.05
CPI INDEX A	1.04	0.95
CPI INDEX B	1.21	1.00
PRISTANE/PHYTANE	0.93	1.39
PRISTANE/nC <sub>17</sub>	0.76	0.92



a - PRISTANE  
b - PHYTANE

CARBON NUMBERS OF NORMAL PARAFFINS INDICATED (20 - nC<sub>20</sub>)



a - PRISTANE  
b - PHYTANE

CARBON NUMBERS OF NORMAL PARAFFINS INDICATED (20 - nC<sub>20</sub>)

## BRIEF DESCRIPTION OF THE ANALYSES PERFORMED BY GEOCHEM

"Screen Analyses" are described in sections A, C and D, "Sample Preparation" in section B, "Follow-up Analyses" in sections E through K and "Correlation Studies" in section L. The analyses can be run on either core or cuttings material with the proviso that samples must be canned for the C<sub>1</sub>-C<sub>7</sub> analysis and should be canned (or at least wet) for the C<sub>4</sub>-C<sub>7</sub> analysis. The other analyses can be run on both canned and bagged samples.

### A) C<sub>1</sub>-C<sub>7</sub> LIGHT HYDROCARBON ANALYSIS

The abundance and composition of the C<sub>1</sub>-C<sub>7</sub> hydrocarbons in sediments reflects their source richness, maturity and the character of the hydrocarbons they can yield. Most importantly, it is extremely sensitive to the presence of migrated hydrocarbons and is an excellent method for their detection. As it provides the 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<sub>1</sub>-C<sub>4</sub> gaseous hydrocarbons (methane, ethane, propane, isobutane and normal butane) and a partial resolution of the C<sub>5</sub>-C<sub>7</sub> gasoline-range hydrocarbons (for their complete resolution see Section E). The ppm abundance of the five gases and of the total C<sub>5</sub>-C<sub>7</sub> 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<sub>1</sub>-C<sub>7</sub> 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.

Sample material remaining after analysis is retained for six months. Unless instructions are received to the contrary, Geochem Laboratories may then destroy the samples.

Our reports incorporate a gross lithological description of all the samples which have been analysed and litho percentage logs. 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,  $C_1-C_7$ ,  $C_4-C_7$ , pyrolysis 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 diagrammatically in our reports in a manner which facilitates comparison with the gross lithology (see Section B) of the samples.

### D) MINI-PYROLYSIS

An ideal screen analysis which provides a definitive measure of potential source richness upon those samples whose organic carbon contents suggest fair or good source potential. This is described in detail in section K.

### E) 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 by capillary gas chromatography and their peak areas electronically integrated.

Normalised compositions, selected ratios and the ppm abundance of the total gasoline-range fraction are tabulated in the report and also presented graphically.

### F) 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, pyrolysis 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 acid digestion and flotation methods which avoid oxidation of the organic matter. It is then mounted on a glass slide and examined at high and low magnifications with a Leitz microscope. Chemical methods measure the total kerogen population but, with this technique, individual particles can be selected for examination and spurious material identified. This is particularly valuable in reworked, contaminated and turbodrilled sediments.

The following data are generated: the types of the organic matter present and their relative abundances, an estimate of the proportion of reworked material, preservation state, the thermal maturity of the non-reworked organic matter using the spore colouration technique.

Our maturation scale has been developed to digitise small but recognisable changes in organic matter colouration resulting from increasing maturity and to place particular emphasis upon the immature to mature transition. In the absence of a universal colouration scale, the most significant points on our scale have been calibrated against equivalent vitrinite reflectance values. The following maturation stages are recognised at the low end of the scale:-

- a) immature; thermal index less than 2- (0.45% Ro)
- b) marginally mature; indices between 2- and 2.  
Minor hydrocarbon generation from amorphous and herbaceous ( $\pm$  algal) organic matter
- c) mature; indices between 2 (0.53% Ro) and 2 to 2+ (0.72% Ro),  
significant generation from amorphous, algal and herbaceous organic matter but wood only marginally mature
- d) oil window; indices of 2 to 2+ (0.72% Ro) through to 3 (1.2% Ro). Peak hydrocarbon generation.

The condensate zone starts at a thermal index of 3 whilst indices of 3+ (2.0% Ro) and higher indicate the eometamorphic dry gas stage.

A total of fourteen types of organic matter are sought based upon the major categories of algal, amorphous, herbaceous (spore, pollen, cuticle), wood, inertinite and resin. This detail is essential for a proper understanding of hydrocarbon source potential as the different sub-groups within each category have different properties.

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

#### G) VITRINITE REFLECTANCE

Vitrinite reflectance is an alternative/confirmatory method for evaluating thermal maturation which is used in conjunction with the visual kerogen analysis. 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 or the thicknesses of section removed by erosion.

Measurements are made upon kerogen separations in conjunction with polished whole rock samples. In general, this analysis is performed upon the same samples as the visual kerogen analysis, thus facilitating a direct comparison of the two sets of results.

If possible, forty to fifty measurements are taken per sample - unless the sediments are organically lean, vitrinite is sparse or only a single uniform population is present. The data are plotted in a histogram which



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, histograms and the reflectivities plotted against depth.

The vitrinite and visual kerogen techniques provide mutually complementary information upon maturity, organic matter type and diagenesis.

#### H) C<sub>15+</sub> EXTRACTION, DEASPHALTENING AND CHROMATOGRAPHIC SEPARATION

Sections "A" and "E" 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 employ pure solvents and have been designed to give reproducible results. Hand picked samples are ground and then solvent extracted in a soxhlet apparatus, or by blending, with dichloromethane (the solvent system can be adapted to client's specifications). After asphaltene precipitation, the total extract is separated by column chromatography or high pressure liquid chromatography into the following fractions: paraffin-naphthene hydrocarbons, aromatic hydrocarbons, eluted NSO's (nitrogen-, sulphur-, and oxygen- containing non-hydrocarbons) and non-eluted NSO's. Note that the non-hydrocarbons are split into three fractions and not reported as a gross value. These fractions can be submitted for further analyses (carbon isotopes, gas chromatography, mass spectroscopy) including correlation studies.

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 diagrammatically.

#### J) GC ANALYSIS OF C<sub>15+</sub> PARAFFIN-NAPHTHENE HYDROCARBONS

The gas chromatographic configurations of the heavy C<sub>15+</sub> 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 rocks 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 separated by high resolution capillary chromatography. Excellent resolution of the individual normal paraffins, isoprenoids and significant individual isoparaffins and naphthenes is achieved. Runs are normally terminated at nC<sub>35</sub>. A powerful in-house microprocessor system is being introduced to correct for the change in response factor with chain length.

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 ( $\pm$  strong pristane peaks) are characteristic of immature land plant organic matter whilst even preferences ( $\pm$  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:

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

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

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.<sub>A</sub> and C.P.I.<sub>B</sub>; pristane to phytane ratio; pristane to nC<sub>17</sub> ratio.

#### K) 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, kerogen and C<sub>15+</sub> analyses.

Small amounts of powdered sample are heated in helium to release the thermal bitumen (up to 340°C) and pyrolysate (340-550°C). The thermal bitumen correlates with the solvent extractable material (see above) whilst the pyrolysate fraction does not exist in a "free" state but is generated from the kerogen, thus simulating maturation in the subsurface. Abundances (weight ppm of rock) are measured with a flame ionisation detector against a standard. Thermal bitumen includes source indigenous, contaminant and migrated hydrocarbons but the pyrolysate abundance is a measure of ultimate source richness. The capillary gas chromatogram of the pyrolysate is used to evaluate the character of the parent organic matter and whether it is oil or gas prone. Peak temperature(s) of pyrolysate evolution is recorded. Carbon dioxide can be measured if requested but is normally ignored as the separation of the organic and inorganic species has been found to be artificial and unreliable.

Pyrolysate yields provide a definitive measure of potential source richness which avoids the ambiguities of the organic carbon data and the problem of contamination. This analysis is also used to evaluate the quality and character of the organic matter and the degree to which it has realised its ultimate hydrocarbon potential. Geochem does not employ the pyrolysis technique to evaluate maturation, preferring the kerogen and vitrinite reflectance analyses which avoid the problem of reworking and hence, are more reliable.

Capillary chromatograms produced for the pyrolysate hydrocarbons range from C<sub>1</sub> (methane) out towards C<sub>35</sub> but exhibit considerable variations. They are used to define whether a source rock will yield oil, condensate or gas. With this new technique, it is now possible to complete the evaluation of a source rock.

The data are tabulated and presented graphically. MINI-PYROLYSIS includes ppm thermal bitumen and ppm pyrolysate. PYROLYSIS also provides the above together with the temperature of peak pyrolysate evolution. The capillary chromatograms of the pyrolysate obtained by PYROLYSIS-GC are reproduced in the report. The Mini-Pyrolysis analysis is recommended as a screening technique.

#### L) 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<sub>4</sub>-C<sub>7</sub> hydrocarbon (gasoline range) analysis. See Section E. Although these hydrocarbons can be affected by migrational/alteration processes, they commonly provide a very useful correlation parameter.
- capillary gas chromatography of the C<sub>15+</sub> paraffin-naphthenes. See section J. The branched+normal paraffin distributions are used to "fingerprint" the samples.
- capillary chromatograms of whole oils and of the C<sub>4+</sub> fraction of source rocks.
- capillary gas chromatography of C<sub>15+</sub> aromatic hydrocarbons. Separate chromatograms of the hydrocarbons and of the sulphur-bearing species are reproduced.
- high pressure liquid chromatograms.
- mass spectrometric carbon isotope analyses of crude oil and rock extract fractions 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 or Galimov 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.
- vanadium and nickel contents.

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

M) ANALYSES FOR SPECIAL CASES

M-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. The pyrolysis analysis is generally preferred to this technique, both methods providing similar information.

M-2) SULPHUR ANALYSIS

The abundance of sulphur in source rocks and crude oils.

M-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.

M-4) 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 normal paraffin distributions.

M-5) 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 determining 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<sub>2</sub>) of the solid bitumen and of the atomic hydrogen to carbon ratio of the insoluble fraction.

N) CRUDE OIL ANALYSIS

N-1) API GRAVITY

This can be performed upon large (hydrometer) and small (SG bottle, pycnometer) samples and even upon stains extracted from sediments (refractive index).

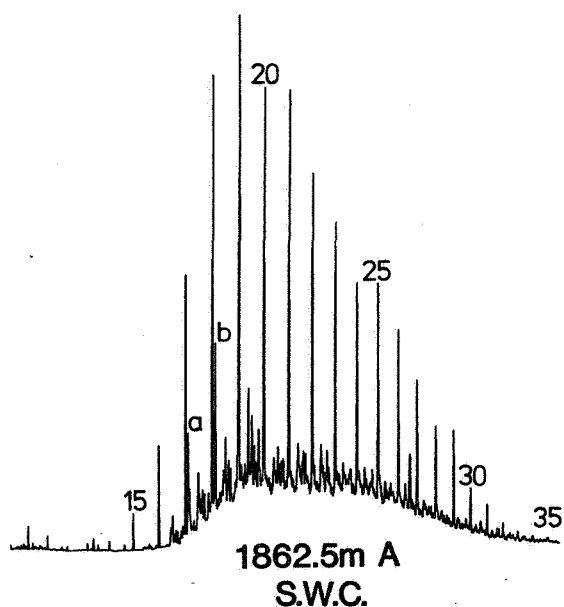
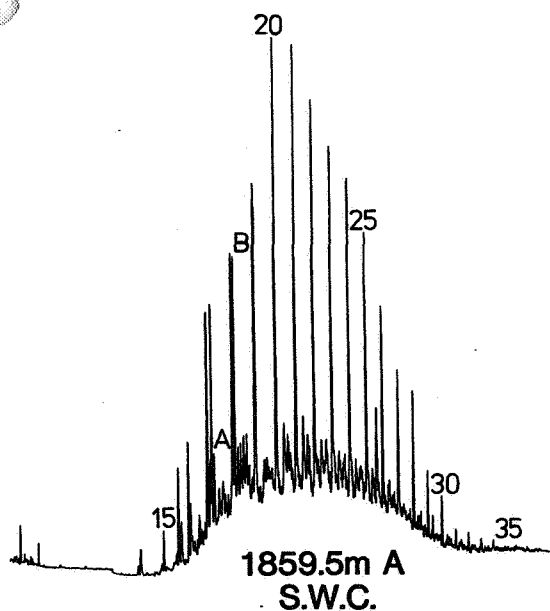
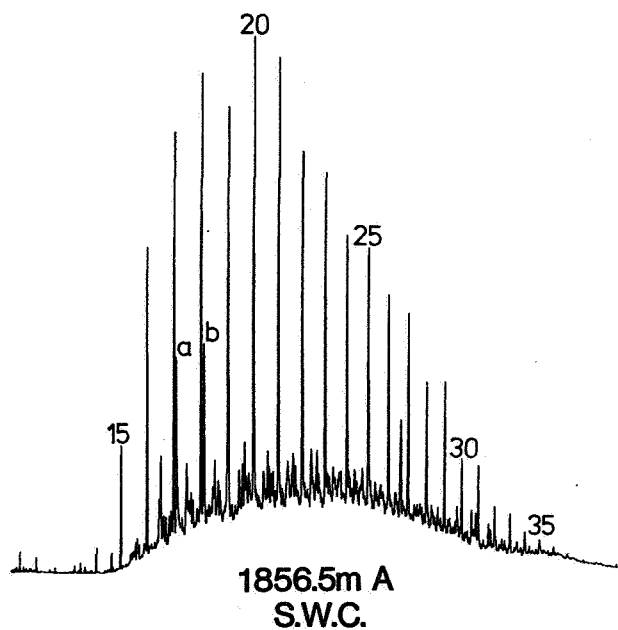
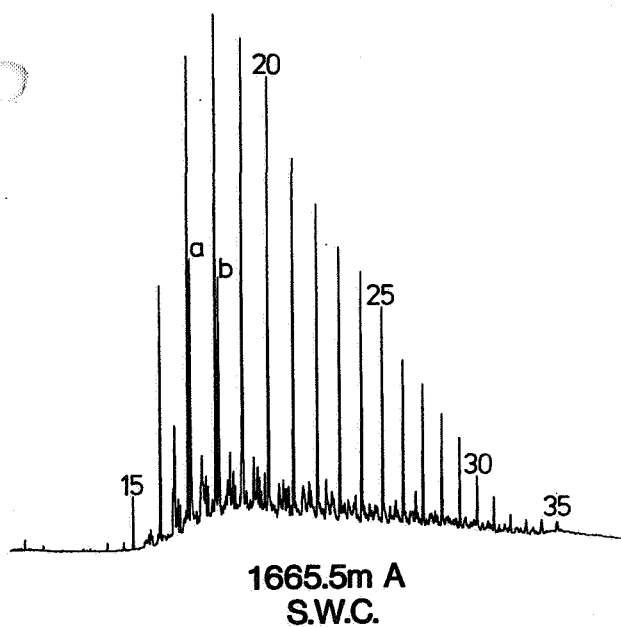
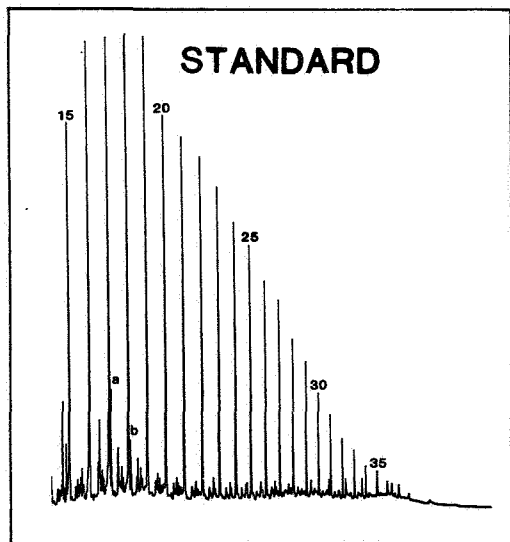
N-2) SULPHUR CONTENTS (ASTM E30-47)

N-3) POUR POINT (ASTM D97-66, IP15/67)

N-4) VISCOSITY (ASTM D445-72, IP71/75)

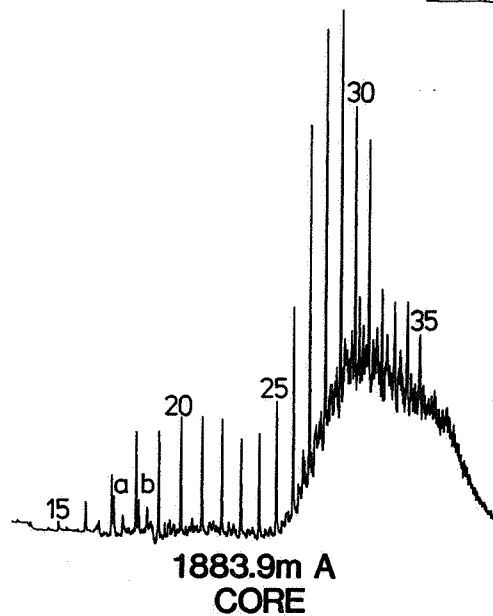
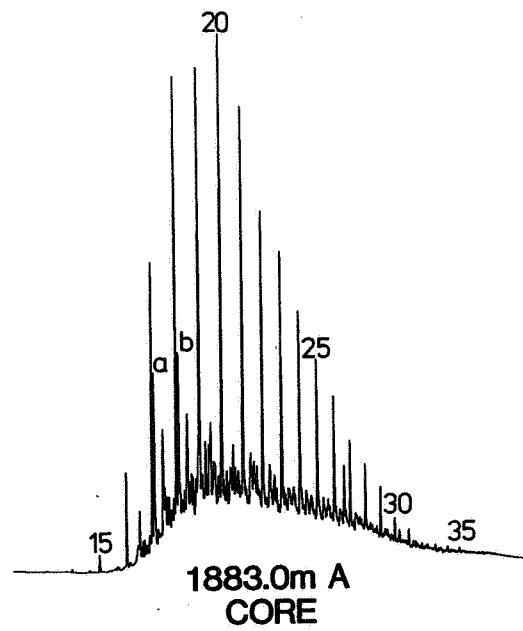
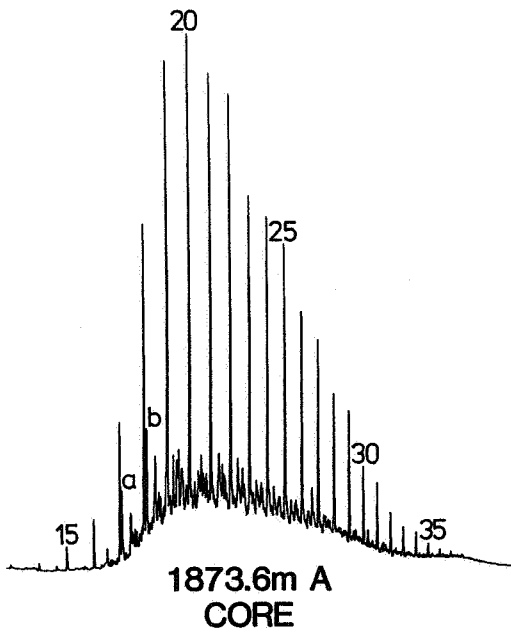
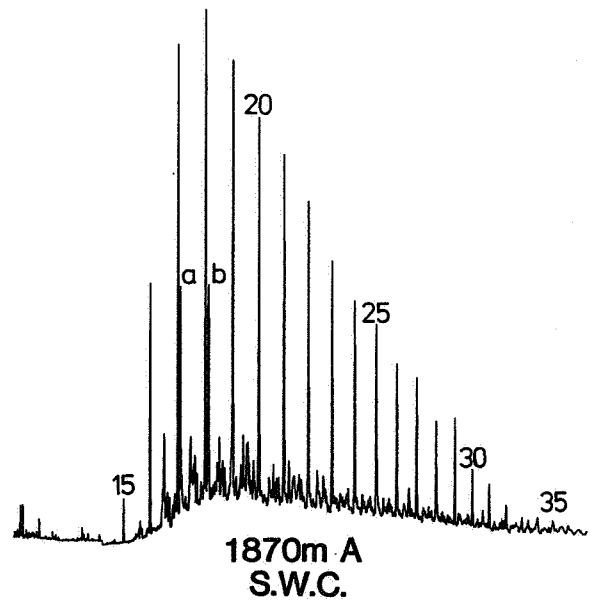
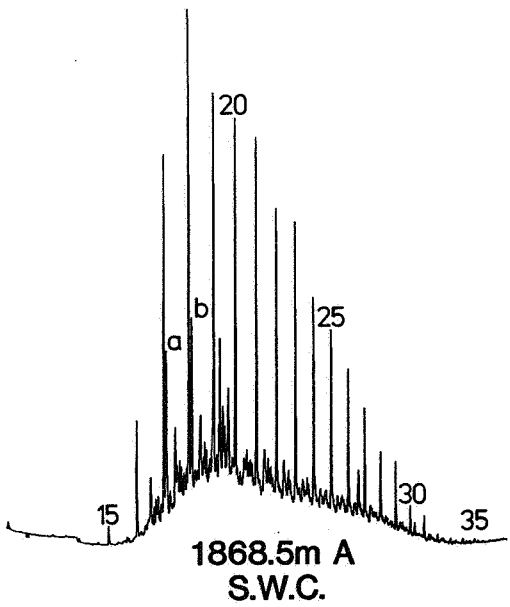
N-5) FRACTIONAL DISTILLATION

Graph of cumulative distillation yield against temperature. Five percent cuts taken for further analysis. Mass spectrometric studies of these fractions provide a detailed picture of the distribution of paraffins and of the various naphthene and aromatic groups within a crude, which is useful both for correlation and for refinery evaluation purposes.



a - PRISTANE  
b - PHYTANE

CARBON NUMBERS OF NORMAL PARAFFINS INDICATED (20 - nC<sub>20</sub>)



a - PRISTANE  
b - PHYTANE

CARBON NUMBERS OF NORMAL PARAFFINS INDICATED (20 - nC<sub>20</sub>)