

U-332



GEOCHEMICAL SERVICE REPORT

Prepared for
SAGA PETROLEUM A.S.

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REGISTRERT
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GEOCHEMICAL EVALUATION OF THE CONDENSATE
FROM 2262 METRES IN SAGA'S 6407/2-1 WELL

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COMPANY PROPRIETARY

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SUMMARY

This condensate is light and sweet.

Although there were problems due to the nature of the sample, it is believed that the 6407/2-1 condensate is lighter than those produced from 6507/11-1, to which it does not appear to correlate.

It is possible that the 6407/2-1 reservoir is being water-washed by moving formation waters.



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INTRODUCTION

This report includes the analytical data obtained for a condensate from 2262 metres in Saga's 6407/2-1 and compares the results to those of the condensates from 6507/11-1.

The sample was actually a mud which did not contain free condensate. After various tests this had, finally, to be recovered by extraction and hence, some of the desired analyses could not be performed (see below).

This project was authorised by T.O. Throndsen, Saga Petroleum A.S., Oslo.

A. ANALYTICAL

The mud sample from 2262 metres in 6407/2-1 was assigned the Geochem job number 667.

The can did not contain free condensate and, as it could not be recovered by physical means, the sample was extracted. It was not possible to perform a distillation or a GOR determination, and there was little point in measuring vanadium and nickel contents upon a mud extract. Finally, due to the lightness of the material, only minor amounts of sterane-terpane material were obtained. As a result the traces of the 191 and 217 fragment ions are poor whilst those of the 239 and 253 fragment ions consisted only of noise.

The tabulated data and the chromatograms are reproduced in this report.

B. GENERAL INFORMATION

Ten (10) copies of this report have been forwarded to T.O. Throndsen at Saga Petroleum in Oslo.

The results of this study are proprietary to Saga Petroleum A.S.

RESULTS AND INTERPRETATION

As the can holding the mud sample did not contain any free liquid hydrocarbons, they had to be recovered from the mud by heating and by solvent extraction techniques. Other hydrocarbons present in the mud (i.e. indigenous to the mud or additive) will, naturally, complicate these analyses and particularly those which depend upon the preliminary C_{15+} solvent extraction step. Therefore the analytical results will be discussed first in order to decide which data should be employed to characterise the oil or condensate in the mud and to effect a correlation with the condensate samples from the 6507/11-1 well.

A. ANALYTICAL

The head space gas contained 65109 ppm of the C_1-C_4 gaseous hydrocarbons (per volume of mud). These gases were wet (71.2% C_{2+}) although not very wet, and had an isobutane to normal butane ratio of slightly less than one.

The detailed gasoline-range analysis was performed upon both the head space gas and the mud samples. The former exhibits severe depletion of the heavier ends, with the butanes and pentanes constituting 60% and the C_7 hydrocarbons only 10% of the total. This depletion is partly controlled by boiling points and, in order to overcome this, the mud sample was analysed. A significant increase in the C_7 hydrocarbons was obtained and this analysis will be used in Section B of this report. However in comparison with the pentanes, some loss of the butanes is suggested and, if allowance is made for this, the increase in the C_7 fraction will be less dramatic.

The C_4-C_{20} chromatogram exhibits a front-end bias and, after C_7 , a slower but somewhat irregular decrease. It is believed from the C_{15+} data (see below) that the heavier fractions are influenced and enhanced by diesel and that, as a result, the true C_{8+} decrease should be more abrupt.

Upon extraction, the mud yielded 7738 ppm C_{15+} hydrocarbons, with the hydrocarbons constituting 94% of the total extract. Clearly, these hydrocarbons are almost entirely "non-indigenous" to the mud. The chromatogram of the paraffin-naphthene fraction shows a rapid decrease in the normal paraffin peaks out to approximately C_{22} , although weaker peaks do tail out to approximately nC_{28} . It would appear that the front ends are influenced by the presence of a

diesel-based additive (the saturate to aromatic ratio of 4.36 is also high), although the "tail" could well be an oil or condensate. Allowing for this it is clear that the oil/condensate should exhibit a more gradual normal paraffin decrease from the light to the heavy ends within the C_{15+} fraction and also that the abundance of the oil/condensate-related hydrocarbons is significantly less than the measured value.

Material heavier than approximately C_{25} is sparse and this is confirmed by the mass spectroscopic data as, even at maximum sensitivity, it was not possible to obtain traces for the 239 and 253 fragment ions and those for the 191 and 217 fragment ions are poor.

In summary therefore, the hydrocarbons in question are light and are condensate in type. The solvent extracted material contains 0.01% sulphur. This is probably fairly representative of the condensate although it should be considered to be a maximum value. However, an attempt to estimate gravity from the extract gave a value of 42° API and this is believed to be too low due to the presence of the diesel-derived material.

B. COMPARISON WITH 6507/11-1 CONDENSATES

The 6407/2-1 condensate is light and sweet. When allowance is made for the presence of diesel, it is believed that this condensate is lighter than those produced from the 6507/11-1 well. This conclusion is supported by the greater proportion of butanes (corrected) and pentanes in the gasoline-range fraction and by the facts that the C_{15+} normal paraffins in the 6507/11-1 condensates extend out to C_{30} quite comfortably and that more of the heavy naphthenic material was present for mass spectroscopic analysis.

Due to the fact that it was not possible to obtain good mass fragmentograms even at maximum sensitivity, it is difficult to use these traces for correlation purposes but even so, the m/e 191 and m/e 217 fragment ions do not appear to correlate.

The contamination discussed above would be expected to affect the C_{15+} total alkane, branched/cyclic alkene and aromatic chromatograms and could explain the lack of correlation on all of these parameters. The same criticism applies to the carbon isotope ratios of the C_{15+} saturates and aromatics, although these are fairly similar to those of the 6507/11-1 condensates, the saturates being

somewhat heavier ($-28.3^{\circ}/\text{oo}$ against $-28.6^{\circ}/\text{oo}$) and aromatics lighter ($-27.7^{\circ}/\text{oo}$ against -26.6 to $-26.8^{\circ}/\text{oo}$).

Thus, insofar as they can be used, the suite of heavy hydrocarbon analyses does not suggest a correlation. This conclusion can be tested with the light hydrocarbon data (gas and gasoline-range) which are not affected by contamination. They indicate significant differences. For example in the gasoline-range fraction, the 6407/2-1 condensate has enhanced proportions of the normal and iso-paraffins and is depleted in the naphthenes. Most significant however is the dramatic drop in the proportion of the aromatics from 15.6-18.3% in 6507/11-1 down to 0.9% in 6407/2-1, a decrease of more than an order of magnitude. A total lack of correlation is suggested, although this depletion in the relatively soluble light aromatics does raise the possibility of water washing in the 6407/2-1 reservoir.

The head space methane is, isotopically, somewhat lighter at $-46.7^{\circ}/\text{oo}$ against $-37.6^{\circ}/\text{oo}$ to $-42.6^{\circ}/\text{oo}$.

C. CONCLUSIONS

The evaluation of the 6407/2-1 condensate was complicated both by the lack of free hydrocarbon liquids for analysis and by the presence of contamination in the mud.

However it would appear that this condensate is lighter than, and does not correlate with, those produced from 6507/11-1.

There is a possibility, which is still tentative at this stage, that the 6407/2-1 reservoir is being water washed by moving formation waters. Alternatively, the condensate could have been produced from close to the condensate-water contact.

TABLE 1
CONCENTRATION (VOL. PPM OF ROCK) OF C₁ - C₇ 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	$\frac{iC_4}{nC_4}$
667-001	2262m.	18724	10647	10981	12036	12721	65109	46385	71.2	34552	0.95

TABLE 2

DETAILED GASOLINE (C4-C7) ANALYSIS

GEOCHEM SAMPLE NUMBER	001	001C
DEPTH	HEAD SPACE	MUD
isobutane	17.45	1.74
n-butane	22.56	5.44
isopentane	8.75	7.79
n-pentane	8.88	11.69
2,2-dimethylB	0.83	0.43
cyclopentane(CP)	2.41	1.55
2,3-dimethylB	0.44	0.21
2-methylP	9.04	6.90
3-methylP	4.43	4.09
n-hexane	8.53	12.25
methylCP(MCP)	2.57	5.32
2,2-dimethylP	0.41	0.56
2,4-dimethylP	0.04	0.07
2,2,3-trimethylB	0.01	0.00
benzene	0.62	0.09
cyclohexane(CH)	2.60	7.32
3,3-dimethylP	0.30	0.00
1,1-dimethylCP	0.00	0.00
2-methylH	1.88	4.06
2,3-dimethylP	0.24	0.68
3-methylH	1.18	3.45
1,c,3-dimethylCP	0.42	1.18
1,t,3-dimethylCP	0.42	1.11
1,t,2-dimethylCP	0.63	2.18
3-ethylP	0.00	0.06
n-heptane	2.25	8.49
methylCH(MCH)	2.38	12.53
1,c,2-dimethylCP	0.44	0.01
toluene	0.27	0.78
ABUNDANCE	86960	44971
MCP/Benzene	4.18	56.06
MCP/MCH	1.08	0.42
CH/MCP	1.01	1.38
iP/nP	0.99	0.67
%n-PARAFFINS	42.22	37.87
%iso-PARAFFINS	45.00	30.05
% NAPHTHENES	11.89	31.20
% AROMATICS	0.89	0.88

TABLE 3A
CONCENTRATION (PPM) OF EXTRACTED C₁₅₊ MATERIAL IN ROCK

GEOCHEM SAMPLE NUMBER	DEPTH	TOTAL EXTRACT	HYDROCARBONS			NON HYDROCARBONS			
			Paraffin- Naphthenes	Aromatics	TOTAL	Precipitated Asphaltenes	Eluted NSO's	Non-eluted NSO's	Sulphur
667-001	2262	8231	6294	1444	7738	141	115	173	63

TABLE 3B
COMPOSITION (NORMALISED %) OF C₁₅₊ MATERIAL EXTRACTED FROM ROCK

GEOCHEM SAMPLE NUMBER	DEPTH	HYDROCARBONS		NON HYDROCARBONS			
		Paraffin – Naphthenes	Aromatics	Preciptd. Asphaltenes	Eluted NSO's	Non eluted NSO's	Sulphur
667-001	2262	76.47	17.54	1.72	1.40	2.10	0.76

TABLE 4
SIGNIFICANT RATIOS (%) OF C₁₅₊ FRACTIONS AND ORGANIC CARBON

GEOCHEM SAMPLE NUMBER	DEPTH	ORGANIC CARBON (wt. %)	HYDROCARBONS	HYDROCARBONS	TOTAL EXTRACT	P-NAPHTHENES
			TOTAL EXTRACT	ORG. CARBON	ORG. CARBON	AROMATICS

667-001	2262	0.72	94.01	107.47	114.31	4.36
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TABLE 5

MEASUREMENTS UPON SOLVENT EXTRACTABLE MATERIAL

SULPHUR CONTENT	0.014%
ESTIMATED API GRAVITY*	42°

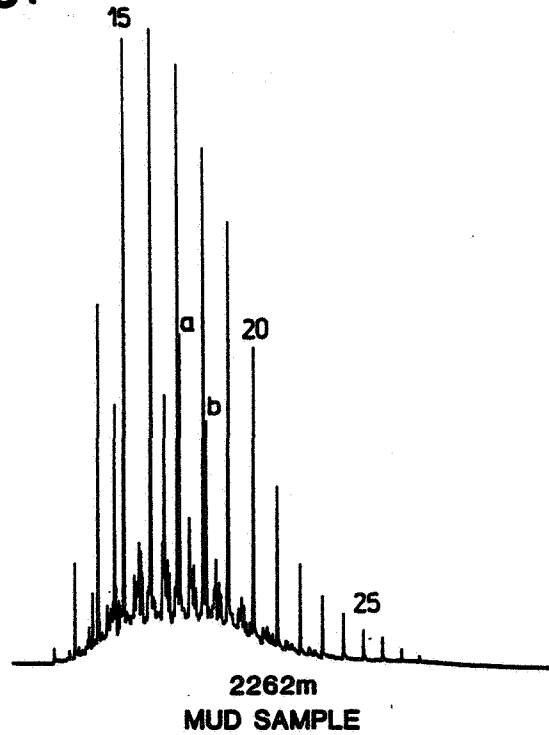
*see text.

TABLE 6

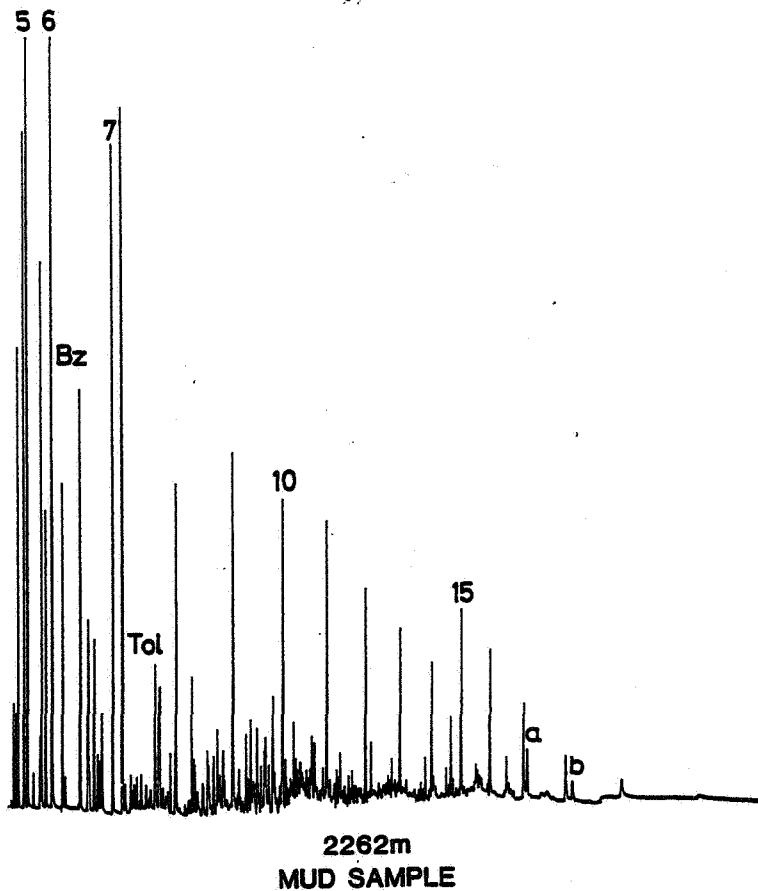
CARBON ISOTOPE DATA $(\text{‰}, \text{PDB})$

<u>SAMPLE</u>	<u>VALUE</u>
METHANE	-46.69
C ₁₅₊ SATURATES	-28.26
C ₁₅₊ AROMATICS	-27.68

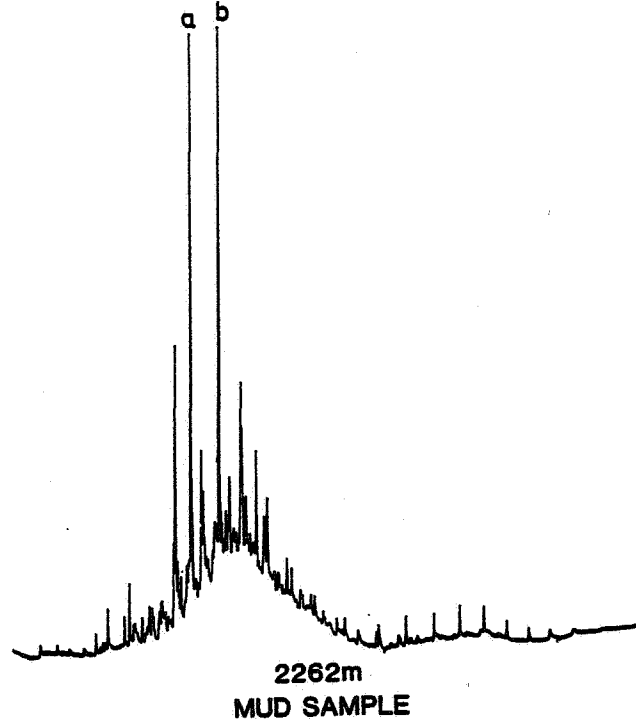
C₁₅₊ PARAFFIN NAPHTHENES



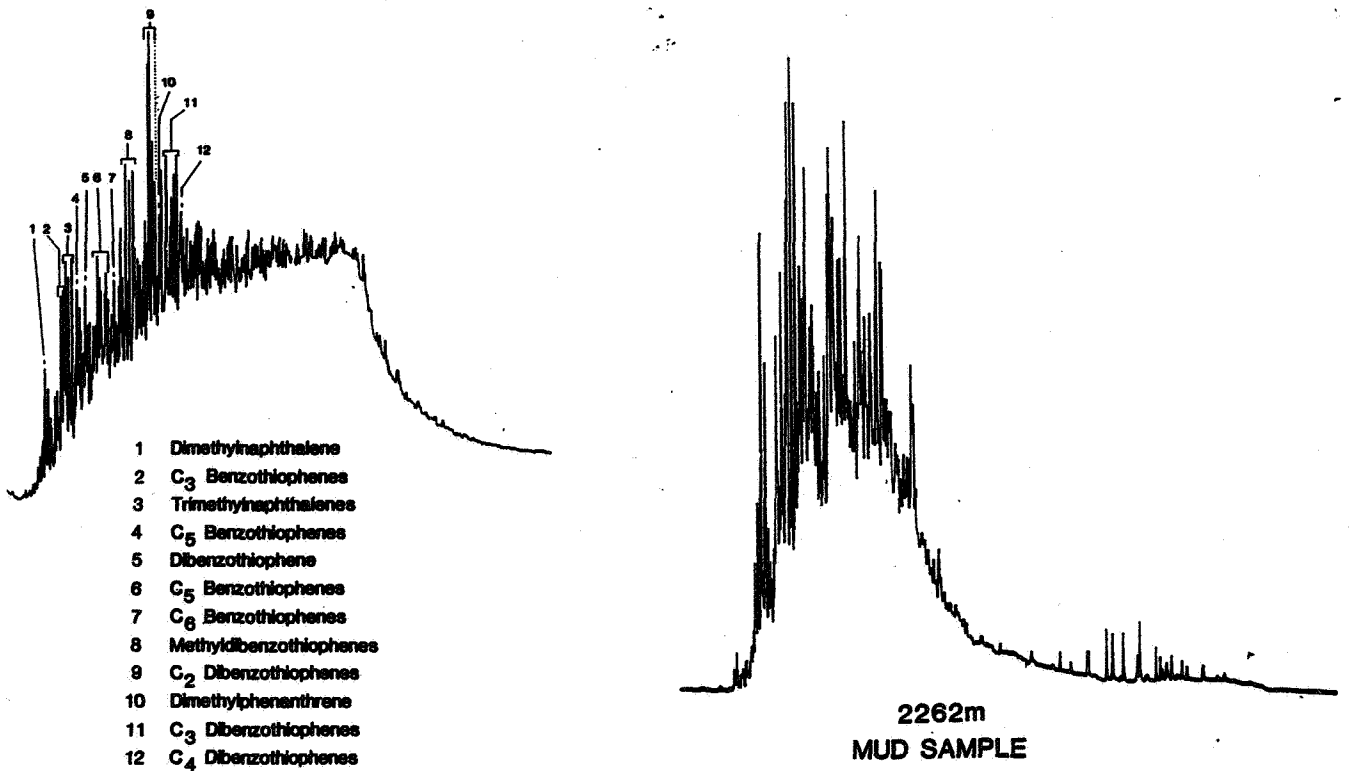
C₄ - C₂₀ CHROMATOGRAM



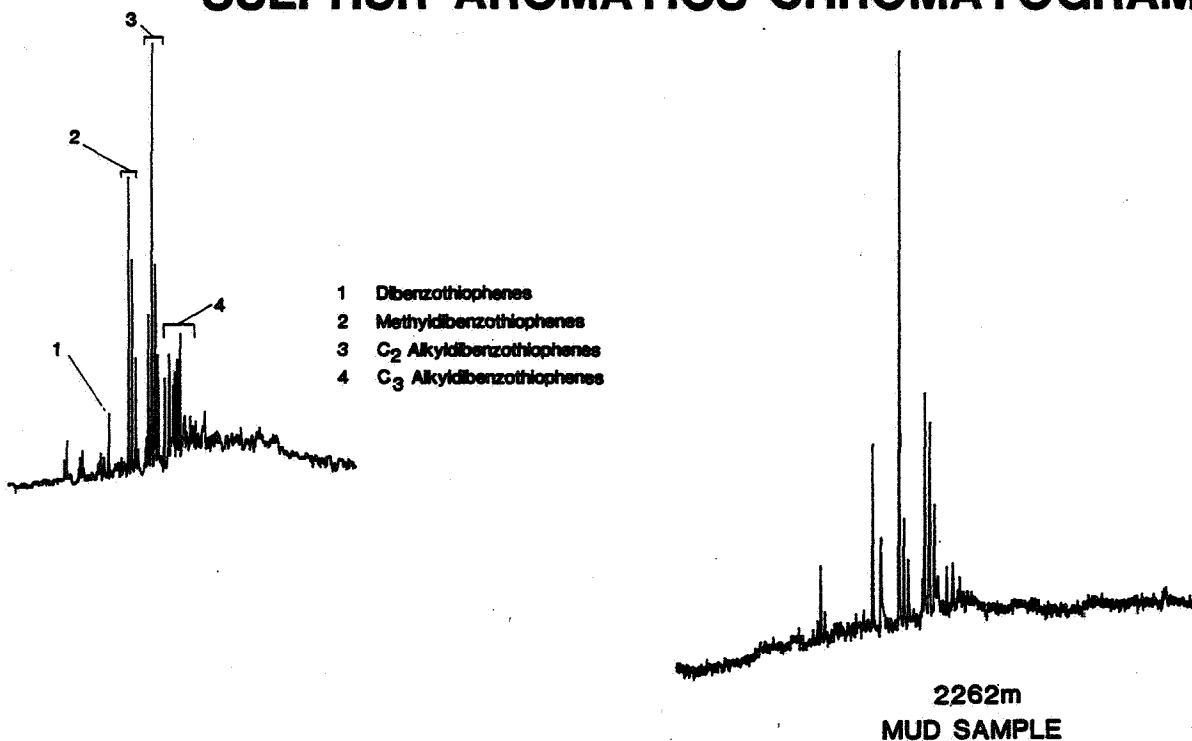
BRANCHED CYCLICS CHROMATOGRAM



AROMATIC CHROMATOGRAM

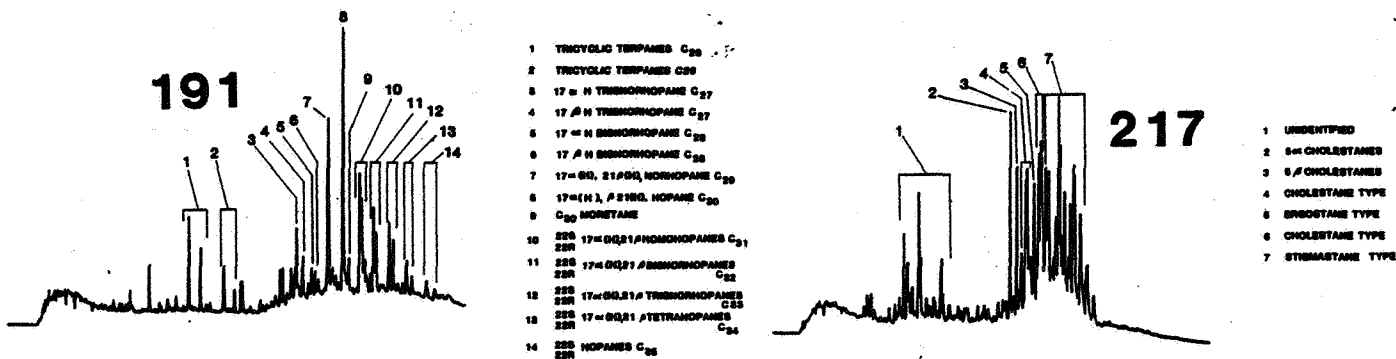


SULPHUR-AROMATICS CHROMATOGRAM



MASSFRAGMENTOGRAMS

TERPANES & STERANES



2262m
 MUD SAMPLE

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 C₁-C₇ analysis and should be canned (or at least wet) for the C₄-C₇ analysis. The other analyses can be run on both canned and bagged samples.

A) C₁-C₇ LIGHT HYDROCARBON ANALYSIS

The abundance and composition of the C₁-C₇ 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 C₁-C₄ gaseous hydrocarbons (methane, ethane, propane, isobutane and normal butane) and a partial resolution of the C₅-C₇ gasoline-range hydrocarbons (for their complete resolution see Section E). The ppm abundance of the five gases and of the total C₅-C₇ 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 C₁-C₇ 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, C₁-C₇, C₄-C₇, pyrolysis and C₁₅+ 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 C₁-C₇ 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 C₄-C₇ HYDROCARBON ANALYSIS

The abundance and composition of the C₄-C₇ 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 C₁₅+ 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 C₁₅+ 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 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) C₁₅₊ 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, high 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 C₁₅₊ PARAFFIN-NAPHTHENE HYDROCARBONS

The gas chromatographic configurations of the heavy C₁₅₊ 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 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 nC₃₅. 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 (≠ 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:

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

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

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_A and C.P.I_B; pristane to phytane ratio; pristane to nC₁₇ 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 C₁₅₊ 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 C₁ (methane) out towards C₃₅ 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 C₄-C₇ 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 C₁₅+ paraffin-naphthenes. See section J. The branched+normal paraffin distributions are used to "fingerprint" the samples.
- capillary chromatograms of whole oils and of the C₈+ fraction of source rocks.
- capillary gas chromatography of C₁₅+ 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 CS₂) 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)

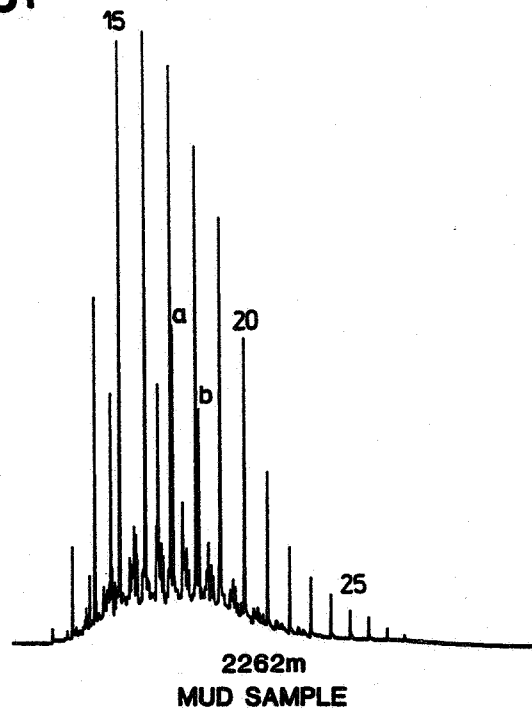
N-3) POUR POINT (ASTM D97-66, IP15/67)

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

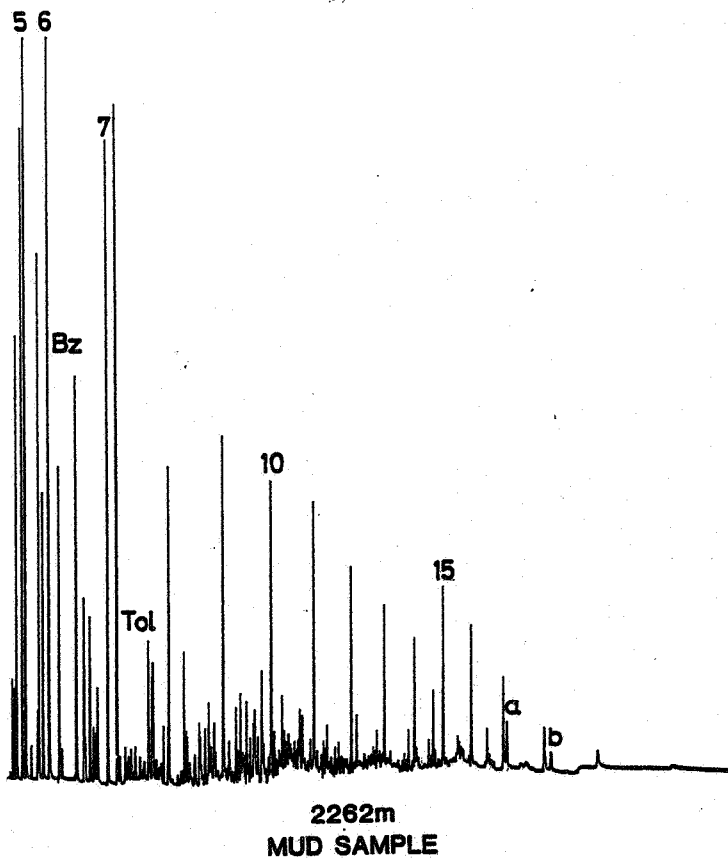
N-5) FRACTIONAL DISTILLATION

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.

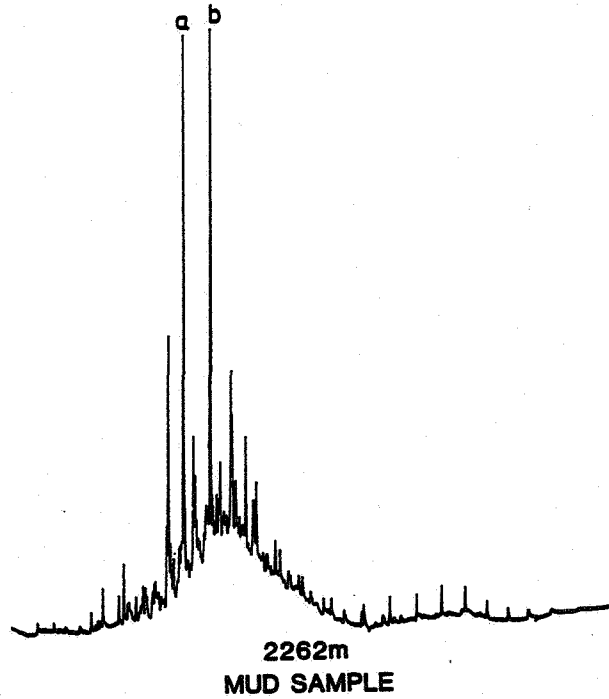
C₁₅₊ PARAFFIN NAPHTHENES



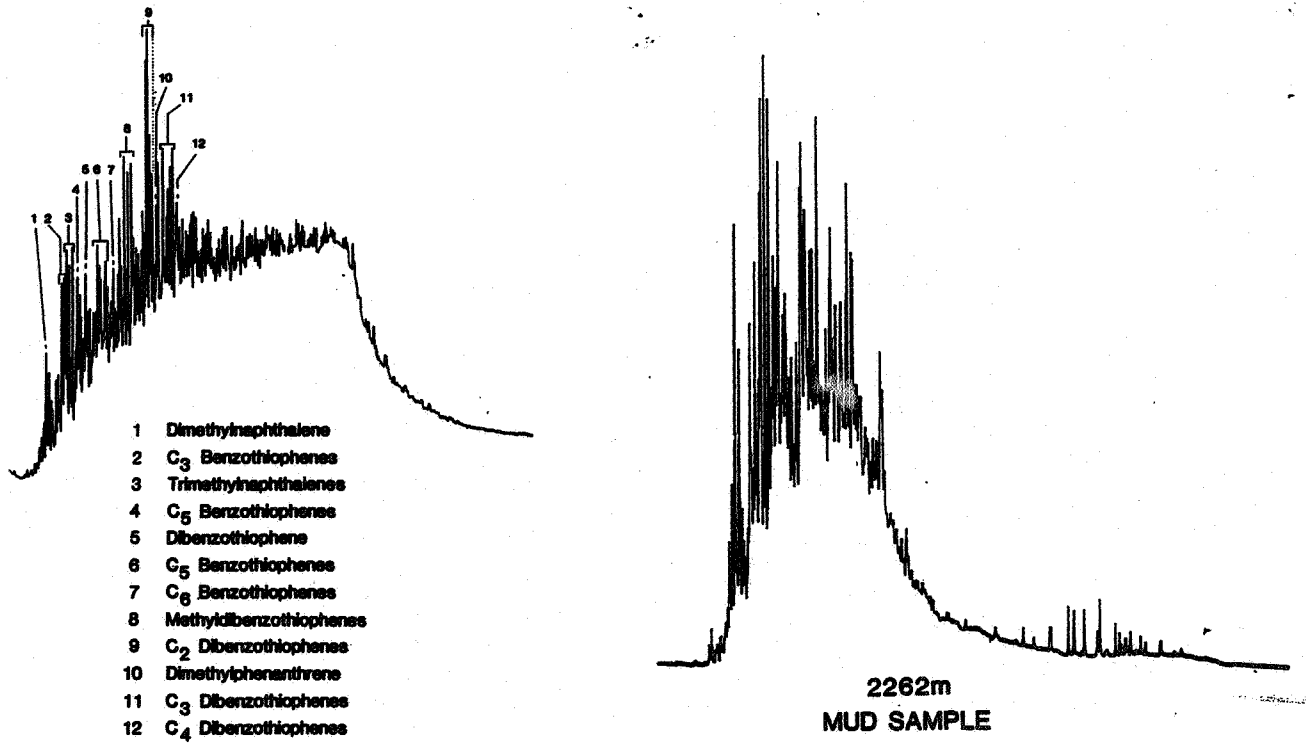
C₄ - C₂₀ CHROMATOGRAM



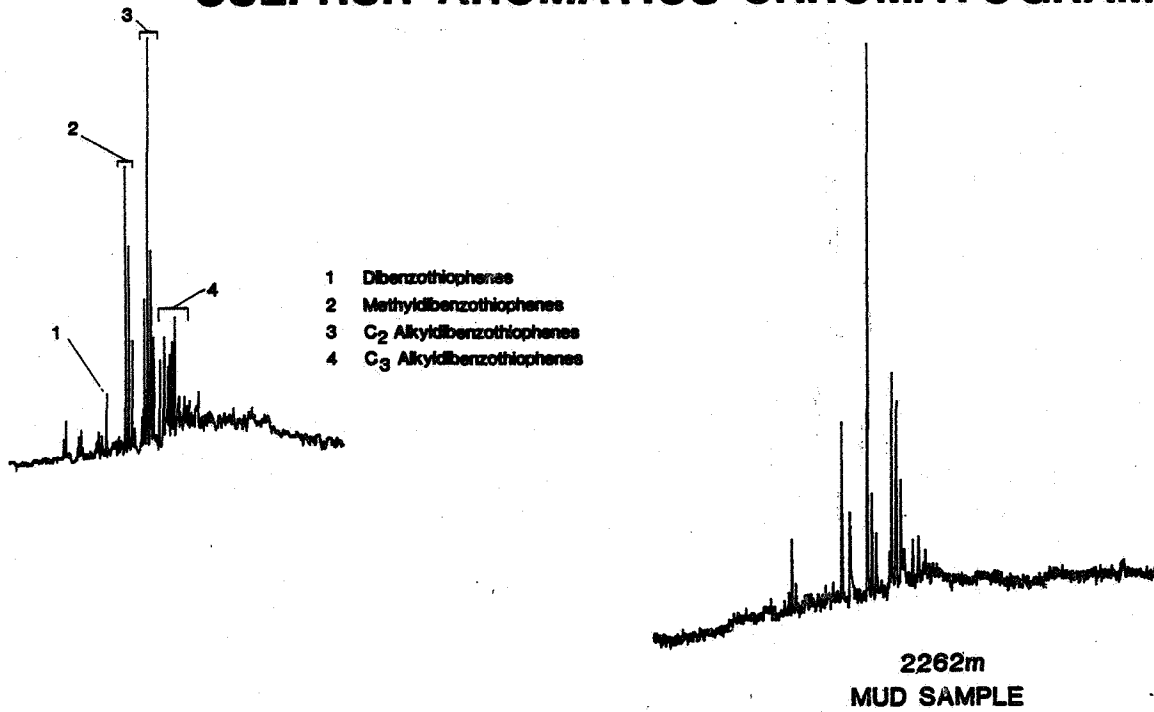
BRANCHED CYCLICS CHROMATOGRAM



AROMATIC CHROMATOGRAM



SULPHUR-AROMATICS CHROMATOGRAM



MASSFRAGMENTOGRAMS

TERPANES & STERANES

