PETROLEUM GEOCHEMISTRY

HYDROCARBON SOURCE ROCK CHARACTERISATION
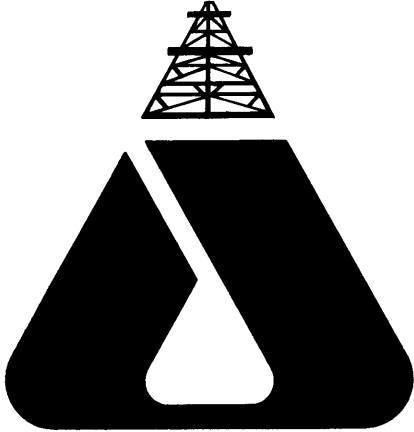
SELENE_1

HYDROCARBON SOURCE ROCK CHARACTERISATION REPORT

SELENE-1

W795

Prepared For: APRIL 1988
PETROFINA EXPLORATION AUSTRALIA S.A.

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GIPPSLAND BASIN. ANALABS. GEOCHEM BOX

HYDROCARBON SOURCE ROCK CHARACTERISATION

SELENE -1

Introduction

Twenty three (23) cuttings samples and one core sample from the well Selene -1, drilled by Phillips Petroleum Co. in the Gippsland Basin, were analysed geochemically. The samples cover a depth range from 2800m to 3380m.

The purpose of this study was to characterise maturity and type of organic source matter in order to attempt to match the source rocks to published analyses of Gippsland oils.

Analytical Procedure

Three (3) samples between 3149.5m and 3380m were analysed by gas chromatography. The dried samples were crushed and solvent extracted, the extractable organic matter was then submitted to liquid chromatography in order to separate saturate, aromatic and NSO fractions. Capillary column gas chromatography was performed on the C12+ components of the saturatee fractions.

Vitrinite reflectance measurements and macoral descriptions were carried out on seventy three (73) samples. Results of the analyses performed are presented in the following figures and tables :-

Type of Analysis	Figures	Table
Extraction and liquid chromatography	–	1
C12+ saturate gas chromatography	–	2
Vitrinite reflectance and maceral description	2	3

The analytical methods applied in this study are described in the "Theory and Methods" chapter at the back of this report.

General Information

Copies of this report have been sent to Mr R Doery of Petrofina Exploration Australia S.A. in Melbourne.

Any questions related to this study may be directed to Dr Birgitta Hartung-Kagi of Analabs in Perth.

All data and interpretations given herein are proprietary to Petrofina Exploration Australia S.A. and are considered as highly confidential material by all Analabs personnel.

Discussion of Extraction and Gas Chromatography Results

Two cuttings (3260 - 3270m, 3370 -3380m) and one core sample (3149.5m) analysed from the well Selene -1 are classified as very good source rocks by their yields of total extract and total hydrocarbons (Table 1). The extracts are richer in aromatic than in saturate compounds, with the amounts of saturates increasing with depth. This feature might be due to an increase in marine organic matter with depth.

This interpretation is supported by gas chromatography results obtained for the saturate fractions (Figure 1). The trace obtained for the core sample (3149.5m) is dominated by high molecular weight compounds in the n-C23+ range. They are characteristic of higher plant waxes and thus of terrestrially - derived organic matter. In sample 3260 - 3270m, a second hump in the C12 to C18 n-alkane range is obvious which is interpreted as an increased input of algal organic material. In the deepest sample analysed, 3370-3380m, this "marine/lacustrine" lower molecular weight range hump is predominant over the "terrestrial" hump in the n=C23 range. That is, the shallower (core) sample indicates predominantly terrestrial organic source matter, whereas the two deeper samples show a bimodal envelope, a hydrocarbon distribution pattern characteristic of a mixture of marine or lacustrine/algal and terrestrial/higher plant organic matter.

All three extracts are immature to date, as indicated by high pristane/n-C17 ratios, low C21 + C22/C28 + C29 values and prominent odd-over-even predominances in the C23+ n-alkane range. Depositional environments of the organic matter charge with depth from a mixed oxidising/reducing to an oxidising, open water environment, as suggested by increasing pristane/phytane ratios.

K.K. No.	Depth (m)	$\bar{R}_V$max	Range	N	Description Including Exinite Fluorescence
x7847	2800 Ctgs	0.40	-	1	Rare phytoplankton, greenish yellow to yellow. (Calcareous claystone>carbonate. Dom sparse, I>E>V.
		$\bar{R}_I$ 1.35	0.83-2.14	6	Inertinite rare to sparse, exinite and vitrinite rare. Dom mainly consists of very fine inertodetrinite. Abundant foraminiferal tests. Iron oxide common. Pyrite abundant.)
x7848	2830 Ctgs	0.40	0.32-0.47	3	Rare phytoplankton, greenish yellow, rare sporinite, yellow. (Calcareous claystone>carbonate>calcareous
		$\bar{R}_I$ 1.34	0.90-1.56	4	sandstone. Dom sparse, I>E>V. Inertinite sparse, exinite and vitrinite rare. Dom mainly consists of very fine inertodetrinite. Glauconite abundant. Abundant foraminiferal tests. Mineral matter fluorescence low. Iron oxide common to abundant. Pyrite abundant.)
x7849	2860 Ctgs	-	-	-	No fluorescing exinite. (Sandstone>calcareous claystone>carbonate. Dom rare, I. Inertinite rare,
		$\bar{R}_I$ 1.38	-	1	vitrinite and exinite absent. Glauconite abundant. Mud additives present. Common foraminiferal tests. Iron oxide common to abundant. Pyrite abundant.)
x7850	2890 Ctgs	-	-	-	No fluorescing exinite. (Calcareous claystone> sandstone>carbonate. Dom rare to sparse, I. Inertinite
		$\bar{R}_I$ 1.39	0.88-2.00	3	rare to sparse, vitrinite and exinite absent. Glauconite common. Foraminiferal tests common. Dom consists of very fine inertodetrinite. Iron oxide sparse. Pyrite common.)
x7851	2900 Ctgs	-	-	-	Rare phytoplankton, greenish yellow to yellow. (Calcareous claystone>sandstone>mud additives. Dom
		$\bar{R}_I$ 1.42	-	1	rare, I>E. Inertinite and exinite rare, vitrinite absent. Common foraminiferal tests. Glauconite sparse. Mud additives major. Iron oxide abundant. Pyrite common to abundant.)
x7852	2930 Ctgs	-	-	-	Rare phytoplankton, yellow. (Sandstone>calcareous claystone>siltstone. Dom rare, I>E. Inertinite and
		$\bar{R}_I$ 1.05	0.76-1.28	3	exinite rare, vitrinite absent. Diffuse humic organic matter rare. Sparse foraminiferal tests. Glauconite rare. Mud additives sparse. Iron oxide sparse. Pyrite common.)
x7853	2960 Ctgs	-	-	-	Rare liptodetrinite, yellow. (Sandstone>>siltstone> claystone. Dom rare, I>E. Inertinite and exinite rare, vitrinite absent. Dom mainly consists of very fine inertodetrinite in claystone. Sandstone barren. Iron oxide sparse. Pyrite sparse.)
x7871	3030-3040 Ctgs	0.44	0.30-0.63	17	Rare sporinite and liptodetrinite, yellow, rare phytoplankton, greenish yellow to yellow. (Sandstone>
		$\bar{R}_I$ 1.29	0.64-1.80	15	siltstone>claystone. Dom sparse, I>V>E. Inertinite and vitrinite sparse, exinite rare. Diffuse humic organic matter sparse. Dom mainly occurs in siltstone. Mud additives common. Iron oxide sparse to common. Pyrite common.)
x7872	3060-3070 Ctgs	0.45	0.33-0.54	28	Rare sporinite and liptodetrinite, yellow. (Calcareous sandstone>siltstone>claystone>carbonate>coal. Coal rare, V. Vitrite. Dom common, V>I>E. Vitrinite sparse to common, inertinite sparse, exinite rare to sparse. Diffuse humic organic matter common. Micrinite abundant in some vitrinite. Rare oil droplets in siltstone. Dom mainly occurs in siltstone. Iron oxide common. Pyrite common to abundant.)

K.K. No.	Depth (m)	$\bar{R}_v$max	Range	N	Description Including Exinite Fluorescence
x7873	3090-3100 Ctgs	0.45	0.33-0.58	26	Common sporinite and sparse liptodetrinite, yellow to orange, sparse cutinite, greenish yellow to dull yellow, rare resinite, greenish yellow, rare <u>Botryococcus</u> related telalginite, bright yellow. (Siltstone> calcareous sandstone>coal. Coal common, V>E. Vitrite>clarite. Dom abundant, V>I>E. Vitrinite abundant, inertinite and exinite sparse. Abundant non fluorescing suberinite in some vitrinite. Diffuse humic organic matter common. Coalified leaf tissues present. Green fluorescing oil droplets in some siltstone. Rare dull orange fluorescing bitumen in siltstone. Iron oxide sparse. Pyrite common.)
x7874	3120-3130 Ctgs	0.44	0.31-0.52	31	Sparse sporinite and liptodetrinite, yellow to orange, sparse cutinite, dull yellow, rare to sparse resinite, greenish yellow. (Siltstone>sandstone>claystone>coal> shaly coal. Coal common, V>I>E. Vitrite>clarite> duroclarite. Shaly coal sparse, V>>E. Vitrite. Dom abundant, V>I>E. Vitrinite common, inertinite sparse to common, exinite sparse. Abundant non fluorescing suberinite in some vitrinite. Diffuse humic organic matter common. Coalified leaf tissues present. Green fluorescing oil droplets in some siltstone. Sparse dull orange fluorescing bitumen in siltstone. Mud additives sparse. Iron oxide rare to sparse. Pyrite common.)
x7875	3140-3150 Ctgs	0.46	0.36-0.57	30	Sparse sporinite and liptodetrinite, yellow to orange, sparse cutinite, dull yellow. (Siltstone>sandstone> claystone>coal>shaly coal. Coal common, V>I>E. Vitrite>clarite>inertite>duroclarite. Shaly coal sparse, V>>E. Vitrite. Dom abundant, V>I>E. Vitrinite common, inertinite and exinite sparse. Most vitrinite heavily suberinized. Micrinite abundant in some vitrinite. Diffuse humic organic matter common. Coalified leaf tissues present. Green fluorescing oil droplets in some siltstone. Rare dull orange fluorescing bitumen in some siltstone. Mud additives common. Iron oxide sparse to common. Pyrite common.)
x7854	3149.5 Core	0.49	0.39-0.63	29	Common sporinite and liptodetrinite, yellow to orange, common cutinite, dull yellow to orange, sparse resinite, yellow, rare ?fluorinite, green. (Fine siltstone> claystone>coal>shaly coal. Coal sparse, V>>E. Vitrite. Shaly coal sparse, V>>E. Vitrite. Dom abundant, V>E>I. Vitrinite and exinite abundant, inertinite sparse. Abundant non fluorescing suberinite in some vitrinite. Coalified leaf tissues present. Some vitrinite heavily micrinitized. Pyrite common.)
x7876	3170-3180 Ctgs	0.50	0.41-0.62	27	Sparse sporinite and liptodetrinite, yellow to orange, sparse cutinite, orange, rare resinite, greenish yellow, rare <u>Botryococcus</u> related telalginite, bright yellow. (Siltstone>claystone>sandstone>coal>shaly coal. Coal abundant, V>E. Vitrite>clarite. Shaly coal sparse, V>E. Clarite. Dom abundant, V>I>E. Vitrinite abundant, inertinite common, exinite sparse to common. Abundant non fluorescing suberinite in some vitrinite. Diffuse humic organic matter abundant. Coalified leaf tissues present. Sparse dull orange fluorescing bitumen in siltstone. Iron oxide sparse. Pyrite common.)

K.K. No.	Depth (m)	$\bar{R}_v$max	Range	N	Description Including Exinite Fluorescence
x7877	3200-3210 Ctgs	0.51	0.43-0.59	26	Sparse sporinite and liptodetrinite, yellow to orange, sparse cutinite, orange, rare resinite, yellow. (Claystone>calcareous sandstone>siltstone>coal>shaly coal. Coal common, V>E. Vitrite>clarite. Shaly coal sparse, V>>E. Vitrite. Dom abundant, V>I>E. Vitrinite abundant, inertinite common, exinite sparse to common. Most vitrinite heavily suberinized. Diffuse humic organic matter common. Micrinite abundant in some vitrinite. Some vitrinite resinous. Coalified leaf tissues present. Sparse dull orange fluorescing bitumen in siltstone. Rare green fluorescing oil droplets in siltstone. Pyrite common to abundant.)
x7878	3230-3240 Ctgs	0.50	0.42-0.62	28	Sparse sporinite and liptodetrinite, yellow to orange, sparse cutinite, orange, rare resinite, greenish yellow. (Claystone>calcareous sandstone>siltstone>coal>shaly coal. Coal sparse, V>E. Vitrite>clarite. Shaly coal sparse, V>>E. Vitrite. Dom abundant, V>I=or>E. Vitrinite abundant, inertinite and exinite sparse to common. Abundant non fluorescing suberinite in some vitrinite. Some vitrinite heavily micrinitized. Coalified leaf tissues present. Rare greenish yellow fluorescing oil droplets in siltstone. Rare dull orange fluorescing bitumen. Pyrite abundant.)
x7879	3260-3270 Ctgs	0.50	0.42-0.61	28	Common cutinite, yellow to weak brown, common sporinite and liptodetrinite, yellow to dull orange, common suberinite, weak brown, sparse resinite, greenish yellow to yellow, rare fluorinite, green, rare bitumen, orange to dull orange. (Siltstone>claystone>sandstone>coal> shaly coal. Coal abundant, V>>E>I. Clarite>vitrite> duroclarite. Shaly coal common, V>E. Clarite. Dom abundant to major, V>E>>I. Vitrinite and exinite abundant, inertinite sparse. Abundant leaf-derived tissue present. Green oil specks present in epiclastics. Micrinite present in vitrinite. Carbonate common. Pyrite abundant.)
x7880	3290-3300 Ctgs	0.52	0.46-0.62	27	Common sporinite and cutinite, yellow to dull orange, common liptodetrinite, yellow to dull orange, common suberinite, dull orange to brown, rare resinite, greenish yellow to orange, rare fluorinite, green, rare bitumen, yellow to dull orange, rare exsudatinite, yellow. (Sandstone>siltstone>claystone>coal>shaly coal. Coal abundant, V>E>I>. Clarite>vitrite= duroclarite. Shaly coal abundant, V>E>>I. Clarite. Dom abundant, V>E>I. Vitrinite common to abundant, exinite common, inertinite sparse. Leaf-derived tissue common. Micrinite abundant in vitrinite. Common green to yellow oil specks and droplets present in siltstone. Carbonate common. Pyrite abundant.)
x7881	3320-3330 Ctgs	0.55	0.45-0.65	28	Abundant sporinite, yellow to dull orange, common cutinite and liptodetrinite, yellow to weak brown, sparse to common suberinite, brown, rare resinite, yellow to dull orange, rare fluorinite, green, rare exsudatinite, yellow to orange. (Siltstone>> sandstone>claystone>coal=shaly coal. Coal common, V>E. Vitrite=clarite. Shaly coal common, V>E>I. Clarite= vitrite=duroclarite. Dom abundant, V>E>I. Vitrinite and exinite abundant, inertinite common. Gelovitrinite abundant in coal. Green to yellow oil specks present in siltstone. Abundant coal cavings present. Carbonate sparse. Pyrite abundant.)

K.K. No.	Depth (m)	$\bar{R}_v$max	Range	N	Description Including Exinite Fluorescence
x7882	3350-3360 Ctgs	0.56	0.50-0.70	27	Abundant sporinite, yellow to dull orange, common cutinite, yellow to dull orange, common suberinite, dull orange to weak brown, common liptodetrinite, yellow to dull orange, sparse resinite, yellow to orange, rare bitumen, greenish yellow, rare fluorinite, green. (Siltstone>sandstone>shaly coal>coal>claystone. Coal major, V>>E>I. Vitrite>clarite. Shaly coal major, V>E>I. Clarite>duroclarite. Dom major, V>E>I. Vitrinite and exinite abundant, inertinite common. Gelovitrinite abundant in coal. Micrinite abundant in vitrinite. Green oil specks and droplets present in siltstone and shaly coal. Pyrite abundant.)
x7883	3380-3390 Ctgs	0.56	0.49-0.69	27	Common cutinite and liptodetrinite, yellow to brown, common sporinite, yellow to dull orange, sparse to common suberinite, brown, rare resinite, yellow, rare bitumen, orange. (Siltstone>sandstone>claystone>coal> shaly coal. Coal abundant, V>I>E. Vitrite=duroclarite> clarite. Shaly coal common, V>>E. Clarite. Dom abundant, V>E>I. Vitrinite and exinite abundant, inertinite sparse. Greenish yellow oil specks present in siltstone. Pyrite abundant.)
x7884	3410-3420 Ctgs	0.55	0.49-0.65	27	Sparse cutinite and liptodetrinite, yellow to brown, sparse sporinite, yellow to dull orange, sparse suberinite, brown, rare resinite, yellow, rare bitumen, dull orange, rare exsudatinite, faint yellow. (Sandstone>siltstone>coal>claystone. Coal abundant, V>E>>I. Vitrite>clarite. Dom abundant, V>E>I> Vitrinite abundant, exinite common, inertinite sparse. Abundant coal cavings present. Pyrite abundant.)
x7885	3440-3450 Ctgs	0.56	0.49-0.71	27	Sparse cutinite and liptodetrinite, yellow to dull orange, sparse suberinite, dull orange to brown, rare to sparse sporinite, orange to dull orange rare resinite, yellow orange. (Sandstone>siltstone>>coal. Coal common, V>>E. Vitrite. Dom common, V>E>I. Vitrinite common, exinite and inertinite sparse. Coal cavings present. Pyrite abundant.)

TABLE 1

Summary of Extraction and Liquid Chromatography

Wellname: SELENE 1   Date of Job: MARCH 1988

A. Concentrations of Extracted Material

				-------Hydrocarbons-------			----Nonhydrocarbons----		
	Weight of Rock Extd.	Total Extract	Loss on Column	Saturates	Aromatics	HC Total	NSO's	Asphaltenes	NonHC Total
Depth(m)	(grams)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
3149.5 CORE	3.6	4222.2	138.9	666.7	777.8	1444.4	2638.9	nd	2638.9
3260.0-3270.0	19.2	3020.8	203.1	599.0	593.7	1192.7	1625.0	nd	1625.0
3370.0-3380.0	26.4	3147.7	401.5	746.2	666.7	1412.9	1333.3	nd	1333.3

TABLE 1

Summary of Extraction and Liquid Chromatography

Wellname: SELENE 1   Date of Job: MARCH 1988

B. Compositional Data

	-----Hydrocarbons-----			----Nonhydrocarbons-----			EOM(mg)	SAT(mg)	SAT	ASPH	HC
Depth(m)	%SAT.	%AROM.	%HC's	%NSO's	%ASPH.	%Non HC's	TOC(g)	TOC(g)	AROM	NSO	Non HC
3149.5 CORE	16.3	19.0	35.4	64.6	nd	64.6	nd	nd	.86	nd	.5
3260.0-3270.0	21.3	21.1	42.3	57.7	nd	57.7	nd	nd	1.01	nd	.7
3370.0-3380.0	27.2	24.3	51.4	48.6	nd	48.6	nd	nd	1.12	nd	1.1

na = not applicable   nd = no data

TABLE 2

Summary of Gas Chromatography Data

Wellname: SELENE 1   Date of Job:MARCH 1988

A. Alkane Compositional Data

Depth(m)	Prist./Phyt.	Prist./n-C17	Phyt./n-C18	CPI(1)	CPI(2)	(C21+C22)/(C28+C29)
3149.5 CORE	3.75	2.50	.67	2.39	2.30	.31
3260.0-3270.0	5.00	1.47	.41	2.61	2.49	.37
3370.0-3380.0	9.64	1.96	.39	2.33	2.26	.33

B. n-Alkane Distributions

DEPTH(m)	nC12	nC13	nC14	nC15	nC16	nC17	iC19	nC18	iC20	nC19	nC20	nC21	nC22	nC23	nC24	nC25	nC26	nC27	nC28	nC29	nC30	nC31
3149.5 CORE	1.0	1.1	1.5	1.7	1.8	1.6	4.1	1.6	1.1	1.7	2.0	2.6	2.9	9.6	4.9	14.7	5.9	14.3	6.3	11.1	2.9	5.7
3260.0-3270.0	1.1	2.4	4.9	6.4	5.5	4.0	5.9	2.9	1.2	2.2	2.3	2.4	2.4	6.1	3.5	10.9	4.3	11.7	4.3	8.8	2.1	4.8
3370.0-3380.0	2.0	5.2	11.9	13.1	8.0	4.3	8.5	2.2	.9	1.4	1.0	1.5	1.6	3.5	2.5	6.6	3.1	8.0	3.1	6.3	1.8	3.5

na = not applicable   nd = no data

SELENE 1, 3149.5m, Core

Saturate Ftaction

C_{12}^+ GLC

31

22

Pr

17

18

Ph

12
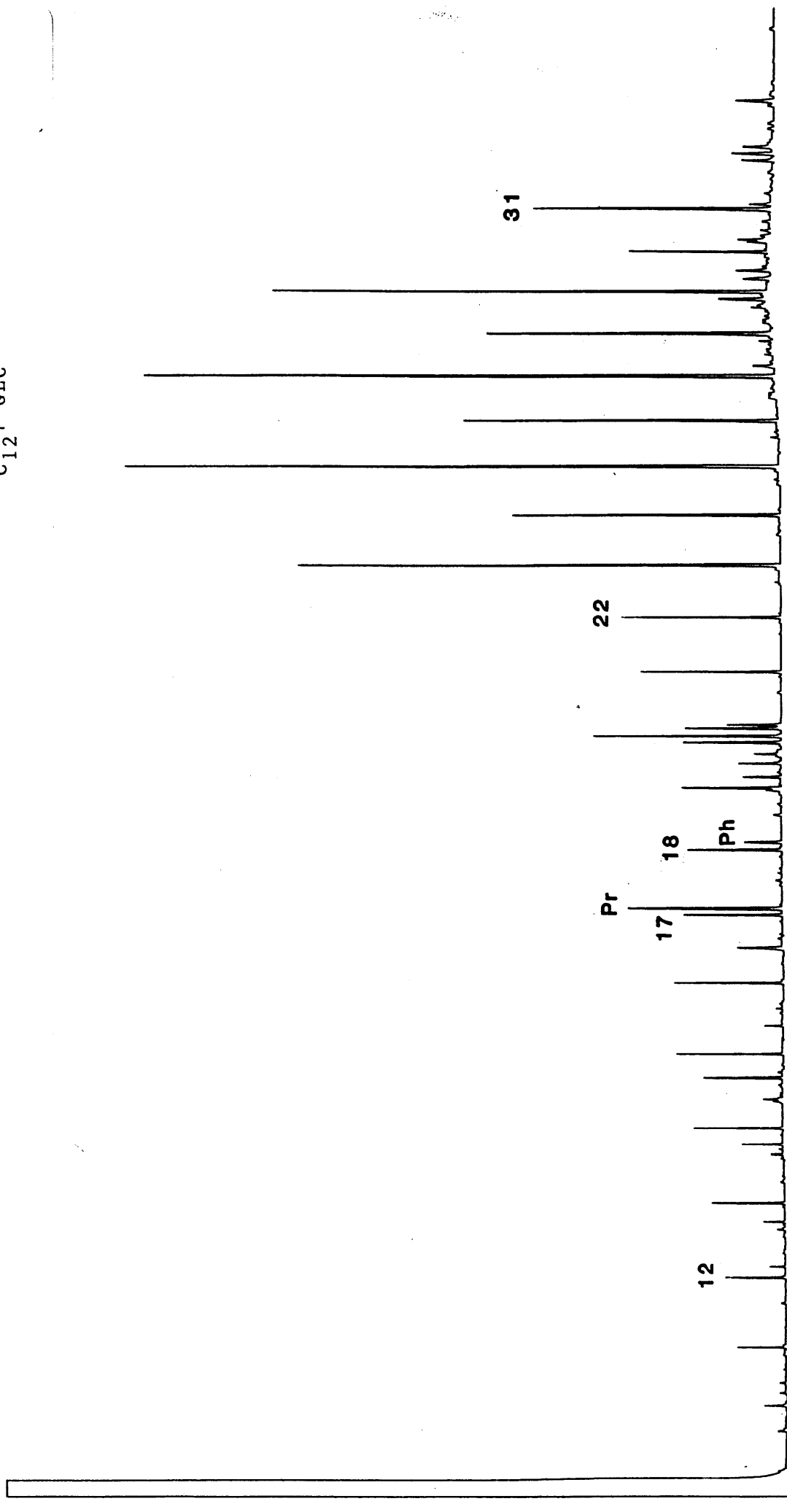
SELENE 1, 3260.0-3270.0m

Saturate Fraction

C_{12}^+ GLC

31

22

17 Pr

18

Ph

12
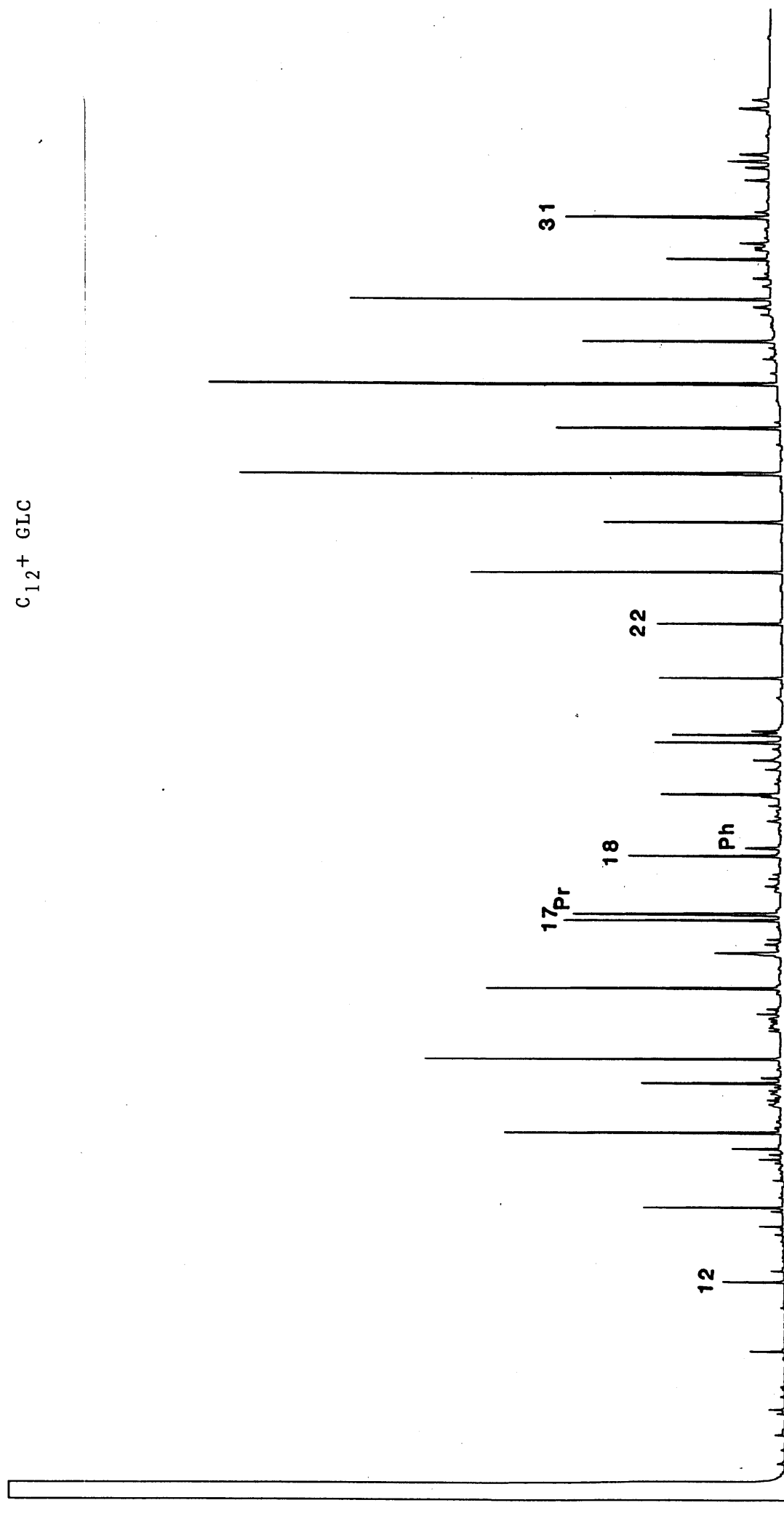
SELENE 1, 3370.0-3380.0m
Saturate Fraction
C_{12}^{+} GLC
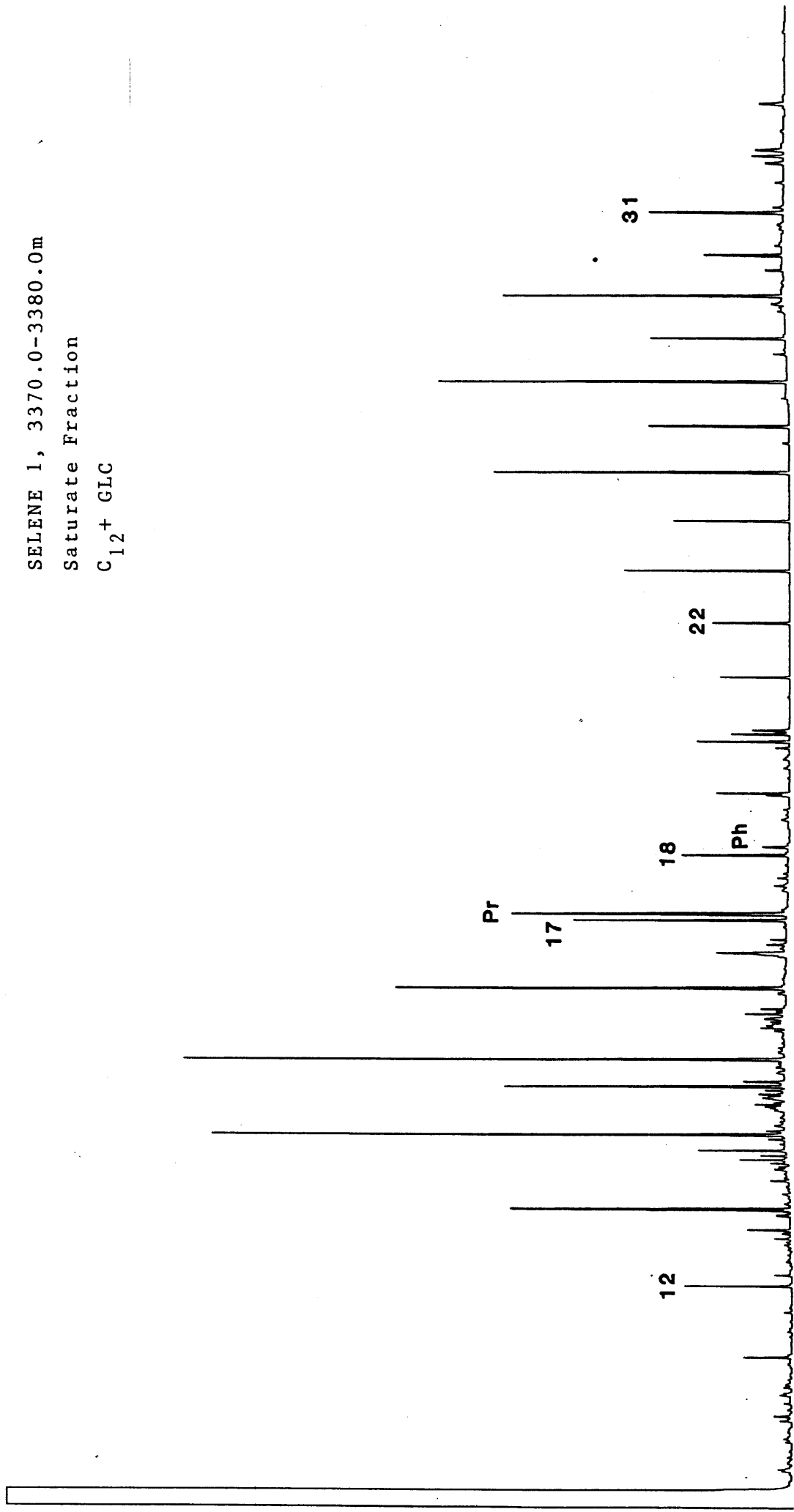
THEORY AND METHODS

This section details a series of geochemical methods which are commonly used in our laboratory, including those used to obtain the data presented in this report. Where applicable, the discussion is accompanied by a summary of the general theory used to interpret the data generated by each method.

1. SEDIMENTARY GAS ANALYSIS

a) Headspace Analysis

Headspace analysis is carried out using sealed containers (usually tinned cans) of wet cuttings. The containers are approximately three quarters filled with the cuttings and water to leave an appreciable headspace into which volatile hydrocarbons contained in the cuttings diffuse.

After covering about 1cm2 of the container lid with silicone and allowing the silicone to dry, the procedure involves placing a small hole in the lid through the silicone, then sampling an aliquot of the headspace gas with a gas injection syringe, and finally gas chromatographing this sample of gas under the following conditions: instrument = Shimadzu GC-8APF; column = 6' x 1/8" Chromosorb 102; column temperature = 110 Deg. C; carrier gas = nitrogen at 23mls/min; injector temperature = 120 Deg. C.; analysis cycle = C1-C4 components are flushed from the column in the forward direction and then the C5-C7 compounds are removed from the column by backflushing.

The integrated areas of peaks representing each of the C1-C7 components of the headspace gas are compared to the areas of corresponding components of a standard gas of known composition. The calculated amount of each component in the sample gas is adjusted for the total headspace volume and reported as ppm (parts of gas per million parts of sediment by volume).

Data from headspace analysis is commonly used to identify the zone of oil generation by plotting gas wetness (C2-C4/C1-C4) expressed as a % against sediment burial depth. Gas containing appreciable quantities of C2-C4 components, termed wet gas (Fuex, 1977), is generally considered to be gas associated with oil generation. In addition, the ratio of isomeric butanes can sometimes be used for assessment of sediment maturity (Alexander et. al., 1981). The amount of gas in sediments can be used to identify zones of significant gas generation and out-of-place gas (LeTran et. al., 1975).

b) Cuttings Gas Analysis

This analysis is the same as Headspace Analysis with the exception that instead of analysing the gas in the container headspace, a known volume of the wet cuttings are transferred to the blender bowl of a Kenwood electronic blender with the lid modified to incorporate a septum, water at 75 Deg. C is added to leave a headspace of 160ml, and the mixture is blended at maximum speed for 2 minutes. Following a 2 minute settling period 1ml of the blending bowl headspace gas is analysed as described in section 1a.

It is recommended that for the most meaningful gas data both headspace and cuttings gas analysis are carried out. In such cases we provide tabulations of the headspace, gas, and combined headspace/cuttings gas data. Normally, the combined data is used for plotting purposes.

2.   SAMPLE PREPARATION

a)   Cuttings
Cuttings samples are inspected by our qualified geological staff and then water washed according to the drilling mud content and lithology. In special cases (e.g. diesel contamination) it is necessary to lightly solvent wash samples. After washing, the samples are air dried, either sieved or picked free of cavings, and crushed to 0.1mm using a ring pulveriser.

b)   Sidewall Cores
Sidewall samples are freed of mud cake and any other visible contaminants, and are also inspected for lithologic homogeneity. For homogeneous samples, the minimum amount of material required for the requested analyses is air dried and handcrushed to 0.1mm. For non-homogeneous samples, the whole sample is air dried and handcrushed to 0.1mm.

c)   Conventional Core and Outcrop Samples
These sample types are firstly inspected for visible contaminants, and where applicable, are freed of these contaminants to the best of our ability. Commonly, the surface of conventional core and outcrop samples are lightly solvent washed. The samples are then crushed to approximately 1/8" chips using a jaw crusher, air dried, and finally further crushed to 0.1mm using a ring pulveriser.

d)   Petroleum/Aqueous Mixtures
The most common sample type in this category are RFT tests containing oil, water and mud. The mixture is placed in a separation funnel and allowed to stand for several hours which enables the petroleum and water/mud fractions to separate. The neat petroleum is isolated by removal of the lower layer (water/mud) from the funnel. To remove the last traces of water and mud, the neat petroleum is centrifuged at moderate speed.

When the volume of petroleum accounts for only a very small part of the sample the method above is unsatisfactory and the petroleum is solvent extracted from the mixture with dichloromethane. The petroleum is recovered by careful evaporation of the solvent from the organic layer.

3.   TOTAL ORGANIC CARBON DETERMINATION

The total organic carbon value (TOC) is determined on the unextracted sediment sample. The value is determined by treating a known weight of sediment with hot dilute HCl for 1 hour to remove carbonate minerals, and then heating the residue to 1700 Deg. C (Leco Induction Furnace CS-044) in an atmosphere of pure oxygen. The carbon dioxide produced is transferred to an infra-red detector which has been calibrated with a series of standards, and the microprocessor of the Leco unit then automatically calculates the % TOC in the sample. To ensure reliable data a standard is run after every 10 samples, regular sample repeats are carried out, and at least one blank determination is carried out for each batch of samples.

The following scales are normally used for source rock classification based on % TOC data:

Classification	Clastics	Carbonates
Poor	0.00 - 0.50	0.00 - 0.25
Fair	0.50 - 1.00	0.25 - 0.50
Good	1.00 - 2.00	0.50 - 1.00
Very Good	2.00 - 4.00	1.00 - 2.00
Excellent	> 4.00	> 2.00

4. ROCK-EVAL PYROLYSIS

Although a preliminary source rock classification is made using TOC data a more accurate assessment accounting for organic source type and maturity is made by pyrolysis analysis. Two types of Rock-Eval pyrolysis services are offered: "one run" which involves pyrolysis of the crushed but otherwise untreated sediment and "two run" which involves pyrolysis of both the crushed, untreated sediment and sediment which has been rendered free of carbonate minerals by treatment with hot dilute HCl. The two run service offers considerably more reliable S3 data.

The method involves accurately weighing approximately 100mg of the sample into a sintered steel crucible and subjecting it to the following pyrolysis cycle:

Stage (i)   -   Sample purged with helium for 3.5 minutes in unheated part of pyrolysis furnace;

Stage (ii)   -   Sample heated at 300 Deg. C for 3 minutes to liberate free petroleum (S1 peak);

Stage (iii)   -   Sample heated from 300 Deg. C to 550 Deg. C at 25 Deg. C/minute to produce petroleum from kerogen (S2 peak). The furnace is maintained at 550 Deg. C for one minute. Carbon dioxide produced during this pyrolysis up to 390 Deg. C in the case of "one run" and 550 Deg. C for "two run" is absorbed on a molecular sieve trap;

Stage (iv)   -   During the cool down period the carbon dioxide produced during pyrolysis is measured (S3 peak).

The units used for Rock-Eval data are as follows:

S1, S2, S3   =   kg/tonne or mg/g of rock

Tmax   =   Deg. C

Hydrogen Index   = $\dfrac{S2}{TOC} \times \dfrac{100}{1}$

Oxygen Index   = $\dfrac{S3}{TOC} \times \dfrac{100}{1}$

Rock-Eval data is most commonly used in the following manner:

(i) S1   -   indicates the level of oil and or/gas already generated by the sample according to the following scale:

S1 (mg/g or kg/tonne)	Classification
0.00 - 0.20	Poor
0.20 - 0.40	Fair
0.40 - 0.80	Good
0.80 - 1.60	Very Good
> 1.60	Excellent

(ii) S1+S2   -   referred to as the genetic potential this parameter is used for source rock classification according to the following criteria:

S1+S2 (mg/g or kg/tonne)	Classification
0.00 - 1.00	Poor
1.00 - 2.00	Marginal
2.00 - 6.00	Moderate
6.00 - 10.00	Good
10.00 - 20.00	Very Good
> 20.00	Excellent

(iii) S1/(S1+S2)-   this parameter is the production index (PI) which is a measure of the level of maturity of the sample. For oil prone sediments, values less than 0.1 are indicative of immaturity, the values increase from 0.1 to 0.4 over the oil window and values greater than 0.4 represent over maturity. For gas prone sediments, the PI data shows a relatively smaller change with increasing maturity.

(iv) Tmax   -   the temperature corresponding to the S2 maxima. This temperature increases with increasingly mature sediments. Values less than 430 Deg. C are indicative of immaturity while values from 430/435 to 460 Deg. C represent the maturity range of the oil window. Tmax values greater than 460 Deg. C are indicative of over maturity.

(v) HI, OI   -   the hydrogen ((S2 x 100)/TOC) and oxygen ((S3 x 100)/TOC) indices when plotted against one another provide information about the type of kerogen contained in the sample and the maturity of the sample. Both parameters decrease in value with increasing maturity. Samples with large HI and low OI are dominantly oil prone and conversely samples with low HI and large OI are at best gas prone.

5.   EXTRACTION OF SEDIMENT SAMPLES

Crushed sediment (maximum of 250g) and 300mls of purified dichloromethane are placed in a 500ml conical flask and are then blended for ten minutes with a Janke and Kunkel Ultra-Turrax T45/2G high efficiency disperser. After a ten minute settling period the solvent is separated from the sediment using a large Buchner filtration system. The extract is recovered by careful evaporation of the solvent on a steam bath and weighed. The weight of extract is used to calculate % EOM and ppm EOM using the following formulae:

$$\% \text{ EOM} = \frac{\text{Wt} \quad \text{EOM}}{\text{Wt Sediment Extracted (g)}} \times \frac{100}{1}$$

$$\text{ppm EOM} = \frac{\text{Wt} \quad \text{EOM (mg)}}{\text{Wt Sediment Extracted (kg)}}$$

The following scale is used to classify the source rock richness of samples based on C12+ extractables:

Classification	ppm Total Extract
Poor	0 - 500
Fair	500 - 1000
Good	1000 - 2000
Very Good	2000 - 4000
Excellent	> 4000

6. SEPARATION OF PETROLEUM INTO CONSTITUENT FRACTIONS

Sediment extracts and crude oil or condensate samples are separated into saturate, aromatic and NSO (asphaltenes plus resins) fractions by medium pressure liquid chromatography (MPLC). That part of the petroleum which is soluble in pentane is applied to the MPLC system via a sample loop and is then pumped using pentane to a partially activated silicic acid pre-column which prevents further movement of the non-hydrocarbon compounds. The hydrocarbon components are pumped further to a Merck Si60 column where the saturate fraction is obtained by forward flushing and the aromatic fraction is recovered by reverse flushing. This separation procedure is monitored using a refractive index detector. To complete the separation the pre-column is removed from the MPLC system and flushed with dichloromethane: methanol (1:10). This non-hydrocarbon fraction is combined with the pentane insoluble material which is not applied to the MPLC system, and is labelled as the NSO fraction. The neat fractions are recovered by careful removal of the solvent by distillation and are weighed.

The weight of each fraction is used to calculate the % of each fraction in the sediment according to the following formulas:

$$\% \text{ Fraction} = \frac{\text{Wt Fraction}}{\text{Wt all Fractions}} \times \frac{100}{1}$$

$$\text{ppm Fraction} = \frac{\text{Wt Fraction (mg)}}{\text{Wt Sediment Extracted (kg)}}$$

The ppm hydrocarbon (saturates and aromatics) and ppm saturate values can be used to classify source rock richness and oil source potential respectively according to the following criteria:

v

Classification	ppm Hydrocarbon	ppm Saturates
Poor	0 – 300	0 – 200
Fair	300 – 600	200 – 400
Good	600 – 1200	400 – 800
Very Good	1200 – 2400	800 – 1600
Excellent	> 2400	> 1600

The composition of the extracts can also provide information about their levels of maturity and/or source type (LeTran et. al., 1974; Philippi, 1974). Generally, marine extracts have relatively low concentrations of saturated and NSO compounds at low levels of maturity, but these concentrations increase with increased maturation. Terrestrially derived organic matter often has a low level of saturates and large amount of aromatic and NSO compounds irrespective of the level of maturity.

N.B.   If requested by a client the NSO fraction is separated into asphaltenes and resins by conventional methods.

7.   EXTRACTABLE/TOTAL ORGANIC CARBON RATIOS

The ratios of EOM(mg)/TOC(g) and SAT(mg)/TOC(g) are determined from the appropriate data. The EOM(mg)/TOC(g) ratio can be used as a maturation indicator, especially if the parameter is plotted against depth for a given sedimentary sequence. In an absolute sense it is less reliable as a maturation indicator, although previous work (Tissot et. al., 1971; LeTran et. al., 1974) suggests that the following criteria can be used to determine maturity with this parameter.

< 50	Low maturity
50 – 100	Moderate maturity
> 100	High maturity

The ratios of EOM(mg)/TOC(g) and SAT(mg)/TOC(g) can be used collectively to provide information about source type. For example, if SOM(mg)/TOC(g) is > 100, suggesting a high level of maturity, but the SAT(mg)/TOC(g) < 20 it is very likely that the organic matter is gas prone. Conversely, the same EOM(mg)/TOC(g) value with a SAT(mg)/TOC(g) value > 40 suggests oil prone source type.

8.   PYROLYSIS GAS CHROMATOGRAPHY

Pyrolysis-gas chromatography (PGC) incorporates a Chemical Data System Pyroprope 150 flash pyrolysis unit interfaced with a capillary gas chromatograph. A sample (5-10mg) of extracted sediment is placed in a quartz tube inside the element coil of the pyrolysis probe and is then heated to 610 Deg. C in a few milliseconds, and is maintained at this temperature for 20 seconds. Products generated from the pyrolysis are swept onto the bonded phase capillary column of the gas chromatograph and are chromatographed from -20 Deg. C (isothermal for two minutes) to 280 Deg. C at 4 Deg. C/minute. The product distribution is dominated by the nature of the kerogen from which it is derived.

9.   C12+ GAS CHROMATOGRAPHY

C12+ gas chromatography is commonly carried out on the saturate fraction but in certain instances is carried out on neat oil, condensate or extract. The analysis is carried out under the following conditions: instrument = Shimadzu GC-9A; column = 50m x 0.2mm ID OV101 vitreous silica; column temperature = programmed from 60 Deg. C

to 280 Deg. C at 4 Deg. C/min; injection system = Grob splitless using a 30 second dump time and split ratio of 25:1, carrier gas = hydrogen at 2mls/min; sample = 1µl of 0.5% soln in pentane.

The following information is commonly obtained from C12+ gas chromatographic analysis:

(a) n-Alkane Distribution - The C12-C31 n-alkane distribution is determined from the area under peaks representing each of these n-alkanes. This distribution can yield information about both the level of maturity and the source type (LeTran et. al., 1974).

(b) Carbon Preference Index - Two values are determined:

$$CPI\ (1) = \frac{(C23 + C25 + C27 + C29)\ Wt\% + (C25 + C27 + C29 + C31)\ Wt\%}{2 \times (C24 + C26 + C28 + C30)\ Wt\%}$$

$$CPI\ (2) = \frac{(C23 + C25 + C27)\ Wt\% + (C25 + C27 + C29)\ Wt\%}{2 \times (C24 + C26 + C28)\ Wt\%}$$

The CPI is believed to be a function of both the level of maturity (Cooper and Bray, 1963; Scalan and Smith, 1970) and the source type (Tissot and Welte, 1978). Marine extracts tend to have values close to 1.0 irrespective of maturity whereas values for terrestrial extracts decrease with maturity from values as high as 20 but do not usually reach a value of 1.0

(c) (C21+C22)/(C28+C29) - This parameter provides information about the source of the organic matter (Philippi, 1974). Generally, terrestrial source material gives values <1.2 whereas a aquatic source material results in values >1.5.

(d) Pristane/Phytane Ratio - This value was determined from the areas of peaks representing these compounds. The ratio renders information about the depositional environment according to the following scale (Powell and McKirdy, 1975):

    < 3.0   Relatively reducing depositional environment
    3.0-4.5   Reducing/oxidizing depositional environment
    >4.5   Relatively oxidizing depositional environment

(e) Pristane/n-C17 Ratio - This ratio was determined from the areas of peaks representing these compounds. The value can provide information about both the depositional environment and the level of maturation (Lijmbach, 1975). Very immature crude oil has a pristane/n-C17 ratio >1.0, irrespective of the depositional environment. However, the following classification can be applied to mature crude oil:

    <0.5   Open water depositional environment
    0.5-1.0   Mixed depositional environment
    >1.0   Peat-swamp depositional environment

In the case of sediment extracts these values are significantly higher and the following classification is used:

<1.0	Open water depositional environment
1.0-1.5	Mixed depositional environment
>1.5	Peat-swamp depositional environment

(f)   Phytane/n-C18 Ratio - This ratio was determined from the areas of peaks representing these compounds. The value usually only provides information about the level of maturity of petroleum. The value decreases with increased maturation.

(g)   Relative Amounts of n-Alkanes and Naphthenes - Since n-alkanes and naphthenes are the two dominant classes of compounds in the saturate fraction, a semi-quantitative estimate of the relative amounts of these compounds can be made from saturate GLC's. This information can be used to assess the degree of maturation and/or the source type of the petroleum (Philippi, 1974; Tissot and Welte, 1978). Very immature petroleum has only small proportions of n-alkanes, but as maturity increases the relative amount of n-alkanes increases. In addition, terrestrial petroleum has a greater proportion of high molecular weight naphthenes than petroleum comprising aquatic source material.

10. API/SPECIFIC GRAVITY

A specific gravity (SG) bottle was accurately weighed, then filled with crude oil at 60 Deg. F and finally reweighed. The weight difference was divided by the weight of an equal volume of water at 60 Deg. F to obtain the specific gravity. The following formula was then used to calcuate the API gravity:

$$\text{API Gravity} = \left[\frac{141.5}{\text{SG (60 Deg. F)}} \right] - 131.5$$

The reported gravity value is the average of duplicate determinations.

11. SULPHUR DETERMINATION

The % sulphur by weight is determined by dissolving 0.5g of the petroleum in 50mls kerosene and then analysing this mixture with an inductively coupled plasma (ICP) instrument which has been calibrated with a series of sulphur standards.

This parameter is influenced by the nature of the source material from which a crude is derived, the depositional environment of the source rocks, and reservoir alteration processed such as bacterial alteration.

12. C1-C31 WHOLE SAMPLE GAS CHROMATOGRAPHY

This method of analysis is normally only applied to oil or condensate samples. The technique provides a "picture" of the sample which shows good resolution of the low, medium and high molecular weight components. Whole sample GC data is considered to be more useful than C12+ saturate fraction GC data for oil or condensate samples.

The analysis is carried out under the same conditions as for the C12+ GC analysis with the following exceptions: column temperature = programmed from -20 Deg. C to 280 Deg. C at 4 Deg. C/min (uses cryogenic mode); injection is carried out in split mode; sample = 0.1 µl of neat petroleum.

C1-C31 analysis data can be used to obtain the same information as that obtained from C12+ GC but further provides detailed compositional data on the C1-C11 fraction and enables calculation of the distillation range of the sample.

13. MOLECULAR SIEVE EXTRACTION

This technique is used to isolate the branched/cyclic alkanes from the saturate fraction for gas chromatography/mass spectometry analysis. A mixture of saturates: 5A molecular sieves: purified benzene in the proportions 1:5:12 by weight is placed in a 100ml round bottom flask and refluxed for 24 hours. After cooling, the seives are filtered from the liquid phase and are washed with 4 x 10ml aliquots of benzene. The liquid phase plus washing are freed of benzene by distillation yielding the branched/cyclic compounds.

14. COMPUTERIZED GAS CHROMATOGRAPHY/MASS SPECTOMETRY (GC/MS)

Gas chromatography/mass spectrometry employs a capillary column gas chromatograph linked in series with a mass spectrometer and data system (GC/MS/DS). As molecules are eluted from the capillary column they are bled into the analyser tube of the mass spectrometer where they are bombarded with high energy electrons and consequently fragment to form several ions each with molecular weights less than that of the parent molecule. The fragmentation pattern is characteristic of the particular molecular type. The spectrum of these ions (referred to as a mass spectrum) is recorded approximately once every second and all of the mass spectra recorded during a GC/MS/DS analysis are memorised by the data system. Since any given class of molecules will breakdown in the analyser type to give one or more characteristic ion fragments of known molecular weight, after a GC/MS/DS analysis it is possible to examine the distribution of compounds within a given class by having the data system reproduce a mass fragmentogram (plot of ion concentration against gas chromatography retention time) representative of the particular class.

GC/MS/DS analyses can be carried out using one of the two following modes of operation:

(i)   Acquire mode - in which all ions in each mass spectrum are memorised by the data system;

(ii)   Selective ion monitoring (SIM) mode - in which only selected ions of interest are memorised by the data system.

At present the sterane/triterpane/bicyclane fraction of petroleum is considered most useful for GC/MS/DS analysis and therefore we commonly use the second of the above mentioned modes of operation and run the following twenty-two ions which are pertinent to the sterane/triterpane/bicuclane fraction.

Ion	Molecular Type
177	Demethylated triterpanes
191	Normal triterpanes
205	Methyl triterpanes
163	Specific dethylated triterpanes
356	Parent ion - C26 triterpanes
370	Parent ion - C27 triterpanes
384	Parent ion - C28 triterpanes
398	Parent ion - C29 triterpanes

412	Parent ion - C30 triterpanes
426	Parent ion - C31 triterpanes
183	Isoprenoids
217	Normal steranes
218	Normal steranes
231	4-methylsteranes
259	Diasteranes
358	Parent ion - C26 steranes
372	Parent ion - C27 steranes
386	Parent ion - C28 steranes
400	Parent ion - C29 steranes
414	Parent ion - C30 steranes

GC/MS/DS analysis of the sterane/triterpane/bicyclane fraction can often provide information about the maturity and source type of petroleum and whether it has been affected by micro-organisms. This technique is also often useful for oil:oil and oil:source rock correlation. The following sections indicate which parameters are used to obtain this information and summarize the theory behind their use.

Maturity

(i) Based on Steranes

(a) The biologically produced $\alpha\alpha\alpha$ (20R) sterioisomer is converted in sediment to a mixture of the $\alpha\alpha\alpha$ (20R) and $\alpha\alpha\alpha$ (20S) compounds. The ratio of

$$C29 \quad \frac{\alpha\alpha\alpha \ (20S)}{\alpha\alpha\alpha \ (20R) + \alpha\alpha\alpha \ (20S)}$$ expressed as a percentage is about 25% at the

onset of oil generation and increases almost linearily to a value of about 50% at the peak of oil generation.

(ii) Based on Triterpanes

(a) The C31, C32, C33, C34 and C35 hopanes have the biological R configuration at C22. On mild thermal maturation equilibration occurs to produce a 60/40 mixture of S/R. This equilibration occurs before the onset of oil generation.

(b) The conversion of the biological $17\beta,21\beta$ hopanes to the corresponding $17\alpha,21\beta$ and $17\beta,21\alpha$ compounds is also maturation dependant. For C30 triterpanes the ratio of $\dfrac{17\beta,21\alpha}{17\alpha,21\beta}$ decreases steadily from a

value of about 0.4 at the onset of oil generation to a value of about 0.1 at peak oil generation.

(c) Two of the C27 triterpanes can also be used as maturity indicators. The ratio of 18 α(H) trisnorhopane to 17 α(H) trisnorhopane increases exponentially with increasing maturity from a value of approximately 0.2 at the onset of oil generation to approximately 1.0 at peak oil generation.

(d) It is our experience that the ratio of the C27 18α(H) + C27 17α(H) triterpanes to C30 17α,21β triterpane is maturity dependent. The ratio decreased from values around 1.0 at the onset of oil generation to a value of approximately 0.4 at peak oil generation. With increasing maturity at levels greater than that equivalent to peak oil generation the ratio

increases steadily to values greater than 3.0.

Source Type

(i) Based on Steranes

Algal organic matter contains steranes in which the C27 compounds are more abundant than the C29 compounds. General aquatic organic matter has approximately equivalent amounts of the C27 and C29 compounds while organic matter rich in land-plants usually has a lot more of the C29 steranes.

(ii) Based on Triterpanes

The triterpane components in petroleum can be derived from both bacteria and higher plants. The common bacterial products are the C27-C35 hopanes and moretanes whereas the higher plant triterpanes are compounds other than hopanes or moretanes and are commonly C30 compounds.

(iii) Based on Diasteranes

The diasteranes are not produced biologically but are formed during early diagenesis from sterane precursors. The diasterane ratios

$$\frac{C27(20R)}{C29(20R)} \quad \text{and} \quad \frac{C27(20R+20S)}{C29(20R+20S)} \quad \text{should reflect the nature of the organic}$$

matter in the same manner as that outlined above for the steranes.

Biodegradation

It has been observed that in severely biodegraded petroleum the series of normal hopanes are converted to a series of A ring demethylated hopanes and the C29 (20R) sterane is selectively removed. For altered crudes which have not been degraded to this extent the severity of biodegradation can often be gauged by studying the isoprenoid and aromatic fractions. However, this type of investigation extends beyond a standard GC/MS/DS analysis.

Correlation

Our present approach to oil:oil or oil:source rock correlation problems is as follows:

(i) Compare the distribution of compounds in the 123, 177, 191, 205, 217, 218, 231 and 259 mass fragmentograms for an oil or sediment extract to the distribution of compounds in the respective fragmentograms for the other oil(s) or sediment extract(s). It is necessary in this type of comparison to make allowance for small variations due to possible maturity differences.

(ii) Examine the fragmentograms for peaks or sets of peaks which may represent compounds that are specific to the geological system under investigation. Normal steranes, diasteranes and bacterial hopanes cannot be used for this purpose because they are present in virtually all crude oils and sediment extracts. However, compounds like higher plant triterpanes, bisnorhopane and botryococcane can often prove very useful for this purpose.

15. CARBON ISOTOPE ANALYSIS

The measurement is carried out on one or more of the following mixtures; topped oil; saturate fraction; aromatic fraction; NSO fraction. The organic matter is combusted at 860 Deg. C in oxygen and the carbon dioxide formed is purified and transferred to an isotope mass spectrometer. The carbon isotope ratio is measured relative to a standard gas of known isotopic composition. In our case the standard gas is prepared from the NBS No. 22 oil. However, since the isotopic relationship between NBS No. 22 oil and the international reference PDB limestone are known, the values are adjusted to be relative to PDB limestone.

Although carbon isotope data has been commonly used for oil:oil and oil:source rock correlation its most significant application is the identification of the source of gas according to the following criteria (Fuex, 1977):

$\delta 13C$ (PDB)	Gas Type
-85 to -58	Biogenic methane
-58 to -40	Wet gas/associated with oil
-40 to -25	Thermal methane

16. VITRINITE REFLECTANCE MEASUREMENT

Vitrinite is a coal maceral which responds to increasing levels of thermal maturity. This response can be measured by the percent of light reflected off a polished surface of a vitrinite particle immersed in oil. Reflectance measurements are made on a number (40 if possible) of vitrinite particles in each sample, in order to establish a range and mean for reflectance values. Immature rocks have low reflectance values (0.2% Ro to 0.6% Ro), with mature values ranging from 0.6% Ro to 1.2% Ro. Very mature values are between 1.2 % Ro and 1.8% Ro, while severely altered rocks have reflectances above 1.8% Ro.

Vitrinite reflectance results are best obtained from coals or rocks deposited in environments receiving large influxes of terrestrially-derived organic matter. Unfortunately, these environments are not conducive to the accumulation of large quantities of oil-prone organic mater. Also vitrinite reflectance cannot be performed on rocks older than Devonian Age, due to the absence of land plants in the older geological time periods.

17. VISUAL KEROGEN

Visual kerogen assessment is carried out by the coal petrologist and/or the palynologist. In the case of the petrologist the assessment is made in reflected light using the plug prepared for vitrinite reflectance measurement, and reports the relative amounts of alginite, exinite, vitrinite and inertinite particles.

Visual study of kerogen by the palynologist is carried out in transmitted light and can indicate the relative abundance, size and state of preservation of the various recognizable kerogen types and hence indicates the source character of a sedimentary rock. In addition, the colour of the kerogen is related to the thermal maturity of the sediments and is often used as a maturation indicator.

The preparation of slides for visual kerogen assessment by the palynologist firstly involves concentration of the organic matter by removal of the rock matrix using hydrochloric and hydrofluoric acid treatment and heavy liquid separation. The organic concentrate is then mounted on a glass slide using Petropoxy.

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APPENDIX 1

SIGNIFICANCE OF
SELECTED PARAMETERS FROM GC/MS ANALYSIS

Parameter	Ion(s)

1. $18\alpha(H)$-hopane/$17\alpha(H)$-hopane (Ts/Tm)   191

2. C30 hopane/C30 moretane   191

3. C31 22S hopane/C31 22R hopane   191

4. C32 22S hopane/C32 22R hopane   191

5. C29 20S $\alpha\alpha\alpha$ sterane/C29 20R $\alpha\alpha\alpha$ steranes   217

6. C29 20S $\alpha\alpha\alpha$ /C29 20R $\alpha\alpha\alpha$ + C29 20S $\alpha\alpha\alpha$ 217

7. $$\frac{\text{C29 } \alpha\alpha\alpha \text{ steranes}}{\text{C29 } \alpha\alpha\alpha \text{ steranes} + \text{C29 } \alpha\beta\beta \text{ steranes}}$$ 217

8. C27/C29 diasteranes   259

9. C27/C29 steranes   217

10. $18\alpha(H)$-oleanane/C30 hopane   191

11. $$\frac{\text{C29 diasteranes}}{\text{C29 } \alpha\alpha\alpha \text{ steranes} + \text{C29 } \alpha\beta\beta \text{ steranes}}$$ 217

12. $$\frac{\text{C30 (hopanes + moretanes)}}{\text{C29 (steranes + diasteranes)}}$$ 191/217

13. C15 drimane/C16 homodrimane   123

14. Rearranged drimanes/normal drimanes   123

15. C15 alkylcyclohexane/C16 homodrimane   83/123

nd = not detectable

Significance of selected parameters from GC-MS analysis

1. 18α (H)-hopane/17α (H)-hopane   (Ts/Tm)

Maturity indicator. The ratio of 18α (H) trisnorhopane to 17α (H) trisnorhopane increases exponentially with increasing maturity from approximately 0.2 at the onset to approximately 1.0 at the peak of oil generation, i.e. Tm decreases with maturity. This parameter is not reliable in very immature samples.

2.   C30 hopane/C30 moretane

Maturity indicator. The conversion of C30 17β, 21β hopane to 17β, 21α moretane is maturity dependent. Values increase from approx. 2.5 at the onset of oil generation to approx. 10. Once the hopane/moretane ratio has reached 10, no further changes occur. A value of 10 is believed to represent a maturity stage just after the onset of oil generation, hopane/moretane ratios are therefore mainly useful as indicators of immaturity in a qualitative sense.

3.&4. C31 and C32 22S/22R hopanes

Maturity indicator. An equilibrium between the biological R- and the geological S- configuration occurs on mild termal maturation. A ratio of S:R = 60:40, i.e. a value of 1.5 characterise this equilibrium which occurs before the onset of oil generation.

5.   C29 20S $\alpha\alpha\alpha$ /C29 20R $\alpha\alpha\alpha$ steranes

Maturity indicator. Upon maturation, the biologically produced 20R stereoisomer is converted into a mixture of 20R and 20S compounds. An equilibrium between the two forms is reached at approximately 55% 20R and 45% 20S compounds. VR equivalents are approximately 0.45% for a 20S/20R value of 0.2 and 0.8% for a 20S/20R value of 0.75. This parameter is most useful between maturity ranges equivalent to 0.4% to 1.0% VR.

6. $C29\ 2OS_{\alpha\alpha\alpha}/C29\ 2OR\ _{\alpha\alpha\alpha} + C29\ 2OS_{\alpha\alpha\alpha}$

Maturity indicator. Different way of expressing the conversion from the biological 2OR to the geological 2OS configuration (see parameter 5). Expressed as a percentage, a value of about 25% indicates the onset of oil generation and of about 50% the peak of oil generation.

7. $C29\ \alpha\beta\beta/C29\ \alpha\alpha\alpha + C29\ \alpha\beta\beta$ steranes

Maturity indicator. The   form is produced biologically, it converts gradually into a mixture of $\alpha\alpha$ (normal steranes) and $\beta\beta$ (isosteranes) compounds upon maturation. Equilibrium is reached at about 65% $\beta\beta$ compounds, which is equivalent to approximately 0.9% VR.

8.&9. C27/C29 diasteranes and steranes

Source indicator. It has been suggested that marine phytoplankton is characterised by a dominance of C27 steranes and diasteranes whereas a preponderance of C29 compounds indicates strong terrestrial contributions. (C28 compounds are nearly always the lowest of the three sterane groups. High proportions of C28 compounds could indicate a contribution from of lacustrine algae). Values smaller than 0.85 for C27/C29 diasterane and sterane ratios are believed to be indicative for terrestrial organic matter, values between 0.85 to 1.43 for mixed organic material, and values greater than 1.43 for an input of predominantly marine organic matter.

As it has shown recently that apparently also pelagic marine sediments can contain a predominance of C29 steranes, the above rules have to be applied with caution. Any simplistic interpretation of C27/C29 steranes and diasteranes can be dangerous and the interpretation of these data should be consistent with other geological evidence.

10. $18\ \alpha\ (H)$ - oleanane/C30 hopane

Source indicator. Oleanane is a triterpenoid compound which has often been reported from deltaic sediments of late Cretaceous to Tertiary age. It is thought to be derived from certain angiosperms which developed in the late Cretaceous. If the 18 (H)-oleanane/C30 hopane ratio is below 10%, no significant proportions of oleanane are present. At higher values, it can be used as indicator for a reducing environment during deposition of land plant-derived organic matter.

11. C29 diasteranes/C29 $\alpha\alpha\alpha$ steranes + C29 $\alpha\beta\beta$ steranes

Source indicator. Parameter used to characterise the oxidity of depositional environments. High values (up to 10) indicate oxic conditions, low values (down to 0.1) indicate reducing environments.

12. C30 (hopanes + moretanes)/C29 (steranes + diasteranes)

Source indicator. Triterpanes are believed to be of prokariotic (bacterial) origin, whereas steranes are derived from eukariotic organisms. This ratio reflects the preservation of primary organic matter derived from eukariots relative to growth and preservation of bacteria in the sediment after deposition (prokariots).

13. C15 drimane/C16 homodrimane

Drimanes and homodrimanes are ubiquitous compounds most likely derived from microbial activity in sediments. The C15 drimane/C16 homodrimane ratio is a useful parameter for correlation purposes in the low molecular weight region, e.g. for condensates which lack most conventional biomarkers. Drimanes are also useful for an assessment of the level of biodegradation as the removal of C14 to C16 bicyclics characterises an extensive level of biodegration.
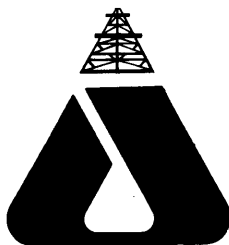

14. Rearranged/normal drimanes

Like parameter 13, for correlation purposes in samples without conventional biomarkers, and to assess level of biodegradation.

15. C15 alkylcyclohexane/C16 homodrimane

Like parameters 13 and 14, useful for correlation purposes. Mainly used for condensates and light oils.

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