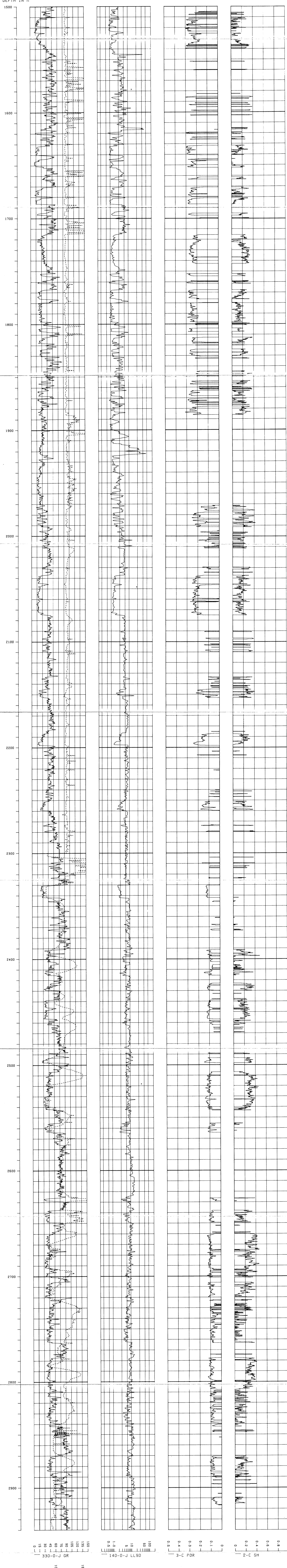
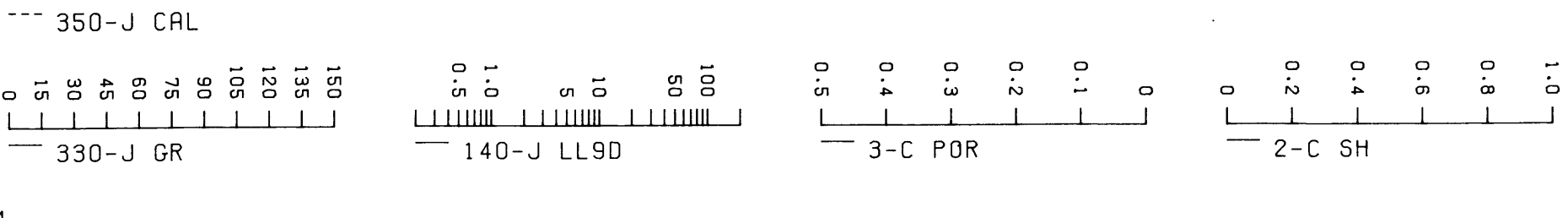


# PETROPHYSICAL EVALUATION SUMMARY

DEPT. NAT. RES. & ENV.  
PE603208

WELL : JUDITH-1  
 RESERVOIRS : LATROBE & GOLDEN BEACH FORMATIONS  
 INTERVAL : 1500m BRT - 2938m BRT  
 DATE : 12/89  
 VERTICAL SCALE : 1:1,000



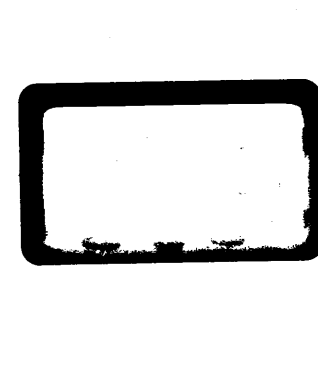
### SUMMARY OF EVALUATION - JUDITH-1

	1504-1886 (LATROBE)	1971-2074 (UPPER GOLDEN BEACH)	2074-2391 (KIPPER SHALE)	2391-2938 mBRT (LOWER GOLDEN BEACH)
<b>GROSS THICKNESS (m)</b>	382	103	317	547
<b>NET Sst. (m)</b>	166	64	58	281
<b>AVERAGE POROSITY (net Sst)</b>	24%	18%	12%	9%
<b>NET Sst/GROSS</b>	43%	62%	18%	51%
<b>NET POROUS Sst.(≥10%)</b>	164	55	42	102
<b>AVERAGE POROSITY (net porous Sst)</b>	24%	20%	15%	11%
<b>NET POROUS Sst/GROSS</b>	43%	54%	13%	19%
<b>SH AVERAGE</b>	16%	17%	17%	25%

DRAW NO 25854

SDA 949  
Encl. 1

flom W.L.R. JUDITH-1 Vol II.



APPENDIX  
RFT Evaluation

JUDITH #1 RFT EVALUATIONIntroduction

A total of 35 pretests were taken in sands over the interval 2300-2900 m bdf. A list of pretest pressures is given in Table 1 and is plotted in Figure 1.

Discussion

The first two pretests were taken in a water bearing sand at 2331.5 m and 2341.6 m and lie on a water gradient.

Other sands evaluated on logs as water bearing (2560.5 m, 2762 m, 2884.5 m) however, do not fall on any water gradient which can be extrapolated from this water sand. A line drawn through the remaining water bearing sands would require an equivalent gradient of 0.67 psi/ft suggesting that the individual pretest pressures are supercharged and/or the sands are of limited extent and are overpressured within individual pressure regimes.

Remaining pretests show signs of tight formation (large pretest draw downs and long duration buildups) supercharging and/or overpressure with considerable scatter observed even within individual sands. Two possible gas columns have been included in Figure 1 from pretests between 2495.5 m to 2535.5 m and from 2670.8 m to 2691.5 m. The large degree of scatter observed, however, casts considerable doubt on the interpretation of these points as true gas columns.

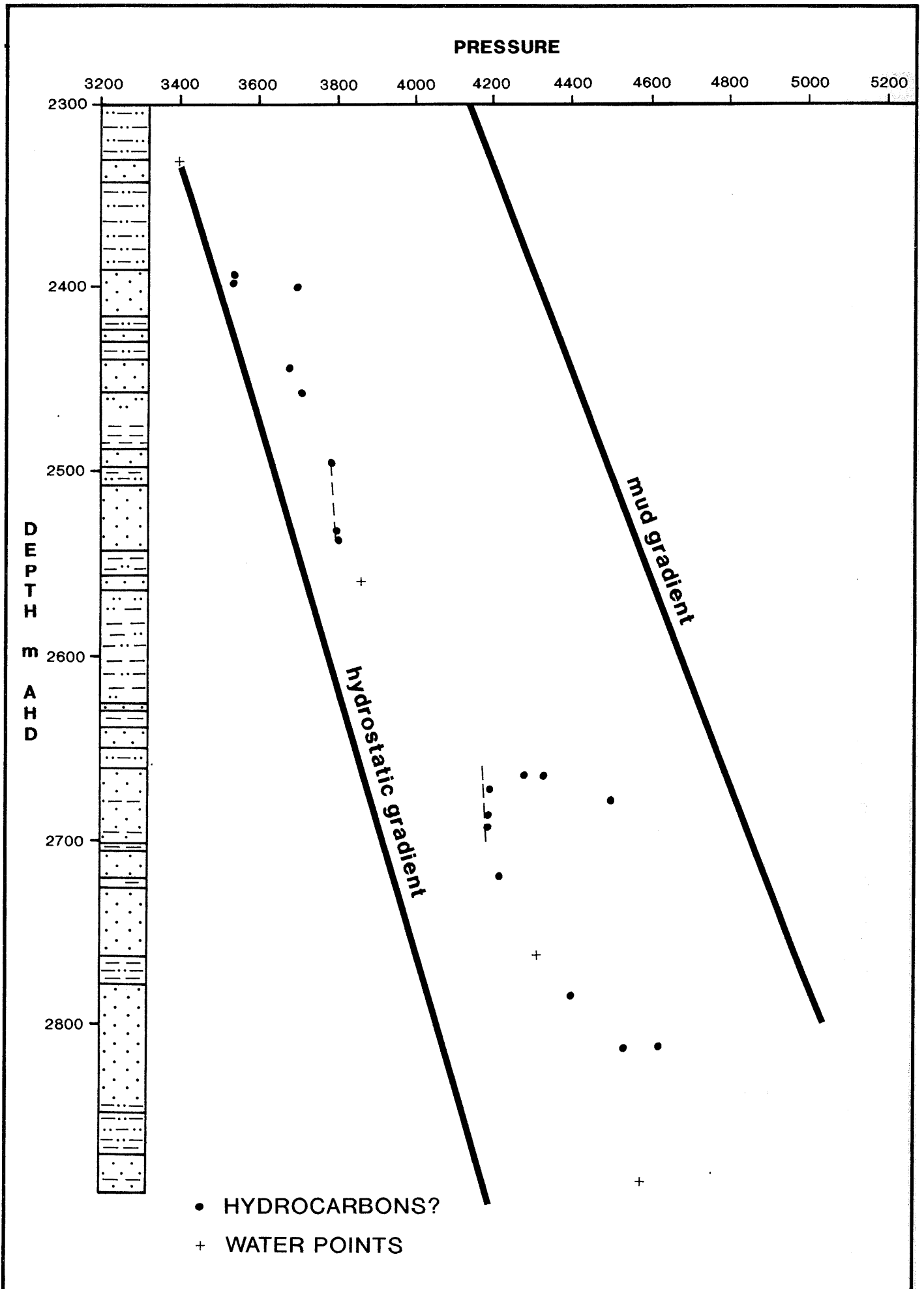
Permeability values calculated for the individual pretests are also listed Table 1. With the exception of the two shallowest pretests and one sand at 2535.5, permeabilities lie in the range 0.05 to 1.6 mD which is supporting evidence for the observed supercharging.

Conclusion

No hydrocarbon columns can be unambiguously deduced from the large scatter of pressures observed. With the exception of the initial water bearing sand at 2330 m, pretest buildups are indicative of low permeability formation.

Table 1

<u>Depth</u> (mbdf)	<u>Build-up Pressure</u> (psia)	<u>Minimum Flowing Pressure</u> (psia)	<u>Drawdown Permeability</u> (mD)
2331.5	3397.2	3391.0	331.0
2341.6	3411.2	3410.0	54.0
2391.3	3538.1	15.6	0.3
2396.1	3534.5	10.2	0.05
2398.2	3693.8	10.1	0.3
2398.7	3695.9	9.6	-
2413.2	8.7	5.2	-
2413.0	8.3	5.4	-
2439.3	9.1	3.8	-
2442.0	3677.3	11.5	0.3
2455.0	3705.0	15.1	0.5
2495.5	3783.9	32.9	0.5
2522.4	5.9	4.0	-
2531.5	3797.9	574.0	0.3
2535.5	3798.2	3712.6	26.0
2555.8	tight	-	-
2559.0	31.8	26.2	-
2560.5	3858.9	1072.4	-
2563.4	19.5	15.5	-
2641.6	seal failure	-	-
2665.5	4279.4	1274.3	0.5
2665.5	4330.4	1249.4	0.3 Repeat
2670.8	4187.2	629.6	0.4
2677.7	11.0	8.2	-
2678.5	4486.5	918.9	0.6
2684.5	4182.2	2527.8	1.2
2691.5	4183.8	-	1.6
2719.4	4216.2	1878.6	0.7
2762.0	4317.3	12.9	0.2
2785.0	4394.2	12.4	0.3
2811.6	4613.7	862.0	0.4
2813.0	4526.4	1634.4	0.4
2871.4	16.0	8.4	-
2884.5	4587.4	1120.0	0.3
2911.0	12.0	8.6	-



APPENDIX 5  
Geochemistry

# PETROLEUM GEOCHEMISTRY

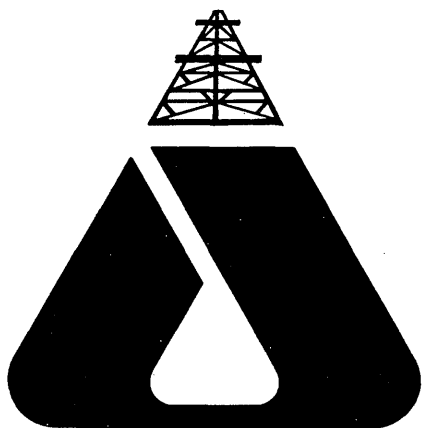
JUDITH 1

DATA REPORT

Prepared for:

THE SHELL COMPANY OF AUSTRALIA

May 1990



## ANALABS

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A Member of the Inchcape Group

TABLE 1

## ROCK-EVAL PYROLYSIS DATA (one run)

WELLNAME = JUDITH 1

DATE OF JOB = NOVEMBER 1989

DEPTH(m)	TMAX	S1	S2	S3	S1+S2	S2/S3	PI	PC	TOC	HI	OI
1555.0	421	0.30	4.89	1.48	5.19	3.30	0.06	0.43	2.40	203	61
1571.5	418	0.51	6.18	0.66	6.69	9.36	0.08	0.56	3.13	197	21
1600.0	425	0.48	11.23	0.35	11.71	32.09	0.04	0.97	1.86	603	18
1610.0	419	0.48	7.40	0.46	7.88	16.09	0.06	0.65	2.87	257	16
1654.0	415	0.27	3.99	0.56	4.26	7.13	0.06	0.35	1.62	246	34
1710.5	419	0.31	5.19	0.35	5.50	14.83	0.06	0.46	2.20	235	15
1764.0	427	0.20	3.85	0.38	4.05	10.13	0.05	0.34	2.08	185	16
1777.5	423	1.02	25.44	1.12	26.46	22.71	0.04	2.20	6.62	384	16
1821.5	422	0.33	2.83	0.35	3.16	8.09	0.10	0.26	2.22	127	15
1835.5	426	0.17	1.98	1.01	2.15	1.96	0.08	0.18	1.42	139	71
1869.5	427	0.18	2.00	0.51	2.18	3.92	0.08	0.18	0.65	307	78
1993.5	431	0.15	2.20	0.35	2.35	6.29	0.06	0.20	1.05	209	33
2023.0	435	0.06	1.98	2.70	2.04	0.73	0.03	0.17	1.85	107	145
2081.0	434	0.14	3.11	3.73	3.25	0.83	0.04	0.27	3.05	101	122
2113.0	434	0.08	1.18	4.37	1.26	0.27	0.06	0.10	0.89	132	491
2163.0	435	0.10	1.89	2.29	1.99	0.83	0.05	0.17	1.25	151	183
2210.5	435	0.16	1.86	1.39	2.02	1.34	0.08	0.17	1.65	112	84
2248.0	436	0.09	1.36	0.90	1.45	1.51	0.06	0.12	1.05	129	85
2268.0	435	0.09	1.44	1.93	1.53	0.75	0.06	0.13	0.95	151	203
2308.0	nd	nd	nd	nd	nd	nd	nd	nd	0.49	nd	nd
2325.0	435	0.09	1.49	1.24	1.58	1.20	0.06	0.13	1.35	110	91
2344.0	433	0.24	2.35	2.47	2.59	0.95	0.09	0.21	1.70	138	145
2364.0	437	0.07	0.47	0.96	0.54	0.49	0.13	0.04	0.50	94	192
2474.0	436	0.16	1.89	1.44	2.05	1.31	0.08	0.17	1.38	136	104
2630.5	441	0.10	1.19	3.94	1.29	0.30	0.08	0.11	0.90	132	437
2721.0	437	0.14	2.24	2.85	2.38	0.79	0.06	0.20	1.05	213	271
2908.0	437	0.17	1.16	1.51	1.33	0.77	0.13	0.11	0.93	124	162
2923.0	436	0.52	3.74	1.80	4.26	2.08	0.12	0.35	2.90	128	62

TMAX = Max. temperature S2  
S1+S2 = Potential yield  
PC = Pyrolysable carbon  
OI = Oxygen Index

S1 = Volatile hydrocarbons (HC)  
S3 = Organic carbon dioxide  
TOC = Total organic carbon  
nd = no data

S2 = HC generating potential  
PI = Production index  
HI = Hydrogen index



K.K. No.	Depth (m)	$\bar{R}_v$ max	Range	N	Description Including Liptinite (Exinite) Fluorescence
v1855	1555.0 SWC 40	0.34	0.28-0.47	28	Common cutinite, yellow to dull orange, sparse sporinite, yellow to orange, rare to sparse resinite and liptodetrinite, yellow to orange. (Siltstone>sandstone. Dom abundant, I>V>L. Inertinite abundant, vitrinite and liptinite common. Pyrite abundant. Iron oxide sparse.)
v1856	1571.5 SWC 39	0.36	0.28-0.47	26	Sparse cutinite, yellow to dull orange, rare to sparse sporinite, yellow to orange, rare resinite, yellow to orange. (Siltstone>shaly coal>coal. Coal rare, vitrinite only. Vitrite. Shaly coal common, V>I>L. Vitrite. Dom abundant, V>I>L. Vitrinite abundant, inertinite common, liptinite sparse. Pyrite abundant. Iron oxide rare.)
v1857	1610.0 SWC 37	0.37	0.29-0.48	26	Sparse cutinite, sporinite and liptodetrinite, yellow to orange, rare to sparse resinite, yellow. (Siltstone>claystone. Dom abundant, I>V>L. All three maceral groups common. Rare bitumen, yellow. Pyrite abundant. Iron oxide sparse to common.)
v1858	1654.0 SWC 35	0.36	0.29-0.43	28	Common cutinite, yellow to dull orange, sparse sporinite, yellow to orange, rare to sparse resinite, yellow to orange. (Siltstone>sandstone>shaly coal. Shaly coal sparse, V>I>L. Vitrite>vitrinertite. Dom abundant, V>I>L. Vitrinite abundant, inertinite and liptinite common. Sparse oil drops, yellow. Pyrite abundant. Iron oxide common.)
v1859	1777.5 SWC 28	0.44	0.36-0.52	26	Common cutinite and sporinite, yellow to dull orange, sparse resinite and liptodetrinite, yellow to dull orange, sparse suberinite, non fluorescing. (Siltstone>shaly coal>coal. Coal abundant, V>>L>I. Vitrite. Shaly coal major, V>>L>I. Vitrite>>clarite. Dom abundant, V>L>I. Vitrinite and liptinite abundant, inertinite sparse. Sparse bitumen, yellow. Pyrite abundant. Iron oxide sparse.)
v1860	1821.5 SWC 26	0.42	0.33-0.54	26	Sparse cutinite and sporinite, yellow to dull orange, rare suberinite, yellow to orange, rare <u>Botryococcus</u> related telalginate, yellow to orange. (Sandstone>siltstone>shaly coal. Shaly coal rare, V>L. Vitrite. Dom abundant, I>V>L. Inertinite common to abundant, vitrinite common, liptinite sparse. Pyrite abundant. Iron oxide common.)

K.K. No.	Depth (m)	$\bar{R}_v$ max	Range	N	Description Including Liptinite (Exinite) Fluorescence
v1861	1835.5 SWC 25	0.45	0.34-0.62	27	Sparse to common cutinite, yellow to dull orange, sparse sporinite, yellow to dull orange, sparse resinite, yellow to orange. (Siltstone>carbonate>sandstone>shaly coal. Shaly coal rare, V>L. Vitrite. Dom abundant, I>V>L. All three maceral groups common. Pyrite abundant. Iron oxide sparse.)
v1862	1869.5 SWC 23	0.41	0.30-0.56	27	Common cutinite, yellow to brown, sparse sporinite, yellow to dull orange, rare resinite, yellow to orange. (Sandstone>siltstone>carbonate>shaly coal. Shaly coal sparse, I>V>L. Inertite>vitrite. Dom abundant, V>I>L. All three maceral groups common. Pyrite sparse to common. Iron oxide sparse.)
v1863	2023.0 SWC 15	0.47	0.38-0.55	28	Sparse cutinite and sporinite, yellow to dull orange, rare resinite, orange. (Siltstone>>carbonate. Dom abundant, I>V>L. Inertinite and vitrinite common, liptinite sparse to common. Iron oxide sparse. Pyrite rare to sparse.)
v1864	2081.0 SWC 13	0.51	0.41-0.62	28	Sparse cutinite, yellow to brown, sparse sporinite, yellow to dull orange, rare resinite, yellow to orange. (Siltstone>>shaly coal. Shaly coal sparse, V>I>L. Vitrinertite>vitrite. Dom abundant, I>V>L. Inertinite abundant, vitrinite common to abundant, liptinite sparse. Pyrite common. Iron oxide sparse.)
v1865	2163.0 SWC 9	0.53	0.40-0.63	27	Sparse cutinite, orange to dull orange, sparse liptodetrinite, yellow to orange, rare sporinite, yellow to dull orange. (Siltstone>>carbonate. Dom common, I>L>or=V. Inertinite common, liptinite and vitrinite sparse. Pyrite and iron oxide sparse.)
v1866	2210.5 SWC 6	0.56	0.41-0.68	27	Sparse cutinite and resinite, orange to brown, rare to sparse sporinite, orange to brown. (Siltstone. Dom abundant, I>L>V. Inertinite abundant, liptinite and vitrinite sparse. Rare bitumen, orange. Iron oxide sparse. Pyrite rare.)
v1867	2325 SWC	0.54	0.44-0.64	27	Sparse cutinite, orange to brown, sparse sporinite, orange to dull orange, rare resinite, orange to dull orange. (Siltstone. Dom abundant, I>V>L. Inertinite common to abundant, vitrinite and liptinite sparse. Iron oxide sparse. Pyrite rare.)

K.K. No.	Depth (m)	$\bar{R}_V$ max	Range	N	Description Including Liptinite (Exinite) Fluorescence
v1868	2344 SWC	0.57	0.43-0.67	26	Sparse cutinite, orange to brown, sparse sporinite, yellow to dull orange, rare resinite, orange to dull orange, rare liptodetrinite, yellow to dull orange. (Siltstone>carbonate. Dom abundant, I>V>L. Inertinite abundant, vitrinite common, liptinite sparse. Pyrite and iron oxide sparse.)
v1869	2364 SWC	0.58	0.50-0.66	7	Rare liptodetrinite and sporinite, orange to dull orange. (Sandstone>siltstone>carbonate>shaly coal. Shaly coal sparse, I only. Inertite. Dom common to abundant, I>L=V. Inertinite common to abundant, liptinite and vitrinite rare.)
v1870	2474 SWC	0.59	0.44-0.72	27	Sparse cutinite and sporinite, orange to brown. (Siltstone>sandstone>shaly coal. Shaly coal sparse, V>I>L. Vitrite>vitrinertite(V). Dom abundant, I>V>L. Inertinite and vitrinite common, liptinite sparse. Pyrite and iron oxide sparse.)
v1871	2630.5 SWC	0.61	0.48-0.75	23	Rare cutinite and liptodetrinite, orange to dull orange. (Calcareous siltstone>carbonate>sandstone>?coal. ?Coal is rare and possibly occurs as intraclasts. Dom common, I>V>L. Inertinite common, vitrinite sparse, liptinite rare. Pyrite common. Iron oxide rare.)
v1872	2721 SWC	0.72	0.54-0.89	27	Sparse cutinite, orange to brown, sparse phytoplankton, yellow to dull orange, rare to sparse sporinite, yellow to dull orange. (Carbonate>calcareous siltstone. Dom abundant, V>I>L. All three maceral groups common. Pyrite common. Iron oxide rare.)
v1873	2923 SWC	0.78	0.65-0.92	27	Sparse cutinite, orange to brown, sparse resinite, orange to dull orange, rare to sparse liptodetrinite, yellow to dull orange, rare sporinite, orange to brown. (Carbonate>siltstone>sandstone>shaly coal>coal. Coal abundant, V>I>L. Vitrinertite>vitrite>clarodurite>clarite=inertite. Shaly coal abundant, V>I>L. Vitrite>vitrinertite>inertite>clarodurite. Dom abundant, V>I>L. Vitrinite abundant, inertinite common to abundant, liptinite sparse. Pyrite common. Iron oxide sparse.)

## 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 1cm<sup>2</sup> 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:

<u>Classification</u>	<u>Clastics</u>	<u>Carbonates</u>
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 =  $\frac{S2}{TOC} \times \frac{100}{1}$

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

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:

<u>S1 (mg/g or kg/tonne)</u>	<u>Classification</u>
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:

<u>S1+S2 (mg/g or kg/tonne)</u>	<u>Classification</u>
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  $((S2 \times 100)/TOC)$  and oxygen  $((S3 \times 100)/TOC)$  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:

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

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

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

<u>Classification</u>	<u>ppm Total Extract</u>
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:



<u>Classification</u>	<u>ppm Hydrocarbon</u>	<u>ppm Saturates</u>
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 Pyroprobe 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 = 1  $\mu$  l 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:

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

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

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 an 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 calculate 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 processes 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 spectrometry 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 sieves 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 SPECTROMETRY (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/bicucane fraction.

<u>Ion</u>	<u>Molecular Type</u>
177	Demethylated triterpanes
191	Normal triterpanes
205	Methyl triterpanes
163	Specific dehylyated 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) stereoisomer is converted in sediment to a mixture of the  $\alpha\alpha\alpha$  (20R) and  $\alpha\alpha\alpha$  (20S) compounds. The ratio of  $\alpha\alpha\alpha$  (20S) to  $\alpha\alpha\alpha$  (20R) +  $\alpha\alpha\alpha$  (20S) expressed as a percentage is about 25% at the onset of oil generation and increases almost linearly 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  $17\beta,21\alpha$  to  $17\alpha,21\beta$  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  $18\alpha$  (H) trisnorhopane to  $17\alpha$  (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  $18\alpha$  (H) + C27  $17\alpha$  (H) triterpanes to C30  $17\alpha,21\beta$  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  
$$\frac{C27(20R)}{C29(20R)} \text{ and } \frac{C27(20R+20S)}{C29(20R+20S)}$$
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):

<u><math>\delta^{13}C</math> (PDB)</u>	<u>Gas Type</u>
-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.

## REFERENCES

- Alexander, R., Kagi, R. I. and Woodhouse, G. W. "Measurement of thermal maturation of petroleum by proton magnetic resonance spectroscopy". *Nature*, 276, 1978, 598.
- Alexander, R., Kagi, R. I. and Woodhouse, G. W. "A new method for measuring the maturity of petroleum in source rocks". *APEA J.*, 19, 1979, 90-93.
- Alexander, R., Kagi, R. I. and Woodhouse, G. W. "Variation in the Ratio of Isomeric Butanes in the Carnarvon Basin of Western Australia". *Adv. in Org. Geochem.*, 1981, pp 76-79.
- Cooper, J. E. and Bray, E. E. "A postulated role of fatty acids in petroleum formation". *Geochim. Cosmochim. Acta*, 27, 1963, 1113-1127.
- Fuex, A.N., 1977. "The Use of Stable Carbon Isotopes in Hydrocarbon Exploration". *J. Geochem. Expl.*, 7, 155-188.
- Gransch, J. A. and Eisma E. "Characterization of the insoluble organic matter of sediments by pyrolysis". *Advances in Organic Geochemistry*, 1966, 407-426.
- Hunt, J. M. "Geochemistry of Petroleum". *Am. Assoc. Pet. Geol. Continuing Education Lecture Series*.
- LeTran, K., 1975. "Analyse et Etude des Hydrocarbures Gazeux Occlus dans le Sediments: Exemples d'Application a l'exploration petroliere". *Bull. Centre Rech. Pau*, 9, 223-243.
- LeTran, K., Connan J. and Van der Weide, B. "Diagenesis of organic matter and occurrence of hydrocarbons and hydrogen sulphide in the S. W. Aquitaine Basin". *Bull. Centre Rech., Pau-SNPA*, 8, 1974, 111.
- Lijmbach, G. W. M. "On the origin of petroleum". *Proc. 9th World Petroleum Congress*, 2, 195, 357-369.
- Mackenzie, A. S. et. al., 1980. Molecular parameters of maturation in the Toarcian Shales, Paris Basin, France-1. Changes in the configurations of acyclic isoprenoids, steranes and triterpanes. *Geochim. Cosmochim. Acta*, 44:1709:1721.
- Philippi, G. T. "The influence of marine and terrestrial source material on the composition of petroleum". *Geochim. Cosmochim. Acta*, 38, 1974, 947.
- Powell, T. G. and McKirdy, D. M. "Geological factors controlling crude oil composition in Australia and Papua New Guinea". *Amer. Assoc., Petrol. Geol.*, 59, 1975, 1176.
- Scalan R. S. and Smith J. E. "An improved measure of the odd-even predominance in the normal alkanes of sediment extracts and petroleum". *Geochim. Cosmochim. Acta*, 34, 1970, 611-620.
- Seifert, W. K. 1978. Steranes and terpanes in kerogen pyrolysis for correlation of oils and source rocks. *Geochim. Cosmochim. Acta*, 42:473-484.



- Seifert, W. K. and Moldowan, J. M. 1979. "Application of biological marker chemistry to petroleum exploration". Special paper, 10th World Petroleum Congress, Bucharest.
- Seifert, W. K. and Moldowan, J. M. 1978. "Application of steranes, terpanes and monoaromatics to the maturation, migration and source of crude oils". *Geochim. Cosmochim. Acta*, 42:77-95.
- Seifert, W. K. and Moldowan, J. M. 1979. "The effect of biodegradation on steranes and terpanes in crude oils". *Geochim. Cosmochim. Acta* 43:111-126.
- Seifert, W. K. and Moldowan, J. M. 1981. "Paleoreconstruction by biological markers". *Geochim. Cosmochim. Acta*, 45:783-794.
- Stahl, W. J. "Carbon and nitrogen isotopes in hydrocarbon research and exploration". *Chem. Geol.*, 20, 1977, 121-149.
- Stahl, W. J. "Source rock-crude oil correlation by isotopic type-curves". *Geochim. Cosmochim. Acta*, 42, 1978, 1573-1577.
- Tissot, B. et. al. "Origin and evolution of hydrocarbons in early Toarcian shales, Paris Basin, France". *Amer. Assoc. Petrol. Geol.*, 55, 1971, 2177.
- Tissot, B. et. al. "Influence of nature and diagenesis of organic matter in the formation of petroleum". *Amer. Assoc. Petrol. Geol.*, 58, 1974, 499.
- Tissot, B. and Welte, D. H. "Petroleum Formation and Occurrence". Springer-Verlag. Berlin, Heidelberg, New York, 1978.
- Welte, D. H., et. al. "Correlation between petroleum and source rock". *Proc. 9th World Petroleum Congress*, 2, 1975, 179-191.

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. C29 $\alpha\alpha\alpha$ steranes	217
----- C29 $\alpha\alpha\alpha$ steranes + C29 $\alpha\beta\beta$ steranes	217
8. C27/C29 diasteranes	259
9. C27/C29 steranes	217
10. 18 $\alpha$ (H)-oleanane/C30 hopane	191
11. C29 diasteranes	217
----- C29 $\alpha\alpha\alpha$ steranes + C29 $\alpha\beta\beta$ steranes	217
12. C30 (hopanes + moretanes)	191/217
----- 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.  $18\alpha$  (H)-hopane/ $17\alpha$  (H)-hopane (Ts/Tm)

Maturity indicator. The ratio of  $18\alpha$  (H) trisnorhopane to  $17\alpha$  (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.  $T_m$  decreases with maturity. This parameter is not reliable in very immature samples.

2. C30 hopane/C30 moretane

Maturity indicator. The conversion of C30  $17\beta$ ,  $21\beta$  hopane to  $17\beta$ ,  $21\alpha$  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 thermal 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.  $C_{29} 2OS_{\alpha\alpha\alpha} / C_{29} 2OR_{\alpha\alpha\alpha} + C_{29} 2OS_{\alpha\alpha\alpha}$

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.  $C_{29} \alpha\beta\beta / C_{29} \alpha\alpha + C_{29} \alpha\beta\beta$  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.  $C_{27}/C_{29}$  diasteranes and steranes

Source indicator. It has been suggested that marine phytoplankton is characterised by a dominance of  $C_{27}$  steranes and diasteranes whereas a preponderance of  $C_{29}$  compounds indicates strong terrestrial contributions. ( $C_{28}$  compounds are nearly always the lowest of the three sterane groups. High proportions of  $C_{28}$  compounds could indicate a contribution from lacustrine algae). Values smaller than 0.85 for  $C_{27}/C_{29}$  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  $C_{29}$  steranes, the above rules have to be applied with caution. Any simplistic interpretation of  $C_{27}/C_{29}$  steranes and diasteranes can be dangerous and the interpretation of these data should be consistent with other geological evidence.

10.  $18 \alpha (H) - \text{oleanane}/C_{30} \text{ hopane}$

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  $18 \alpha (H) - \text{oleanane}/C_{30} \text{ hopane}$  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  $\alpha\alpha$  steranes + C29  $\alpha\beta\beta$  steranes

Source indicator. Parameter used to characterise the oxidicity 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 biodegradation.

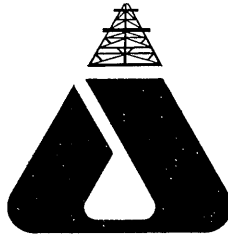
14. Rearranged/normal drimanes

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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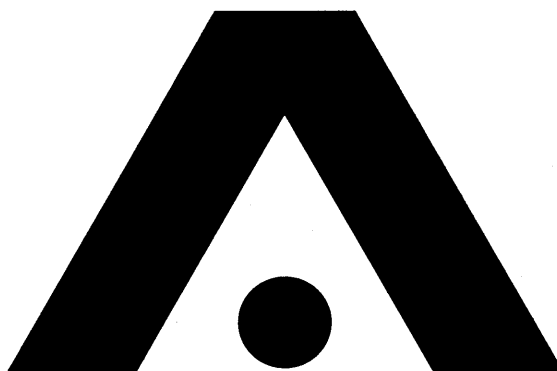
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APPENDIX 6

Petrography

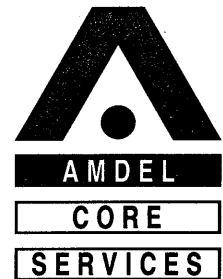


**AMDEL**

**CORE**

**SERVICES**





14 December 1989

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Shell Company of Australia  
1 Spring Street  
MELBOURNE VIC 3000

Attention: EXO

**REPORT: 001/005**

**CLIENT REFERENCE:** ITC 03147/EXO  
**MATERIAL:** Sidewall Cores  
**LOCALITY:** Judith -1  
**WORK REQUIRED:** Petrography Services

Please direct technical enquiries regarding this work to B G Steveson.

*Brian Steveson*

Dr Brian G Steveson  
Manager Australasia  
on behalf of Amdel Core Services Pty Ltd

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Amdel Core Services Pty Limited  
Incorporated in South Australia

1. INTRODUCTION

## 1. INTRODUCTION

Five sidewall cores from Judith -1 were received for petrography.

An impregnated thin section was prepared from each and these were examined by conventional means. 300 points were counted in each thin section. Photomicrographs were taken to illustrate significant features of the rocks.

In summary, the samples are sandstones which are characterised particularly by the abundance of "clay" rich lithic fragments. During compaction and lithification these have been squeezed so as to fill intergranular spaces and choke pore throats. This has been the most important process which has affected porosity modifications to the original sand.

The development of authigenic carbonate and kaolinite has been much less significant petrophysically.

2. P E T R O L O G Y

Judith No 1 - Sidewall Core 12 - 2688 m

Rock Name: Compact Lithic Sandstone

Thin Section: The mineralogy of the sample as determined by point counting is as follows:

Component	%
Quartz and Quartzite	58
Soft argillaceous clasts	29
Rigid Siliceous clasts	2
Carbonate	7
Pores	2
Kaolinite	2
Opagues	Trace
Feldspar/Heavy Minerals	Trace

Fine-grained heterogeneous material is abundant in this rock and this is interpreted, with confidence, as being derived from original lithic fragments. In many instances the outlines of the original lithic grains can be seen and this applies particularly to siliceous, strong lithologies rather than to the softer, more argillaceous lithic fragments. Some of these give the appearance in places, of being matrix but their heterogeneity is taken as a clear indication that they are derived from sand-grade lithic fragments and not from a muddy matrix.

The lithic material consists, particularly from a petrophysical point of view, of two types of rocks: those which retain compact detrital outlines and therefore may be regarded as part of the framework of the rock; and deformed argillaceous lithic fragments which appear to have been squeezed between the detrital grains and now fill intergranular space where they occur. As the rock now appears, the inter-quartz material is simply a dense aggregate of varied fine-grained material and there is little or no porosity in most fields of view. The more abundant types of lithic grains are cherts, fine-grained siliceous silty rocks and phyllosilicate-rich shales which have been deformed. There are rare instances of what appear to be fine-grained siliceous volcanics, some large aggregates of fine-grained carbonate which maybe derived from limestone fragments and some examples of opaques which may have been original fragments of some kind.

Authigenic minerals are represented by carbonate and kaolinite. Carbonate, as well as forming as what are taken to be limestone fragments, occurs as widely distributed fine-grained material which has probably replaced some types of lithic fragments. It is thought unlikely that the carbonate is a significant void-filling phase. Authigenic kaolinite, by contrast, forms monomineralic aggregates generally not more than 0.2 mm in size. These are featureless fine-grained aggregates and are taken to be pore filling precipitates. The kaolinite is not abundant and probably contributed little to occlusion of the original porosity (compared to compaction and deformation of the lithic fragments).

Much of the apparent porosity in the thin section is thought to be derived from fracturing of the rock during collection of the sidewall core and it appears to the author unlikely that the in-situ rock contained very much porosity or permeability.

Quartz grains are well to moderately well-sorted and commonly range in size from approximately about 0.2 mm to the order of about 0.7 mm. The average grain size is a little difficult to determine but is probably at least 0.3 mm. Some of the grains have been fractured during collection of the side-wall core but, disregarding this, it appears likely that the detrital grains were mainly separated from each other by fine-grained material as a result of deformation of soft lithic fragments.

Judith No 1 - Sidewall Core 18 - 2532 m

Rock Name: Lithic Sandstone

Thin Section: The volume percentages of the minerals determined by point counting are as follows:

Component	%
Quartz and Quartzite	48
Soft argillaceous clasts	22
Rigid Siliceous clasts	8
Carbonate	8
Pores	9
Kaolinite	5
Feldspar/Heavy Minerals	Trace

This is a well sorted sandstone in which the average grain size of the majority of the grains is approximately 0.2 - 0.25 mm. Quartz grains are equant in shape and range from angular to sub-round in outline. A very small proportion of the quartz grains show narrow overgrowths. It appears that some of the angularity of the quartz is due to partial corrosion by cement (especially carbonate) and partly to the development of long and curved contacts. It is difficult to see in a sidewall core the overall significance of pressure solution effects but there are certainly areas of the thin section in which more than half of the grains show more than simply touching, tangential contacts. Minor detrital phases are a few grains of clear microcline and rare instances of non-twinned feldspar which is probably orthoclase. The latter generally shows a slight turbid alteration. Lithic fragments are somewhat more abundant and are quite varied. Probably the most abundant types are grains of chert and rather more indeterminate fine-grained quartz/clay/mica aggregates. The latter are probably best referred to as metasedimentary types. The thin section contains one or two instances of finely intergrown quartz/feldspar lithic grains and these appear to be related to high level igneous rocks such as granophyres.

The rock contains, apart from traces of quartz overgrowths alluded to above, two diagenetic cement minerals: kaolinite and a carbonate. The kaolinite is generally present as monomineralic aggregates of relatively well-crystallised but fine-grained material. This shows no internal textures (such as might be present in kaolinite which has replaced a pre-existing mineral) and it is concluded that the kaolinite is simply a precipitate which filled pore spaces. The carbonate cement has a somewhat patchier distribution and it commonly forms crystals which are equant and irregular in shape and up to 0.1 mm in size. Some of these are distributed as single crystals throughout the rock but elsewhere they form loose and irregular aggregates commonly up to about 0.3 mm in size. In places somewhat ragged crystals of carbonate occur within aggregates of kaolinite and, although this texture cannot be interpreted unambiguously, it probably indicates that the carbonate crystalized after the kaolinite.

Thin sections of sidewall cores are not an ideal medium for estimating the amount of porosity in the rock but an attempt has been made to count the pores. It should be noted, however, that there is likely to be significant overestimation of the in-situ porosity by this counting method. The pores which appear to be an integral part of the rock are commonly not more than 0.25 mm in size and are probably reasonably well-interconnected in three dimensions. It is difficult to estimate to what extent the pores are of secondary origin but it seems likely that at least one third of the pores are probably large enough to be included in this category.



Judith No 1 - Sidewall Core 23 - 2428.5 m

Rock Name: Compact Carbonate-Cemented Lithic Sandstone

Thin Section: The volume percentages of the minerals determined by point counting are as follows:

Component	%
Quartz and Quartzite	53
Soft argillaceous clasts	26
Rigid Siliceous clasts	9
Carbonate	8
Pores	3
Kaolinite	1
Feldspar/Heavy Minerals	Trace

This sample is richer in lithic fragments and correspondingly deficient in pores compared to sidewall core 18. There are numerous aggregates of fine-grained minerals in this rock which form patches of the order of 0.1 - 0.3 mm in size which, because of their heterogeneity, are interpreted as being compressed and possibly partly re-crystallized remnants of lithic fragments. To a large extent it is the compaction and squeezing of these between the more rigid quartz grains which has resulted probably in a relatively early decrease in the porosity in the original sand. What porosity remained was probably occluded largely by the precipitation of kaolinite and, more particularly, carbonate. As a result of these processes the sample appears to be rather impervious and probably essentially impermeable.

The rock is well-sorted and quartz grains mostly range from 0.2 - 0.35 mm in size. Most are equant in shape and generally are angular. There is evidence of pressure solution effects on the quartz grains and the development of concavo-convex grain boundaries. More commonly however, the quartz grains are separated from each other by fine-grained aggregates of either lithic material or cements. Feldspar is present only in trace amounts in this rock but has the same characteristics as those described in sidewall core 18.

A large proportion of the volume of the rock is composed of fine-grained material which appears to be derived from original fine-grained lithic fragments which have been distorted during compaction of the rock. In addition, some may have been partly re-crystallized and some partly invaded by later carbonate cement so that the textures are obscure in many areas. It seems likely, from a mineralogical point of view, that the material consists of quartz with smaller amounts of phyllosilicates, including clays and mica. Chert is less abundant than in sidewall core 18 and there is much more material which can probably be thought of as fine-grained metasilstones and metamorphosed shales.

Carbonate is essentially a cementing phase and much of it forms rather irregular and porous aggregates of equant anhedral crystals commonly less than 0.1 mm in size. Such material is widely distributed throughout the whole area of the rock and is associated in rather varied patchy aggregates with the fine-grained lithic material which it appears to have partly replaced. Elsewhere carbonate

forms finer-grained aggregates which are much larger than this; they range in size up to about 0.5 mm. The origin of such large aggregates of carbonate is probably related to the deformation of original limestone fragments.

The rock contains only trace amounts of authigenic kaolinite and there are small amounts of stable heavy minerals of which tourmaline appears to be the most abundant.

Judith No 1 - Sidewall Core 25 - 2392.5 m

Rock Name: Coarse Lithic Sandstone

Thin Section: The volume percentages of the minerals determined by point counting are as follows:

Component	%
Quartz and Quartzite	72
Soft argillaceous clasts	16
Rigid Siliceous clasts	4
Carbonate	5
Pores	3
Feldspar	Trace

This is a relatively coarse-grained sandstone and the average grain size of quartz and quartz-rich lithic fragments is probably at least 0.4 mm. There is a fairly wide size range from approximately 0.2 - 0.8 mm and the sample appears somewhat less well sorted than the two finer-grained rocks described immediately above. The rock contains a high proportion of quartzite grains (this may be a function of the coarse-grained nature of the sandstone but, including these with the single crystals of quartz, the grains are generally equant in shape and angular in outline with a few instances of sub-round grains. None of the grains show overgrowths. There is considerable evidence of the development of long contacts between the grains even though this is inhibited, to some extent, by the abundance of fine-grained lithic material which has been squeezed between the grains. The extent of pressure solution is also difficult to determine because the sidewall core tends to fracture along grain margins and disrupts these parts of the thin section.

Feldspars are present in only trace amounts and only two grains were unambiguously identified in the thin section. These tend to be towards the finer end of the grain size distribution and one is a perthite and the other has a rather indeterminate banded twinning pattern and may well be some kind of orthoclase. Lithic material is relatively abundant and includes a large amount of fine-grained phyllosilicate-rich material as well as finer-grained quartz/mica/clay lithologies. The phyllosilicate-rich rocks are metamorphosed aluminous sediments, with well developed banded textures which have been, now distorted and curved as the lithic fragments have been distorted around the more rigid quartz grains during compaction. Many of these aggregates are as much as 1.0 mm in length and relatively narrow. Most consist of birefringent sericite or micaceous material and in some there is a considerable amount of fine-grained carbonate. It seems likely that this carbonate is introduced material, although there is no specific evidence for this. Elsewhere lithic fragments are more quartz-rich and can be considered as metamorphosed siltstones and they have a more equant outline and clearly were somewhat more rigid than the micaceous or argillaceous lithologies. As in the sample described immediately above, there are a few large aggregates of very fine-grained carbonate which were probably limestone lithic fragments.

Occlusion of the porosity of the original sandstone occurred in this rock to a moderate extent as a result of pressure solution effects on the quartz grains but, more significantly, by the deformation and squeezing of relatively soft lithic fragments between the quartz grains. Carbonate may be a cementing phase but it appears not to be void-filling but, rather, has replaced some of the lithic material. No authigenic kaolinite was identified.

The description above refers to the bulk of the thin section but it should be recorded that a significant proportion of the rock (as represented by the sidewall core) is a bed of a dark ferruginous and argillaceous silty shale.

Judith No 1 - Sidewall Core 29 - 2332 m

Rock Name: Compact Lithic Sandstone

Thin Section: The volume percentages of the minerals determined by point counting are as follows:

Component	%
Quartz and Quartzite	66
Soft argillaceous clasts	26
Rigid Siliceous clasts	2
Pores	4
Opagues	2
Feldspar/heavy minerals	Trace

This sample has been somewhat more damaged during collection of the sidewall core and is, correspondingly, somewhat more difficult to interpret. This applies particularly to rather fine-grained quartz aggregates between larger grains. These are taken to be derived from fragmentation of sand-grade grains and it is thought likely that the sample probably originally showed considerable pressure solution effects and the development of long and concavo-convex boundaries. Even so there is a considerable amount of fine-grained lithic material.

The quartz grains appear to have been well-sorted about an average size of approximately 0.3 mm. Some grains are mainly surrounded by lithic material and retain sub-angular to sub-round original detrital outlines but more have at least some evidence of the development of long contacts which developed as a result of pressure solution. It is likely that this was an early stage in the occlusion of the original porosity of the sandstone. Lithic fragments include both phyllosilicate-rich foliated metasedimentary rocks and fine-grained siliceous lithologies. The latter generally retain equant detrital outlines but the phyllosilicate-rich rocks are commonly extremely distorted in shape and tend to fill intergranular spaces where they occur and it is thought that this process has been probably the most significant in reducing the porosity of the rock. Both the fine-grained quartz lithologies (mainly chert) and the metamorphosed shales testify to the presence of sedimentary rocks in the provenance terrains.

The sample contains only traces of feldspar and small amounts of stable heavy minerals. In one area of the thin section there are large aggregates of an opaque mineral and these are in some instances as much as 1.0 mm in size. These aggregates tend to fill intergranular spaces and probably represent a late introduction of ferruginous material into the rock. Also present is an elongate raft of a dark ferruginous siltstone. This is several millimetres in length and generally about 0.5 - 1.0 mm in thickness. Carbonate is irregularly distributed throughout the rock (mainly as a fine-grained replacement of lithic material) and this, too, probably represents material introduced into the rock at a relatively late stage in the diagenetic history of the sample.

3. PHOTOMICROGRAPHS

3. **PHOTOMICROGRAPHS**

Photomicrographs have been taken to show features of the rocks.

The caption for each photomicrograph shows SWC, depth, length of long dimension and either PPL (plane polarised light) or CL (crossed Nicols).