ROBERTSON RESEARCH INTERNATIONAL LIMITED

INTERIM REPORT NO 3026P

REPORT ON A MATURATION AND SOURCE ROCK

POTENTIAL STUDY OF THE SECTION 1,200 TO

4,014 METRES OF THE MOBIL NORWAY 33/12-5 WELL,

NORWEGIAN NORTH SEA

by

B. S. COOPER

C. DARLINGTON

M. J. FISHER

D. B. CAULFEILD-BROWNE

J. S. BUTTERWORTH

Project No. RRI/756/IID/2234

MARCH, 1976

Prepared for :

Mobil Exploration Norway Inc.,
P. O. Box 510,
Bǿrehaugeni,
Stravanger,
Norway.

C O N T E N T S

T A B L E S

F I G U R E S

A P P E N D I C E S

INTRODUCTION

This Interim Report concerns geochemical analyses performed on the Tertiary, Cretaceous, and parts of the Triassic as penetrated by the Mobil Norway 33/12-5 Well. Further samples are to be received from the client and should they merit investigation the results will be incorporated into a final report.

A study of light hydrocarbons, spore colouration, kerogen type, vitrinite reflectivity and source rock potential has been carried out on samples from the section 1,200 to 4,014 metres of the Mobil Norway 33/12-5 Well.

The maturation of the samples was determined at approximately sixty metre intervals throughout the section excepting parts of the Triassic section where the vitrinite reflectivity method and light hydrocarbon analysis were not considered useful tools. Organic carbon content screening was carried out from 1,200 to 3,354 metres and on the basis of these results samples for source rock analysis were selected.

The samples were received as wet ditch cuttings preserved in drilling mud, and, after washing with cold water and removal of contaminants, (mainly walnut shell and mica), were considered to be of fair to good quality for geochemical analysis.

The age of the section reported here ranges from Oligocene to Upper Triassic.

RESULTS AND INTERPRETATION

In this chapter the results of the maturation and source rock evaluation
are described separately and integrated in the Conclusion.

A.   MATURATION EVALUATION

Three methods have been used to assess the maturation state of the section,
they are light hydrocarbons, spore colouration and vitrinite reflectivity
analyses.

1.   Light Hydrocarbon Analysis   (Table 1 and Figures 1 and 2)

The gaseous and gasoline range (C_1 to C_4 and C_5 to C_7), hydrocarbons
have been analysed to determine the quantities and relative proportions
of the absorbed hydrocarbons in the kerogen. A total of thirty-three samples
has been analysed over the section 1,200 to 3,326 metres.

Gaseous Hydrocarbons   (Figure 1)

Hydrocarbons in the range C_1 to C_4, (methane to n-butane), were found
to be present in very small quantities of less than one part per million.
Some loss of these hydrocarbons has undoubtedly occured, though the relative
proportions of the gases should be virtually unaffected. It is usual for
immature sediments to contain only methane of biogenic origin, but as a
result of increasing maturation mature sediments normally contain up to 70%
wet gas with the relative proportion of methane decreasing gradually until organic
metamorphism is reached when methane again is predominant.

The results of the analysis show that down to a depth of 2,472 metres, the
total gaseous hydrocarbon content is low and ethane alone is associated
only occasionally with methane. Below this depth the gaseous hydrocarbon
contents show an increase to generally more than 100 ppb and the remaining
C_3 and C_4 hydrocarbons are usually present, though often only in trace quantities.
Below 2,472 metres depth the section appears mature.

Gasoline Hydrocarbons (Figure 2)

Maturity is usually indicated when all the constituent gasolines of the C_5 to C_7 range, (Table 1), are present in approximately equal amounts and when the total quantity of these hydrocarbons exceeds 100 ppb.

During analysis, especially on samples from depths of between 1,800 and 2,538 metres, very large gas expansions occured on heating the samples and the gas emitted could not be fully contained. From the results it appears that the samples above 2,361 metres depth contained either very small quantities of gasoline hydrocarbons or only a few of the component hydrocarbons were present which suggest that the sediments are immature. In view of the distribution and relative proportion of hydrocarbons in the 2,361 metre sample, at least a transitional state of maturity appears to exist and, below about 2,600 metres, the section is indicated to be mature for oil-generation from suitable types of organic matter.

2. Spore Colouration Analysis (Table 2 and Figure 4)

Kerogen maturation during diagenesis has been described by a number of workers who have referred specifically to modifications of sporopollenin. The process of maturation is considered to increase the visible colour density of sporopollenin from pale yellow, through orange and brown to black. A ten-point scale of colour indices has been used in this study which comprises samples over the section from 1,200 to 4,014 metre.

Between depths of 1,200 and 2,700 metres spore colour indices increase in value from 2 to 4. Within the Cretaceous sediments the rate of increase in spore colour appears to be greater than in the overlying Tertiary, From these results it seems likely that the transition from immaturity to maturity for oil-prone types of organic matter takes place at about 2,300 metres at which depth spore colour indices of 3 are reached.

Samples from 2,760 and 2,820 metres were found to be barren of any indigenous palynomorphs. Samples from 3,096 to 4,014 metres depth gave spore colour indices of 5.5 to 6.5-7 which suggests a fairly uniform increase in spore colour through

this part of the Triassic section. On extrapolation, these results suggest a spore colour value of about 5.5 to be attained by the Triassic sediments directly below the Lower Cretaceous - Triassic unconformity. The change in spore colour index from a value of 4.0 at 2,700 m in depth in the Cretaceous to a value of 5.5 extrapolated through the Triassic could also, like the discontinuity in reflectivity values, arise from the unconformable break between Cretaceous and Triassic. However, the possibility of overpressuring in the Cretaceous shales, causing a thermal barrier and an impermeable seal, must also be considered since it could give rise to a rapid change in temperature and laterally control the migration path of the hot waters originating at greater depths. The Triassic section would be quite mature for oil generation if suitable organically rich sediments occur.

Kerogen Description (Table 2)

A proportional description of the dominant kerogen components has been made on unsieved samples used in slides for biostratigraphic analysis.

From 1,200 to about 1,746 metres the dominant kerogen types are vitrinite, (mainly telinite), and sapropel. Below this depth and throughout the remainder of the section the vitrinite component is lower and rarely exceeds 30% of the total kerogen. Within this lower interval inertinite, especially semifusinite is generally predominant, while the amount of sapropelic material is fairly variable and occasionally exceeds one third of the total kerogen between 2,121 and 2,640 metres. The Triassic sediments are particularly dominated by semifusinite.

3. Vitrinite Reflectivity Analysis (Table 3 and Figure 3)

The results of the vitrinite reflectivity analysis are considered to give a fair representation of the vitrinite rank gradient for the section after allowing for the presence of mainly reworked material particularly below about 2,000 metres depth, (figure 3).

The trend from the Oligocene down to the base of the Lower Cretaceous is quite well defined with reflectivities being interpreted as increasing

from about 0.18% at 1,200 metres to about 0.50% at 2,700 metres. The rate

of increase in vitrinite reflectivity does appear to be greater in the

Cretaceous sediments than in the overlying Tertiary. These results indicate

that humic, gas-prone organic material is only likely to have reached early

maturity at the base of the Cretaceous interval. The sediments may, however, be

sufficiently mature for the generation of oil from suitable sapropelic or

exinite organic matter at depths below about 2,300 m at which depth vitrinite

reflectivities of 0.35% are attained.

Within the Triassic interval of this section only two samples were analysed,

the mainly red-bed samples being considered too low in organic content to

contain a sufficient quantity of vitrinite for measurement. Samples from

2,760 and 2,820 metres gave reflectivities varying from 0.35% (caved material),

to 0.86%, with well defined reflectivities of 0.67% and 0.61%. These results

illustrate the slightly higher level of maturation in the Triassic sediments,

consistent with the presence of an unconformity.

On investigation of the samples in ultraviolet light no distinguishable

trend in fluorescence colours could be seen through the section. However,

it was noted that the Tertiary samples contained mainly pale yellow fluorescing

material while those of Cretaceous age exhibited organic material with

chiefly yellow, golden yellow and yellow-orange fluorescence.

4.   Comparison of Maturation Indices   (Figure 4)

Light hydrocarbon, spore colouration and vitrinite reflectivity analyses

have been used in a composite evaluation of the well section, the three methods

being in close agreement in their estimation of maturity.

Spore colouration and vitrinite reflectivity have suggested that oil-prone

types of organic material will become mature at about 2,300 metres depth while

light hydrocarbon analysis indicates that from about 2,300 to 2,600 metres

a transitional state of maturity exists for this type of organic matter. Hence,

below 2,600 metres oil generation is likely from suitable organically rich

- 5 -

sediments. In view of the vitrinite reflectivity measurements, gas generation from humic organic matter only seems possible below about 2,700 metres and the humic materials of the Tertiary and Cretaceous sediments are immature. Indeed the Cretaceous-Triassic unconformity may mark the boundary between immaturity and maturity for gas sourcing organic matter.

B.   Source Rock Evaluation   (Table 4 and Figure 5)

Initially samples were chosen for organic carbon content determination at short intervals of mainly less than twenty-five metres over the section 1,200 to 3,354 metres. On the basis of these results and, on considering the types of lithologies present, source rock analysis was carried out on selected samples usually at intervals of 60 metres within the Tertiary and Cretaceous. Shorter intervals were analysed between 2,646 and 2,841 metres to include the mature Cretaceous shales and the upper parts of the Triassic sequence. No source rock analyses were carried out on samples below 2,841 metres in view of the organic leanness and the presence of usually non-prospective lithological types. The well section has been divided into five intervals for description in view of the geochemistry and stratigraphy.

1.   Interval 1,200 - 1,908m (Tertiary) Samples 1 to 36

This interval was found to consist of a sequence of almost entirely olive-grey shale. Organic carbon contents between 1,200 and 1,308 metres are average for shale type lithologies ranging from 0.91% to 1.72%, though . contents of organic carbon are low over the remainder of the interval varying from 0.32% to 0.71%.

The amount of material extractable in organic solvents is very low ranging from 25 ppm to 250 ppm while the proportion of extractable organic material varies from 0.5% to 2.2%. Hydrocarbon abundances are also extremely low, all of the analysed samples containing less than 20 ppm hydrocarbons.

In general, sediments are considered to be insufficiently rich in organic carbon and hydrocarbon to have any potential as prospective hydrocarbon source rocks.

2.   <u>Interval 1,920 - 2,325 m</u> (<u>Cretaceous</u>)   <u>Samples 37 to 58</u>

This interval consists of grey and olive-grey shales of generally low, though variable, organic carbon content ranging from 0.34% to 0.91% except for the richer samples 50 and 54 with 1.46% and 1.90% respectively.

The extractability of the samples is quite low ranging from 1.8% to 3.2% the amounts of material extractable varying from 90 ppm to 165 ppm. The abundance of hydrocarbons is very low at less than 20 ppm in all the analysed samples.

These results suggest that the sediments are lean in organic matter and contain only limited amounts of hydrocarbons which prevent them from having a significant potential as hydrocarbon source rocks.

3.   <u>Interval 2,340 - 2,721 m</u> (<u>Cretaceous</u>)   <u>Samples 59 to 82</u>

Organic carbon contents in this dominantly shale interval are somewhat higher than in the preceding two intervals. The majority of the samples have organic carbon contents of greater than 1%,no sample having a content of less than 0.59%. Two samples, 59 and 80, have above average organic carbon contents of 5.8% and 4.8% respectively.

The amount of material extractable in organic solvents varies from 1.9% to 7.1% and the amount of extractable material is generally higher than for the two shallower intervals. Hydrocarbon contents are quite low and not greater than 35 ppm apart from the 140 ppm content of the composite sample 61 to 63 and the 150 ppm content of sample 82.

Apart from these two latter mentioned samples none of the remaining samples have potential as oil source rocks due to their very low hydrocarbon contents. Samples 59 and 80, do contain sufficient amounts of organic material for the sourcing of gaseous hydrocarbons if mature humic material is present in the sediments. Sample 82 and the composite sample, 61-63, have sufficient organic carbon and hydrocarbons to suggest that the sediments have a fair potential for the sourcing of liquid hydrocarbons provided the sediments have reached the appropriate level of maturity.

4. <u>Interval 2,739 - 2,841m (Triassic) Samples 83 to 88</u>

Over this short interval the dominant lithology changes gradually from grey shale to red-brown shale, while the organic carbon content ranges from 0.32% to 0.69% and appears to decrease with depth. Grey shales, hand picked from samples 84 and 88, contain 2.06% and 0.99% of organic carbon respectively. From both the geochemical results and biostratigraphical evidence it appears that large quantities of caved Cretaceous sediment are present in these samples. The presence of these cavings will greatly affect the true chemical composition of the Triassic sediments and it is suspected that most of the hydrocarbons found in these samples are not indigenous to the Triassic.

Extractabilities are wide ranging, varying from 3.1% to 16.6%, while sample 88 has a high, 41.7%, extractability which is suggestive of oil-staining. Hydrocarbon contents are quite variable, though generally low, only the presumed oil-stained sample 88 has a hydrocarbon content in excess of 115 ppm.

In view of the uncertain reliability of these chemical parameters it is believed that this Triassic interval is devoid of any potential oil or gas source rocks.

5. <u>Interval 2,859 - 3,354 m (Upper Triassic) Samples 89 and 112</u>

This interval consists of mainly red-brown siltstones and shales only occasionally interspersed with light grey siltstone or mudstone and traces of dark grey shale. Only organic carbon content determination was carried out on these samples, contents ranging from 0.09% to 0.54%. The majority of samples have organic carbon contents of less than 0.30%. A hand-picked dark grey shale from sample 112 contained 0.91% organic carbon.

It is considered doubtful whether any of the sediments within this interval could have source rock potential in view of their low organic contents and moreover, their deposition in an oxidising environment. No further oil stain was seen.

CONCLUSION

From the results of the maturation and source rock evaluation of

samples from the interval 1,200 to 4,014 metres of the Mobil Norway

33/12-5 Well the following conclusions have been reached:-

i.   Interval 1,200 - 1,908m. The sediments in this interval were found

to be immature for the generation of both gaseous and liquid hydrocarbons.

Only very low concentrations of hydrocarbon were found and the organic richness

of the samples was mainly well below average for shale type lithologies.

ii.   Interval 1,920 - 2,325m. Within this interval the sediments are mainly

immature for the generation of oil from oil-prone types of organic matter,though

it is believed that a state of transitional maturity is entered around 2,300

metres depth. Humic, gas-prone types of organic matter are as yet immature

for gas generation. Hydrocarbon concentrations are presently very low and

organic carbon content rarely rise above average. The sediments appear to

have no hydrocarbon source potential at the level of maturity measured.

iii. Interval 2,340 - 2,721 m. This interval is transitionally mature to

mature for oil generation from suitable types of organic matter,though still

immature for the generation of gas from humic material. Samples from 2,382 to

2,421 metres and from 2,721 metres indicate sediments with a fair potential

for sourcing oil. At 2,682 metres a 4.8% organic carbon content was noted

and if suitably mature this interval could source gaseous hydrocarbons.

iv.   Interval 2,739 - 2,841 m. This short interval is mature for gas and

oil generation from appropriate types of organic matter. However,the

hydrocarbon and organic carbon contents of these samples are thought unreliable

due to the contribution of caved, and almost certainly richer, material from

the overlying Cretaceous into the Triassic. In view of this,the interval

is thought non-prospective for hydrocarbon sources.

v.   Interval 2,859 - 4,014m. This interval is again quite mature for oil and

gas generation from suitable types of organic matter. Only a small part of
the interval was analysed for organic carbon content and light hydrocarbons.
The general organic leanness the abundance of inertinitic organic matter seen
during kerogen description and the generally oxidising conditions prevailing
during deposition vitiate against any hydrocarbons source horizons being
present.

TABLE 1

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY   WELL 33/12-5   LOCATION NORWEGIAN N. SEA

GAS $(C_1 - C_4)$

SAMPLE NO.	1		4		7		10	
DEPTH METRES	1200-1206		1260-1266		1320-1326		1380-1386	
	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B.	%C_1-C_4	P.P.B	%C_1-C_4
C_1	180	100	50	100	130	57	*	*
C_2	*	*	*	*	100	43	*	*
C_3	*	*	*	*	*	*	*	*
iC_4	*	*	*	*	*	*	*	*
nC_4	*	*	*	*	*	*	*	*
TOTAL	180	(100)	50	(100)	230	(100)	*	*

GASOLINE RANGE $(C_5 - C_7)$

SAMPLE NO.	1		4		7		10	
DEPTH METRES	1200-1206		1260-1266		1320-1326		1380-1386	
	P.P.B.	%C_5-C_7	P.P.B.	%C_5-C_7	P.P.B	%C_5-C_7	P.P.B.	%C_5-C_7
ISO-PENTANE	*	*	*	*	*	*	*	*
N-PENTANE	40	9	Tr	Tr	1040	86	570	78
CYCLOPENTANE	*	*	*	*	*	*	*	*
2-ME. PENTANE	*	*	*	*	*	*	Tr	Tr
3-ME. PENTANE	*	*	*	*	*	*	*	*
N-HEXANE	170	39	90	53	90	7	70	10
ME. CYCLOPENTANE	*	*	Tr	Tr	Tr	Tr	*	*
CYCLOHEXANE	*	*	*	*	*	*	*	*
2-ME. HEXANE	*	*	*	*	*	*	*	*
3-ME. HEXANE	Tr	Tr	*	*	*	*	*	*
3-ETHYLPENTANE	Tr	Tr	*	*	*	*	*	*
N-HEPTANE	50	11	Tr	Tr	Tr	Tr	*	*
BENZENE	40	9	*	*	*	*	30	4
DIME. PENTANE	*	*	*	*	*	*	*	*
ME. CYCLOHEXANE	140	32	80	47	80	7	60	8
TOTAL	440	(100)	170	(100)	1210	(100)	730	(100)

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT ___MOBIL NORWAY___   WELL ___33/12-5___   LOCATION ___NORWEGIAN N. SEA___

GAS (C₁ – C₄)

SAMPLE NO.	13		16		19		22	
DEPTH METRES	1440-1446		1500-1506		1560-1566		1620-1626	
	P. P. B	%C₁ - C₄	P.P. B	%C₁ - C₄	P. P. B	%C₁ - C₄	P.P.B	%C₁ - C₄
C₁	80	100	Tr	Tr	Tr	Tr	*	*
C₂	*	*	*	*	*	*	*	*
C₃	*	*	*	*	*	*	*	*
iC₄	*	*	*	*	*	*	*	*
nC₄	*	*	*	*	*	*	*	*
TOTAL	80	(100)	Tr	*	Tr	*	*	*

GASOLINE RANGE (C₅ – C₇)

SAMPLE NO.	13		16		19		22	
DEPTH METRES	1440-1446		1500-1506		1560-1566		1620-1626	
	P. P. B.	%C₅ - C₇	P. P. B.	%C₅ - C₇	P. P. B	%C₅ - C₇	P. P. B.	%C₅ - C₇
ISO-PENTANE	*	*	*	*	*	*	*	*
N-PENTANE	40	57	40	57	*	*	27	23
CYCLOPENTANE	*	*	*	*	*	*	*	*
2-ME. PENTANE	*	*	*	*	*	*	*	*
3-ME. PENTANE	*	*	*	*	*	*	*	*
N-HEXANE	30	43	30	43	*	*	60	52
ME. CYCLOPENTANE	*	*	*	*	*	*	*	*
CYCLOHEXANE	*	*	*	*	*	*	*	*
2-ME. HEXANE	*	*	*	*	*	*	*	*
3-ME. HEXANE	*	*	*	*	*	*	*	*
3-ETHYLPENTANE	*	*	*	*	*	*	*	*
N-HEPTANE	*	*	*	*	*	*	*	*
BENZENE	Tr	Tr	*	*	*	*	*	*
DIME. PENTANE	*	*	*	*	*	*	*	*
ME. CYCLOHEXANE	Tr	Tr	*	*	*	*	28	24
TOTAL	70	(100)	70	(100)	*	*	115	(100)

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY   WELL 33/12-5   LOCATION NORWEGIAN N. SEA

GAS ($C_1 - C_4$)

SAMPLE NO.	25		28		31		34	
DEPTH METRES	1680-1686		1740-1746		1800-1806		1860-1866	
	P.P.B	%C_1-C_4	P.P.B.	%C_1-C_4	P.P.B.	%C_1-C_4	P.P.B.	%C_1-C_4
C_1	Tr	Tr	21	100	21	100	51	84
C_2	Tr	Tr	Tr	Tr	*	*	10	16
C_3	*	*	*	*	*	*	*	*
iC_4	*	*	*	*	*	*	*	*
nC_4	*	*	*	*	*	*	*	*
TOTAL	Tr	Tr	21	(100)	21	(100)	61	(100)

GASOLINE RANGE ($C_5 - C_7$)

SAMPLE NO.	25		28		31		34	
DEPTH METRES	1680-1686		1740-1746		1800-1806		1860-1866	
	P.P.B.	%C_5-C_7	P.P.B.	%C_5-C_7	P.P.B	%C_5-C_7	P.P.B.	%C_5-C_7
ISO-PENTANE	*	*	3	1	5	2	*	*
N-PENTANE	19	24	35	15	268	93	*	*
CYCLOPENTANE	*	*	13	5	Tr	Tr	*	*
2-ME. PENTANE	*	*	3	1	Tr	Tr	*	*
3-ME. PENTANE	*	*	Tr	Tr	Tr	Tr	*	*
N-HEXANE	33	41	81	34	15	5	*	*
ME. CYCLOPENTANE	*	*	4	2	*	*	*	*
CYCLOHEXANE	*	*	*	*	*	*	*	*
2-ME. HEXANE	*	*	*	*	*	*	*	*
3-ME. HEXANE	*	*	*	*	*	*	*	*
3-ETHYLPENTANE	*	*	*	*	*	*	*	*
N-HEPTANE	*	*	*	*	*	*	*	*
BENZENE	*	*	61	26	*	*	*	*
DIME. PENTANE	*	*	*	*	*	*	*	*
ME. CYCLOHEXANE	28	35	38	16	Tr	Tr	*	*
TOTAL	80	(100)	238	(100)	288	(100)	*	*

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY   WELL 33/12-5   LOCATION NORWEGIAN N. SEA

GAS (C₁– C₄)

SAMPLE NO.	37		40		43		47	
DEPTH METRES	1920–1926		1980–1986		2046–2052		2121–2127	
	P. P. B.	%C_1-C_4	P. P. B	%C_1-C_4	P. P. B.	%C_1-C_4	P. P. B	%C_1-C_4
C_1	33	100	13	100	129	69	185	97
C_2	*	*	*	*	58	31	5	3
C_3	*	*	*	*	*	*	*	*
iC_4	*	*	*	*	*	*	*	*
nC_4	*	*	*	*	*	*	*	*
TOTAL	33	(100)	13	(100)	187	(100)	190	(100)

GASOLINE   RANGE   (C₅ – C₇)

SAMPLE NO.	37		40		43		47	
DEPTH METRES	1920–1926		1980–1986		2046–2052		2121–2127	
	P. P. B.	%C_5-C_7	P. P. B.	%C_5-C_7	P. P. B	%C_5-C_7	P. P. B.	%C_5-C_7
ISO-PENTANE	5	2	Tr	Tr	5	7	*	*
N-PENTANE	82	39	104	85	41	56	*	*
CYCLOPENTANE	7	3	*	*	*	*	*	*
2-ME. PENTANE	6	3	*	*	3	4	*	*
3-ME. PENTANE	3	1	*	*	Tr	Tr	*	*
N-HEXANE	60	29	18	15	24	33	*	*
ME. CYCLOPENTANE	8	4	*	*	*	*	*	*
CYCLOHEXANE	*	*	*	*	*	*	*	*
2-ME. HEXANE	*	*	*	*	*	*	*	*
3-ME. HEXANE	*	*	*	*	*	*	*	*
3-ETHYLPENTANE	*	*	*	*	*	*	*	*
N-HEPTANE	*	*	*	*	*	*	*	*
BENZENE	4	2	*	*	*	*	*	*
DIME. PENTANE	*	*	*	*	*	*	*	*
ME. CYCLOHEXANE	33	16	Tr	Tr	*	*	*	*
TOTAL	208	(100)	122	(100)	73	(100)	*	*

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY   WELL 33/12-5   LOCATION NORWEGIAN N. SEA

GAS (C₁ - C₄)

SAMPLE NO.	51		60		67		71	
DEPTH METRES	2181-2187		2361		2472-2478		2532-2538	
	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4
C_1	87	95	108	100	329	79	42	100
C_2	5	5	Tr	Tr	24	6	Tr	Tr
C_3	*	*	*	*	*	*	*	*
iC_4	*	*	*	*	21	5	*	*
nC_4	*	*	*	*	44	11	Tr	Tr
TOTAL	92	(100)	108	(100)	418	(100)	42	(100)

GASOLINE RANGE (C₅ - C₇)

SAMPLE NO.	51		60		67		71	
DEPTH METRES	2181-2187		2361		2472-2478		2532-2538	
	P.P.B.	%C_5-C_7	P.P.B.	%C_5-C_7	P.P.B	%C_5-C_7	P.P.B	%C_5-C_7
ISO-PENTANE	Tr	Tr	48	11	*	*	*	*
N-PENTANE	25	39	57	13	147	91	*	*
CYCLOPENTANE	*	*	Tr	Tr	*	*	*	*
2-ME. PENTANE	Tr	Tr	55	13	*	*	*	*
3-ME. PENTANE	Tr	Tr	42	10	*	*	*	*
N-HEXANE	39	61	63	15	15	9	*	*
ME. CYCLOPENTANE	*	*	15	3	*	*	*	*
CYCLOHEXANE	*	*	11	3	*	*	*	*
2-ME. HEXANE	*	*	16	4	*	*	*	*
3-ME. HEXANE	*	*	34	8	*	*	*	*
3-ETHYLPENTANE	*	*	14	3	*	*	*	*
N-HEPTANE	*	*	27	6	*	*	*	*
BENZENE	*	*	7	2	*	*	*	*
DIME. PENTANE	*	*	Tr	Tr	*	*	*	*
ME. CYCLOHEXANE	*	*	44	10	*	*	*	*
TOTAL	64	(100)	433	(100)	162	(100)	*	*

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY   WELL 33/12-5   LOCATION NORWEGIAN N. SEA

GAS ($C_1 - C_4$)

SAMPLE NO.	75		79		85		86	
DEPTH METRES	2595-2601		2658-2664		2781		2799	
	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4
C_1	62	86	5	100	283	92	508	86
C_2	10	14	Tr	Tr	19	6	24	4
C_3	*	*	*	*	Tr	Tr	*	*
iC_4	*	*	*	*	Tr	Tr	34	6
nC_4	*	*	*	*	7	2	22	4
TOTAL	72	(100)	5	(100)	309	(100)	588	(100)

GASOLINE RANGE ($C_5 - C_7$)

SAMPLE NO.	75		79		85		86	
DEPTH METRES	2595-2601		2658-2664		2781		2799	
	P.P.B.	%C_5-C_7	P.P.B.	%C_5-C_7	P.P.B	%C_5-C_7	P.P.B.	%C_5-C_7
ISO-PENTANE	31	7	68	13	68	15	67	14
N-PENTANE	66	15	108	20	109	5	106	21
CYCLOPENTANE	11	2	3	1	12	3	8	2
2-ME. PENTANE	31	7	57	11	31	7	47	10
3-ME. PENTANE	16	4	25	5	22	5	22	4
N-HEXANE	122	28	98	18	53	11	56	11
ME. CYCLOPENTANE	21	5	19	4	19	4	30	6
CYCLOHEXANE	11	2	9	2	12	3	19	4
2-ME. HEXANE	10	2	16	3	18	4	18	4
3-ME. HEXANE	21	5	28	5	32	7	26	5
3-ETHYLPENTANE	4	1	7	1	17	4	15	3
N-HEPTANE	49	11	51	10	24	5	24	5
BENZENE	8	2	3	1	11	2	14	3
DIME. PENTANE	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
ME. CYCLOHEXANE	61	14	42	8	33	7	42	9
TOTAL	442	(100)	534	(100)	466	(100)	494	(100)

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY WELL 33/12-5 LOCATION NORWEGIAN N. SEA

GAS ($C_1 - C_4$)

SAMPLE NO.	88							
DEPTH METRES	2841		2868-2899		2929-2960		2990-3021	
	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4	P.P.B	%C_1-C_4
C_1	283	88	108	96	124	93	175	73
C_2	24	7	5	4	10	7	22	9
C_3	*	*	*	*	*	*	43	18
iC_4	Tr	Tr	*	*	*	*	*	*
nC_4	14	4	*	*	*	*	*	*
TOTAL	321	(100)	113	(100)	134	(100)	240	(100)

GASOLINE RANGE ($C_5 - C_7$)

SAMPLE NO.	88							
DEPTH METRES	2841		2868-2899		2929-2960		2990-3021	
	P.P.B.	%C_5-C_7	P.P.B.	%C_5-C_7	P.P.B	%C_5-C_7	P.P.B.	%C_5-C_7
ISO-PENTANE	19	6	3	2	3	2	*	*
N-PENTANE	38	11	29	20	25	17	7	36
CYCLOPENTANE	15	4	20	14	13	9	*	*
2-ME. PENTANE	19	6	3	2	5	3	*	*
3-ME. PENTANE	9	3	3	2	3	2	*	*
N-HEXANE	57	17	53	36	50	33	12	64
ME. CYCLOPENTANE	14	4	6	4	6	4	*	*
CYCLOHEXANE	11	3	*	*	*	*	*	*
2-ME. HEXANE	16	5	*	*	*	*	*	*
3-ME. HEXANE	21	6	4	3	4	3	Tr	Tr
3-ETHYLPENTANE	11	3	*	*	*	*	*	*
N-HEPTANE	37	11	Tr	Tr	Tr	Tr	*	*
BENZENE	32	9	15	10	30	20	Tr	Tr
DIME. PENTANE	Tr	Tr	*	*	*	*	*	*
ME. CYCLOHEXANE	39	12	11	7	11	7	Tr	Tr
TOTAL	338	(100)	147	(100)	150	(100)	19	(100)

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT MOBIL NORWAY   WELL 33/12-5   LOCATION NORWEGIAN N. SEA

GAS ($C_1 - C_4$)

SAMPLE NO.								
DEPTH METRES	3051-3082		3112-3143		3173-3204		3234-3265	
	P.P.B	%$C_1 - C_4$	P.P.B	%$C_1 - C_4$	P.P.B	%$C_1 - C_4$	P.P.B.	%$C_1 - C_4$
C_1	59	59	38	47	143	85	62	86
C_2	20	20	10	12	12	7	10	14
C_3	21	21	*	*	14	8	Tr	Tr
iC_4	*	*	11	13	*	*	*	*
nC_4	*	*	22	28	Tr	Tr	Tr	Tr
TOTAL	100	(100)	81	(100)	169	(100)	72	(100)

GASOLINE RANGE ($C_5 - C_7$)

SAMPLE NO.								
DEPTH METRES	3051-3082		3112-3143		3173-3204		3234-3265	
	P.P.B.	%$C_5 - C_7$	P.P.B.	%$C_5 - C_7$	P.P.B	%$C_5 - C_7$	P.P.B.	%$C_5 - C_7$
ISO-PENTANE	3	4	5	5	Tr	Tr	*	*
N-PENTANE	14	18	25	24	8	15	8	12
CYCLOPENTANE	15	19	6	6	5	9	5	8
2-ME. PENTANE	3	4	5	5	Tr	Tr	Tr	Tr
3-ME. PENTANE	Tr	Tr	3	3	Tr	Tr	Tr	Tr
N-HEXANE	29	37	35	34	14	26	17	26
ME. CYCLOPENTANE	Tr	Tr	4	4	*	*	Tr	Tr
CYCLOHEXANE	*	*	*	*	Tr	Tr	*	*
2-ME. HEXANE	*	*	*	*	12	22	Tr	Tr
3-ME. HEXANE	Tr	Tr	Tr	Tr	6	11	Tr	Tr
3-ETHYLPENTANE	*	*	*	*	*	*	6	9
N-HEPTANE	Tr	Tr	Tr	Tr	Tr	Tr	7	11
BENZENE	*	*	9	9	9	17	11	17
DIME. PENTANE	*	*	*	*	*	*	*	*
ME. CYCLOHEXANE	14	18	11	10	Tr	Tr	11	17
TOTAL	78	(100)	103	(100)	54	(100)	65	(100)

TABLE 1 (Cont'd)

GASEOUS AND GASOLINE RANGE HYDROCARBONS

CLIENT........ MOBIL NORWAY .... WELL .... 33/12-5 .... LOCATION .... NORWEGIAN N. SEA

GAS ($C_1 - C_4$)

SAMPLE NO.								
DEPTH METRES	3295-3326							
	P.P.B	%$C_1 - C_4$	P.P.M.	%$C_1 - C_4$	P.P.M.	%$C_1 - C_4$	P.P.M.	%$C_1 - C_4$
C_1	323	96						
C_2	15	4						
C_3	*	*						
iC_4	*	*						
nC_4	*	*						
TOTAL	338	(100)						

GASOLINE RANGE ($C_5 - C_7$)

SAMPLE NO.								
DEPTH METRES	3295-3326							
	P.P.B.	%$C_5 - C_7$	P.P.B.	%$C_5 - C_7$	P.P.B	%$C_5 - C_7$	P.P.B.	%$C_5 - C_7$
ISO-PENTANE	*	*						
N-PENTANE	10	10						
CYCLOPENTANE	10	10						
2-ME. PENTANE	Tr	Tr						
3-ME. PENTANE	Tr	Tr						
N-HEXANE	20	19						
ME. CYCLOPENTANE	4	3						
CYCLOHEXANE	*	*						
2-ME. HEXANE	*	*						
3-ME. HEXANE	Tr	Tr						
3-ETHYLPENTANE	*	*						
N-HEPTANE	*	*						
BENZENE	61	58						
DIME. PENTANE	*	*						
ME. CYCLOHEXANE	Tr	Tr						
TOTAL	105	(100)						

TABLE 2

SPORE COLOURATION AND KEROGEN DESCRIPTION DATA

WELL: 33/12-5   LOCATION: NORWEGIAN NORTH SEA

SAMPLE DEPTH (METRES)	KEROGEN DESCRIPTION IN PERCENT – UNSIEVED SAMPLES					
	Telinite	Collinite	Fusinite	Semifusinite	Sapropel	Spore Colour Index
1200-06	35	10	10	15	30	2
1236-42	35	10	10	15	30	2.5
1320-26	35	10	5	20	30	2
1362-68	30	10	10	15	35	2
1440-46	25	15	15	15	30	2-2.5
1500-06	20	5	5	20	50	2
1560-66	20	5	<5	20	55	2-2.5
1620-26	10	5	5	30	50	2.5
1680-86	20	10	5	20	45	2.5
1740-46	20	10	15	15	40	2-2.5
1800-06	10	25	5	55	5	–
1860-66	10	20	10	45	15	2.5
1902-08	15	20	10	40	15	–
1962-68	10	20	5	55	10	–
2025	5	20	10	55	10	2
2085	10	15	10	45	20	–
2121-27	10	15	15	25	35	2-2.5
2163	5	15	20	35	25	–
2220	<5	10	10	20	60	2
2277	5	15	10	40	30	2.5-3
2301	5	15	10	55	15	–
2340	10	10	15	35	30	–
2397	10	15	20	25	30	3
2463	5	15	15	20	45	–
2532-38	5	10	20	20	45	3-3.5
2640	5	5	15	35	40	3-3.5
2700	10	15	15	35	25	4
2760	5	10	25	40	25	*
2820	5	15	15	60	5	*
3096	–	–	–	–	–	5.5-6
3144-80	10	15	15	60	<5	6
3216-82	5	15	30	30	20	6-6.5
3318-36	5	5	20	40	30	–
3342-60	<5	5	20	45	30	6
3660-702	10	15	5	55	15	–
3702-08	25	<5	5	45	25	6.5
3869-990	5	5	20	40	30	–
3978-84	10	20	15	55	10	–
3993-4014	10	15	15	35	25	6.5-7

TABLE 3

MATURATION EVALUATION DATA

COMPANY: MOBIL NORWAY   WELL: 33/12-5   LOCATION: NORWEGIAN N. SEA

SAMPLE DEPTH (METRES) OR NOTATION	SAMPLE TYPE	GENERALISED LITHOLOGY	MAXIMUM PALAEOTEMP-ERATURE °F	VITRINITE REFLECTIVITY %	Exinite Fluorescence	LIGHT HYDROCARBONS
1. 1200-06	Ctgs	Sh, ol-gy		0.23	Yellow	Immature
3. 1236-42	"	Ditto		0.18	Yellow	–
4. 1260-66	"	Ditto		–	–	Immature
7. 1320-26	"	Ditto		0.21	Yellow	Immature
9. 1362-68	"	Ditto		0.19	Yellow	–
10. 1380-86	"	Ditto		–	–	Immature
13. 1440-46	"	Ditto		0.55	Yellow	Immature
16. 1500-06	"	Ditto		0.84	Yellow	Immature
19. 1560-66	"	Ditto		0.34	Barren	Immature
22. 1620-26	"	Ditto		*	*	Immature
25. 1680-86	"	Ditto		–	–	Immature
28. 1740-46	"	Sh, ol-gy/brn-gy		0.24	Yellow	Immature
31. 1800-06	"	Sh, lt gy		0.32	Yellow	Immature
34. 1860-66	"	Ditto		*	*	Immature
36. 1902-08	"	Sh, ol-gy/brn-gy		0.29	occ. brown	–
39. 1962-68	"	Sh, ol-gy		0.27	Yellow	–
40. 1980-86	"	Sh, lt gy		–	Yellow	Immature
43. 2046-52	"	Ditto		–	–	Immature
45. 2085	"	Ditto		0.29	Yellow	–
47. 2121-27	"	Sh, gy		0.29	Yel/Orange	Immature
50. 2163	"	Ditto		0.36	Yel/Orange	–
51. 2181-87	"	Ditto		–	–	Immature
53. 2220	"	Sh, lt ol-gy		0.45	Yellow	–
56. 2277	"	Sh, gy		0.36	Yel/Orange	–
57. 2301	"	Ditto		*	Yel-or/Or	–
59. 2340	"	Ditto		0.48	Barren	–
60. 2361	"	Ditto		–	–	Transitional
62. 2397	"	Ditto		0.44	Yel-or/Or	–
66. 2463	"	Ditto		0.38	Yellow	–
67. 2472-78	"	Ditto		–	–	Transitional
71. 2532-38	"	Sh, dk gy		0.40	Yel/Orange	Transitional
75. 2595-601	"	Sh, gy		–	–	Mature?
77. 2640	"	Ditto		0.50	Yellow	–
79. 2658-64	"	Sh, dk gy		–	–	Mature

TABLE 3 (Cont'd)

MATURATION EVALUATION DATA

COMPANY: MOBIL NORWAY   WELL: 33/12-5   LOCATION: NORWEGIAN N. SEA

SAMPLE DEPTH (METRES) OR NOTATION	SAMPLE TYPE	GENERALISED LITHOLOGY	MAXIMUM PALAEOTEMP- -ERATURE °F	VITRINITE REFLECTIVITY %	Exinite Fluorescence	LIGHT HYDROCARBONS
81. 2700	Ctgs	Sh, gy		0.62	Barren	–
84. 2760	"	Sh, dk gy		0.67	Yel-or/yel	–
85. 2781	"	Ditto		–	–	Mature
86. 2799	"	Ditto, slty		–	–	Mature
87. 2820	"	Sh, lt gy		0.61	yellow	–
88. 2841	"	Ditto + 60% red-brn sh		–	–	Mature
2868-99	"	Sltst, red brn + mnr gy sh		–	–	)
2929-60	"	Ditto + 15% ditto		–	–	)
2990-3021	"	Sltst/sh, dk red brn		–	–	)
3051-82	"	Ditto		–	–	) Mature, but low
3112-43	"	Sh, red-brn		–	–	) amounts
3173-204	"	Ditto + tr mica		–	–	)
3234-65	"	Ditto + 30% wht sst		–	–	)
3295-3326	"	Ditto + med gy sh		–	–	)

T
R
I

TABLE 4

SOURCE ROCK EVALUATION DATA

COMPANY: MOBIL NORWAY WELL: 33/12-5 LOCATION: NORWEGIAN N. SEA

SAMPLE DEPTH (METRES) OR NOTATION	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TOTAL EXTRACT P.P.M.	EXTRACT % OF ORGANIC CARBON	HYDRO-CARBONS P.P.M. OF ROCK	HYDRO-CARBONS % OF EXTRACT	TOTAL ALKANES % HYDRO-CARBONS
1. 1200-06	Ctgs	Ol-gy sh	0.91	170	1.9	<20	–	–
2. 1218-24	"	Ditto	1.15	–	–	–	–	–
3. 1236-42	"	Ol-gy sh + snd	1.44	250	1.7	<20	–	–
4. 1260-66	"	Ditto + 50% lt ol-gy sltst + tr bit	1.72	–	–	–	–	–
5. 1278-84	"	Ditto + 50% ditto	1.43	–	–	–	–	–
6. 1302-08	"	Ditto + 25% ditto + qtz – tourmaline	1.22	–	–	–	–	–
7. 1320-26	"	Ditto	0.63	140	2.2	<20	–	–
8. 1338-44	"	Ditto + fossil frags + granite	0.65	–	–	–	–	–
9. 1362-68	"	Ditto	0.45	–	–	–	–	–
10. 1380-86	"	Ditto	0.56	120	2.1	<20	–	–
11. 1398-1404	"	Ditto + mnr snd	0.51	–	–	–	–	–
12. 1422-28	"	Ditto	0.37	–	–	–	–	–
13. 1440-46	"	Ditto	0.43	95	2.2	<20	–	–
14. 1458-64	"	Ol-gy sh	0.69	–	–	–	–	–
15. 1482-88	"	Ditto	0.71	–	–	–	–	–
16. 1500-06	"	Ditto	0.51	105	2.1	<20	–	–
17. 1518-24	"	Ditto	0.69	–	–	–	–	–
18. 1542-48	"	Ditto	0.50	–	–	–	–	–
19. 1560-66	"	Ditto	0.58	100	1.7	<20	–	–
20. 1578-84	"	Ditto	0.54	–	–	–	–	–
21. 1602-08	"	Ditto	0.53	–	–	–	–	–
22. 1620-26	"	Ditto	0.54	70	1.3	<20	–	–
23. 1638-44	"	Ditto + mnr brn-gy sh	0.61	–	–	–	–	–
24. 1662-68	"	Ditto + 10% ditto	0.47	80	1.7	<20	–	–
25. 1680-86	"	Ditto + 20% brn-gy sh	0.32	–	–	–	–	–
26. 1698-1704	"	Ditto + 25% ditto	0.24	–	–	–	–	–
27. 1722-28	"	Ditto + 10% ditto	0.60	–	–	–	–	–
28. 1740-46	"	Ol-gy sh + 40% lt brn /brn gy sh	0.70	70	1.0	<20	–	–
29. 1758-64	"	Ol-gy/Ol-blk/brn-gy sh	0.65	–	–	–	–	–
30. 1782-88	"	Ditto	0.58	–	–	–	–	–

TABLE 4 (Cont'd)

SOURCE ROCK EVALUATION DATA

COMPANY: MOBIL NORWAY WELL: 33/12-5 LOCATION: NORWEGIAN N. SEA

SAMPLE DEPTH (METRES) OR NOTATION	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TOTAL EXTRACT P.P.M.	EXTRACT % OF ORGANIC CARBON	HYDRO-CARBONS P.P.M. OF ROCK	HYDRO-CARBONS % OF EXTRACT	TOTAL ALKANES % HYDRO-CARBONS
31. 1800-06	Ctgs	Lt ol-gy sh + 15% ol-gy sh	0.36	30	0.8	<20	–	–
32. 1818-24	"	Lt ol-gy sh	0.34	–	–	–	–	–
33. 1842-48	"	Lt ol-gy/gn-gy sh	0.32	–	–	–	–	–
34. 1860-66	"	Ditto + 10% ol-gy ditto	0.48	25	0.5	<20	–	–
35. 1878-84	"	Lt ol-gy/gn-gy sh	0.42	–	–	–	–	–
36. 1902-08	"	Varig ol-gy/brn-gy sh	0.36	50	1.4	<20	–	–
37. 1920-26	"	Lt ol-gy sh	0.41	–	–	–	–	–
38. 1938-44	"	Ol-gy sh	0.38	–	–	–	–	–
39. 1962-68	"	Ol-gy sh + tr ol-blk slty sh	0.34	–	–	–	–	–
40. 1980-86	"	Lt gy sh	0.43	110	2.6	<20	–	–
41. 1998-2004	"	Lt gy calc mdst	0.71	–	–	–	–	–
42. 2025	"	Lt-gy calc mdst	0.42	90	2.1	<20	–	–
43. 2046-52	"	Lt gy sh + mica	0.77	–	–	–	–	–
44. 2064	"	Lt gy calc mdst	0.77	–	–	–	–	–
45. 2085	"	Lt gy calc sh	0.72	–	–	–	–	–
46. 2103	"	Gy calc sh + tr red mdst	0.50	160	3.2	<20	–	–
47. 2121-27	"	Ditto	0.91	–	–	–	–	–
48. 2145	"	Ditto	0.57	–	–	–	–	–
49. 2154	"	Ditto	0.71	–	–	–	–	–
50. 2163	"	Ditto	1.46	–	–	–	–	–
51. 2181-87	"	Gy sh	0.60	–	–	–	–	–
52. 2205	"	Ol-gy sh	0.41	–	–	–	–	–
53. 2220	"	Lt ol-gy calc sh	0.91	165	1.8	<20	–	–
54. 2241	"	Ditto + 15% red brn sh	1.90	–	–	–	–	–
55. 2265	"	Med gy sh	0.47	–	–	–	–	–
56. 2277	"	Ditto	0.55	150	2.7	<20	–	–
57. 2301	"	Ditto + 30% ol-gy slty sh	0.64	–	–	–	–	–
58. 2325	"	Ditto	0.74	135	1.8	<20	–	–
59. 2340	"	Ditto	5.8	–	–	–	–	–
60. 2361	"	Ditto	1.19	–	–	–	–	–

TABLE 4 (Cont'd)

SOURCE ROCK EVALUATION DATA

COMPANY : MOBIL NORWAY   WELL : 33/12-5   LOCATION : NORWEGIAN N. SEA

SAMPLE DEPTH METRES) OR NOTATION	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TOTAL EXTRACT P.P.M.	EXTRACT % OF ORGANIC CARBON	HYDRO-CARBONS P.P.M. OF ROCK	HYDRO-CARBONS % OF EXTRACT	TOTAL ALKANES % HYDRO-CARBONS
61. 2382	Ctgs	Med gy sh	1.02	)				
62. 2397	"	Ditto	1.66	) 385	3.1	140	37	65
63. 2421	"	Med gy sltst + 50% lt gy sst	0.97	)				
64. 2433	"	Gy sh + 40% wht calc sst	0.69	–	–	–	–	–
65. 2454	"	Ditto + brn-yel mdst + wht calc sst	0.72	–	–	–	–	–
66. 2463	"	Ditto + mnr ditto + mnr ditto	0.88	–	–	–	–	–
67. 2472-78	"	Gy sh with slty bands	0.88	170	1.9	<20	–	–
68. 2493	"	Ditto	0.91	–	–	–	–	–
69. 2514	"	Ditto	0.78	–	–	–	–	–
70. 2526	"	Laminated gy sh + wht sltst	0.59	240	4.1	35	15	49
71. 2532-38	"	Med dk gy sh + slt	1.07	–	–	–	–	–
72. 2556	"	Ditto	1.35	–	–	–	–	–
73. 2577	"	Ditto	1.00	–	–	–	–	–
74. 2580	"	Ditto	1.26	–	–	–	–	–
75. 2595-2601	"	Gy calc sh	0.97	195	2.0	<20	–	–
76. 2619	"	Ditto	1.32	–	–	–	–	–
77. 2640	"	Ditto	1.02	–	–	–	–	–
78. 2646	"	Med dk gy calc sh	1.44	410	2.8	<20	–	–
79. 2658-64	"	Ditto	1.24	–	–	–	–	–
80. 2682	"	Med gy sh	4.8	1870	3.9	20	1	61
81. 2700	"	Ditto	0.86	–	–	–	–	–
82. 2721	"	Ditto + 10% red-brn sh + yell mdst + mnr gn-gy cong	0.58	410	7.1	150	37	93
83. 2739	"	Ditto + 20% ditto + 50% crs snd	0.52	290	5.6	115	40	89
84. 2760	"	Dk gy sh + 50% red-brn/yell sh	0.69	215	3.1	20	9	100
85. 2781	"	Ditto + 30% ditto	0.34	200	5.9	55	27	68
86. 2799	"	Gy sh/lt gy sltst + 50% red-brn sh + 10% fn snd	0.32	375	11.7	35	36	91

TABLE 4 (Cont'd)

SOURCE ROCK EVALUATION DATA

COMPANY: MOBIL NORWAY   WELL: 33/12-5   LOCATION: NORWEGIAN N. SEA

SAMPLE DEPTH METRES OR NOTATION	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TOTAL EXTRACT P.P.M.	EXTRACT % OF ORGANIC CARBON	HYDRO-CARBONS P.P.M. OF ROCK	HYDRO-CARBONS % OF EXTRACT	TOTAL ALKANES % HYDRO-CARBONS
87. 2820	Ctgs	Lt gy sh + 60% ditto	0.37	615	16.6	115	19	73
88. 2841	"	Ditto + ditto	0.58	2420	41.7	1680	69	64
89. 2859	"	Ditto + 70% red-brn sltst	0.25	–	–	–	–	–
90. 2880	"	Red brn calc sltst + 10% lt gy calc slty sh	0.23					
91. 2904	"	Ditto + 50% mic slty sh	0.20					
92. 2922	"	Ditto + 15% lt gn-gy calc mic sst	0.33					
93. 2946	"	Ditto + 5% lt gn-gy calc sh	0.46					
94. 2970	"	Ditto + 5% ditto + 5% calc mic sst	0.31					
95. 2994	"	Dk med-brn calc sltst + 20% lt gn-gy mic sst	0.54					
96. 3018	"	Ditto + 20% ditto	0.15					
97. 3036	"	Ditto	0.14					
98. 3054	"	Ditto + 30% wht sst	0.09					
99. 3072	"	Ditto	0.10					
100. 3096	"	Ditto + 50% wht sst	0.25					
101. 3120	"	Ditto + mica	0.37					
102. 3144-80	"	Red-brn calc sltst + mnr dk gy sh	0.25					
103. 3168	"	Ditto + tr dk gy sh	0.29					
104. 3192	"	Ditto + ditto	0.15					
105. 3216	"	Ditto + 30% wht sst	0.11					
106. 3234	"	Ditto + 30% ditto	0.23					
107. 3258	"	Lt gy calc sltst containing blk particles + 20% red-brn calc mdst	0.32					
108. 3282	"	Dk red-brn sl calc sltst + med gy sh	0.19					
109. 3300	"	V lt gy sl calc mdst + 20% red-brn sl calc mdst	0.14					
110. 3318	"	Red-brn sl calc mdst + med gy sh	0.30					

TABLE 4 (Cont'd)

SOURCE ROCK EVALUATION DATA

COMPANY: MOBIL NORWAY   WELL: 33/12-5   LOCATION: NORWEGIAN N. SEA

SAMPLE DEPTH (METRES OR NOTATION)	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TOTAL EXTRACT P.P.M.	EXTRACT % OF ORGANIC CARBON	HYDRO-CARBONS P.P.M. OF ROCK	HYDRO-CARBONS % OF EXTRACT	TOTAL ALKANES % HYDRO-CARBONS
111. 3336	Ctgs	Red-brn sl calc mdst + 20% lt gy calc sst	0.23					
112. 3354	"	Ditto + 10% dk gy sh	0.26					
ORGANIC CARBON DETERMINATIONS								
84. 2760		Dk gy sh	2.06					
88. 2841		Lt gy sh	0.99					
112. 3354		Dk gy sh	0.91					

FIGURE I

GASEOUS (C₁ – C₄) HYDROCARBONS

COMPANY : MOBIL NORWAY   WELL : 33/12-5   LOCATION : NORWEGIAN NORTH SEA

TOTAL GAS (P.P.B.)   % WET GAS (C₂ to C₄)
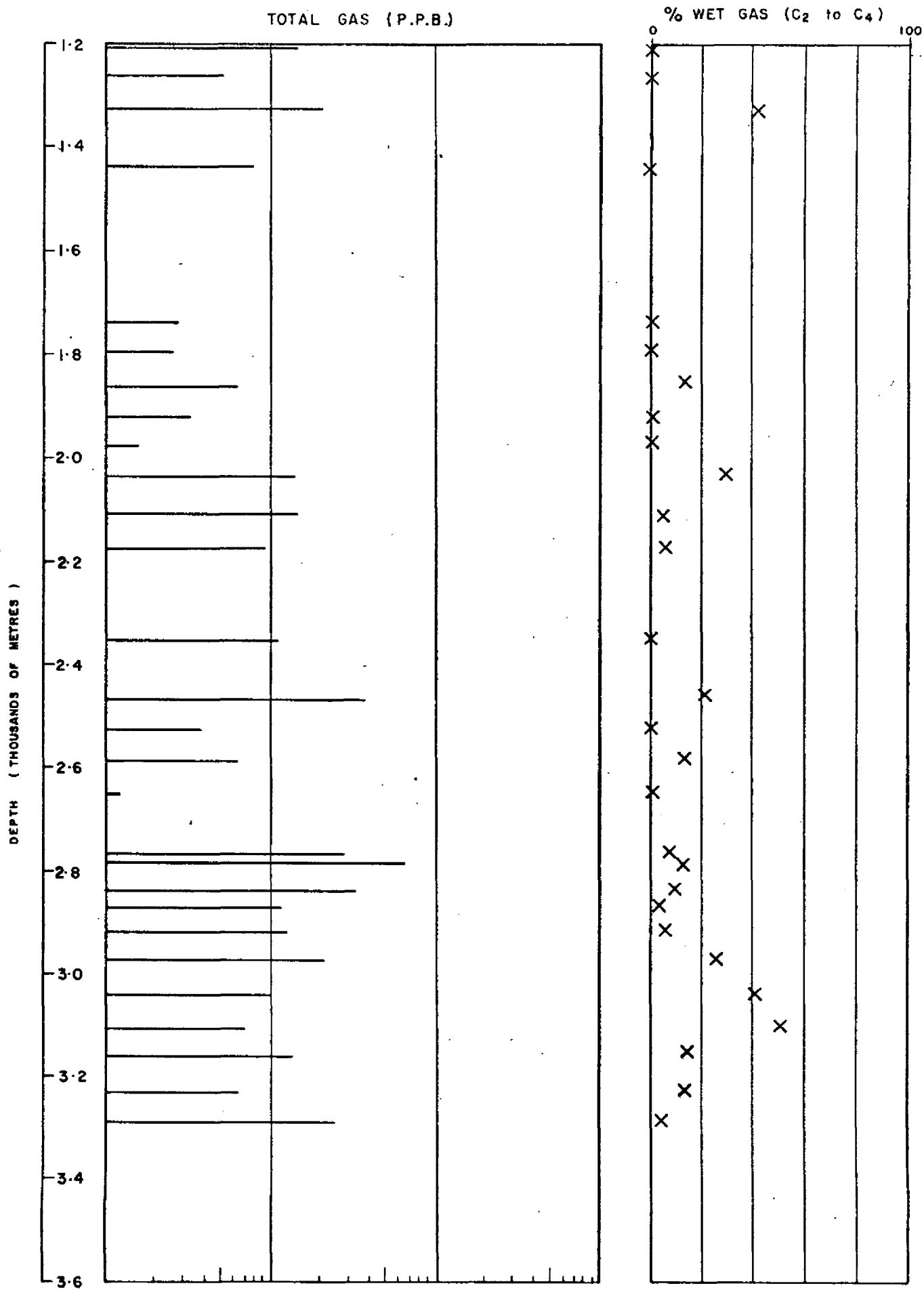
FIGURE 2

GASOLINE RANGE (C$_5$–C$_7$) HYDROCARBONS

COMPANY: MOBIL NORWAY   WELL: 33/12-5   LOCATION: NORWEGIAN NORTH SEA

ABUNDANCE (P.P.B.)

CHROMATOGRAM TYPE

A, IMMATURE ;   B, TRANSITIONAL ;   C, OIL-LIKE
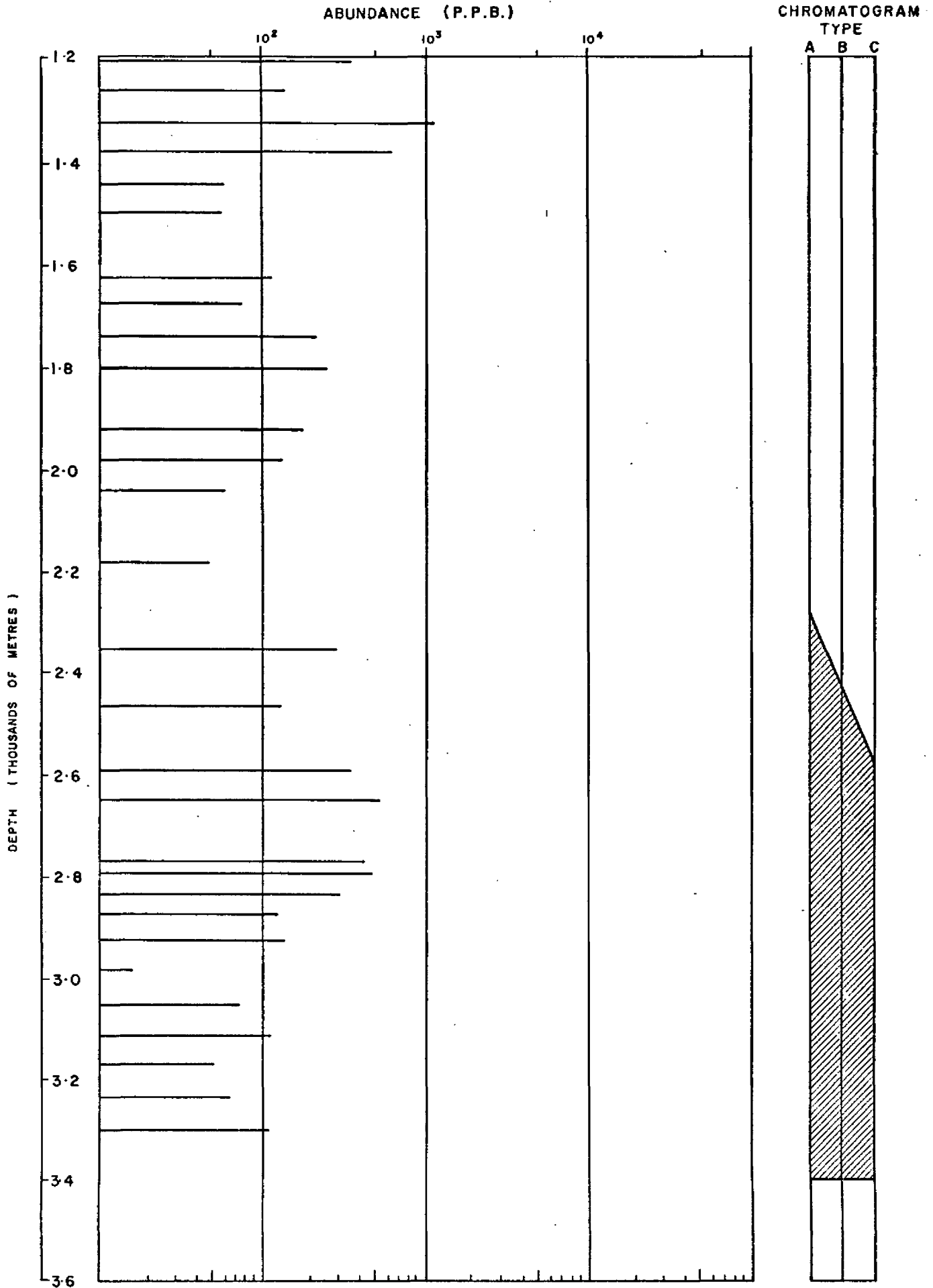
FIGURE 3

VITRINITE REFLECTIVITY AGAINST DEPTH

COMPANY : MOBIL NORWAY   WELL : 33/12-5   LOCATION : NORWEGIAN NORTH SEA

TRUE REFLECTIVITIES

REWORKED MATERIAL   X

CAVINGS

DEPTH (THOUSANDS OF METRES)

PERCENTAGE REFLECTIVITY IN OIL
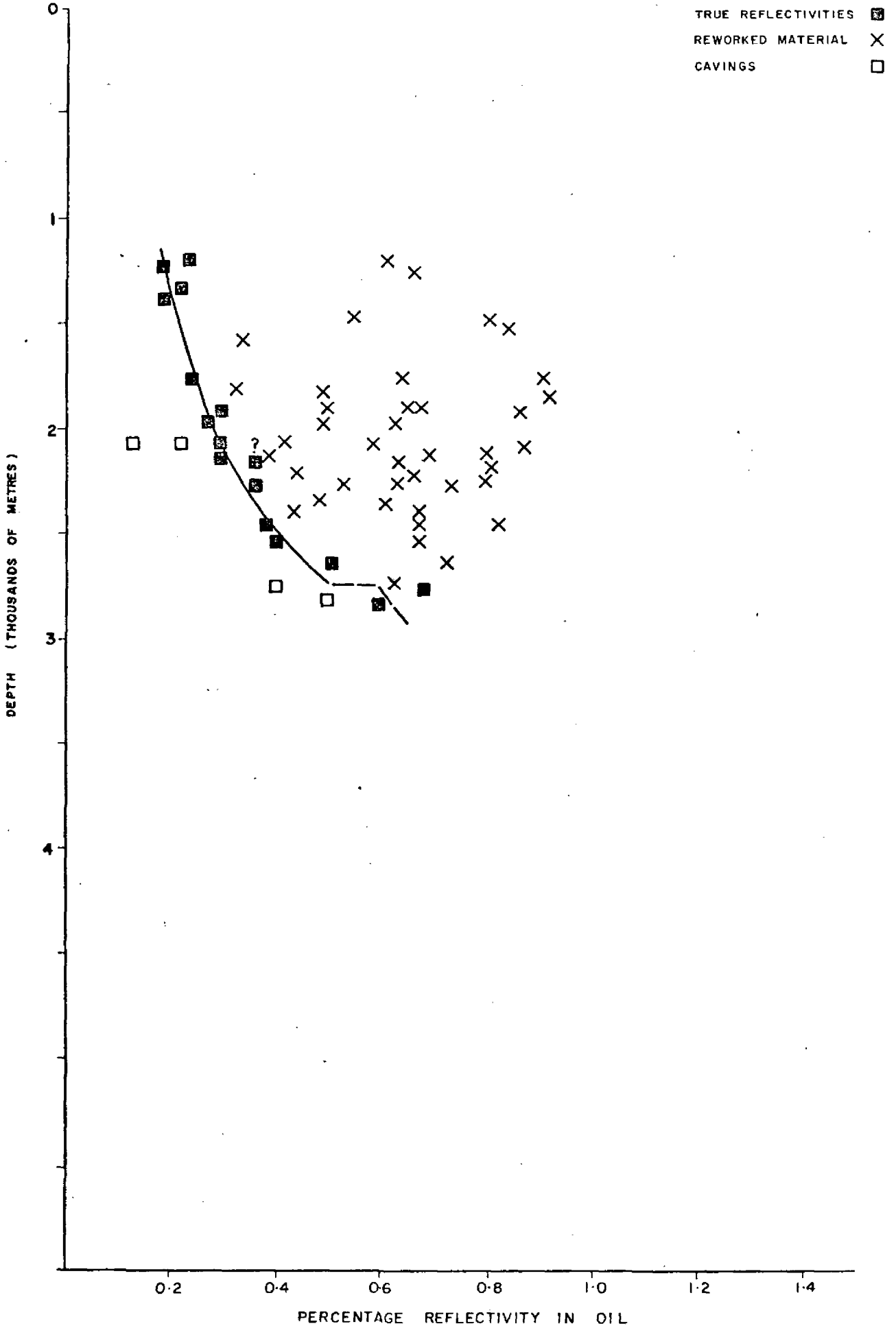
FIGURE 4

MATURATION INDICES AGAINST DEPTH

COMPANY : MOBIL NORWAY   WELL : 33 / 12-5   LOCATION : NORWEGIAN NORTH SEA

Light Hydrocarbons
Immature

Transitional

Mature

DEPTH (THOUSANDS OF METRES)

		2	3	4	5	6	7	8	9	10	SPORE COLOURATION INDEX	△ ———
			·5						1·0	1·2	1·5 %	VITRINITE REFLECTIVITY VALUES ▣ — —
			150						300		350 °F	MAXIMUM PALAEOTEMPERATURES ○ — ·· —
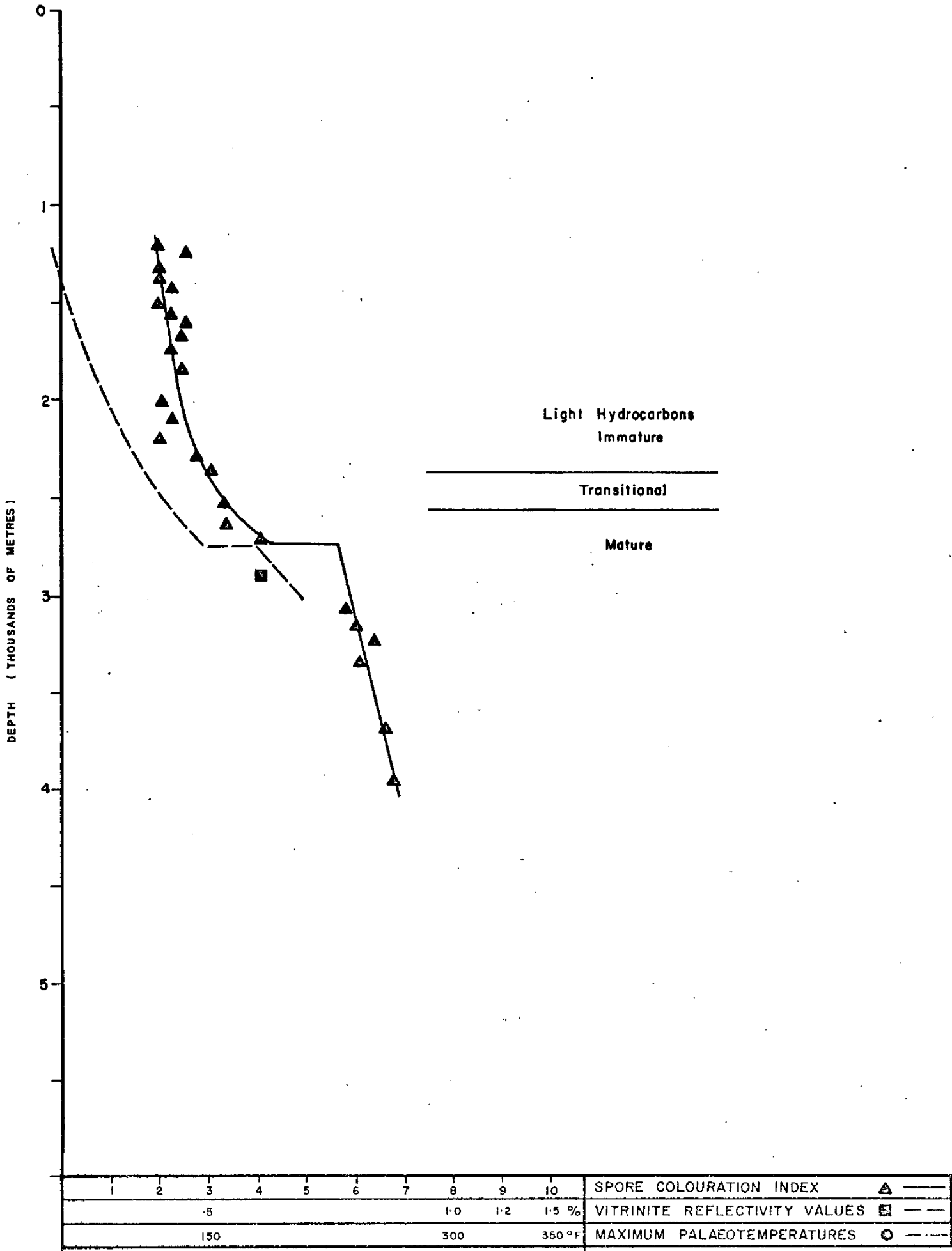
SOURCE ROCK SUMMARY CHART

COMPANY · MOBIL NORWAY   WELL · 33/12-5   LOCATION · NORWEGIAN NORTH SEA
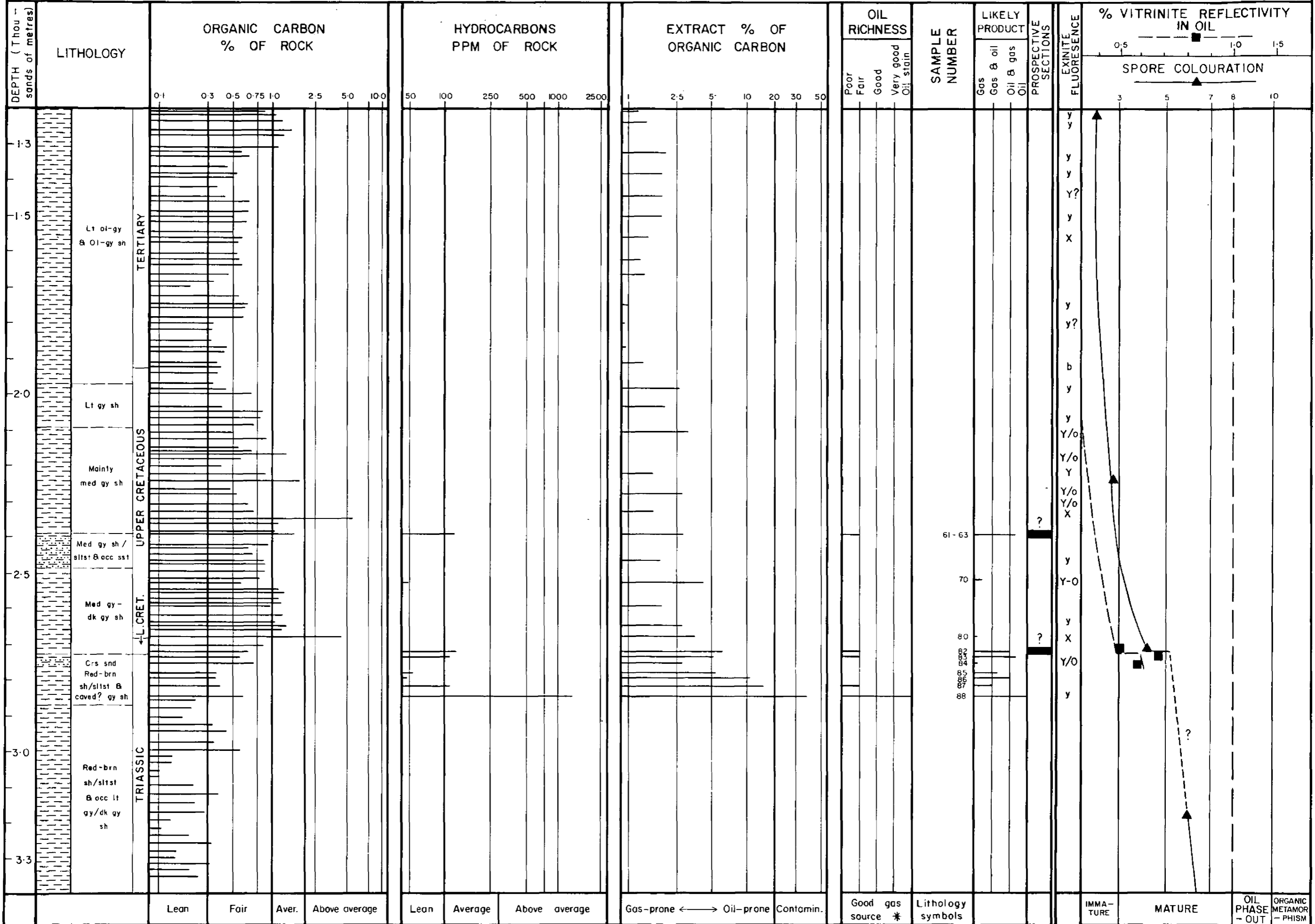
FIGURE 5

Drawing No. 026P / 2234 / 3262

EXINITE FLUORESCENCE   Abundant exinite content B } Orange-brown O } Orange Y } Yellow G } Yellow-green   No observed fluorescence X
Moderate exinite content b } brown   o } orange   y } yellow   g } green

APPENDIX I

ABBREVIATIONS USED IN ANALYTICAL DATA SHEETS

| - | - | Sample not analysed |
| * | - | No results obtained |

C.M.T.	-	Cement	L.C.M.	-	Lost circulation material
Cht	-	Chert	Qtz	-	Quartz
Snd	-	Sand	Sst	-	Sandstone
Slt	-	Silt	Sltst	-	Siltstone
Cgl	-	Conglomerate	Mdst	-	Mudstone
Clyst	-	Claystone	Cly	-	Clay
Sh	-	Shale	Dol	-	Dolomite
Lstn	-	Limestone	Chk	-	Chalk
Lig	-	Lignite	Musc	-	Muscovite
Sndy	-	Sandy	Slty	-	Silty
Shly	-	Shaly	Arg	-	Argillaceous
Aren	-	Arenaceous	Carb	-	Carbonaceous
Calc	-	Calcareous	Mic	-	Micaceous
Ool	-	Oolitic	Sil	-	Siliceous
Fer	-	Ferruginous	Lam	-	Laminae/laminated
Frags	-	Fragments	Pp	-	Purple
Brn	-	Brown	Yel	-	Yellow
Gy	-	Grey	Gn	-	Green
Ol	-	Olive	Blk	-	Black
Wht	-	White	Bl	-	Blue
Mtl	-	Mottled	Vgt	-	Variegated
Sft	-	Soft	Hd	-	Hard
Tr	-	Trace	Occ	-	Occasional
Sl	-	Slightly	V	-	Very
Lt	-	Light	Dk	-	Dark
Med	-	Medium	Crs	-	Coarse
Mnr	-	Minor (< 10%)	Pyr	-	Pyrite/pyritic

Gy-gn	-	Greyish green	Gn-gy	-	Greenish grey
Gn/gy	-	Green and/to grey			

i

APPENDIX II

DESCRIPTION OF ANALYTICAL AND INTERPRETATIVE TECHNIQUES

SOURCE ROCK POTENTIAL ANALYSIS

1. Definition of Problem

    a. Type of Hydrocarbon

        Compared with their ancient counterparts, recent sediments have low

    hydrocarbon contents and many of the hydrocarbons which are present not

    only in ancient sediments, but also in crude oils, are absent. This is

    particularly true of the hydrocarbons with between two and fourteen

    carbon atoms in the molecule (Sokolov, 1959; Dunton and Hunt, 1962;

    Kvenvolden, 1962) which constitute about 50% of most crudes. Clearly,

    recent sediments cannot yield compounds which they do not contain and

    therefore cannot source oil (Erdman, 1961). The Russians report

    accumulations of biologically-generated dry gas at relatively shallow

    depths (age uncertain) but these occurrences are anomalous and non-

    predictable. With the possible exception of methane, recent sediments

    do not possess a present source potential for hydrocarbons.

        With increasing burial, it is observed that not only are the

    missing hydrocarbons formed, but the total hydrocarbon abundance

    increases (Philippi, 1965). This process is called maturation. The

    hydrocarbons are generated either from kerogen (insoluble organic

    matter) via non-hydrocarbon intermediaries (Tissot et al., 1971) or

    directly from the non-hydrocarbons which were originally present.

    In both cases, the non-hydrocarbons are the common denominator and

    hence source rock evaluation must consider the total soluble extract,

    which is the sum of the non-hydrocarbons (future potential) and the

    hydrocarbons (present potential). Catalytic cracking is probably

significant in hydrocarbon generation, particularly in explaining differences between argillaceous and calcareous rocks, but the preference for normal hydrocarbons rather than their branched isomers shows that <u>thermal cracking is dominant</u> in maturation.

Hence, in response to the greater temperatures generated by increasing depths of burial, a negligible source potential is gradually replaced by a realisable potential for hydrocarbons. The first maturation reactions to occur are those which have low activation energies, such as the thermal generation of dry gas (methane). Light liquid hydrocarbons are still absent at this level of maturation which is termed IMMATURE. Immature rocks cannot source oil and only limited amounts of dry gas should be anticipated.

At higher temperatures, light liquid hydrocarbons are formed by the thermal cracking of larger molecules (Rogers and Koons, 1971; Bailey et al., 1973a; Durand and Espitalie, 1972). The sediments are now MATURE. The initial hydrocarbon liquids which are available for migration away from mature source rocks are heavy condensates (Savvina and Velikhovskii, 1968) and young oils with gravities of approximately 20°API (Rogers, Bailey et al., 1972). Tars result from the alteration of pre-existing crude oils and are not a primary product (Bailey et al., 1973b). As thermal maturation proceeds, more and more of the lighter hydrocarbons are cracked off the heavier compounds and the source rocks yield lighter crudes which ultimately, are replaced by light condensates. Hydrocarbon liquids can only be yielded by mature source rocks and the most prolific generation probably occurs in the centre of the maturation range between approximately 175°F and 275°F (Kartsev et al., 1971; Kontorovich, 1968; Radchenko, 1968; etc.). Although gas may also be found in rocks other than those which are mature, it is within the mature and more advanced stages that the most

copious production occurs (Modelevskiy et al., 1972). Some sediments are gas-prone at levels of thermal alteration equivalent to the mature stage (Staplin, 1969; see below).

At advanced levels of thermal alteration ORGANIC METAMORPHISM destroys not only the ability of source rocks to yield liquid hydrocarbons but also any liquids which had previously accumulated in reservoirs. Only dry gas, which may contain significant amounts of H_2S and CO_2 can now be generated. With progressive metamorphism, the kerogen becomes increasingly rich in carbon and a poorer gas source until eventually it is converted into graphite and loses all potential even for dry gas. The mature level is replaced by the organic metamorphic state at a temperature approximately $150^{\circ}F$ lower than that necessary for greenschist metamorphism (Evans and Staplin, 1971) and hence thousands of feet above the first conventional metamorphism readily visible in hand specimen.

By definition, kerogen is that fraction of the total organic matter (commonly over 90%) which is insoluble in organic solvents. It consists of the organic matter which was sedimented and survived diagenesis, modified by the products of bacterial metabolism. Kerogen varies in character as a function of the proximity of the basin of deposition to sources of land plant and algal (freshwater or marine) debris. Although source rocks are laid down sub-aqueously rather than subaerially, their organic matter may originate either within the water body or from land (Rodionova and Maximov, 1970). This in turn affects the type of hydrocarbons which the sediment will yield : woody organic matter tends to be gas-prone regardless of its level of maturation (Staplin, Bailey et al., 1973); epicuticular plant waxes are a rich source of paraffinic-base crudes (Hedberg, 1968; Biederman, 1969; Reed, 1969), and the associated plant material is a more prolific

source of gas than algal debris, which is primarily a rich source of more normal crudes.

b. Source Richness

Good source rocks must contain abundant hydrocarbons which are able to migrate into the reservoir. Migration is most efficient when the source and reservoir facies are interfingered. Thick shale intervals are less suitable.

Petroleum geochemistry is concerned with the source richness aspect. Lean rocks are unable to yield commercial amounts of hydrocarbons to the reservoir. As major hydrocarbon accumulations are the exception rather than the rule it is likely that the most favourable sources are of above average richness (i.e. shales with more than 1.14% organic carbon and 96 ppm heavy hydrocarbons (Gehman, 1962)), and this is borne out by experience. Although carbonates and particularly argillaceous carbonates, can source oil, the best sources are generally shales and siltstones. Sandstones are seldom significant as their organic matter content is not only low but has been oxidised during deposition, thus largely destroying its hydrocarbon potential. The lagoonal sands described by Palacas et al. (1972) are exceptional in the quality of their organic matter but are still lean.

As the soluble fraction of organic matter (soluble extract or bitumen) is generally less than 10% of the total and of this less than one half is hydrocarbons, sediments with less than approximately 0.3% organic carbon can be ignored. The best sources have more than approximately 2% organic carbon but excessively rich rocks such as oil shales and cannel coals may not realise their anticipated potential for oil (humic coals may be prolific gas sources). This is because migration of the liquid hydrocarbons may be prevented by their adsorption upon the abundant organic matter (Erdman, 1961; Philippi,

1965). As a result, a rock with 100 ppm heavy hydrocarbons (i.e. average shale) may have some source potential for oil if it contains 0.8% organic carbon but not at 8% organic carbon when the hydrocarbon to organic carbon ratio is an order of magnitude lower.

The higher the hydrocarbon to organic carbon ratio, the better the source (Erdman, 1961; Philippi, 1965). Immature rocks may be potentially rich sources but at their present level of maturation have low hydrocarbon to organic carbon ratios. This problem of evaluating future source potential is overcome by considering the ratio of soluble extract to organic carbon.

Source richness is also a function of kerogen type. Algal debris is commonly richer than land plant debris but nevertheless the latter is a perfectly valid exploration objective.

c. Conclusions

Source rock evaluation must include consideration of both the richness of the source and the type of hydrocarbon it will yield in its present maturation state. This necessitates analytical data on the total soluble extract, the proportion of hydrocarbons within it, and the organic carbon content.

2. Analytical Techniques

The analytical laboratory of Robertson Research International Limited is supervised by a qualified chemist. High standards are maintained and blanks are run routinely. Prior to submission for analysis, the samples are washed free from drilling mud and hand picked to remove obvious cavings and particulate contamination reflecting the drilling techniques employed (lost circulation material, paint etc.). Samples are crushed to minus 60 mesh and split into two, one portion being used for organic carbon determination and the other for extraction.

Carbonate material is removed from the first split by acid attack and the organic carbon content then measured with a Leco carbon analyser in which the amount of CO_2 generated by heating is calibrated by the change in thermal conductivity.

The other sample portion is Soxhlet extracted for 12 hours with 2:1 benzene-methanol to give the total soluble extract (saturates, aromatics and resins plus asphaltenes). The extract is then redissolved in n-pentane and saturates and aromatics separated and measured by high pressure liquid chromatography using a carbon specific FID detector for quantitification. This technique is more rapid than conventional liquid chromatography and can handle smaller samples.

3. Presentation and Interpretation of Data

The geochemical interpretation includes graphical presentations to highlight the exploration significance of the data.

Three diagrams are involved in the evaluation of source rock potential. The first of these ("Type of Hydrocarbon Product from Source Rocks") deals with the type of hydrocarbon (gas, oil) which the samples can yield at the present time. The two axes are the proportion of hydrocarbons in the total soluble extract and the proportion of the total organic carbon which the soluble extract constitutes - i.e. it is a plot of maturation state (incorporating the influence of different types of organic matter) against richness. Samples which are heavily oil-stained, or contaminated with other non-indigenous hydrocarbons (e.g. pipe dope etc.) can be recognised and the remainder qualified in terms of the type of hydrocarbon for which they have present potential. This decision is a function of the proportion of hydrocarbons in the total extract; with increasing maturation, the proportion of hydrocarbons increases (Tissot et al., 1971, etc.) indicating the onset and continued enhancement of oil source potential. Naturally there are "grey"

areas between fields; within the central field, oil potential increases at the expense of gas in an upwards direction. The ratio of saturated (paraffins) to aromatic hydrocarbons is also considered but does not appear in the diagram. If a sample has some oil potential, its richness can be evaluated with the next diagram.

The source richness of samples which are sufficiently mature to yield oil can be determined directly from a plot of hydrocarbon abundance against organic carbon content ("Mature Source Rock Richness"). An estimate can also be made of the potential richness of immature samples (i.e. richness if the sample were mature in a down-dip position). The plot is divided into fields which are labelled to facilitate an evaluation of the relative amounts of liquid hydrocarbons which can be anticipated from a particular sediment. Samples with less than 0.3% organic carbon and 100 ppm hydrocarbons are considered to be too lean to constitute an effective source. Oil potential is divided from gas-with-minor-oil potential by the 100 ppm hydrocarbon line up to an organic carbon content of 1% using the reasoning that an effective oil source must be richer than the average shale (96 ppm hydrocarbons, 1.14% organic carbon; Gehman, 1962). In more organically-rich sediments, natural chromatography may prevent the release of liquid hydrocarbons into the reservoir and hence the extension of the boundary follows a hydrocarbon to organic carbon ratio value of 0.01. The oil field is divided into fair (commercial oil in non-frontier areas), good (major oil, commercial in all areas) corresponding closely with Philippi's (1965) definition of a source rock, and very good (highly desirable) source rocks. If the hydrocarbon to organic carbon ratio is above 0.2, the sample is oil-stained or otherwise contaminated with non-indigenous hydrocarbons. Naturally, lesser contamination may be present in samples which apparently possess oil source potential. The recognition of such effects requires an experience factor. Samples which fall into the gas-with-oil or gas field

may contain significant quantities of heavy hydrocarbons but cannot source significant oil due to natural chromatography or the inadequate generation of the lighter liquid hydrocarbons necessary for migration. The potential of mature (oil-prone) samples equivalent to the immature (gas-prone) samples which were analysed can be estimated by assuming that ultimately, approximately 50% of the total extract will be converted into hydrocarbons.

The final diagram ("Source Rock Summary Chart") integrates the lithology of the samples as analysed, with certain analytical results (organic carbon content and hydrocarbon abundance with appropriate cut-offs, and EPOC, extract percent of organic carbon, which is the percentage of the organic carbon soluble in organic solvents), and the interpretations derived above (richness and product type). Maximum palaeotemperature measurements are included for ease of reference and comparison. The data are plotted against depth and the good source intervals can be recognised at a glance. EPOC is a measure of the potential source quality of immature samples, and the required additional burial to achieve maturity can be estimated from the temperatures necessary for maturity and the palaeogeothermal gradient. Using the same reasoning, the depth to organic metamorphism (and hence dry gas potential) can be estimated. If a section is gas-prone the maximum palaeotemperature can indicate why : immaturity, metamorphism, or organic matter unfavourable for oil generation.

Following the discovery of liquid hydrocarbons, it is important for future play evaluations to recognise those intervals which have demonstrated their oil potential.

4.   References

BAILEY, N.J.L., EVANS, C.R. and MILNER, C.W.D., 1973a. Applying Petroleum Geochemistry to the Search for Oil: Examples from the Western Canada Basin. Bull. Am. Assoc. Petrol. Geol. (in press).

BAILEY, N.J.L., KROUSE, H.R., EVANS, C.R. and ROGERS, M.A., 1973b. Alteration
of Crude Oil by Waters and Bacteria: Evidence from Geochemical and
Isotope Studies. Bull. Am. Assoc. Petrol. Geol., v. 57, no. 7, pp.1276-90.

BIEDERMAN, E.W., 1959. Significance of High Wax Oils With Respect to the
Genesis of Petroleum: commentary. Bull. Am. Assoc. Petrol. Geol.,
v. 53, pp. 1500-1502.

DUNTON, M.L. and HUNT, J.M., 1962. Distribution of Low Molecular-Weight
Hydrocarbons in Recent and Ancient Sediments. Bull. Am. Assoc. Petrol.
Geol., v. 46, pp. 2246-2258.

DURAND, B. and ESPITALIE, J., 1972. Formation et Evolution des Hydrocarbures
de C_1 a C_{15} et des Gaz Permanents dans les Argiles du Toarcien du
Bassin de Paris. In Advances in Organic Geochemistry, 1971, editors
H.R.V. Gaertner and H. Wehner, Pergamon Press, pp. 455-468.

ERDMAN, J.G., 1961. Some Chemical Aspects of Petroleum Genesis Related to
the Problem of Source Bed Recognition. Geochim. et Cosmochim. Acta,
v. 22, no. 1, pp. 10-36.

EVANS, C.R. and STAPLIN, F.L., 1971. Regional Facies of Organic Metamorphism.
Can. Inst. Mining Met. Spec. Vol., no. 11, pp. 517-520.

GEHMAN, H.M., 1962. Organic Matter in Limestones. Geochim. et Cosmochim.
Acta, v. 26, pp. 885-897.

HEDBERG, H.D., 1968. Significance of High-Wax Oils with Respect to Genesis
of Petroleum. Bull. Am. Assoc. Petrol. Geol. v. 52, no. 5, pp. 736-750.

KARTSEV, A.A., VASSOEVICH, N.B., GEODEKIAN, A.A. et al., 1971. The Principal
Stage in the Formation of Petroleum. 8th World Pet. Cong., Proc. v.2,
pp. 3-11.

KONTOROVICH, A.E., 1968. Scheme for the Identification of Oil-Producing
Sediments. Acad. Sci. U.S.S.R., Dokl., Earth Sci. Sect., v. 179,
pp. 153-155.

KVENVOLDEN, K.A., 1962. Normal Paraffin Hydrocarbons in Recent Sediments
from San Francisco Bay, California. Bull. Am. Assoc. Petrol. Geol.,
v. 46, pp. 1643-1652.

MODELEVSKIY, M.S., SOKOLOVA, O.N. and FAYNGERSH, L.A., 1972. Formation of
Gas Deposits by Catagenesis of Coal Measures. Int. Geol. Rev.,v. 14,
no. 12, pp. 1293.

PALACAS, J.G., LOVE, A.H., and GERRILD, P.M., 1972. Hydrocarbons in Estuarine
Sediments of Choctawhatchee Bay, Florida, and their Implications for
Genesis of Petroleum. Bull. Am. Assoc. Petrol. Geol., v. 56, no. 8,
pp. 1402-1418.

PHILIPPI, G.T., 1965. On the Depth, Time and Mechanism of Petroleum
Generation. Geochim. et Cosmochim. Acta, v. 29, pp. 1021-1049.

RADCHENKO, O.A., 1968. The Mechanism of Oil Generation. Acad. Sci. U.S.S.R.,
Dokl., Earth Sci. Sect., v. 182, pp. 186-188.

REED, K.J., 1969. Environment of Deposition of Source Beds of High Wax Oils. Bull. Am. Assoc. Petrol. Geol., v. 57, pp. 1502-1506.

RODIONOVA, K.F. and MAXIMOV, S.P., 1970. Diagnostic Criteria for Oil and Gas Source Rocks. Sov. Geol., no. 11, pp. 3-10.

ROGERS, M.A., BAILEY, N.J.L., EVANS, C.R. and McALARY, J.D., 1972. An Explanatory and Predictive Model for the Alteration of Crude Oils in Reservoirs in the Western Canada Basin. 24th Int. Geol. Cong., Montreal, Canada, Sect. V Reports, pp. 48-55.

ROGERS, M.A. and KOONS, C.B., 1971. Generation of Light Hydrocarbons and Establishment of Normal Paraffin Preferences in Crude Oils. Origin and Refining of Petroleum-Advances in Chemistry Series 103. Am. Chem. Soc., Washington, D.C., pp. 67-80.

SAVVINA, Ya D. and VELIKHOVSKII, A.S., 1968. The Possibility of Using the Equilibrium Constant of Hydrocarbon Isomerisation Reactions for Determining the Temperature of Oil and Condensate Formation. Gazovaya Promyshlennost, v. 5, pp. 8-11.

SOKOLOV, V.A., 1959. Possibilities of Formation and Migration of Oil in Young Sedimentary Deposits. Proc. Lvov Conf., May 8-12, 1957, Moscow.

STAPLIN, F.L., 1969. Sedimentary Organic Matter, Organic Metamorphism, and Oil and Gas Occurrence. Bull. Can. Pet. Geol., v. 17, pp. 47-66.

STAPLIN, F.L., BAILEY, N.J.L., POCOCK, S.A.J. and EVANS, C.R., 1973. Metamorphism of Sedimentary Organic Matter. Talk at A.A.P.G.-S.E.P.M. Convention, Anaheim, April, 1973.

TISSOT, B., DEBYSER, Y.C., DEROO, G. and OUDIN, J.L., 1971. Origin and Evolution of Hydrocarbons in the Early Toarcian Shales, Paris Basin, France. Bull. Am. Assoc. Petrol. Geol., v. 55, no. 12, pp. 2177-2193.

APPENDIX II

MAXIMUM PALAEOTEMPERATURE ANALYSIS

1.   Definition of Problem

Recent sediments not only have a lower total abundance of hydrocarbons than more ancient sedimentary rocks, but those hydrocarbons with between two and fourteen carbon atoms in the molecule which are present in ancient sediments and which constitute up to fifty percent of a typical crude oil, are largely absent (Sokolov, 1957; Dunton and Hunt, 1962; Kvenvolden, 1962). Hence such rocks are unable to source oil (Erdman, 1961) but may have a limited potential for dry gas. Russian authors have reported accumulations of biologically-generated (biogenic) gas from young sediments but such instances are anomalous, non-predictable and cannot form the basis of an exploration play. With burial, hydrocarbon abundance increases (Philippi, 1965; Tissot et al., 1971) and more significantly, the previously absent lighter liquid hydrocarbons appear (Rogers and Koons, 1972; Durand and Espitalie, 1973; Bailey et al., 1973). This process is called maturation. Although catalytic cracking is undoubtedly significant, particularly in explaining differences between argillaceous and calcareous source rocks, the preference displayed for straight-chain compounds rather than their branched isomers indicates that maturation is dominated by the thermal cracking of pre-existing large molecules. In other words, it is <u>temperature</u> dependent.

As the formation temperatures due to burial increase, but prior to the appearance of all the C_2 to C_{14} hydrocarbons, the rocks develop some, but still limited, potential for dry gas. At this level of maturation they are still described as "IMMATURE".

When a complete spectrum of hydrocarbons has been generated, the sediments possess the ability to source liquid hydrocarbons and are termed

"MATURE". The initial products are heavy condensates (Savvina and Velikhovskii, 1968), and young oils (not tars) with gravities of around 20°API (Rogers, Bailey et al., 1972). As the maturation process proceeds, lighter oils are generated until eventually the heavier molecules are largely broken down and a potential for light condensate results. Naturally, the oil-condensate boundary is transitional. Liquid hydrocarbons can only be sourced by mature sediments. The most prolific gas sources correspond either to the mature or more advanced levels of thermal alteration (Modelevsky et al., 1972). With further thermal alteration only the lightest hydrocarbon, methane, is left and the source rocks only have a potential for dry gas. This is termed the level of "ORGANIC METAMORPHISM" and again, is transitional to the mature stage. Particularly in carbonates, the gas may be sour (Kozlov, 1950). Organic metamorphism occurs at temperatures approximately 150°F lower than those corresponding to the onset of the greenschist facies of conventional metamorphism (Evans and Staplin, 1971). The organic matter in "sediments" which have suffered greenschist facies metamorphism is converted to graphite and does not retain any potential for hydrocarbons.

Gas may be sourced without oil but oil is always accompanied by gas and hence the term "oil potential" is purely relative. Some sediments which should be sufficiently mature to source oil are in fact gas-prone due to the character of the kerogen which they contain (Staplin, 1969; Staplin, Bailey et al., 1973). Woody kerogen tends to yield dominantly gas whilst non-woody land plant material and algal debris are both oil-prone if mature, although the former yields more associated gas and requires a somewhat higher temperature to become mature (Nalivkin et al., 1967; Kontorovich, 1968). The influence of organic matter type is evaluated by integrating maximum palaeo-temperature with source rock potential analysis unless a palynological examination is requested.

The length of time over which a sediment is exposed to a given temperature is also important as time and temperature are to some degree exchangeable and a reaction will proceed more nearly to completion if a longer time is allowed (Lopatin, 1971; Welte, 1972). The effect of time can be gauged from the fact that a Cretaceous sediment becomes mature at a temperature approximately $10^{\circ}F$ lower than that necessary for a comparable Miocene rock.

Although the effects of kerogen type and time must be recognised, temperature dominates the maturation process. Approximate values can be applied to the various levels of maturation discussed above :
$150^{\circ}F$ for the immature gas to mature transition (Correia, 1969; Kartsev et al., 1971; Louis and Tissot, 1967; Kontorovich, 1968); $300^{\circ}F$ for the oil to light condensate transition (Momper, 1972) and $350^{\circ}F$ for the condensate to metamorphosed dry gas transition (Evans and Staplin, 1971; Momper, 1972). If the temperature to which a rock has been exposed can be measured, the sediment can be fitted into the correct slot (immature, mature, metamorphosed) and predictions can be made concerning neighbouring sections with different burial histories.

2.   Analytical Techniques

Samples are washed and hand-picked to remove both contamination introduced during drilling and caved material, before being described and then submitted for analysis. The inorganic material is qualitatively removed by digesting the samples with acid and the kerogen concentrate is washed with an organic solvent to remove non-indigenous hydrocarbons.

During thermal cracking, free radicals (with unpaired electrons) are generated (Duchesne et al., 1961; Retcofsky et al., 1968; Marchand et al., 1969). Those which are associated with aromatic ring structures are protected from further reaction and provide a record of the thermal history

of the kerogen. Hence, the higher the maximum temperatures to which the sample is exposed, the greater the number of unpaired electrons per unit of kerogen. These unpaired electrons are studied with an electron spin resonance spectrometer which measures the absorption, by kerogen placed in a varying magnetic field, of a fixed microwave frequency. Three parameters are obtained:

a. Ng - the number of unpaired electrons per gramme
          of organic carbon;

b. g - the spectroscopic splitting factor;

c. W - the width of the resonance signal in gauss.

Several hundred samples which, from geological and palaeontological reasoning, are believed to be at their maximum depth of burial at this time, have been selected as standards. Their formation temperatures are known from reliable formation and drillstem tests and from E-log measurements. The three ESR parameters discussed above have been calibrated against these formation temperatures and hence the maximum palaeotemperatures of unknown samples can be established. The practical application of ESR techniques has been discussed by Pusey (1973).

Internal standards are run constantly and reproducibility is excellent. ($\pm$ 15 ^{o}F).

3. Presentation and Interpretation of Data

The maximum palaeotemperature values are presented in tabular form and are illustrated graphically in two diagrams to facilitate their direct correlation with other geological data.

The first diagram is a plot of maximum palaeotemperature values against present-day depth of burial. A regression line is fitted to the data points and its correlation coefficient calculated (the data may indicate several legs rather than a single regression line). Its slope gives the

palaeothermal gradient and the temperature at which it intercepts the surface is also quoted. Surface intercepts significantly higher than the temperatures prevailing in the basin of deposition, and jumps within the subsurface data points, both indicate the removal of section by erosion. Igneous activity may be recognised by distortion of the data.

The relevance of maximum palaeotemperature measurements to petroleum geochemistry is illustrated by the second diagram ("Source Rock Product as a Function of Thermal Alteration") which is a plot of temperature against the age of the rock (in millions of years). Uphole samples are plotted towards the top of the diagram and those which have experienced higher temperatures occur lower down.

The diagram is divided into three major fields all of which are transitional one to the other, but within each of which there is a most likely product :

1. The immature field has a potential only for dry gas and not for oil or other liquid hydrocarbons. Indeed, except at higher temperatures, it generally has a poor potential even for gas.

2. The mature field is the only one from which liquid hydrocarbons can be sourced. At the low temperature end it is prone to yield heavy condensates and young oils with gravities around 20°API. With higher temperatures, lighter oils are sourced until eventually, the oil field phases into the light condensate field within which the probability of oil diminishes progressively and that of gas increases. Oil potential is probably maximal between 175°F and 275°F. Oil generation is always accompanied by gas.

3. The field of organic metamorphism has a potential only for dry gas- sometimes with significant non-hydrocarbon contents. In carbonates the gas may be sour. At more advanced levels of metamorphism the

kerogen becomes increasingly carbon-rich and possesses a lower potential which is effectively destroyed prior to the onset of greenschist metamorphism.

Oil may be accumulated in an immature section if the reservoir is in communication with mature source rocks downdip. In contrast, organic metamorphism destroys not only the oil potential of source rocks but also any liquid hydrocarbons which had accumulated in reservoirs and hence metamorphosed sections are always dry gas objectives.

In addition to evaluating the present maturation state of a section, maximum palaeotemperature measurements can also be used predictively. For example, if a well only penetrated immature strata, the palaeothermal gradient can be projected (assuming constancy) downwards to estimate the depths at which the temperatures necessary for the onset of maturation and also organic metamorphism are achieved, thus defining the "oil envelope". Such predictions can also be extrapolated to include potential plays in nearby areas with similar depositional histories to provide pre-drill information.

It should be noted that interpretations discussed above may not apply to over-pressured sections due to the restraints imposed upon migration in such intervals.

A simplified composite of these two diagrams is included in the Source Rock Summary Chart to facilitate the integration of the total data pertaining to source rock evaluation.

4. References

BAILEY, N.J.L., EVANS, C.R. and MILNER, C.W.D., 1973. Applying Petroleum Geochemistry to the Search for Oil: Examples from the Western Canada Basin. Bull. Am. Assoc. Petrol. Geol., (in Press).

CORREIA, M., 1969. Contribution a la Recherche de Zones Favourable a la Genese du Petrole par l'Observation Microscopique de la Matiere Organique Figuree. Rev. Inst. Franc. Petrole, v. 24, no. 12, pp. 1417-1447.

DURAND, B. and ESPITALIE, J., 1972. Formation et Evolution des Hydrocarbures de C_1 a C_{15} et des Gaz Permanents dans les Argiles du Toarcien du Bassin de Paris. In Advances in Organic Geochemistry, 1971, editors H.R.V. Gaertner and H. Wehner, Pergamon Press, pp. 455-468.

DUCHESNE, J., DEPIREUX, J., and VAN DER KAA, J.M., 1961. Origin of Free-Radicals in Carbonaceous Rocks. Geochim. et Cosmochim. Acta, v. 23, pp. 209-218.

ERDMAN, J.G., 1961. Some Chemical Aspects of Petroleum Genesis Related to the Problem of Source Bed Recognition. Geochim. et Cosmochim. Acta, v. 22, no . 1 pp. 10-36.

EVANS, C.R. and STAPLIN, F.L., 1971. Regional Facies of Organic Metamorphism. Can. Inst. Mining Met. Spec. Vol., No. 11, pp. 517-520.

KARTSEV, A.A., VASSOEVICH, N.B., GEODEKIAN, A.A. et al., 1971. The Principal Stage in the Formation of Petroleum. 8th World Pet. Cong., Proc., v.2, pp. 3-11.

KONTOROVICH, A.E., 1968. Scheme for the Identification of Oil Producing Sediments. Acad. Sci. U.S.S.R., Dokl, Earth Sci. Sect., v. 179, pp. 153-155.

KOZLOV, A.L., 1950. Problems on the Geochemistry of Natural Gases. Gostoptelchizdat, Moscow.

KVENVOLDEN, K.A., 1962. Normal Paraffin Hydrocarbons in Recent Sediments from San Francisco Bay, California. Bull. Am. Assoc. Petrol. Geol., v. 46, pp. 1643-1652.

LOPATIN, N.V. , 1971. Temperature and Geological Age as Factors in Coalification. Izv. Akad. Navk. S.S.S.R., Ser. Geol. 1971, no . 3 pp. 95-105.

LOUIS, M.C. and TISSOT, B.P., 1967. Influence de la Temperature et de la Pression sur la Formation des Hydrocarbures dans les Argiles a Kerogene. Proc. of 7th World Pet. Cong., v. 2, pp. 47-60.

MARCHAND, A , LIBERT, P. and COMBAZ, A., 1969. Physico-Chemical Characterisation Tests of the Diagenesis of Several "Biologically Homogenous" Organic Rocks. Rev. Inst. Franc. Petrole, v. 24, no. 1, pp. 3-20.

MODELEVSKIY, M.S., SOKOLOVA, O.N. and FAYNGERSH, L.A., 1972. Formation of Gas Deposits by Catagenesis of Coal Measures. Int. Geol. Rev., v. 14, no. 12, pp. 1293.

MOMPER, J.A., 1972. Evaluating Source Beds for Petroleum. Talk at A.A.P.G.-S.E.P.M. Meeting, Denver, Colo., April, 1972.

PHILIPPI, G.T., 1965. On the Depth, Time and Mechanism of Petroleum Generation. Geochim. et Cosmochim. Acta, v. 29, pp. 1021-1049.

PUSEY, W.C., 1973. The ESR-Kerogen Method - How to Evaluate Potential Gas and Oil Source Rocks. World Oil, April, 1973, pp. 71-74.

RETCOFSKY, H.L., STARK, J.M. and FRIEDEL, R.A., 1968. Electron Spin Resonance in American Coals. Anal. Chem. v. 40, no. 11, pp. 1699-1704.

ROGERS, M.A. and KOONS, C.B., 1971. Generation of Light Hydrocarbons and Establishment of Normal Paraffin Preferences in Crude Oils. Origin and Refining of Petroleum-Advances in Chemistry Series 103. Am. Chem. Soc., Washington, D.C., pp. 67-80.

ROGERS, M.A., BAILEY, N.J.L., EVANS, C.R. and McALARY, J.D., 1972. An Explanatory and Predictive Model for the Alteration of Crude Oils in Reservoirs in the Western Canada Basin. 24th Int. Geol. Cong., Montreal, Canada, Sect. V Reports, pp. 48-55.

SAVVINA, Ya D. and VELIKHOVSKII, A.S., 1968. The Possibility of Using the Equilibrium Constant of Hydrocarbon Isomerisation Reactions for Determining the Temperature of Oil and Condensate Formation. Gazovaya Promyshlennost, v. 5, pp. 8-11.

SOKOLOV, V.A., 1959. Possibilities of Formation and Migration of Oil in Young Sedimentary Deposits. Proc. Lvov Conf., May 8-12, 1957, Moscow.

STAPLIN, F.L., 1969. Sedimentary Organic Matter, Organic Metamorphism, and Oil and Gas Occurrence. Bull. Can. Pet. Geol., v. 17, pp. 47-66.

STAPLIN, F.L., BAILEY, N.J.L. POCOCK, S.A.J. and EVANS, C.R., 1973. Metamorphism of Sedimentary Organic Matter. Talk at A.A.P.G.-S.E.P.M. Convention, Anaheim, April, 1973.

TISSOT, B., DEBYSER, Y.C., DEROO, G. and OUDIN, J.L., 1971. Origin and Evolution of Hydrocarbons in the Early Toarcian Shales, Paris Basin, France. Bull. Am. Assoc. Petrol. Geol., v. 55, no. 12, pp. 2177-2193.

WELTE, D.H., 1972. Petroleum Exploration and Organic Geochemistry. Jour. Geochem. Expl., v.1, no. 1, pp.117-136.

VITRINITE REFLECTIVITY ANALYSIS

1. Definition of Problem

Recent and very immature sediments can yield biologically-generated dry gas (which is only trapped under unusual conditions such as gas hydrate formation) but cannot source either oil or condensate. In response to the higher temperatures resulting from increased depths of burial, immature rocks become mature and then, at even higher temperatures, organically metamorphosed. This is discussed in greater detail in the 'Source Rock Potential' section. As immature sediments generally have little economic significance, whereas only mature sediments can yield oil, and metamorphosed sediments have a potential only for dry gas (often in major amounts), it is important to recognise the maturation state of the source rocks in the section.

This can be achieved by measuring the reflectivity (i.e. the proportion of the light from the light source which is reflected by the polished surface) of vitrinite macerals within the total kerogen. As the level of maturation increases, so too do the vitrinite reflectivity values, which can therefore be used to estimate the maturation state of the kerogen.

2. Analytical Techniques

The rock cuttings are mounted in a one-inch block of clear plastic resin and then ground and polished using successively finer grades of alumina until a good surface is achieved.

Reflectivity determinations are carried out on a Leitz M.P.V. microphotometer using optical glasses as standards. The field of measurement is adjusted to the size of the particle but is generally in the order of 2-3 microns. All measurements are made at a wavelength of 546 nm in oil of R.I. 1.516.

Whenever possible, twenty vitrinite particles are measured in sediment samples and the results used to construct a histogram and to calculate the mean value of the sample.

Using the whole sediment sample rather than a kerogen concentrate has the following advantages :

- it is easier to distinguish vitrinite from the other kerogen macerals, the measurement of which would give incorrect results;

- reworked and caved material can be more easily recognised and avoided;

- the possibility of alteration (oxidation) of the vitrinite during concentration is eliminated;

- oxidation caused by the excessive heating inherent in incorrect sample drying techniques (e.g. infra-red lamps) at the wellsite can be recognised and avoided.

3. Presentation and Interpretation of Data

An advantage of this method is that individual macerals can be examined and only those which are truly representative (i.e. ignoring reworked, caved and artificially oxidised material) recorded. Reworked material is commonly present and is a serious disadvantage of all the methods which involve the examination and measurement of the gross kerogen rather than of its individual macerals, as maturation levels significantly too high may be indicated. If this is the case then, for example, an uninteresting immature interval may be interpreted to be a prospective mature horizon. The same would be true if an interpretation were based upon artificially oxidised material whereas the use of caved sediments would underestimate the true level of maturation.

The analytical data, a histogram of these reflectivity determinations and the mean values for each sample are presented. In some cases three mean values are quoted; one referring to those measurements which are considered to be representative of the indigenous, unoxidised vitrinite (underlined), one referring to measurements on caved material, and one referring to reworked material. In most cases only one or two values will be quoted depending on the depth in the section. In addition, the equivalent, dry-ash-free carbon content of an equivalent coal is supplied for comparison with the work of Teichmuller (1971). Two diagrams are involved in the interpretation of the results. The first is a plot of the change in vitrinite reflectance with depth in the well section. Reflectivity determinations based upon indigenous material are distinguished from those which are judged to be caved or reworked. A line is fitted to the selected data points. The second diagram is a plot of depth in the well section against the carbon content of an equivalent coal on the dry-ash-free basis. This diagram is included to give an indication of the 'rank' gradient down the hole.

4. References

TEICHMÜLLER, M., 1971. Application of Coal Petrographic Methods in Oil and Gas Exploration. Erdol Kohle, v. 24, no. 2, pp. 69-76.

TEICHMÜLLER, M. and TEICHMÜLLER, R., 1971. Geological Aspects of Coal Metamorphism. In Coal and Coal-Bearing Strata, Murchison, D.G. and Westol, T.S., editors, Oliver & Boyd, Edinburgh, pp. 233-260.