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COMPANY INCORPORATED IN U.K. NO. 1509402
VAT REGISTRATION NO. 354 0213 94

DIRECTORS: T. DORAN
V.L. ROVEDA
S.P. LOWE
D.R. WHITBREAD

UNIT 14, PARAMOUNT INDUSTRIAL ESTATE,
SANDOWN ROAD, WATFORD WD2 4XA.
TEL: 43196 TELEX: 8812973

PETROLEUM GEOCHEMISTRY REPORT

PREPARED FOR

STATOIL

Geochemical Source Rock Evaluation of Sediments from the Shetland and Dunlin Groups of NOCS Well: 34/10-12.

November 1981.

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Contents

Summary

Fifty canned cuttings samples 15 from the Shetland Group and 26 from the Dunlin Group of NOCS Well:34/10-12 were used for a comprehensive geochemical source rock study. Maturity estimations using Vitrinite Reflectance measurements, Spore Colouration ratings and CPI values from Soluble Extract Studies, suggested all the sediments examined to be immature for any hydrocarbon generation. Maturity estimations were complicated by the presence of lignite, which was believed to be caved from the Tertiary section of this well.

The hydrocarbon potential of siltstones and mudstones selected by hand picking from the Shetland Group was found to be poor. Siltstones and mudstones from the Dunlin Group were rated, as having moderate hydrocarbon potential. These moderate sources were typed as being predomiantly gas prone, but with significant additional potential to source light oils.

1. Introduction

A total of fifty canned cuttings samples were used to complete a detailed geochemical study of the Shetland and Dunlin Groups of Offshore Norwegian Well: 34/10-12. Fifteen samples were selected for the coverage of the Shetland Group (1797 - 2913 m) and twenty-six were selected for the coverage of the Dunlin Group (2257 - 2675 m). Nine additional samples were selected from the intervals 2013 - 2257 m and from the base of the Dunlin Group to T.D., for vitrinite reflectance measurements only. The purpose of completing these reflectance measurements was to correlate the values statistically with those from the Shetland and Dunlin Groups, to obtain a depth/trend relationship from which hydrocarbon generation thresholds could be calculated. Spore Colouration ratings from Visual Kerogen descriptions and Soluble Extract Studies were used to support the reflectance measurements, in assessing the true maturation levels.

Pyrolysis techniques were used to establish the hydrocarbon source potential at all stratigraphic levels and the likely hydrocarbon products or source type where the potentials were sufficiently high. Hydrocarbon typing using pyrolysis was supported by the Visual Kerogen descriptions completed at the same depth. Total Organic Carbon measurements were also completed, to provide additional information concerning the richness of the sediments, as defined solely by their organic contents.

2. Samples and Techniques

All the cuttings samples were received in tin cans which were then washed to remove all traces of drilling mud. All these washed samples were air dried under controlled conditions at 40^{o}C

The samples were then carefully hand picked to remove obvious caved material and concentrate a single, potentially organic rich lithology (e.g. mudstones, shales etc.) of similar shape, size and appearance. The general quality of the cuttings suggested that they contained significant quantities of caved material. It was noted that the majority of samples contained lignite, which was believed to be caved from the Tertiary and was therefore avoided for the most part. This was particularly true for those samples used for assessing the hydrocarbon potential of the siltstones and mudstones. Walnut shells were also observed ca 1860 m.

Samples for Vitrinite Reflectance measurements were ground to a rock flour, mounted in an epoxy resin block, the surface of which was examined microscopically. Reflectivity values were measured using a reflected light microscope, with an oil immersion objective. The results of these measurements are shown in Table 1.

Samples for Visual Kerogen description were treated with mineral acid. The remaining debris was sedimented onto a microscope slide and examined using a transmitted light microscope. The results of the Visual Kerogen descriptions and assessments of Spore Colouration are shown in Table 2. The range of the Spore Colouration is from 1 - 7 and the colour taken as representing the onset of liquid hydrocarbon generation is 3/4.

Samples for Total Organic Carbon measurements were finely ground and sieved to achieve homogeneity, then digested with fuming hydrochloric acid to remove mineral carbonate. The decarbonated samples were then combusted in a Carlo Erba 1106 Carbon, Hydrogen, Nitrogen analyser and their total organic carbon content determined, relative to those of calibrated standards. The results of these measurements are shown in Table 3.

Samples for Screening Pyrolysis were also ground and sieved and then examined using a modified Hewlett-Packard 5711 Gas Chromatograph, to measure their ultimate hydrocarbon potential. Samples were heated to an initial temperature of 250°C, then ramped to 550°C. Two peaks were evolved, which are conventionally referred to as P1 and P2 and were related to those of a calibrated standard. The results of screening pyrolysis are shown in Table 4.

Ground samples for Extended Pyrolysis were extracted with dichloromethane before being heated to 550°C and examined using a modified Hewlett-Packard 5880 Gas Chromatograph. The hydrocarbons evolved were separated according to their boiling points on a non-polar, fused silica capillary column.

Ground samples used for Soluble Extract Studies were extracted with geochemical grade dichloromethane, using a high velocity liquid mixer. Excess solvent was removed by evaporation and the remaining extract was separated on activated silica, to provide a saturate alkane fraction for gas chromatographic analysis. The saturate alkane fractions were examined by quartz capillary gas chromatography using a Carlo Erba 2151 gas chromatography with Grob-type splitless injector system. The results of these measurements are represented in Table 5.

3. Results and Discussion

(a) Maturity

The results from both Vitrinite Reflectance measurements (Table 1) and Spore Colouration ratings from Visual Kerogen Descriptions (Table 2) indicated, that all the sediments examined were immature for any hydrocarbon generation. The threshold values for the onset of liquid hydrocarbon generation used by Paleochem are Ro = 0.55% and a Spore Colour rating of 3/4. CPI values from Soluble Extract Studies (Table 6) of $>$1.3 also supported the level of immaturity indicated from Vitrinite Reflectance and Spore Colours. No depth/Reflectance trend relationship could be established due to the persistence of caved lignite in the samples. Statistical correlation of the reflectivity values believed to be the least affected by this phenomenon gave no statistically reliable correlation. Therefore no reliable generation thresholds could be established.

(b) Source Potential

(i) Hydrocarbon Potential

Samples having total organic carbon values below 0.5% are generally regarded as containing insufficient organic material to be of commercial value (2). Thus this value is used as a cut-off point in this report and sediments with organic carbon values less than 0.5% are regarded as having no significant source potential.

Source potential ratings based on conventional geochemical data are given below.

Poor Potential	Less than 0.5%
Moderate Potential	0.5% to 1.5%
Good Potential	Greater than 1.5%

Pyrolytic methods are widely used for estimating the generating capabilities of potential source rocks (3). Pyrolysis techniques have superseded the more traditional method of assessing hydrocarbon potential using total organic carbon measurements, because they provide more meaningful data. Pyrolysis does not take into account any reworked material and/or inertinite present in source rocks, which adds to the organic carbon value, but has very limited or no hydrocarbon potential.

The first peak (P1) is often considered as representative of the quantity of free hydrocarbons that were present in the sediment at the time of sampling. The second peak (P2) is considered to be representative of the quantity of hydrocarbons present in the sediment and yet to be generated. The P2 peak is produced by conversion of the Kerogen in the rock sample by thermal cracking in the instrument. This is generally considered to be a reasonable estimate of the amount of hydrocarbons, which could theoretically be generated by complete conversion of the Kerogen in sediments under natural conditions throughout their geological lifetime. Both the P1 and P2 yields are expressed in Kg./tonne.

Comparison of pyrolysis data with conventional geochemical data to provide a source potential rating gives the P2 hydrocarbon potential in practical exploration terms (4):

Poor	0.1 to 1.5 Kg./tonne
Moderate	1.5 to 5.0 Kg./tonne
Good	Greater than 5.0 Kg./tonne

The total organic carbon contents (TOC) of mudstone and siltstone sediments from the Shetland Group were considered to range from poor to moderate (TOC = 0.38 - 0.69% wt.), with the exception of a lignite examined at 2005/20 m (TOC = 57.20%). This lignite may not be in situ, but was the dominant lithology in this particular sample. Screening Pyrolysis measurements downrated the moderate ratings from TOC measurements to poor and rated all the siltstone/mudstone sediments examined from the Shetland Group interval as having poor potential. This downgrading in hydrocarbon potential may be due to the presence of significant quantities of reworked material and inertinite in these sediments.

It was noted that sediments in the depth interval 1855 to 1945 m had significant quantities of in situ hydrocarbons (P1), in relation to the amount of Kerogen breakdown products (P2). It is unfortunate, but during conventional pyrolysis some of the P1 can be eluted with the P2 fractions (5). It is Paleochem practise to extract samples, where the P1 is above a threshold value of 10% of the P2 value and to repeat the measurement of P2 after extraction.

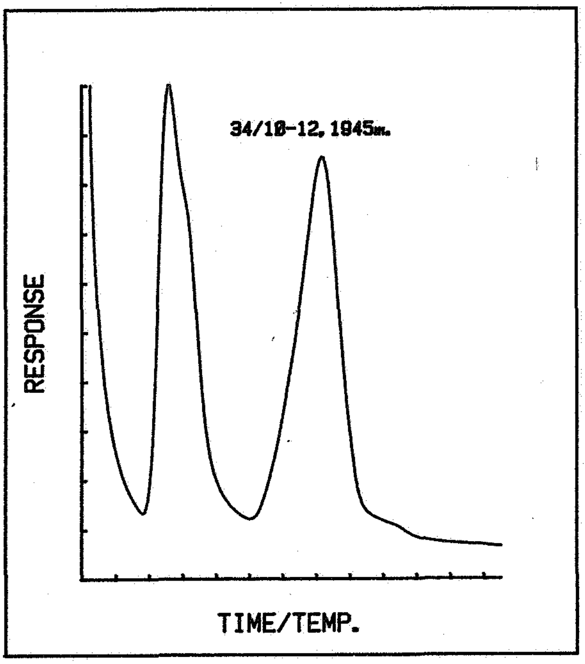


FIG. 1A

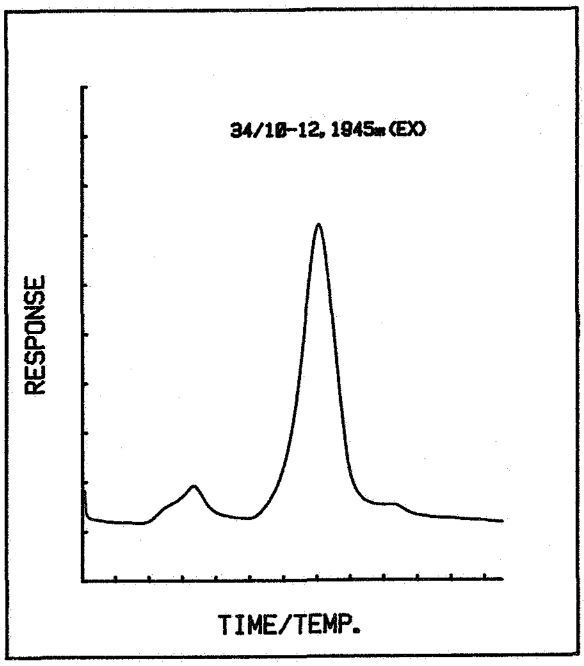


FIG. 1B

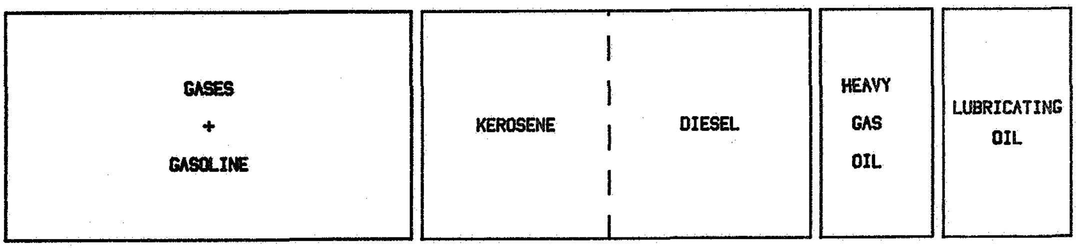
Fig.1A shows the sample from 1930/45, where the quantity of in situ hydrocarbons is large compared with the Kerogen breakdown products. The second trace (Fig.1B) shows the pyrogram of the same sample, after it had been exhaustively extracted with dichloromethane. It is clear from Fig.1B that the hydrocarbon potential has been reduced significantly by extraction (from P2 = 0.7 to P2 = 0.4 Kg./tonne) and the potential measured on the extracted sample was over optimistic.

TOC measurements completes on mudstone/siltstone lithologies from the Dunlin Group suggested these sediments to have moderate to good hydrocarbon potential (TOC % wt. range 0.89 - 1.82). Screening Pyrolysis measurements downrated these hydrocarbon potential ratings to moderate, with P2 values ranging from 1.4 - 2.9 Kg./tonne. This downrating was also thought to be the effect of the presence of reworked material and inertinite in these sediments. Two lignites examined in the Dunlin Group interval were rated as having good hydrocarbon potential, as would be expected. However, in the absence of a well log, it is not known whether or not these lignites were in situ.

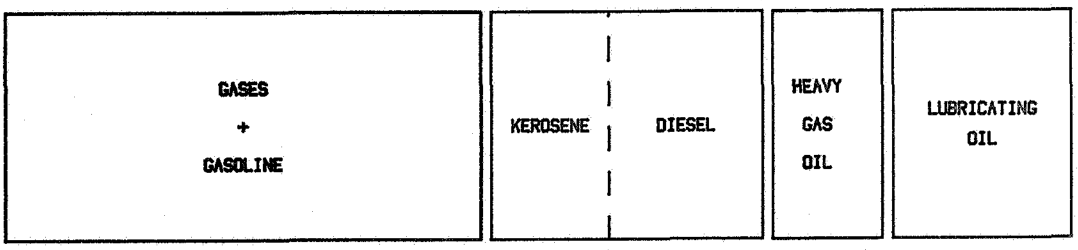
(ii) <u>Hydrocarbon Type</u>

Hydrocarbon Typing from Visual Kerogen Descriptions suggested sediments from the Shetland Group to be predominantly gas prone, whilst those from the Dunlin Group were considered to represent mixed source types. In view of the poor hydrocarbon potential rating for the Shetland Group from Screening Pyrolysis measurements, no Extended Pyrolysis measurements were completed in this interval, with the exception of the walnut shells found in abundance at 1855/70 m and lignite found in abundance at 2005/20 m.

The walnut shells were found to be more gas than oil prone, but less gas prone than the lignite examined.

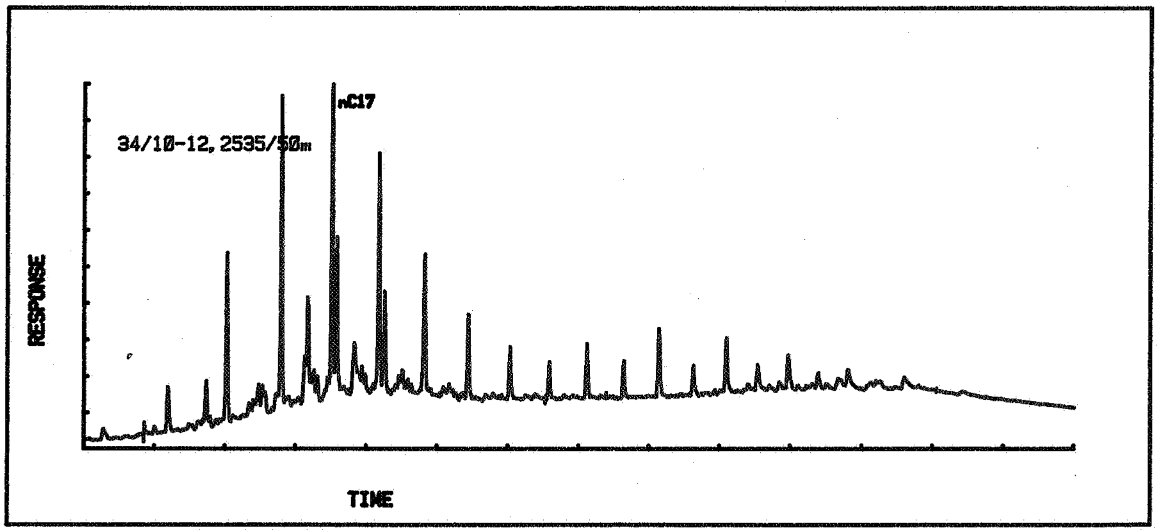


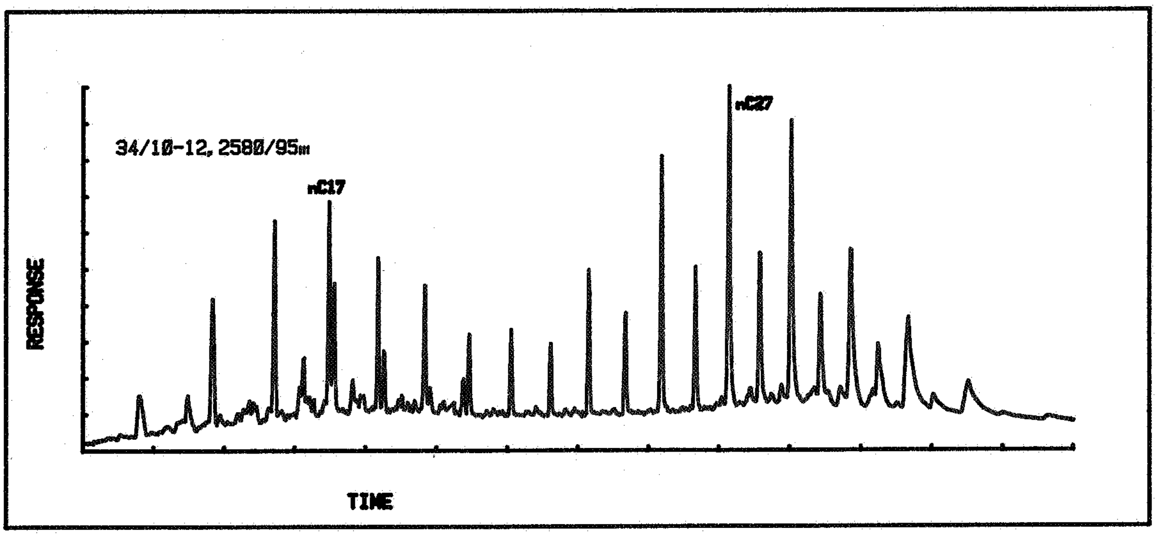
WALNUT SHELLS



LIGNITE

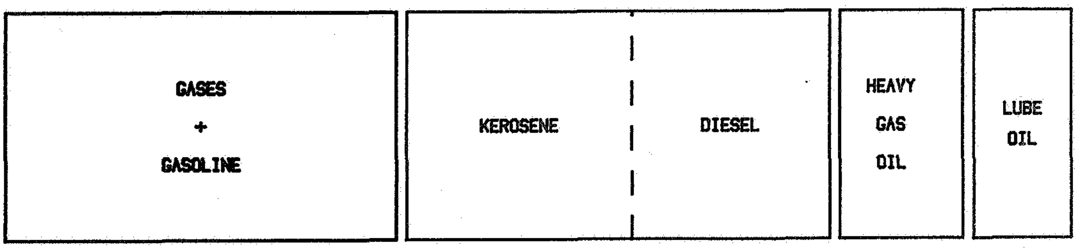
Soluble Extract Studies were considered to be unreliable for hydrocarbon typing in this instance, due to the presence of hydrocarbon contamination present in the sediments available for examination. This was evidenced by the quantities of in situ hydrocarbons demonstrated from Screening Pyrolysis studies. It was not possible to establish from the n-alkane distributions of the sediment extracts from either the Shetland or Dunlin Groups the origin of these in situ hydrocarbons. It is suggested that they comprise a significant proportion of diesel fuel from the drilling process. The n-alkane distributions of the sediment extracts varied widely, as shown by the two chromatograms below.



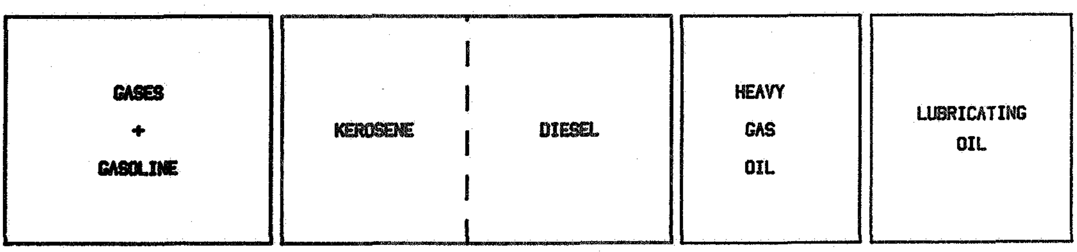


The chromatogram from 2535 - 50 m shows a predominance of n-alkanes eluting around n-C_{17}, in contrast to the chromatogram from 2580 - 95 m, which peaks at $n-C_{27}$. It is suggested this is due to a greater proportion of diesel fuel present in the extract from 2535 - 50 m than the extract from 2580 - 95 m. Further evidence for this suggestion is given by the significant decrease in the pristane/phytane ratio of the 2535 - 50 m extract, relative to the pristane/phytane ratio of the 2580 - 95 m extract.

Visual Kerogen Descriptions of sediments from the Dunlin Group classed them as being predominantly gas prone, though there was evidence of some amorphous Kerogen and hence an indication of subordinate oil proness, in the section between 2500 and 2700 m. This view was supported by Extended Pyrolysis Data, which showed a significant decrease in the quantity of gases plus gasoline range hydrocarbons eluted from Kerogens in the section 2500 to 2700 m, relative to the hydrocarbons eluted from Kerogens above these depths.



2355m



2610m

A significant feature of the Extended Pyrolysis Data is the significantly large quantity of kerosene and diesel range hydrocarbons, which evolve from these Dunlin Kerogens.

This suggests that the liquid hydrocarbons generated from these Kerogens would be light in character.

4. Conclusions

1) All the sediments examined from both the Shetland and Dunlin Groups were immature for any hydrocarbon potential.

2) Hydrocarbon Potential ratings completed on sediments from the Shetland Group indicated them to have only poor potential for generating hydrocarbons, if mature. Sediments fromthe Dunlin Group were rated, as having moderate potential to generate hydrocarbons.

3) Hydrocarbon Typing completed in detail on sediments from the Dunlin Group suggested them to be predominantly gas prone, but to have significant potential in addition to source light oils.

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4.	Clementz D.M., Demaison G.J., Daly A.R.	OTC (1979) page 465.
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Well: 34/10-12

	VITRINITE REFLECTANCE DATA	
Depth m.	Reflectivity Ro $_{(Ave)}$	
	Autochthonous	Allochthonous
1795/10	0.33 $_{(11)}$	
1825/40	0.29 $_{(2)}$	
1840/55	0.38 $_{(5)}$	
1870/85	0.35 $_{(9)}$	
1885/00	0.33 $_{(1)}$	0.50 $_{(1)}$
1900/15	0.33 $_{(20)}$	
1930/45	0.33 $_{(21)}$	
1945/60	0.38 $_{(9)}$	
1960/75	0.42 $_{(3)}$	
1990/05	0.35 $_{(3)}$	
2050/65	*0.28 $_{(21)}$	
2110/25	*0.29 $_{(22)}$	
2170/85	0.38 $_{(22)}$	
2230/45	*0.34 $_{(25)}$	
2260/75	*0.34 $_{(21)}$	
2305/20	*0.28 $_{(2)}$ 0.37 $_{(4)}$	
2335/50	*0.31 $_{(22)}$	

Table 1.

Well: 34/10-12

VITRINITE REFLECTANCE DATA		
Depth m.	Reflectivity Ro (Ave)	
	Autochthonous	Allochthonous
2355/70	*0.33 (20)	
2370/85	*0.31 (23)	
2385/00	*0.32 (21)	
2415/30	0.40 (21)	
2430/45	0.36 (21)	
2445/60	*0.33 (8)	
2475/90	0.37 (23)	
2490/05	0.38 (10)	
2505/20	*0.33 (22)	
2535/50	0.37 (9)	
2550/65	0.40 (24)	
2565/80	*0.34 (22)	
2595/10	*0.31 (22)	
2610/25	*0.34 (22)	
2625/40	*0.29 (22)	
2655/70	*0.36 (21)	
2670/85	0.38 (20)	

Table 1 - continued.

Well: 34/10-12

	VITRINITE REFLECTANCE DATA	
Depth m.	Reflectivity $Ro_{(Ave)}$	
	Autochthonous	Allochthonous
2700/15	$0.41_{(21)}$	
2730/45	$0.38_{(22)}$	
2760/75	$0.45_{(23)}$	
2775/90	$0.41_{(21)}$	

* Caved lignite?/Cavings

Figures in Parenthesis refer to the number of measurements completed.

Table 1 - continued.

Well No: 34/10-12

VISUAL KEROGEN DATA

Depth m.	Cuticle	Brown Wood	Black Wood &Inertinite	Amorphous Vascular	Amorphous Algal	Predominant Source Type	Colour Maturation Rating
1810/25	-	Trace	Common	Trace	Trace	None	2 to 3
1840/55	-	Trace	Common	Trace	Trace	None	2/3 to 3
1870/85	-	Trace	Common	Trace	?Common	None/?Oil	2 to 3
2005/20	-	Abundant	Abundant	Trace	-	Gas	3
2245/60	Trace	Abundant	Common	Abundant	-	Gas	3
2275/90	Trace	Abundant	Common	Trace	-	Gas	3
2305/20	Trace	Common	Abundant	Trace	-	Gas	3
2340/55	Trace	Trace/ Abundant	Trace	-	-	None?	3
2370/85	-	Trace/ Abundant	Abundant	Common	?Trace	None?	3
2460/75	Trace	Abundant	Common	Trace	-	Gas	3
2505/20	Trace	Common/ Abundant	Abundant	Common	?Common	Gas/?Sub.Oil	3
2535/50	Trace	Common	Common	Common	?Common	Gas/?Sub.Oil	3

Table 2.

Well No: 34/10-12

VISUAL KEROGEN DATA

Depth m.	Cuticle	Brown Wood	Black Wood &Inertinte	Amorphous Vascular	Amorphous Algal	Predominant Source Type	Colour Maturation Rating
2580/95	Trace	Trace/ Common	Common	Common	?Trace	Gas?	3
2640/55	Trace	Common/ Abundant	Common	Trace	?Common	Gas/?Sub.Oil	3
2655/70	Trace	Trace	Common	Trace	?Common	Gas/?Sub.Oil	3

Table 2 - continued.

Well No: 34/10-12

General Well Data

Sample Type	Stratigraphy	Depth m	Lithology	Total Organic Carbon Content (TOC) % wt.
Cuttings	Shetland Group	1810/25	Mudstone	0.42 (0.44R)
Cuttings	Shetland Group	1825/40	Mudstone	0.39
Cuttings	Shetland Group	1840/55	Mudstone	0.39
Cuttings	Shetland Group	1855/70	Mudstone	0.50
Cuttings	Recent	1855/70	Walnut Shell	
	Shetland Group	1870/85	Siltstone	0.38
Cuttings	Shetland Group	1885/00	Mudstone	0.49
Cuttings	Shetland Group	1900/15	Mudstone	0.63
Cuttings	Shetland Group	1915/30	Siltstone	0.57
Cuttings	Shetland Group	1930/45	Mudstone	0.69
Cuttings	Shetland Group	1945/60	Siltstone	0.58
Cuttings	Shetland Group	1960/75	Siltstone	0.56
Cuttings	Shetland Group	1975/90	Siltstone	0.61
Cuttings	Shetland Group	1990/05	Siltstone	0.56
Cuttings	Shetland Group	2005/20	Lignite	57.20
Cuttings	Dunlin Group	2260/75	Mudstone	0.89
Cuttings	Dunlin Group	2260/75	Lignite	50.10
Cuttings	Dunlin Group	2275/90	Siltstone	1.25 (1.24R)
Cuttings	Dunlin Group	2305/20	Siltstone	1.57
Cuttings	Dunlin Group	2335/40	Siltstone	1.53
Cuttings	Dunlin Group	2340/55	Siltstone	1.81

Table 3.

Well No: 34/10-12

General Well Data

Sample Type	Stratigraphy	Depth m	Lithology	Total Organic Carbon Content (TOC) % wt
Cuttings	Dunlin Group	2335/70	Siltstone	1.47
Cuttings	Dunlin Group	2370/85	Siltstone	1.59
Cuttings	Dunlin Group	2385/00	Siltstone	1.45
Cuttings	Dunlin Group	2400/15	Siltstone	1.54
Cuttings	Dunlin Group	2415/30	Siltstone	1.35
Cuttings	Dunlin Group	2430/45	Siltstone	1.47
Cuttings	Dunlin Group	2445/60	Siltstone	1.82
Cuttings	Dunlin Group	2460/75	Siltstone	1.30 (1.23R)
Cuttings	Dunlin Group	2475/90	Siltstone	1.42
Cuttings	Dunlin Group	2490/05	Siltstone	1.44
Cuttings	Dunlin Group	2505/20	Siltstone	1.24
Cuttings	Dunlin Group	2520/35	Siltstone	1.35 (1.37R)
Cuttings	Dunlin Group	2535/50	Siltstone	1.35
Cuttings	Dunlin Group	2550/65	Siltstone	1.32
Cuttings	Dunlin Group	2565/80	Siltstone	1.38
Cuttings	Dunlin Group	2580/95	Siltstone	1.46
Cuttings	Dunlin Group	2595/10	Siltstone	1.39
Cuttings	Dunlin Group	2610/25	Siltstone	1.70
Cuttings	Dunlin Group	2625/40	Siltstone	1.54
Cuttings	Dunlin Group	2640/55	Siltstone	1.53

Table 3 - continued.

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Well No: 34/10-12

General Well Data

Sample Type	Stratigraphy	Depth m	Lithology	Total Organic Carbon Contents (TOC) % wt
Cuttings	Dunlin Group	2655/70	Siltstone	1.62
Cuttings	Dunlin Group	2655/70	Lignite	57.4

R = Repeat Value

Table 3 - continued.

PALEOCHEM

Well No: 34/10-12

Pyrolysis Data

Depth m	Yield (Kg./tonne) P1 Peak	P2 Peak
1810/25	0.1	0.3
1825/40	0.1	0.2
1840/55	<0.1	0.3
1855/70	0.3	0.5
1855/70 Walnuts	40.6	14.0
1870/85	0.1	0.3
1885/90	0.2	0.4
1900/15	0.3	0.6
1915/30	0.3 (0.3 Rpt)	0.4 (0.3 Rpt)
1930/45	0.6	0.7
1945/60	0.1	0.3
1960/75	0.1	0.4
1975/90	0.1	0.4
1990/05	<0.1	0.4
2005/20	4.3	63.2
2260/75	0.4	0.9
2260/75 Lignite	6.5	112.7
2275/90	0.4	1.2
2305/20	0.1	1.6
2335/40	0.1	1.9
2340/55	0.1	2.9

Table 4.

PALEOCHEM

Well No: 34/10-12

Pyrolysis Data

Depth m	Yield (Kg./tonne) P1 Peak	P2 Peak
2355/70	<0.1	2.0
2370/85	0.1	2.1
2385/00	0.2	1.8
2400/15	0.1	1.6
2415/30	0.1 (0.1 Rpt)	1.3 (1.4 Rpt)
2430/45	<0.1	1.4
2445/60	0.3	1.9
2460/75	0.2	1.6
2475/90	0.2	1.7
2490/05	0.2	2.6
2505/20	0.1	2.3
2520/35	0.1	2.3
2535/50	0.2	1.8
2550/65	0.1	1.9
2565/80	0.1	2.2
2580/95	0.2	2.1
2595/10	0.1	1.9
2610/25	0.1	2.1
2625/40	0.1	1.9
2640/55	0.1	2.1
2655/70	0.2	2.9
2655/70 lignite	2.5	61.6

Table 4 - continued.

Well No: 34/10-12

SOLUBLE EXTRACT DATA

Depth m.	Total Soluble Extract (TSE) % wt.	Saturate Alkane Content (SAC) % TSE	Carbon Preference Index (CPI)
1810/25	0.006	12.5	1.3
1840/55	*0.005	25.9	1.7
1870/85	0.003	62.00	1.7
2005/20	0.024	11.5	+
2245/60	0.034	10.0	1.7
2275/90	0.017	19.6	1.9
2305/20	0.007	26.1	1.6
2340/55	0.023	43.1	+
2370/85	0.017	17.5	1.7
2460/75	0.026	45.5	1.6
2505/20	0.018	1.1	1.7
2535/50	0.036	52.6	1.3
2580/95	0.028	24.9	1.6
2640/55	0.012	36.5	1.3
2655/70	0.028	44.3	1.9

* Some material lost before weighing.

Table 5.

\+ CPI value not calculated due to short n-alkane range.