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**RIJSWIJK, THE NETHERLANDS**

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GEOCHEMICAL INVESTIGATION OF THE JURASSIC BRORA  
BEACH SEDIMENTS (EAST SCOTLAND) AND THEIR  
CORRELATION WITH THE BEATRICE CRUDE  
by

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Sponsor: Shell Expro

Investigation 9.12.263

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### SUMMARY

A geochemical investigation of samples collected by Vlierboom (Shell Expro) from the Brora beach section (East Scotland) has been carried out at the request of Shell Expro.

The results indicate that three source rock types are present, viz:

#### Oil source rocks

1. Type A, characterised by sapropelic organic matter, dinoflagellates/sporinites and detrital landplant matter, observed in Kimmeridgian sediments.
2. Type B, characterised by laminated sapropelic organic matter of algal/bacterial origin. Botryococcus algal colonies, sporinites and detrital landplant matter, observed in Bathonian sediments, directly under the Brora coal.

#### Gas source rock

3. Type C, characterised by abundant landplant matter, mainly vitrinite, sporinite and liptodetrinite, viz. the Brora coal and associated carbonaceous shales.

A comparison of all geochemical parameters of the laboratory-matured samples with those of the Beatrice oil shows that the oil was probably expelled from source matter that is very similar to that of sample VB-718 (type B above, Bathonian Great Estuarine Series). Note that comparable organic matter (Algal source rocks) is also present in the Devonian and Carboniferous strata.

### KEYWORDS

Geochemistry, source rock analysis, extract analysis, Brora beach section, Jurassic, oil source rock, Beatrice crude oil, source rock/crude oil correlation.

GEOCHEMICAL INVESTIGATION OF THE JURASSIC BRORA BEACH  
SEDIMENTS (EAST SCOTLAND) AND THEIR CORRELATION WITH  
THE BEATRICE CRUDE

Part I: Source rock detection and evaluation

1. INTRODUCTION

Two types of immature middle and upper Jurassic oil source rocks are present in the Brora outcrop area, East Scotland (see location map, Fig. 1) viz,:

Type A, characterised by bacterial SOM,

dinoflagellates/sporomorphs and detrital land-plant matter in the marine Callovian and Kimmeridgian sequences and

Type B, characterised by laminated SOM of algal/bacterial origin, Botryococcus algal colonies, Sporomorphs and detrital land-plant matter, restricted to the Bathonian coastal plain deposits.

Additional pyrolysis sniffing,  $C_R/C_T$  and maceral analyses were requested for surface samples\* from the Brora outcrop along the Scottish east coast.

2. RESULTS

2.1 Amount of organic matter

2.1.1. Pyrolysis sniffing (Enclosure 1 and Table 3)

The source rock indications based on pyrolysis sniffing values ( before and after chloroform extraction) have been plotted in enclosure 1.

- a) Very low source rock indications in the range of 5 to 15 psu\*\* were obtained from samples VB 702, 703, 704, 705, 706, and 707, all belonging to the DUNROBIN BEDS (Pliensbachian) and from samples VB 709 (Brora Argillaceous Beds) and sample VB 710 (upper part Allt Na Cuile Sandstones).

\* Samples collected by F.W. Vlierboom, Uee/35, Shell U.K.

\*\* Pyrolysis sniffing units.

- b) Low to medium source rock indications in the range 65 to 270 psu were obtained from samples VB 711, 712, 713, 714, 715 and 716, belonging to the Kimmeridgian Clay Formation.
- c) High source rock indications (more than 900 psu) were obtained from the Bathonian coal (VB 708) and the underlying Great Estuarine Series (Bathonian) samples VB 717, 718 and 719.

#### 2.1.2. Organic carbon content (enclosure 1 and Table 3)

The non-carbonate organic carbon percentages of selected samples are shown in enclosure 1. They confirm the results of the pyrolysis sniffing, viz.:

- a) the samples with low organic carbon percentages (0.3 to 0.9%w) correspond with very low psu values
- b) the samples with low to medium psu contain organic carbon, varying from 4,5 to 6,9%.
- c) the samples with high psu contain organic carbon, varying from 22,9 to 40,8%

#### 2.2. Type of organic matter

##### 2.2.1. Pyrolysis gas chromatography

The pyrolysis gas ratios of the analysed samples indicate the presence of organic matter of the mainly humic to kerogeneous type (see geochemical log, encl. 1 and Table 3).

##### 2.2.2. $C_R/C_T$ ratios

The  $C_R/C_T$  ratios of the analysed samples can be subdivided into two groups (enclosure 1 and Table 3).

- a) Those with  $C_R/C_T$  values varying between 0.77 and 0.91, which correspond to the mainly humic to mixed types as obtained by pyrolysis gas chromatography.
- b) and those with  $C_R/C_T$  values varying between 0.45 and 0.52, which correspond to the kerogenous type as obtained by pyrolysis gas chromatography. In general, the  $C_R/C_T$  ratios of the above-mentioned samples are influenced by the presence of

detrital landplant matter and by a slight degree of oxidation.

### 2.2.3. Incident light microscopy (Table 4)

Pieces of the samples embedded in polyester resin and polished perpendicular to the bedding have been investigated under the microscope with incident normal (tungsten) light with and without crossed nicols and with incident ultra-violet light (fluorescence microscopy). The following maceral associations were observed:

- a) Kimmeridgian (samples VB 710 to 716): Bacterial SOM with abundant dinoflagellates, liptodetrinite, detrital land plant matter and associated framboidal pyrite.
- b) Bathonian (samples VB 708, 717, 718 and 719)  
VB 708: detrital vitrinite in bacterial SOM, many sporinites, liptodetrinite and few botryococci.  
VB 718 and 719: matrix consisting of bacterial SOM and laminated algae. Botryococci and sporinites are present.  
VB 717: Bacterial SOM with many ? dinoflagellates, sporinites.

The amount and the habitat of the organic matter which is a prerequisite for efficient oil expulsion, has been observed in the Kimmeridgian and Bathonian oil source rocks.

### 2.3. Vitrinite reflectance

An excellent DOM histogram was obtained from the Brora coal (sample collected by W.G. Townson) indicating VR 0.44 (DOM 54). Sample VB-708 (Carbonaceous shale contains few vitrinite 1 particles with DOM 53-54 (VR 0.42-0.44).

The vitrinite particles observed in MO 81 and Mo 84 (Kimmeridge Clay Formation) revealed too low VR values of respectively 0.36 (DOM 50) and 0.38 (DOM 51). These low reflectances may be due to:

- a) impregnation from the bacterial SOM, in which they were embedded and/or
- b) bacterial degradation of vitrinite 1 (hydrogen poor) to vitrinite 2 (hydrogen richer)

## Part II: EXTRACT ANALYSIS

### 1. INTRODUCTION

Geochemical analysis have been carried out on extracts of the original and laboratory matured source rock samples VB 708, VB 713 and VB 718.

### 2. MATURITY

The intensity of the non-normal alkanes in the gas chromatograms of the saturated hydrocarbons of the original samples (Fig. 2, 3 and 4) indicate that the samples VB 708 and VB 713 are immature. The DOM of oil of VB 713 cannot be determined due to the small quantity of extract. DOM of oil values of 55 and 63 were obtained from samples VB 708 and VB 718, respectively. The former DOM value (viz. 55) is in agreement with the vitrinite reflectance values of the Brora coal, viz, DOM=54 and of those measured in sample VB 708, viz. DOM=53-54.

### 3. TYPE OF ORGANIC MATTER

The shape of the gas chromatograms of the saturated hydrocarbons (Figs. 2, 3, 4) and the parameters m1 and m2 (Fig. 6) for the original and laboratory-matured samples indicate the following source matter types.

- a. VB 713 (Kimmeridgian): contains sapropelic organic matter with a contribution of algae and probably landplant waxes and resins.
- b. VB 708 (Bathonian): contains a significant contribution of landplant waxes and resins.
- c. VB 718 (Bathonian): sapropelic organic matter with a significant contribution of algae and probably a minor contribution of plant waxes.

#### 4. ENVIRONMENT OF DEPOSITION

The sulphur contents and the contents of vanadyl/nickel porphyrins in the original samples, as well as the pristane/n-C<sub>17</sub> ratios in the laboratory-matured samples (Tables 1 and 2), suggest the following environment of deposition:

VB 708: landplant matter deposited in sulphate-containing reducing environment.

VB 713: marine.

VB 718: Coastal marine.

#### 5. POSSIBLE SOURCE ROCK/BEATRICE CRUDE OIL CORRELATION

(Fig. 2, 3, 4, 5, 6, Tables 1 and 2).

Based on the gas chromatograms of the saturated hydrocarbons, the parameters M<sub>1</sub> and M<sub>2</sub> and the pristane/n-C<sub>17</sub> alkane ratios obtained from the original and laboratory-matured samples, one tends to conclude that the source rock matter which has generated the Beatrice crude is very similar to that present in sample VB-718. The slight differences in pristane/n-17 alkane and phytane/n-C<sub>18</sub> alkane ratios between the extract of the long heated sample VB-718 and the Beatrice crude oil indicate that the source rock of the Beatrice crude oil contains more sapropelic organic matter and fewer algae than was observed in sample VB-718.

### Part III; CONCLUSIONS

1. Three source rock types can be distinguished in the Brora beach section, viz:

#### Oil source rocks

Kimmeridgian oil source rocks (VB 710 through 716),

Characterised by bacterial sapropelic organic matter, dinoflagellates/sporinites and detrital landplant particles.

Bathonian oil source rocks (VB 717, 718 and 719) samples VB 718 and 719, directly underneath the Brora coal, are

characterised by laminated algal/bacterial sapropelic organic

matter, Botryococcus algal colonies, sporinites and detrital landplant matter. Sample VB 717 has a similar maceral association as that described for the above-mentioned Kimmeridgian oil source rocks.

Gas source rock

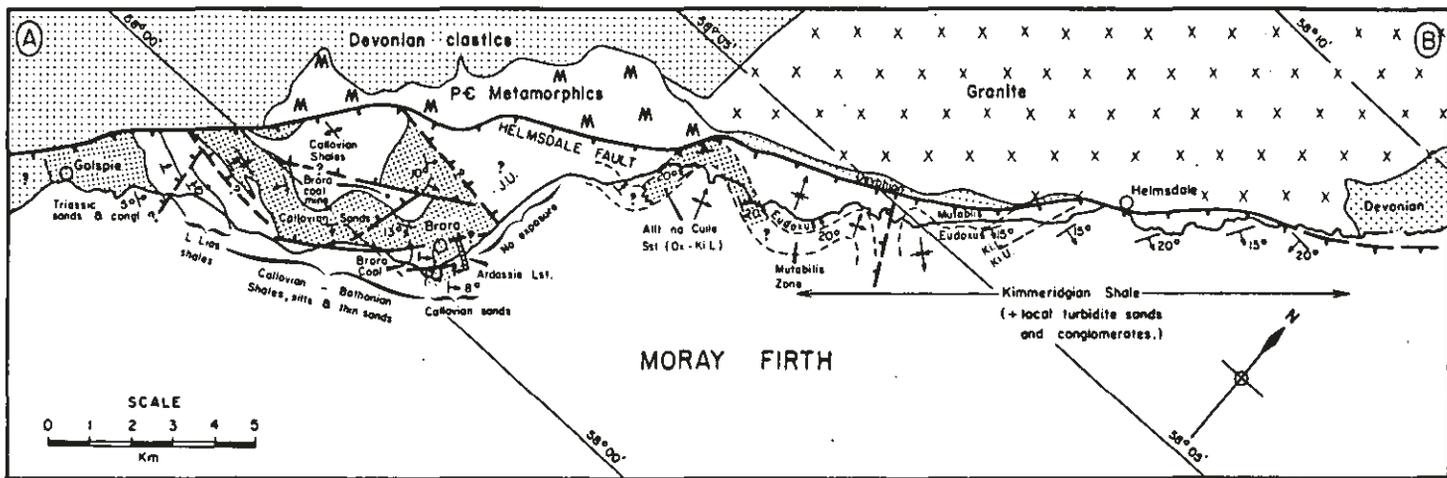
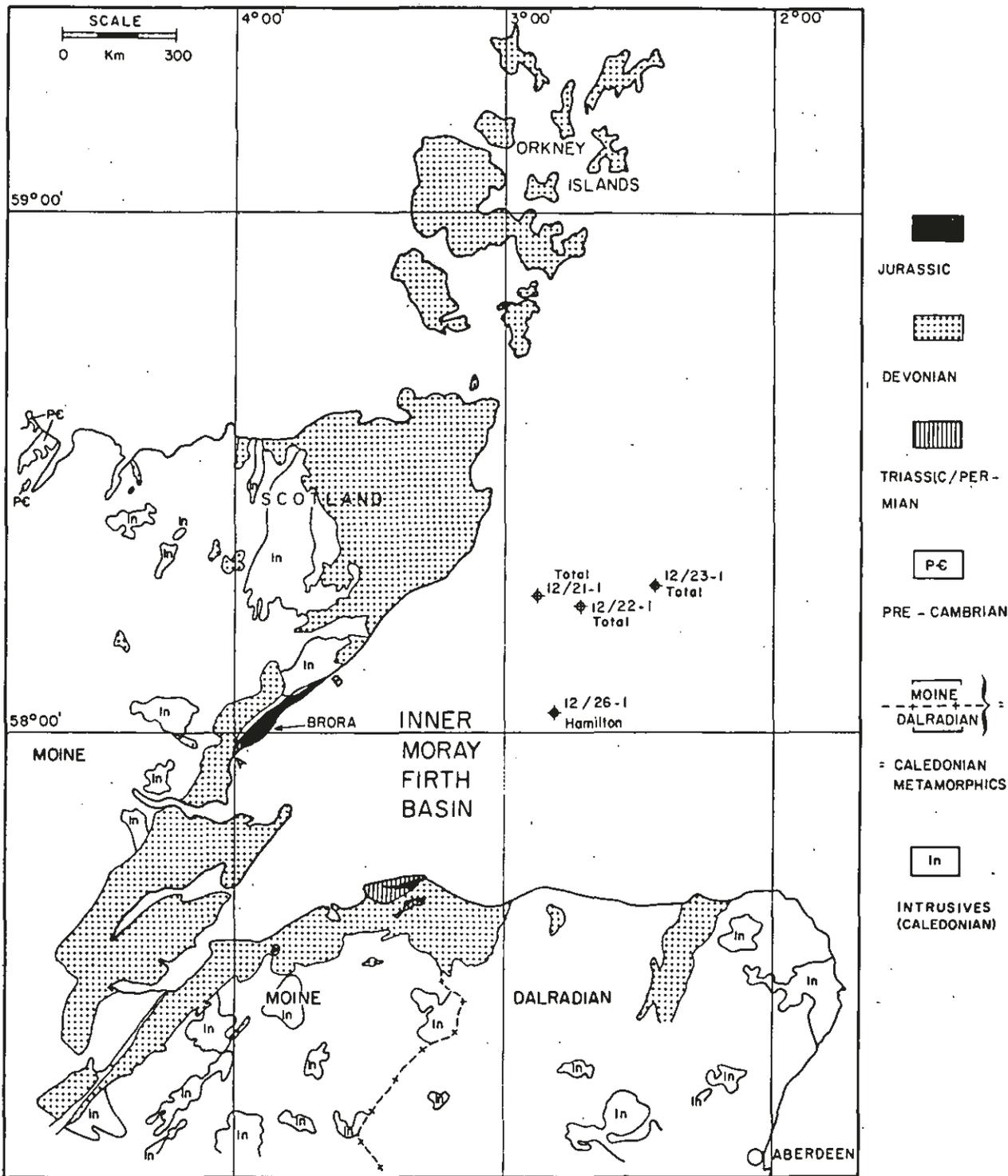
The Bathonian Brora coal and associated carbonaceous shales are characterised by abundant vitrinite and liptodetrinite..

2. Vitrinite reflectance measurements of the Brora coal and carbonaceous shale (VB 708) indicate a DOM interval of VR 0.42-0.44 (DOM 53-54). C<sub>29</sub> analyses of VB 708 and VB-718 resulted in DOM of VR 0.47 and 0.73 respectively (DOM 55 and 63 respectively). We conclude that DOM interval VR 0.42-0.47 (DOM interval 53-55) is probably the correct DOM for the brora beach section, if the other geochemical parameters are also taken into account.

3. Mass spectrometric data of the heated samples VB-713 and VB-718 indicate that both samples could be related to the Beatrice crude. However, the gaschromatogram of the heated VB-718 is much more similar to that of the Beatrice oil than the gaschromatogram of the heated VB-713.

Therefore, we favour organic matter similar to that observed in VB-718 as the most likely source for the Beatrice crude. The source rock for the Beatrice crude, however, contains more sapropelic organic matter and fewer algae than was observed in sample VB 718.

Note that comparable organic matter (Algal source rocks) is also present in the Devonian and Carboniferous strata.



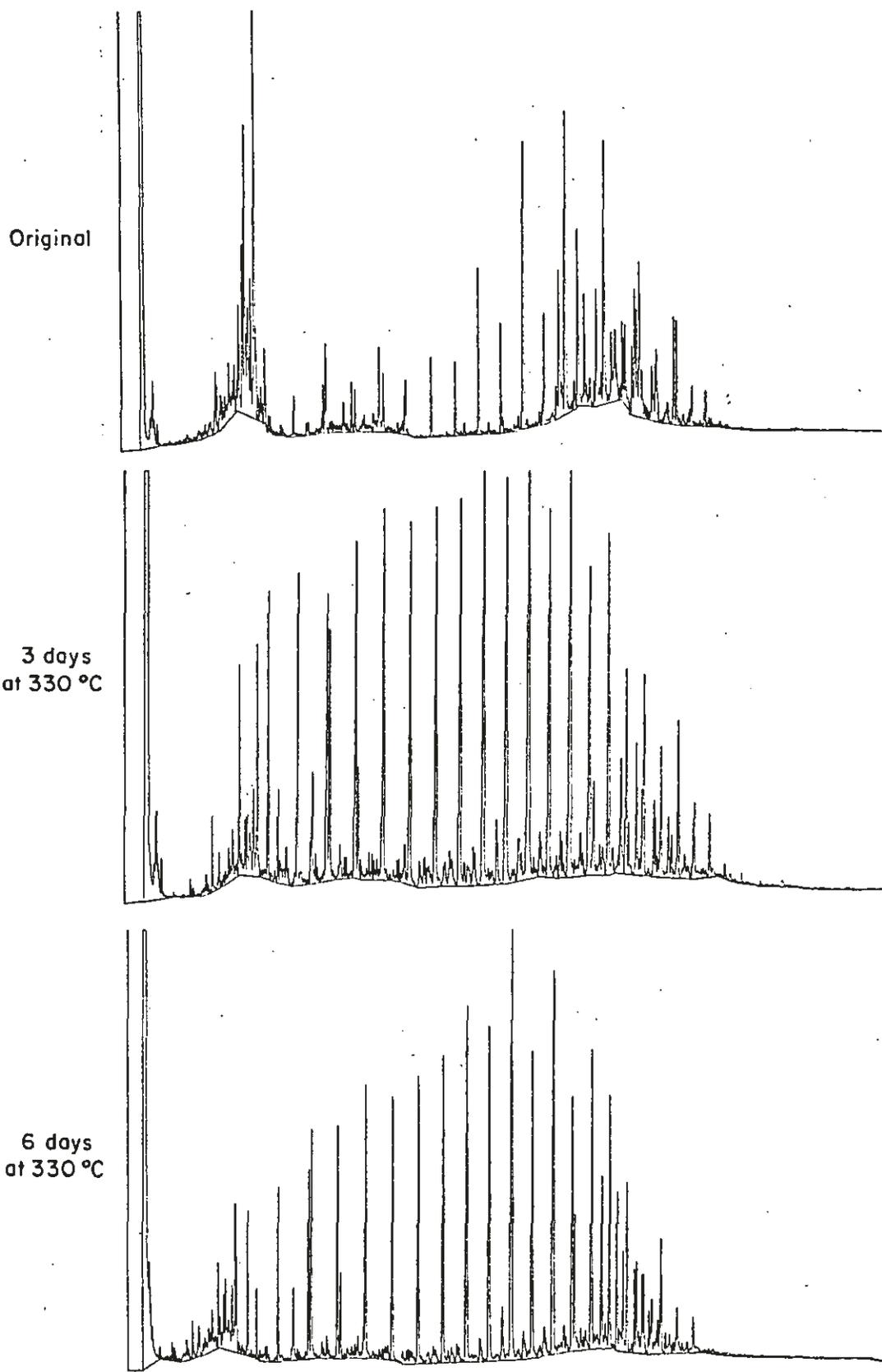
(Data from Shell UK, Expl. Dep.)

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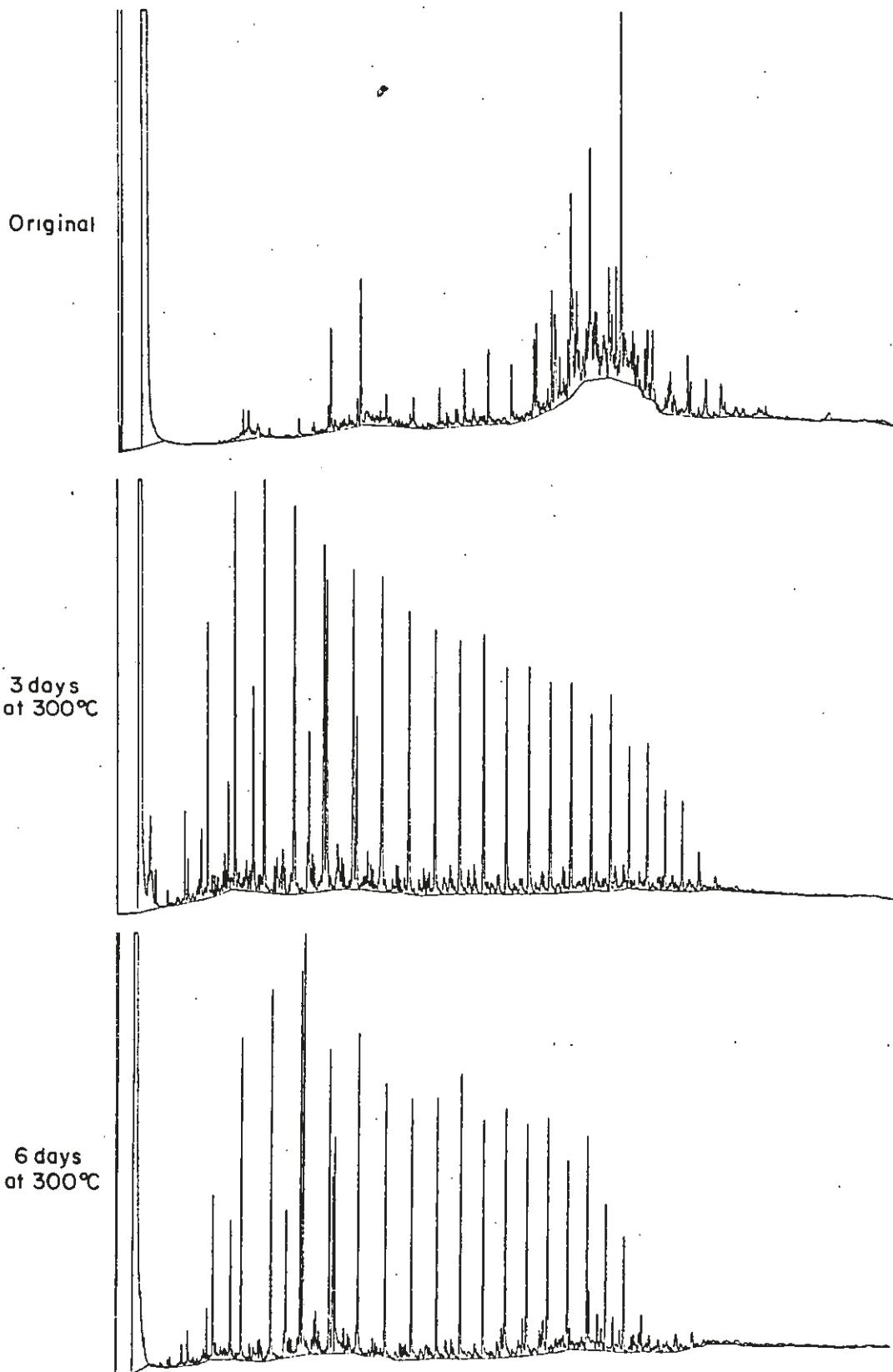
LOCATION MAP: JURASSIC ONSHORE SECTION BRORA AREA, EAST SUTHERLAND SCOTLAND

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FIG. 1

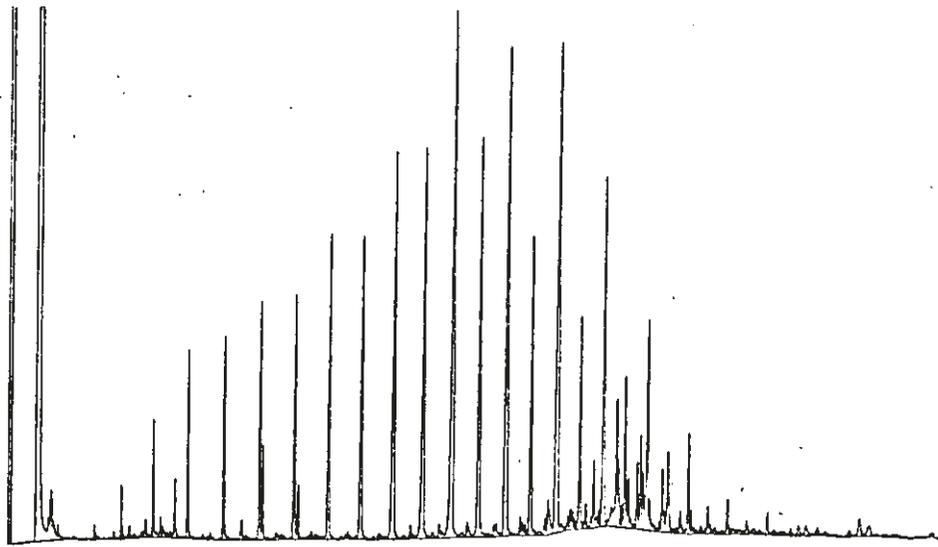


GAS CHROMATOGRAMS OF SATURATED HYDROCARBONS OF  
BATHONIAN SAMPLE VB-708. (Brora coal)

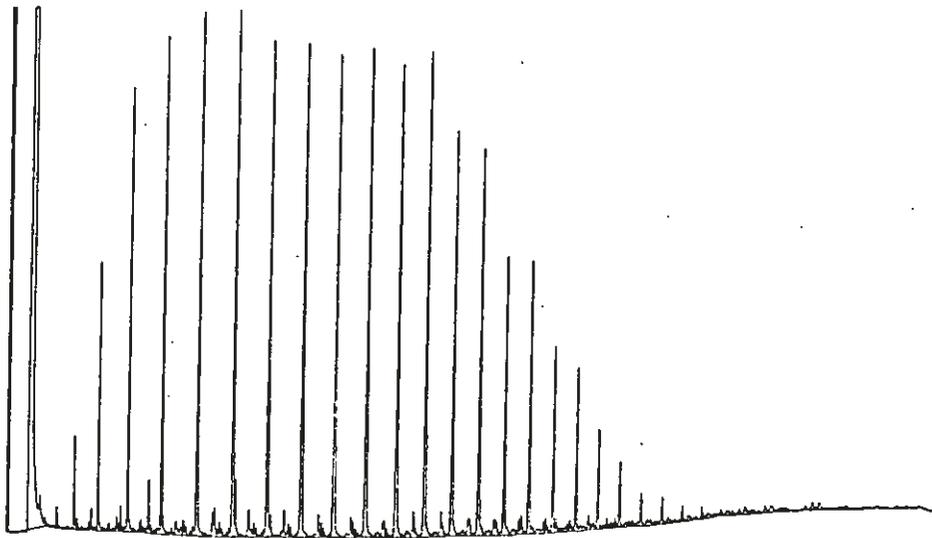


GAS CHROMATOGRAMS OF SATURATED HYDROCARBONS OF KIMMERIDGE SAMPLE VB-713 (Kimmeridge Clay Formation)

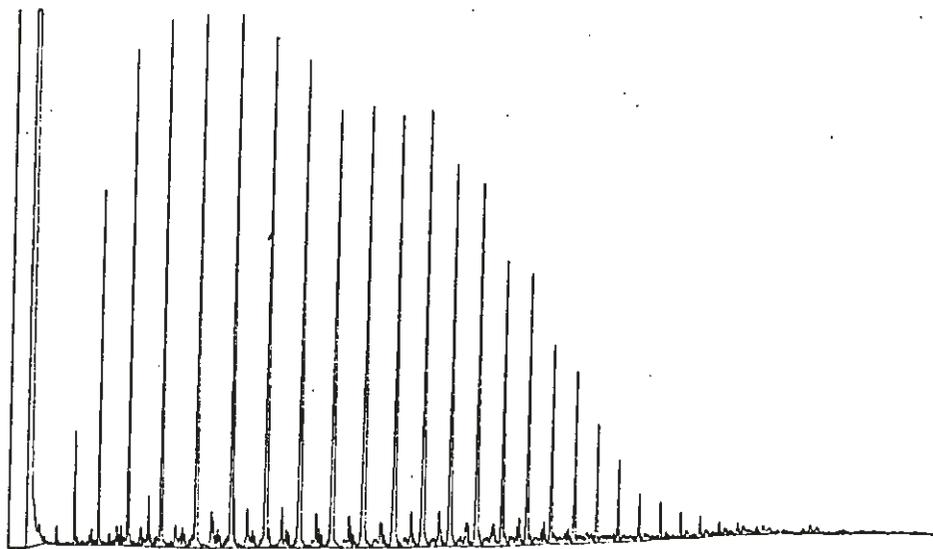
Original



3 days  
at 330°C

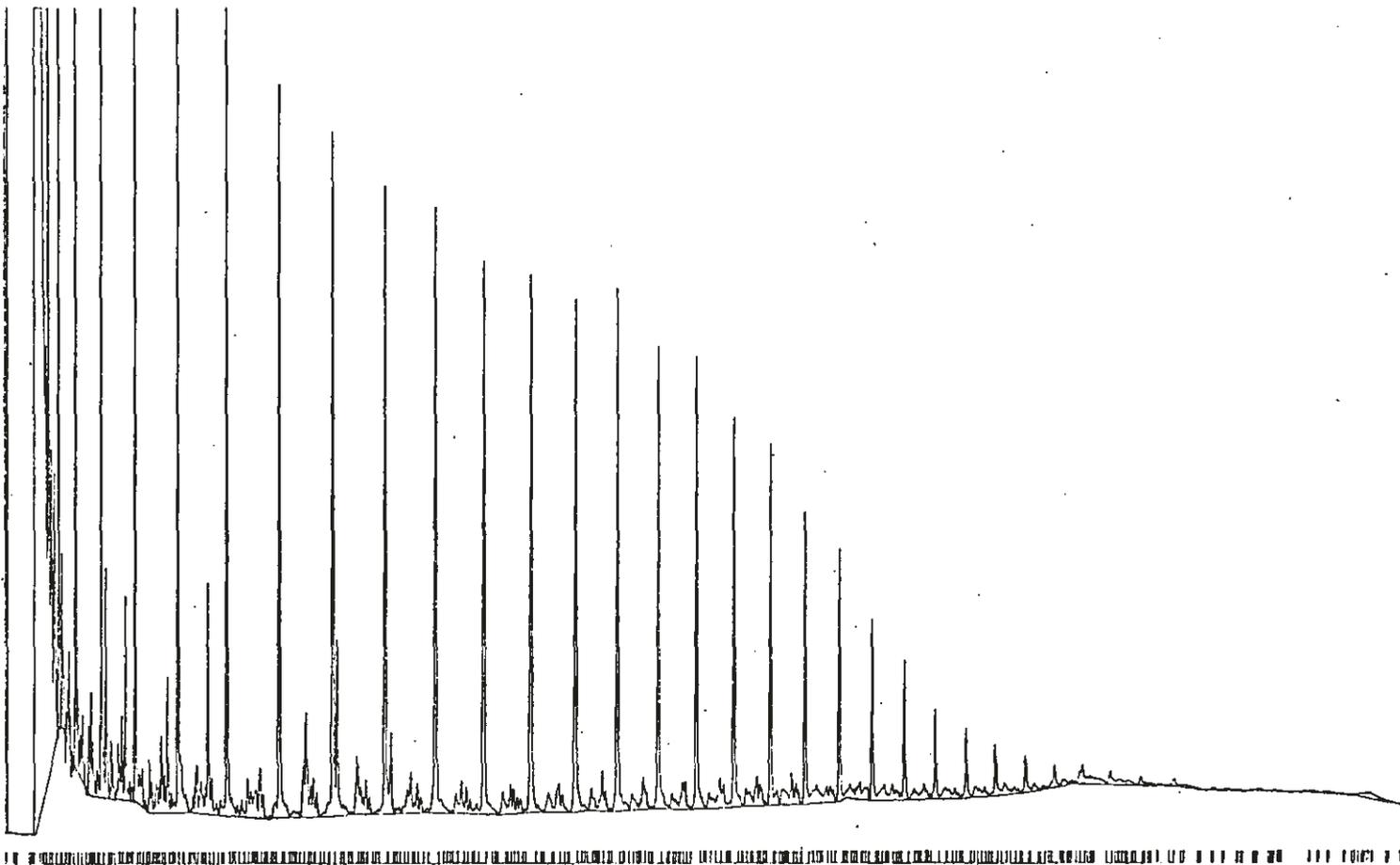


6 days  
at 330°C



GAS CHROMATOGRAMS OF SATURATED HYDROCARBONS OF  
BATHONIAN SAMPLE VB-718. (Great Estuarine Series)

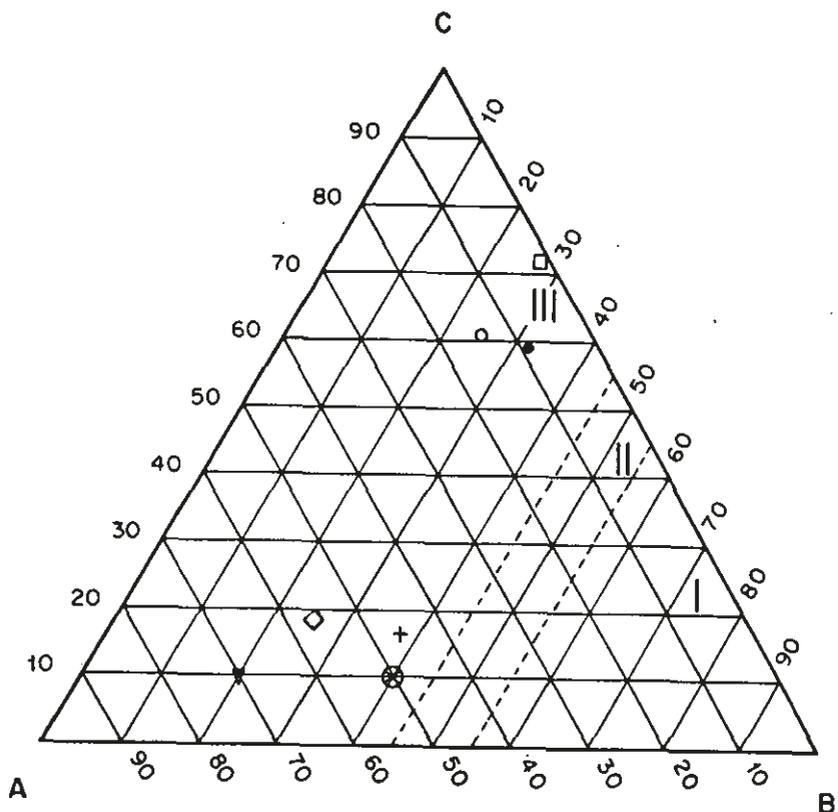
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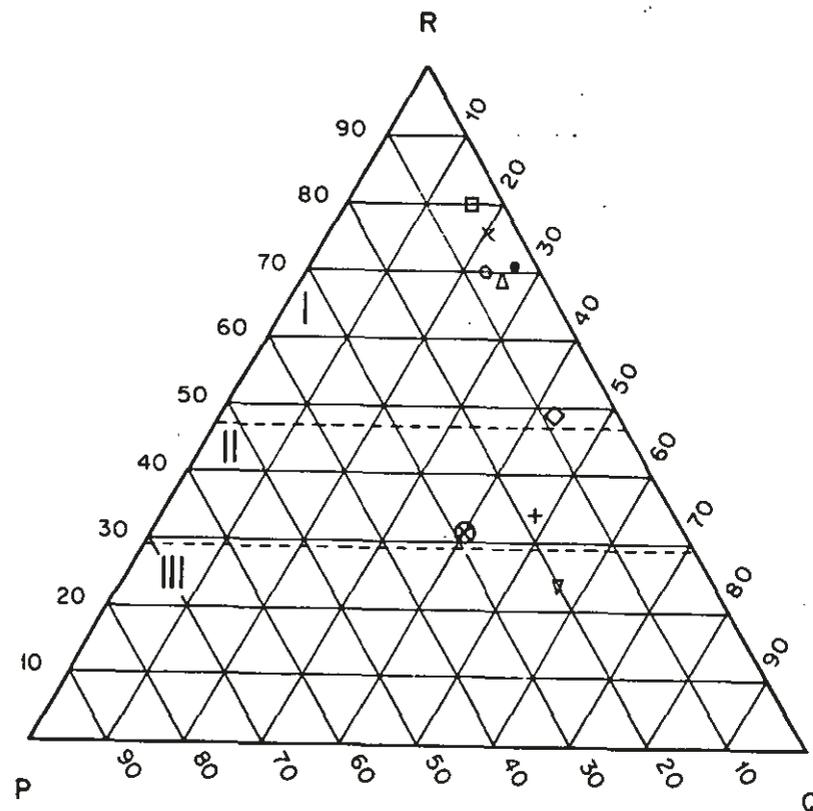
GAS CHROMATOGRAM OF SATURATED HYDROCARBONS,  
BEATRICE CRUDE.

FIG. 3  
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PARAMETER M1



PARAMETER M2



- I LANDPLANT DERIVED CRUDES WITH SUBSTANTIAL RESIN CONTRIBUTION TO SOURCE MATTER
- II CRUDES OF MIXED ORIGIN
- III CRUDES DERIVED FROM SOM AND/OR ALGAL MATTER

- VB708
- VB708 3D 330
- VB708 6D 330
- △ VB713
- + VB713 3D 330
- × VB718
- ◇ VB718 3D 330
- ▽ VB718 6D 330
- ⊗ Beatrice oil

C<sub>15</sub> AND C<sub>30</sub> - RING DISTRIBUTION OF ORIGINAL AND LABORATORY-HEATED BRORA SAMPLES AND OF THE BEATRICE OIL.

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TABLE 1 - GEOCHEMICAL DATA OF EXTRACTS

Sample	Depth	artificial maturation	% et. ac. extract	% C <sub>org</sub> after extr.	extr. C <sub>org</sub>	% S	porphyrins		pr ph	pr nC <sub>17</sub>	ph nC <sub>18</sub>	parameter M1			parameter M2			DOM of oil
							V ppm	Ni ppm				A	B	C	P	Q	R	
VB 708			2.7	23.3	0.11	9.8	< 2	< 1	1.9	1.8	0.9	1	27	72	4	16	80	55
"	short		3.9	22.0	0.18	1.8	< 2	< 1	2.7	0.8	0.3	14	25	61	7	23	70	
"	long		3.6			2.6	1.2	0.4				9	32	59	2	27	71	
VB 713			0.4	6.9	0.06	29.6	2750	<40	0.7	3.8	4.9	-	-	-	5	26	69	
"	short		1.0	6.3	0.16	2.3	180	9±2	2.1	0.8	0.5	46	38	16	18	48	34	
"	long		1.0			2.4	1.1	0.6	-	-	-	-	-	-				
VB 718			1.6	23.6	0.07	22.1	<20	155	1.6	0.4	0.2	-	-	-	4	21	75	63
"	short		11.3	15.9	0.71	1.9	<12	11±1	2.2	0.1	0.05	56	25	19	9	42	49	
"	long		12.0	14.1	0.85	1.3	< 1	<15	1.6	0.1	0.04	70	20	10	20	59	23	

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TABLE - 2 GEOCHEMICAL DATA OF OIL

Samp.	Depth	API grav	Spec. % w. % boll. sulph.	<u>C<sub>7</sub>-distribution</u>									<u>Mass spectrometry</u>						DOM of oil			
				<u>C<sub>7</sub>-alkane</u>			<u>C<sub>7</sub>-alk/naph.</u>			<u>C<sub>7</sub>-alk/naph/arom</u>			<u>parameter M1</u>			<u>parameter M2</u>						
				pr ph	pr nC <sub>17</sub>	ph nC <sub>18</sub>	nC <sub>7</sub>	mono br.	poly br.	nC <sub>7</sub>	naph. br.	nC <sub>7</sub>	naph. br.	arom	A	B	C	P		Q	R	
Beatrice	39	0.8299	0.2	1.9	0.2	0.1	58	25	17	35	40	25	59	39	2	50	40	10	28	40	32	71

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TABLE 3

## BRORA SECTION

SAMPLE NO.	TYPE OF SAMPLE	SOURCE ROCK INDICATION	SOURCE ROCK INDICATION	TYPE OF ORGANIC MATTER	ORGANIC CARBON CONTENT %W	CR/CT
		BEFORE EXTR.	AFTER EXTR.			
702	O	5	-		-	
703	O	5	-		.3	
704	O	5	-		.8	
705	O	5	-		-	
706	O	5	-		-	
707	O	5	-		.8	
708	O	> 900	> 900	MH	40.8	0.79
708	O	> 900	> 900	MH	41.7	0.77
709	O	10	-		-	
710	O	10	-		.9	
711	O	140	165	M	4.9	0.84
712	O	65	65	MH	4.5	0.83
713	O	255	270	M	6.9	0.81
714	O	235	205	M	6.7	0.87
715	O	140	190	M	6.0	0.84
716	O	150	130	MH	6.8	0.91
717	O	> 900	> 900	MH	22.9	0.78
718	O	> 900	> 900	K	23.2	0.52
719	O	> 900	> 900	K	28.1	0.45

TYPE OF SAMPLE C = CUTTINGS, R = CORE, S = SIDEWALL SAMPLE  
O = SURFACE SAMPLE

CONTAMINATION : W = WALNUT FRAGMENTS OR SOME SIMILAR PRODUCT,  
E = CELLOPHANE SHREDS, F = FIBRES, P = PLASTIC OR PAINT AND  
C = CONTAMINATED BUT KIND NOT SPECIFIED

A DASH (-) INDICATES TEST NOT MADE, ASTERISKS INDICATE THE  
ORGANIC CARBON CONTENT IS THE AVERAGE FOR THE SAMPLES CONCERNED

TABLE 4 -MACERAL ANALYSIS (incident light microscopy)

VB 708:	- common	vitronite, sporinite and liptodetrinite
	- few	sapropelic organic matter, <sup>(SOM)</sup> cutinite, botryococcus, fusinite and micrinite
	- rare	resinite and exsudatinite
VB 713:	- common	sapropelic organic matter
	- few	vitronite, liptodetrinite and microplankton
	- rare	sporinite, tasmanites, exsudatinite and fusinite
VB 717:	- abundant	microplankton
	- common	sapropelic organic matter, sporinite and liptodetrinite
	- few	vitronite and fusinite
VB 718:	- abundant	sapropelic organic matter of algal type
	- few	vitronite, sporinite, liptodetrinite and botryococcus
	- rare	fusinite
VB 719:	- abundant	sapropelic organic matter of algal type
	- few	vitronite, sporinite, liptodetrinite and botryococcus
	- rare	fusinite

# GEOCHEMICAL LOG

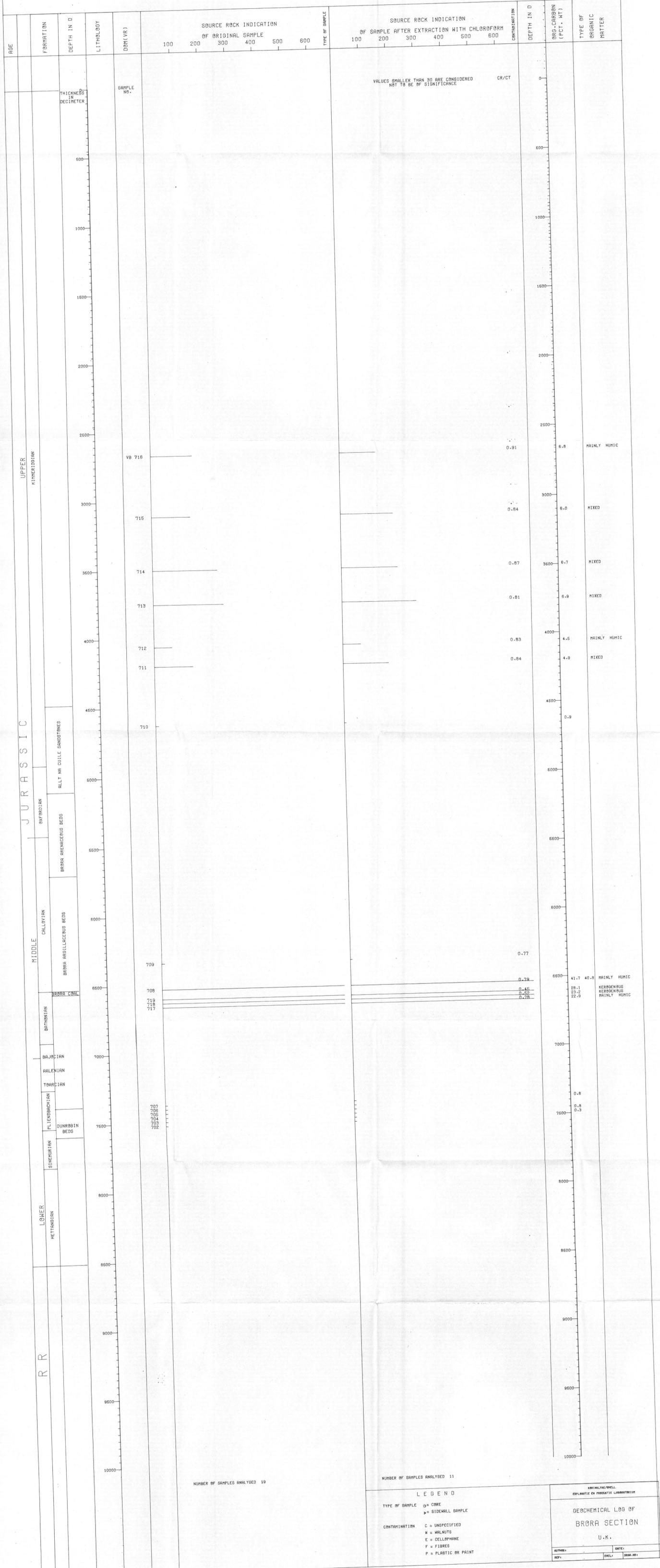
WELL

BRØRA SECTION

SCALE 1:1000

LOCATION

REGES IDENTIFIER



NUMBER OF SAMPLES ANALYSED 19

NUMBER OF SAMPLES ANALYSED 11

### LEGEND

- TYPE OF SAMPLE
  - = CORE
  - ◐ = SIDEWALL SAMPLE
- CONTAMINATION
  - C = UNSPECIFIED
  - H = WALNUTS
  - E = CELLULOSE
  - F = FIBRES
  - P = PLASTIC OR PAINT

GEOCHEMICAL LOG OF  
BRØRA SECTION  
U.K.

DATE:	DATE:
BY:	BY: