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GCB/85/84

JUNE 1984

GEOCHEMISTRY BRANCH

THE PETROLEUM GEOCHEMISTRY OF HALTENBANKEN

by

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Memorandum

BP

To A.K. Yeats, BP Pet Dev Norway

From M.J. Gibbons, Geochemistry Branch

Our ref GCB/85/84 Date 22nd June, 1984

Your ref

Subject <u>THE PETROLEUM GEOCHEMISTRY OF HALTENBANKEN</u>

Yet again the correlation data are not conclusive. The Kimmeridge Clay is the probable source of the 6407/1-2 oil but either the Kimmeridge Clay or the Coal Unit or both could have sourced the 6407/1-2 and 6507/11-1 condensates. Certainly the Coal Unit in 6507/12-1 has good to excellent potentials for oil and gas.

A generation and expulsion profile has been derived for the Kimmeridge Clay Formation in the Haltenbanken area.

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INDEX SHEET

Report Number (internal only): GCB/85/84

Title: THE PETROLEUM GEOCHEMISTRY OF HALTENBANKEN

Author(s): M.E. DUNN

Company: BP

Date of Report: JUNE 1984

Keywords: GEOCHEMISTRY, SEDIMENT, OIL, SOURCE ROCK

Country or Area (if applicable): NORWAY

Well Names (if applicable):

Oil/Gas Field Names (if applicable):

PLEASE COMPLETE IF REPORT REFERS TO GEOGRAPHICAL/GEOLOGICAL AREA

Area Covered:	Northernmost Latitude	d	m	S
	Westernmost Longitude	d	m	S
	Southernmost Latitude	d	m	S
	Easternmost Longitude	d	m	S

Sedimentary Basin:

Stratigraphy: (Youngest Age)

(Oldest Age)

Indexer: M.E. DUNN .... Date: 22nd June, 1984 ....

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1. INTRODUCTION

The two principal source rocks of the Haltenbanken area are thought to be

a) the Upper Jurassic Kimmeridge Clay Formation (predominately oil prone) and

b) the Lower Jurassic Coal Unit (predominantly gas prone).

Previous analysis of light oils/condensates from 6407/1-2, 6407/2-1 and 6507/11-1 suggested the only significant oil/condensate source rock in the region is in the Upper Jurassic (Curran, 1984) although there remains the possibility that the Lower Jurassic coals and mudstones may also be a significant source for liquid petroleum.

With regard to timing of generation there were two major sedimentation periods on Haltenbanken:

i) Cretaceous sedimentation, a result of Late Jurassic rifting.

ii) Late Tertiary sedimentation (Pliocene-present day), as mid-ocean ridge spreading led to a more westerly tilting of the area with consequent rapid progradation of sediment from the Norwegian mainland. This process is still active today.

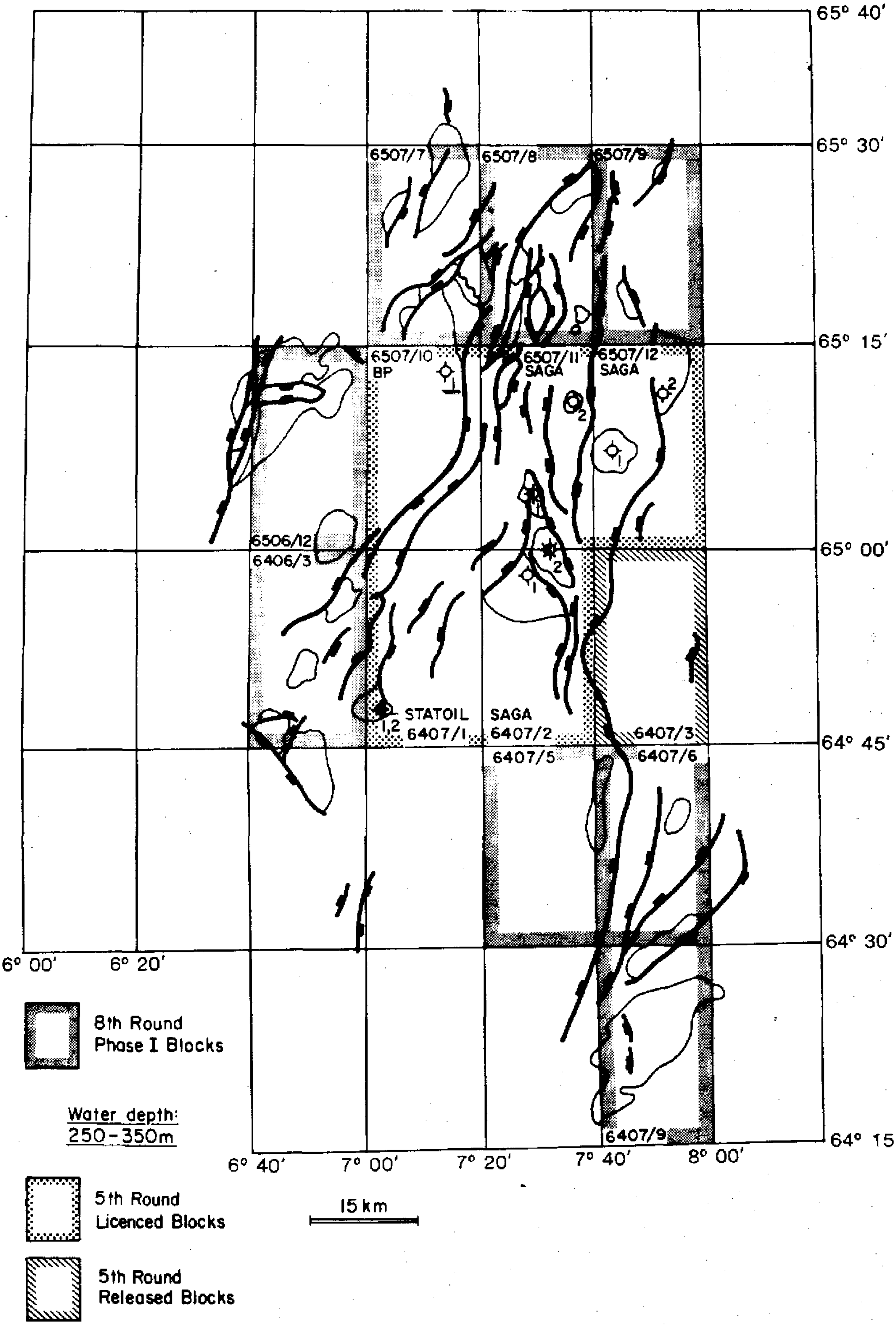
The main aims of the study are to

i) Examine cuttings from the Coal Unit in 6507/12-1 to determine their source potential.

ii) Correlate the Kimmeridge Clay and the Coal Unit with the light oil/condensate samples.

iii) Derive a general generation and expulsion profile as a function of depth/temperature for the Kimmeridge Clay Formation.

BP has access to information from 6 wells 6407/1-2, /2-1, 6507/10-1, /11-1, /12-1 and /12-2 (fig.1).



Ref:	LOCATION MAP OF 8th ROUND PHASE I BLOCKS	Fig: 1
Date: SEPT 1983	HALTENBANKEN	Drg no: 8247

2. RESULTS AND DISCUSSION

i) Source Potential and Type

Pyrolysis screening and total organic carbon determinations (TOC%wt) were carried out on 40 bulked cuttings samples from the Coal Unit in 6507/12-1 and 23 bulked cuttings samples from the Kimmeridge Clay in 6 Haltenbanken wells. The organic richness, source potential and type for the Coal Unit are summarised as follows (numbers of samples analysed in parentheses)

Depth (m)	Average P_2 (kg/tonne)	Average TOC (%wt)	GOGI
2511-2583	18.5 (7)	14.0 (7)	0.28 (1)
2589-2676	60.0 (8)	34.3 (8)	0.32 (2)
2691-2715	11.2 (3)	7.2 (3)	-
2727-2850	35.3 (13)	21.6 (13)	0.38 - 0.48 (4)
2856-2940	11.0 (9)	9.0 (9)	0.42 (1)

The Coal Unit (interbedded mudstones, sandstones, siltstones and coals), which is 424m thick in 6507/12-1, shows good to excellent source potential for both oil and gas. Previous work by Woodhouse and Ward 1983, on 3 SWC (mudstones/coals) from the Coal Unit in 6507/10-1 (395m thick) also indicated excellent source potential for gas and oil (P_2 = 30.2 - 246 kg/tonne; GOGI = 0.38 - 0.55).

The organic richness, source potential (fig.2) and type of the Kimmeridge Clay are as follows:

Well	Average P_2 (kg/tonne)	Average TOC (%wt)	GOGI
6507/12-2	0.7 (2)	1.1 (2)	-
6507/11-1	0.6 (5)	1.2 (5)	-
6507/10-1	13.2 (6)	5.3 (6)	0.16 (1)
6507/12-1	7.7 (2)	4.5 (2)	0.19 (1)
6407/2-1	21.5 (6)	5.8 (6)	0.14 (1)
6407/1-2	8.2 (4)	4.5 (4)	0.28 (1)

The Kimmeridge Clay shows good to excellent source potential for oil in 6507/10-1, 12-1 and 6407/2-1 and good source potential for oil and gas (due to maturity) in 6407/1-2.

ii) Oil-Source Rock Correlation

Additional analyses (carbon isotopes, GC, GC-MS) of the Coal Unit in 6507/12-1 and the Kimmeridge Clay in 6507/10-1, 6407/2-1 and 6407/1-2 have been carried out and the results integrated with previously acquired source rock data and used in the following correlation study (data for 3 oils summarised by Curran, 1984).

SOURCE POTENTIAL FOR THE KIMMERIDGE CLAY IN THE HALTENBANKEN AREA

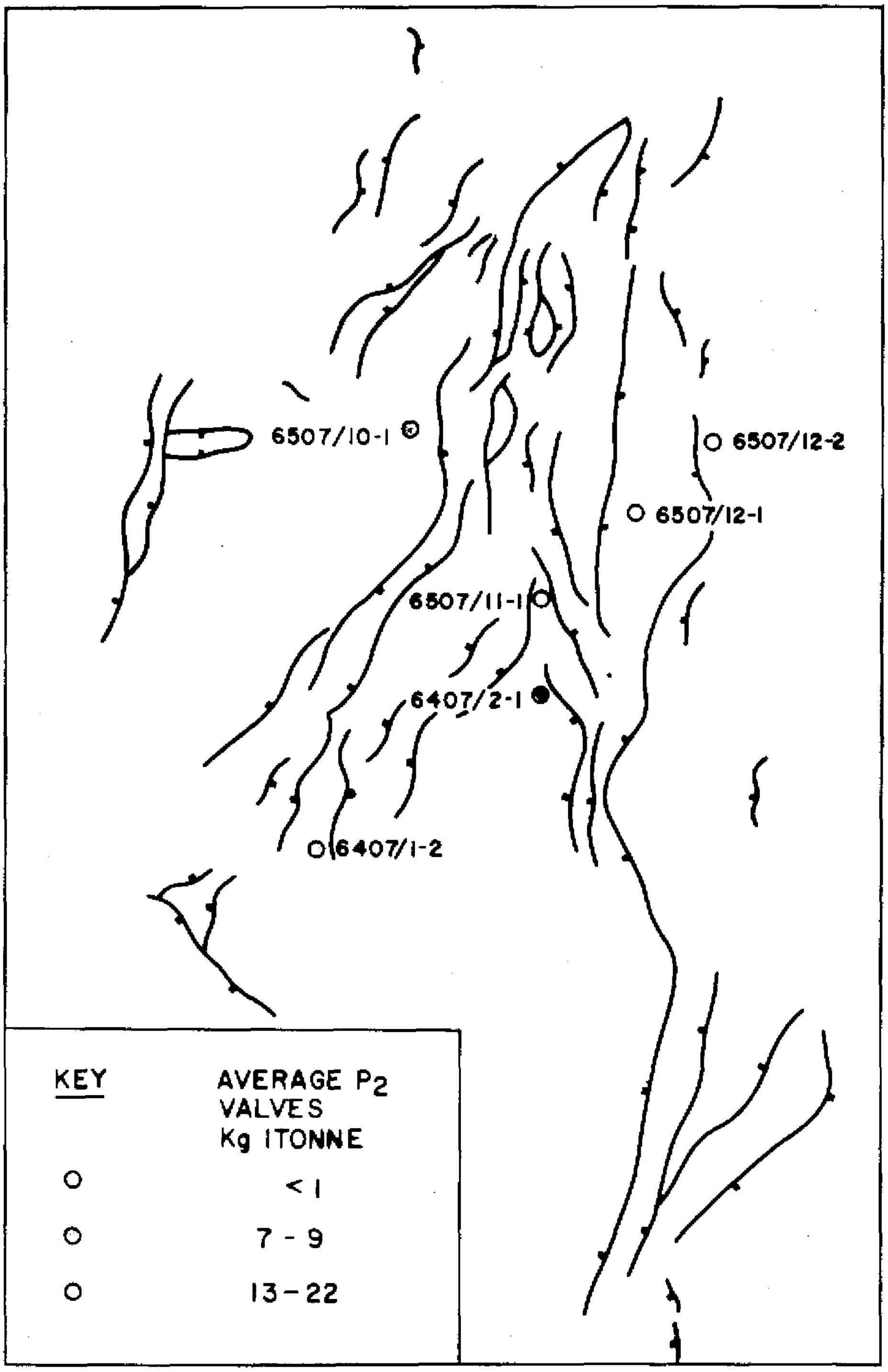


FIG. 2.

a) Carbon Isotopes

The carbon isotope values for the three oils and their possible source rocks are summarised in fig.3. The ranges of values for the Kimmeridge Clay ($\delta^{13}C$ = -25.4 to -30.5) and the Coal Unit ($\delta^{13}C$ = 25.3 to -28.7) kerogens and the Kimmeridge Clay ($\delta^{13}C$ = -28.0 to -31.6) and the Coal Unit ($\delta^{13}C$ = -27.4 to -27.9) TSE's show considerable overlap. The 6407/1-2 Galimov curve (fig. iv) is typical of Kimmeridge Clay sourced oils in the North Sea. The heavier isotope values for the 6407/2-1 and 6507/11-1 oil fractions may be due to either:

i) sourcing from Kimmeridge Clay at high maturity (with increasing maturity there is a shift to heavier carbon isotope values) or

ii) a predominantly Coal Unit source or

iii) a mixture of (i) and (ii).

Geochem Labs quote carbon isotope values for the head space methane of the 6507/11-1 oil (-37.6 to -42.6^{o}/oo) and the 6407/2-1 oil (-46.7^{o}/oo). The isotope values for 6507/11-1 may be due to a mixed kerogen source, whereas the value for 6407/2-1 is typical of a marine source (based on our present data base for gases).

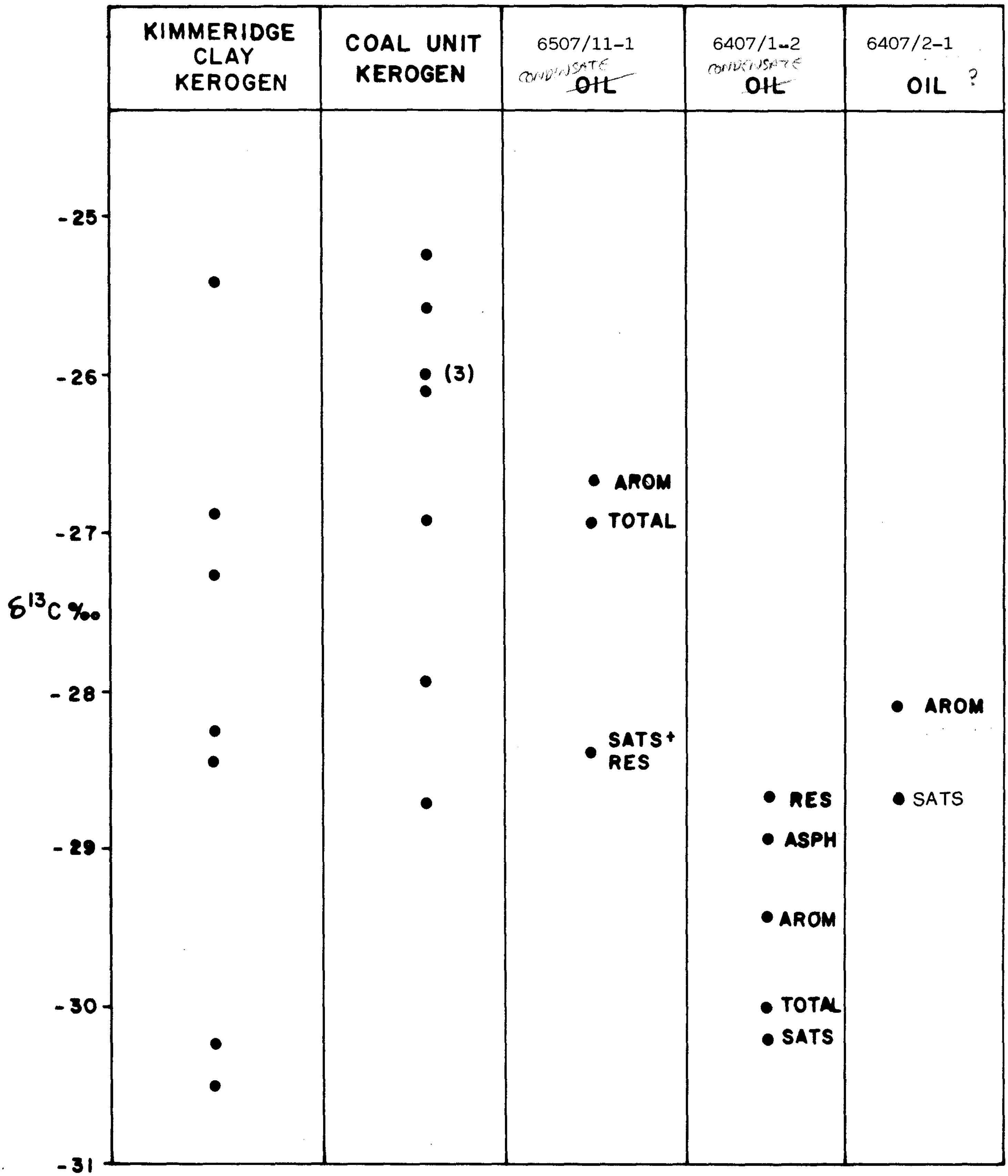
b) GC Analysis

The SAC chromatograms for the Kimmeridge Clay Formation (fig.v) are typical of a predominantly algal source (i.e. front-end biased) whereas the chromatograms for the immature Coal Unit in 6507/12-1 (fig.vi) contain significant proportions of higher land-plant derived material. However the SAC chromatograms for the moderately mature Coal Unit in 6407/1-2 (as analysed by KFA; fig. vii) show predominantly front-end biased distributions, largely as a consequence of increased maturity. The SAC chromatograms for the 6407/1-2, 6407/2-1 and 6507/11-1 light oils/condensates are all front-end biased (fig. viii, ix and x respectively). It is thus not possible to rule out either the Kimmeridge Clay or the Coal Unit as a source of these light oils/condensates on the basis of their SAC chromatograms.

The pristane/phytane ratios for the Kimmeridge Clay range between 0.86 and 1.6 compared to values for the Coal Unit of between 1.6 and 5.3. The 6407/1-2 oil has a pristane/phytane ratio of 1.23 which suggests a Kimmeridge Clay source. The 6507/11-1 light oil has a pristane/phytane ratio of 2.31 which may be a result of a Coal Unit source or a Kimmeridge Clay/Coal Unit source or a more mature Kimmeridge Clay source (pristane/phytane ratios in oils increase with increasing maturity). Thus it is not possible to distinguish the source of the 6507/11-1 condensate based on pristane/phytane ratios.

low mat
high mat

SUMMARY OF CARBON ISOTOPE DATA FOR HALTENBANKEN SOURCE ROCKS/OILS.



$\delta\, C^{13}$ ‰ (NBS 22) = -29·8

FIG. 3.

c) GC-MS Analysis

The molecular maturity parameters indicate that the 6407/1-2 oil is a moderately mature light oil. The sterane distributions for this oil and the Kimmeridge Clay extracts are very similar, characterised by the presence of low molecular weight steranes, diasteranes and low C_{29} contents, whereas the Coal Unit extract distributions are characterised by the relative absence of the low molecular weight steranes and diasteranes and high C_{29} sterane contents. This is illustrated by a plot of the S3 ratios (fig. xxvi). Due to co-elution of X (bisnorhopane) beneath the C_{29} sterane peak only one Kimmeridge Clay sample may be plotted.

The triterpane distributions for the Kimmeridge Clay are characterised by the presence of X, which is absent in the triterpane distributions for the Coal Unit. Component X is present in a relatively low concentration in the 6407/1-2 oil, since X decreases in concentration with increasing maturity (as shown by the Kimmeridge Clay extracts in 6507/10-1, 6407/2-1 and 6407/1-2 respectively).

The values of the M2 and M3 molecular parameters (1.22 and 0.96 respectively) suggest a maturity equivalent to ca. 1.0%R_o for the 6507/11-1 oil sample (Mason, 1983). The S1, S2 and A1 molecular ratios derived from the sterane and triterpane distributions (these molecules are present in very low concentrations in this sample) indicate a much lower maturity, which suggests that these molecules have probably been picked up on the migration pathway and are not indigenous. Consequently, the sterane and triterpane distributions for the 6507/11-1 condensate should not be used for correlation purposes.

The 6407/2-1 condensate analysed by Geochem Labs contains only minor amounts of steranes and triterpanes (indicating high maturity) and they give no useful information for correlation purposes. A sulphur profile of the oil also is indicative of high maturity levels.

d) Summary of Oil-Source Rock Correlation

The sterane and triterpane distributions, pristane/phytane ratio and the Galimov distribution for the 6407/1-2 oil sample indicate that the Kimmeridge Clay is the most likely source. This makes sense geologically as the structure is a simple, domal, 4 way dip closure with no faults within the drainage area to provide communication between the Brent and the Cook Formation reservoirs (fig.4).

There is geological evidence to suggest that the Brent and the Cook Formations in the 6407/2-1 and 6507/11-1 structures are in fault communication (fig.4), thus these condensates may contain a contribution from the Coal Unit.

The geochemical evidence, however, is inadequate to rule out either of these source rocks or, more importantly, to quantify their significance. Although the Coal Unit shows excellent source potential for

MODEL FOR HYDROCARBON MIGRATION AND ENTRAPMENT, HALTENBANKEN

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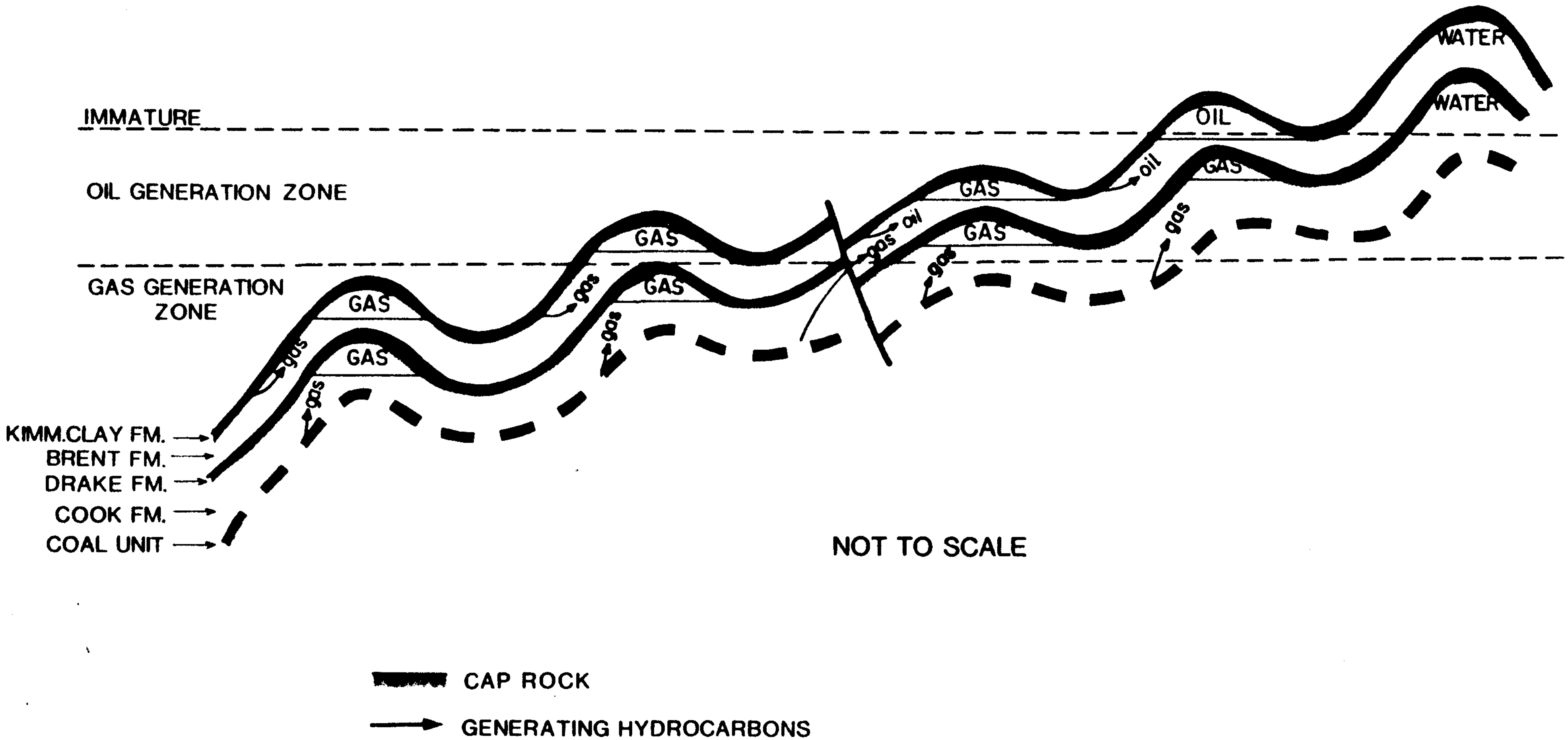

Fig: 4

Drg no: 8331

gas and oil, our present knowledge of generation/expulsion of hydrocarbons from coals is such that we cannot predict or quantify what products are likely to be expelled.

iii) Generation and Expulsion Profile for the Kimmeridge Clay Fm

The aim of this part of the study is to calculate the generation profile and expulsion efficiency of the Kimmeridge Clay in Haltenbanken as a function of depth and temperature. All the necessary data for this approach are summarised in table 20.

The Kimmeridge Clay shows good source potential for oil in 6507/10-1, 6407/1-2 and 6407/2-1 (fig.2). Maturity estimates based on GC-MS analysis, indicate that the Kimmeridge Clay is immature in 6507/10-1, marginally mature in 6407/2-1 and moderately mature in 6407/1-2.

The expressions derived by Mackenzie and Quigley (ref.11) assume that the organic matter type does not vary significantly. The hydrocarbon generation index (HGI), oil generation index (OGI), gas generation index (GGI), oil expulsion efficiency (OEE) and hydrocarbon expulsion efficiency (HEE) are defined in fig.5 and the results of the calculations are summarised as follows:

Well and Depth of Kimmeridge Clay	**HGI**	**HEE**	**OGI**	**OEE**	**GGI**
6407/2-1 2899m	0.2	0	0.19	0	0.3
6407/1-2 3540m	0.6	0.34	0.63	0.28	0.37

The data indicate that there has been significant oil generation (OGI = 0.63), minor gas generation (GGI = 0.37) and expulsion of moderate amounts of oil (OEE = 0.28) by 3540m. This OEE value is lower than was expected from previous work, but it was calculated from one data point only. There is a clear increase in the HGI with increasing molecular ratios A1 and A3;

Definition of generation and expulsion parameters

$$HGI = \frac{\text{Total hydrocarbons generated + initial hydrocarbons}}{\text{Total hydrocarbon potential}}$$

$$OGI = \frac{\text{Total oil generated + initial oil}}{\text{Total oil potential}}$$

$$GGI = \frac{\text{Total gas generated + initial gas}}{\text{Total gas potential}}$$

$$OEE = \frac{\text{Total oil expelled}}{\text{Total oil in system}}$$

$$HEE = \frac{\text{Total hydrocarbons expelled}}{\text{Total hydrocarbons in system}}$$

fig.(5)

Well and depth of Kimmeridge Clay	**A1**	**A3**	**CALCULATED HGI**	**PREDICTED HGI**
6407/2-1 2899m	0.46	0.17	0.2	0 - 0.2
6407/1-2 3540m	0.91	0.43	0.6	0.3 - 0.7

HGI values may be predicted from theoretical curves derived from the kinetics of the A1 and A3 reaction and the kinetics of kerogen breakdown (Quigley and Mackenzie, 1984) on the assumption that the vitrinite/vitrinite + exinite proportion in the kerogen is approximately 10%. The calculated HGI values for the Kimmeridge Clay in Haltenbanken clearly fall within the range of the predicted HGI values.

The isotherm plot (fig.6) for the Kimmeridge Clay in 6407/1-2 indicates that during the Cretaceous there was a period of rifting which resulted in subsidence and consequent infill. However it was the rapid Tertiary sedimentation (thermal history is approximately 3-4°C/Ma) that significantly matured the Kimmeridge Clay Formation in 6407/1-2.

The generation profile for the Kimmeridge Clay in Haltenbanken as a function of temperature (calculated using HGI, A1 and A3 ratios, vitrinite/vitrinite + exinite proportion and thermal history estimates) indicates that most hydrocarbon generation (HGI = 0.2 - 0.8) will take place between 120 and 140°C (fig.7).

In the 6407/1-2 well, the temperature measured within the Brent Formation reservoir (underlies the Kimmeridge Clay Formation) is 137°C. The calculated HGI of 0.63 for the Kimmeridge Clay and the reservoir temperature of 137°C in 6407/1-2 are compatible with the calculated generation curve for the Kimmeridge Clay in Haltenbanken.

The calculation of the inferred temperature range is based on our current understanding and theoretical modelling of the kinetics of the A1 and A3 reactions and the kinetics of the kerogen breakdown.

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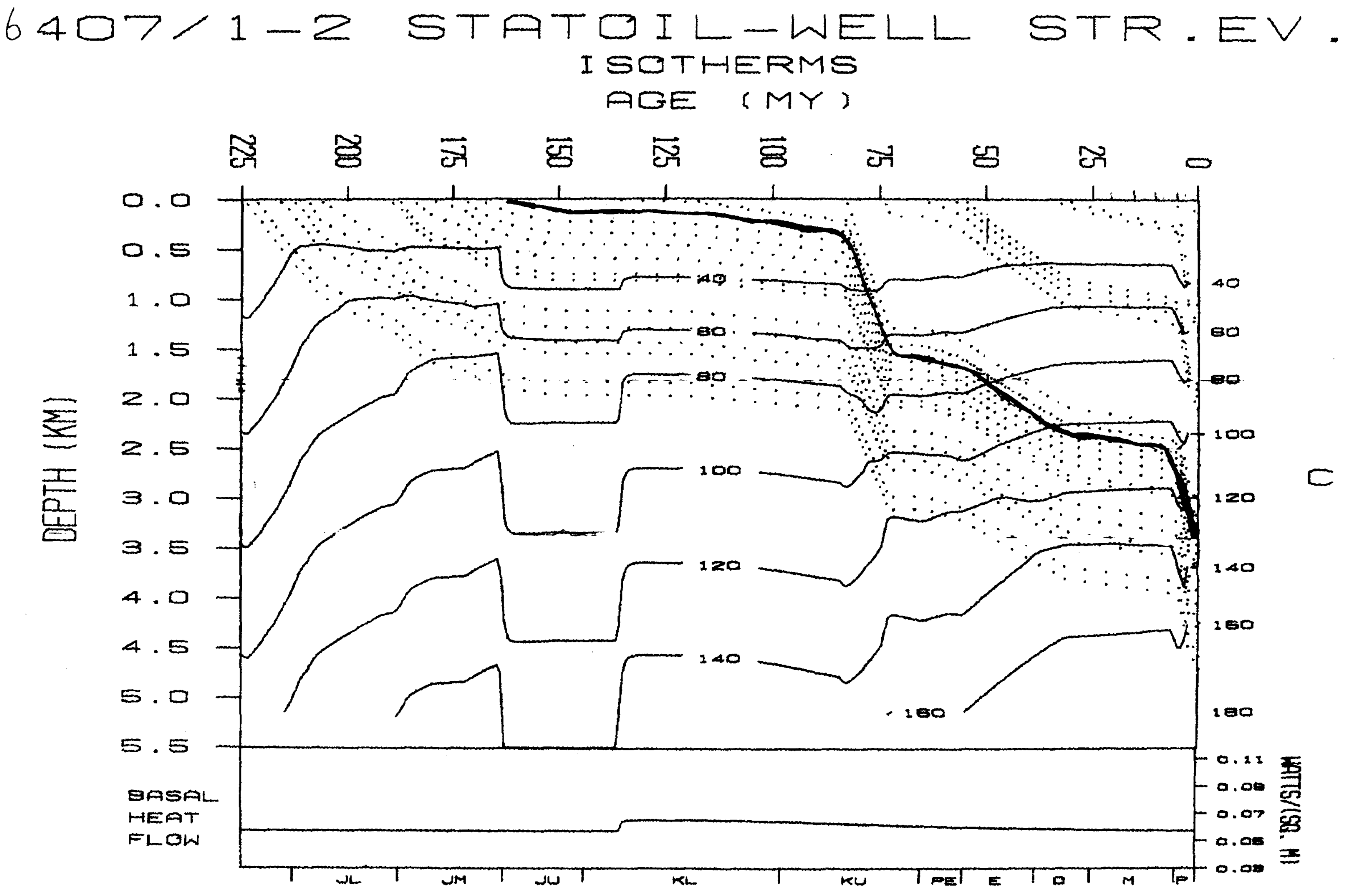

6407/1-2 STATOIL-WELL STR.EV.
ISOTHERMS
AGE (MY)
225
200
175
150
125
100
75
50
25
0
DEPTH (KM)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
40
60
80
100
120
140
160
180
C
BASAL
HEAT
FLOW
0.11
0.09
0.07
0.05
0.03
WATTS/SQ. M
JL
JM
JU
KL
KU
PE
E
O
M
P

fig. 6

GENERATION PROFILE FOR THE KIMMERIDGE CLAY IN HALTENBANKEN

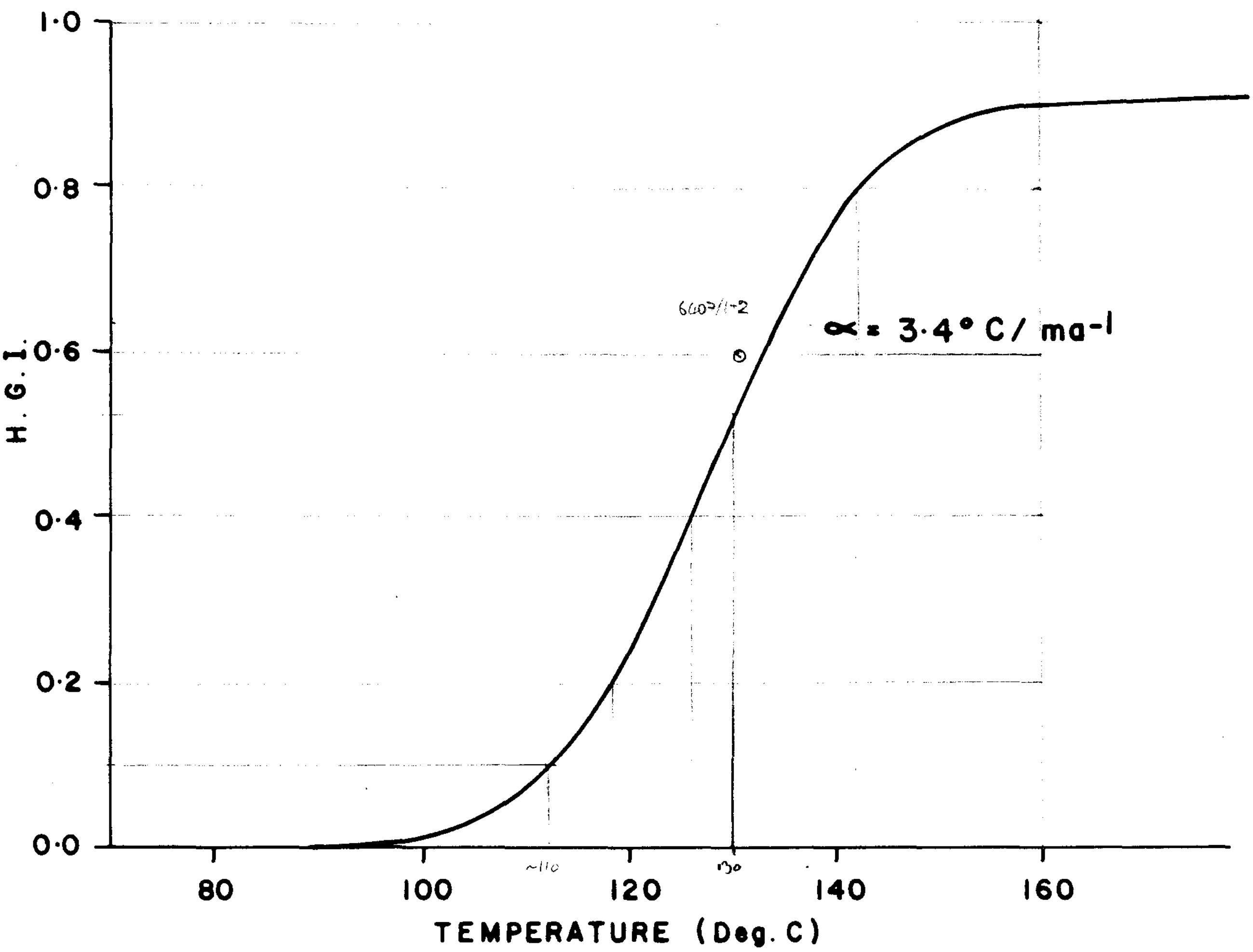

FIG. 7

3. CONCLUSIONS

1) The Kimmeridge Clay shows good source potential for oil in 6507/10-1, 6507/12-1 and 6407/2-1. The more mature section in 6407/1-2 (the only study well where the Kimmeridge Clay is significantly mature) has good residual potential for oil and gas.

2) The Coal Unit shows good to excellent source potential for oil and gas in 6507/12-1 and 6507/10-1.

3) The Kimmeridge Clay is the most likely source of the 6407/1-2 oil. Neither the Kimmeridge Clay nor the Coal Unit may be ruled out as a source of the 6407/2-1 and 6507/11-1 condensate samples.

4) Significant hydrocarbon generation (HGI = 0.6) from the Kimmeridge Clay of Haltenbanken occurs by ca. 3500m. This generation occurred as a result of Late Tertiary sedimentation in 6407/1-2. The inferred temperature range for the main phase of hydrocarbon generation (HGI = 0.2 - 0.8) from the Kimmeridge Clay is 120 - 140^{o}C.

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LITHOLOGY AND STRATIGRAPHY TABLE 1

WELL: 6507/12-1

LOCATION: NORWAY

DEPTH (m)		LITHOLOGY
2035.00		MUDSTONE -dk gy 50% :MUDSTONE -brn 50%
2050.00		MUDSTONE -gy brn 50% :MUDSTONE -blk 50%
2496.00		MUDSTONE -dk gy 50% :SILTSTONE -wh 50%
2511.00		MUDSTONE -dk gy 50% :SILTSTONE -gy wh 50%
2532.00		MUDSTONE -dk gy 50% :SILTSTONE -gy wh 50%
2547.00		
2565.00		MUDSTONE -dk gy 50% :MUDSTONE -blk carb 25% :SILTSTONE -wh g
2571.00		MUDSTONE -blk carb 80% :SILTSTONE -wh gy 20 %
2583.00		MUDSTONE -blk carb 30% :SILTSTONE -wh gy 40 % :SANDSTONE -wh
2589.00	KIMM. CLAY 2032 - 2052M	MUDSTONE -blk carb 80% :SILTSTONE -wh gy 20 %
2601.00		COAL-blk 100%
2619.00	COAL UNIT 2496 - 2920M	COAL-blk 100%
2625.00		COAL-blk 100%
2640.00		COAL-blk 100%
2655.00		COAL-blk 100%
2661.00		MUDSTONE -blk carb 95% :SILTSTONE -wh gy 5%
2676.00		MUDSTONE -blk carb 95% :SILTSTONE -wh gy 5%
2691.00		SILTSTONE -wh gy 50% :MUDSTONE -gy 50%
2709.00		SILTSTONE -wh gy 20% :MUDSTONE -dk gy carb 80%
2715.00		MUDSTONE -dk gy carb 100% + tr coal
2727.00		COAL-blk 95% :MUDSTONE -dk gy silty 5%
2733.00		MUDSTONE -blk carb 100%
2745.00		COAL-blk 100%
2751.00		MUDSTONE -gy-dk gy 100%
2763.00		MUDSTONE -gy-dk gy silty 100%
2778.00		SILTSTONE -gy-dk gy 100%
2784.00		SILTSTONE -wh gy 20% :MUDSTONE -dk gy carb 80%
2796.00		MUDSTONE -gy-dk gy 100%
2802.00		COAL-blk 20% :MUDSTONE -gy-dk gy silty 80%
2814.00		COAL-blk 100%

LITHOLOGY AND STRATIGRAPHY

TABLE 2

WELL: 6507/12-1

LOCATION: NORWAY

DEPTH (m)		LITHOLOGY
2820.00		MUDSTONE -dk gy carb 100%
2832.00		MUDSTONE -gy-dk gy 100% + tr sst
2838.00		SANDSTONE -5% :SILTSTONE -wh gy 10% :MUDSTONE -gy-dk gy 85%
2850.00		SANDSTONE -10% :SILTSTONE -wh gy 10% :MUDSTONE -gy 80%
2856.00		MUDSTONE -dk gy silty 60% :SANDSTONE -wh gy 40%
2868.00		SANDSTONE -wh gy 50% :MUDSTONE -gy 50%
2874.00	KIMM. CLAY 2032 - 2052M	MUDSTONE -blk carb70% :SILTSTONE -wh gy 25% :SANDSTONE -5%
2886.00	COAL UNIT 2496 - 2920M	MUDSTONE -gy-dk gy 50% :COAL-blk 50%
2892.00		MUDSTONE -gy dk gy 100%
2904.00		MUDSTONE -blk carb 70% :SILTSTONE -wh gy 30 %
2910.00		MUDSTONE -blk carb 90% :SILTSTONE -wh gy 10 %
2925.00		MUDSTONE -blk carb 100%
2940.00		MUDSTONE -gy-dk gy 70% :SILTSTONE -wh gy 30 %

S O U R C E   R O C K   Q U A L I T Y   I N D I C A T O R S   TABLE 3

WELL: 6507/12-1

LOCATION: NORWAY

KC

DEPTH (m)		PICKED LITH	P1 (kg/t)	P2 (kg/t)	GOGI	HI	TOC (%)
2035.00		BULKED	0.4	8.0	0.19	178	4.5
2050.00		BULKED	0.4	7.3		166	4.4
2496.00		BULKED	0.9	18.5		152	12.2
2511.00		BULKED	0.7	21.0		136	15.4
2532.00		BULKED	0.9	14.1		76	18.5
2547.00		BULKED	1.8	22.7		142	16.0
2565.00		BULKED	0.7	16.7		140	11.9
2571.00		BULKED	0.9	33.2	0.28	160	20.8
2583.00		BULKED	0.2	3.4		103	3.3
2589.00		BULKED	1.7	56.4			
2601.00		BULKED	1.6	75.4	0.32	192	39.2
2619.00		BULKED	1.1	67.1		216	31.1
2625.00		BULKED	1.8	80.5		164	49.1
2640.00		BULKED	1.2	60.2		138	43.6
2655.00		BULKED	1.2	84.2		190	44.2
2661.00		BULKED	0.8	25.2		155	16.3
2676.00		BULKED	1.1	31.4	0.32	189	16.6
2691.00		BULKED	0.2	4.2		111	3.8
2709.00		BULKED	0.8	14.0		169	8.3
2715.00		BULKED	0.5	15.5		160	9.7
2727.00		BULKED	1.9	54.8		185	29.7
2733.00		BULKED	1.0	30.2		179	16.9
2745.00		BULKED	1.8	68.5	0.48	155	44.2
2751.00		BULKED	1.0	43.2		169	25.5
2763.00		BULKED	0.9	29.3		149	19.6
2778.00		BULKED	0.5	16.3		161	10.1
2784.00		BULKED	0.9	20.8		148	14.1
2796.00		BULKED	0.7	30.1	0.42	164	18.4
2802.00		BULKED	0.9	37.9		158	24.0
2814.00		BULKED	1.3	77.0	0.38	178	43.3
2820.00		BULKED	0.6	30.9		118	26.2
2832.00		BULKED	0.4	11.6	0.38	85	13.6
2838.00		BULKED	0.4	8.4		94	8.9
2850.00		BULKED					7.7
2856.00		BULKED	0.1	2.1		66	3.2
2868.00		BULKED	0.2	4.0		95	4.2

S O U R C E   R O C K   Q U A L I T Y   I N D I C A T O R S   TABLE 4

WELL: 6507/12-1

LOCATION: NORWAY

DEPTH (m)		PICKED LITH	P1 (kg/t)	P2 (kg/t)	GOGI	HI	TOC (%)
2874.00		BULKED	4.0	7.9		95	8.3
2886.00		BULKED	1.1	25.0		140	17.9
2892.00		BULKED	0.6	7.2		113	6.4
2904.00		BULKED	0.4	10.0		128	7.8
2910.00		BULKED	1.0	19.3	0.42	130	14.8
2925.00		BULKED	0.9	19.4		140	13.9
2940.00		BULKED	0.1	4.4		102	4.3

PYROLYSIS-PGC DATA TABLE 5

WELL: 6507/12-1

LOCATION: NORWAY

DEPTH (m)		C1-C5 (%)	C6-C9 (%)	C10-C13 (%)	C14-C22 (%)	C23-C36 (%)	GOGI	HI	TOC (%)
2035.00		16	16	20	29	19	0.19	178	4.5
2571.00		22	9	14	24	31	0.28	160	20.8
2601.00		24	10	13	23	29	0.32	192	39.2
2676.00		25	8	13	24	30	0.32	189	16.6
2745.00		32	8	13	20	27	0.48	155	44.2
2796.00		30	8	13	21	29	0.42	164	18.4
2814.00		27	7	13	21	32	0.38	178	43.3
2832.00		28	9	14	21	29	0.38	85	13.6
2910.00		30	91	62	32	22	0.42	130	14.8

SOLUBLE EXTRACT DATA   TABLE 6

WELL: 6507/12-1

LOCATION: NORWAY

DEPTH (m)		TOC (%)	TSE (%)	TSE/TOC	SAC/TOC	SAC (%)	AROM (%)	RES (%)	ASPH (%)	CPI	PR/PH	PR/C17	PH/C18
2601.00		39.2	0.473	12	3	22.6	40.2	37.2	5.1	2.40	3.40	1.40	0.50
2655.00		44.2	0.780	18	6	33.9	33.3	32.8	11.6	1.90	3.40	1.40	0.60
2709.00		8.3	0.389	47	22	46.5	26.0	27.5	12.5	1.20	1.70	0.70	0.50
2745.00		44.2	0.467	11	2	17.2	44.1	38.7	25.4	2.00	4.50	2.40	0.70
2814.00		43.3	0.480	11	2	20.3	41.3	38.4	10.9	2.20	5.30	1.80	0.40
2892.00		6.4	0.188	29	14	48.4	22.9	28.6	1.2	1.80	1.90	0.70	0.50

M O L E C U L A R   S O U R C E   R O C K   I N D I C A T O R S - S A T U R A T E S   TABLE 7

WELL: 6507/12-1

LOCATION: NORWAY

Coal Unit

DEPTH (m)	H1	H2	H3	H4	H5	H6	H7	H8	H9	S1	S2	S3	S4	S5
2601.00	0.11	0.14	0.76			0.07	0.36		0.41	0.21	0.63	8:32:60		
2655.00	0.28	0.28	0.76		100:106:50:29:13:14	0.21	0.49	0.53	0.62			24:28:48	26:29:45	
2709.00	0.47	0.41	0.85		100:101:55:48:21:25	0.45	0.59	0.60	0.66			32:31:38	27:30:43	
2745.00	0.18	0.32	0.74		100:83:28:7:2:2	0.02	0.34	0.29	0.31			10:20:70		
2892.00	0.40					0.33						29:26:46	22:25:53	

C A R B O N   I S O T O P E   R A T I O S   TABLE 8

WELL: 6507/12-1

LOCATION: NORWAY

DEPTH (m)	PICKED LITHOLOGY	SAMPLE	ISOTOPE RATIO (per mil)
2050.00	BULKED	KEROGEN	-27.3
2601.00	BULKED	KEROGEN	-25.3
2655.00	BULKED	KEROGEN	-26.0
		TSE	-27.8
2709.00	BULKED	KEROGEN	-26.9
		TSE	-27.6
2745.00	BULKED	KEROGEN	-27.9
		TSE	-29.9
2814.00	BULKED	KEROGEN	-26.0
		TSE	-27.5
2892.00	BULKED	KEROGEN	-25.6
		TSE	-27.4

C-12/C-13 ISOTOPIC RATIOS ARE RELATIVE TO
PDB STANDARD:NBS-22 AT -29.8 per mil

LITHOLOGY DESCRIPTIONS FOR THE KIMMERIDGE CLAY CUTTINGS

TABLE 9

Well/depth (M)	Lithology
6407/1-2	
3532.5	MDST gy - dkgy 100%
3540	MDST gy - dkgy 100%
3550	MDST gy - dkgy 100%
3577	MDST gy - dkgy 100%
6407/2-1	
2851	MDST gy - dkgy 100%
2860	MDST gy - dkgy 100%
2869	MDST dkgy 100%
2875	MDST dkgy 100%
2890	MDST dkgy 100%
2899	MDST dkgy 100%
6507/12-2	
1875	MDST gy - 95% MDST blk carb 5%
1880	MDST ox. 30% MDST gy grn 65% MDST carb 5%

LITHOLOGY DESCRIPTIONS FOR THE KIMMERIDGE CLAY CUTTINGS

TABLE 10

Well/depth (M)	Lithology
6507/10-1	
2780	MDST gy 90%, MDST ox. 5%, LMST Wh 5%
2786	MDST gy 70%, MDST ox.30%
2792	MDST gy 70%, MDST ox.30%
2798	MDST gy 50%, DOL.buff 50%
2804	MDST dkgy 90%, MDST ox. 5%, SLTST gry 5%
2810	MDST dkgy 95%, MDST ox. 5%
6507/11-1	
2344	MDST gy 100%
2347	MDST gy 100%
2350	MDST gy 100%
2353	MDST gy 100%
2356	MDST gy 100%

SOURCE ROCK QUALITY FOR THE KIMMERIDGE CLAY

TABLE 11

Well/depth (M)	P1 (kg/t)	P2 (kg/t)	HI	TOC (%)
6407/1-2				
3532.5	1.8	10.1	235	4.3
3540	1.7	7.6	138	5.5
3550	0.8	2.6	72	3.6
3577	0.1	12.6	274	4.6
6407/2-1				
2851	0.3	2.7	104	2.6
2860	0.3	6.5	216	3.0
2869	0.8	15.5	316	4.9
2875	1.5	31.7	440	7.2
2890	2.3	40.3	463	8.7
2899	1.9	32.7	389	8.4
6507/12-2				
1875	0.3	1.0	62	1.6
1880	0.1	0.3	50	0.6

SOURCE ROCK QUALITY FOR THE KIMMERIDGE CLAY

TABLE 12

Well/depth (m)	P1 (kg/t)	P2 (kg/t)	HI	TOC (%)
6507/10-1				
2780	0.1	3.7	142	2.6
2786	0.2	7.9	138	5.7
2792	0.3	11.4	292	3.9
2798	1.1	18.5	280	6.6
2804	0.6	17.3	303	5.7
2810	0.8	20.2	272	7.4
6507/11-1				
2344	0.1	0.3	30	1.0
2347	0.1	0.3	30	1.0
2350	0.2	0.4	33	1.2
2353	0.6	1.5	107	1.4
2356	0.1	0.4	29	1.4

PYROLYSIS - PGC DATA FOR KIMMERIDGE CLAY

TABLE 13

Well/Depth (M)		C1 - C5	C6 - C9	C10 - C13	C14 - C22	C23 - C36	GOGI
6507/10-1	2804 M	14	15	16	27	29	0.16
6407/2-1	2899	13	14	16	26	31	0.14
6407/1-2	3540	22	19	18	25	17	0.28

SOLUBLE EXTRACT DATA FOR THE KIMMERIDGE CLAY

TABLE 14

Well/Depth (M)	TSE (%)	TSE/TOC	SAC/TOC	SAC (%)	AROM (%)	RES (%)	ASPh (%)	CPI	PR/PH	PR/C17	PH/C18
6507/10-1 2804(M)	0.430	75	25	34.4	41.2	24.4	8.6	1.09	1.6	1.7	1.2
6407/2-1 2899(M)	0.684	81	14	17.4	43.1	39.5	11.1	0.98	0.89	1.8	2.4
6407/1-2 3540(M)	0.676	147	47	31.7	47.4	20.9	8.2	0.99	0.92	0.8	0.9

MOLECULAR SOURCE ROCK INDICATORS - SATURATES

TABLE 15

Well/Depth (M)	H1	H2	H3	H5	H6	H7	H8	H9	S1	S2	S3
6507/10-1 2804(M)	0.53	0.52	0.88	100: 98: 95: 45 : 26: 77	0.42	0.62	0.63	0.27	-	-	-
6407/2-1 2899(M)	0.52	0.50	0.91	100: 88: 38: 42 : 19: 29	0.28	0.64	0.68	0.64	-	-	-
6407/1-2 3540(M)	0.59	0.59	0.92	-	-	0.58	0.62	0.64	-	-	53:21:26

MOLECULAR SOURCE ROCK INDICATORS - AROMATICS

TABLE 16

Well/Depth (M)	A1	A2	A3	A4	M2	M3
6507/10-1 2804 (M)	0.33	0.30	0.20	0.07	0.58	0.53
6407/2-1 2899 (M)	0.46	0.42	0.17	0.05	0.65	0.49
6407/1-2 3540 (M)	0.91	0.66	0.43	0.22	0.48	0.41

CARBON ISOTOPE RATIOS FOR KIMMERIDGE CLAY

TABLE 17

Well/Depth (M)	Picked Lithology	Sample	Isotope Ratio (Per Mil)
6507/10-1 2804(M)	Bulked	Kerogen TSE	- 28.3 - 28.0
6407/2-1 2899(M)	Bulked	Kerogen TSE	- 30.5 - 31.6
6407/1-2 3540(M)	Bulked	Kerogen TSE	- 26.9 - 28.5

SUMMARY OF GEO CHEM DATA FOR THE KIMMERIDGE CLAY IN 6507/10-1

(DATA FROM WOODHOUSE & WARD, 1983)

TABLE 18

Depth	Lithology	P2 (kg/t)	GOGI	TOC (%wt)	H Index	TSE/TOC $^{o}/oo$	Formation	$\delta^{13}C$ Kerogen
2785	MDST	67.7	0.14	10.9	621	46	Kimmeridge Clay	- 29.8
2790	MDST	59.3	0.22	8.6	689	-	"	-
2797	MDST	42.2	0.28	8.5	496	40	"	- 28.0
2803	MDST	21.9	0.19	-	-	-	"	-
2808	MDST	0.1	-	-	-	-	"	-
2810	MDST	50.4	0.25	9.6	525	26	"	- 25.4
2831	MDST	1.4	-	1.9	73	-	"	-

SUMMARY OF GEOCHEMICAL DATA FOR THE COAL UNIT IN 6507/10-1

(DATA FROM WOODHOUSE AND WARD, 1983)

TABLE 19

Depth	Lithology	TOC	$\delta^{13}C$ Kerogen	GOGI	P2(kg/t)
3462	COAL	65.8	- 25.6	0.55	245
3499	MDST	10.9	- 25.7	0.39	30.2
3506	COAL	61.2	- 28.3	0.34	246
3550	MDST	0.62	-	-	0
3603	CARB.MDST	1.1	-	-	0

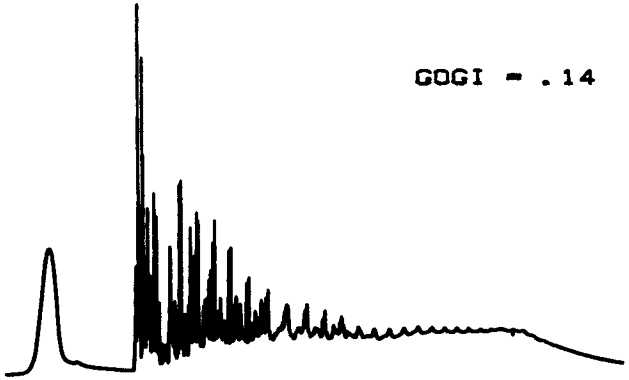
SUMMARY OF GEOCHEMICAL DATA FOR

THE KIMMERIDGE CLAY

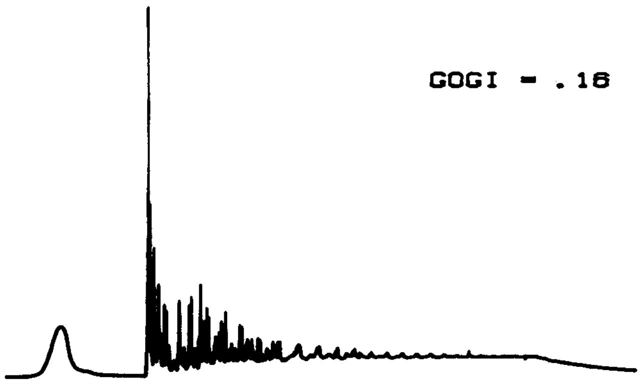
TABLE 20

Well	Formation	P2 (kg/t)	GOGI	H Index	TOC %	$\frac{TSE}{TOC}$ ‰	DATA Source
6507/10-1	Kimmeridge Clay	25.8 (13)	0.20 (6)	348 (11)	7.4 (11)	46.8 (4)	Ward & Woodhouse (1983) this study
6407/2-1	Kimmeridge Clay	18.6 (6)	0.14 (1)	321 (6)	5.8	81.4 (1)	this study
6407/1-2	Kimmeridge Clay	8.1 (4)	0.28 (1)	180 (4)	4.5	122.9(1)	this study

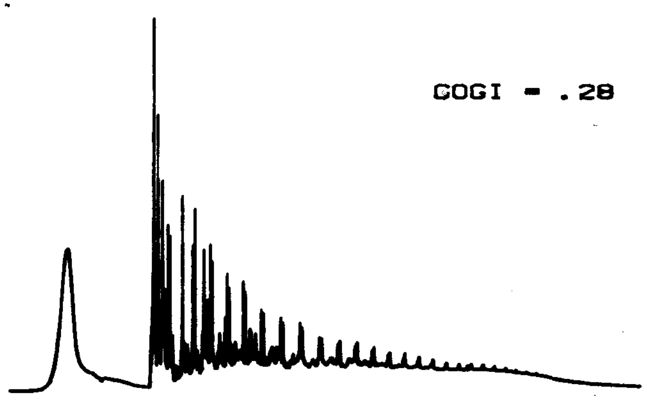
NUMBER OF MEASUREMENTS GIVEN IN PARENTHESIS



SAMPLE:6407/2-1 2899



SAMPLE:6507 /10-1 2804

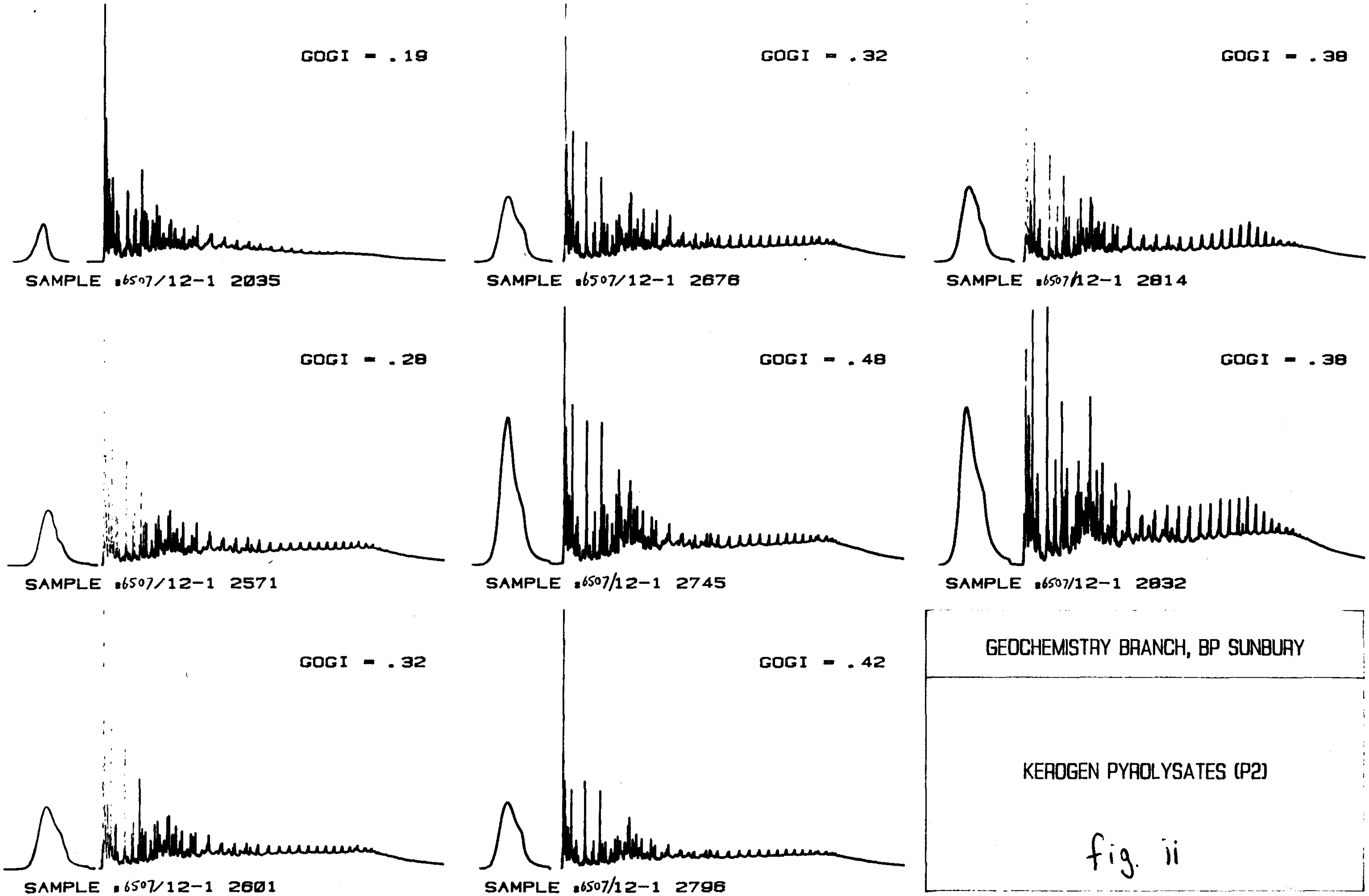


SAMPLE:6407 /1-2 3540

GEOCHEMISTRY BRANCH, BP SUNBURY

KEROGEN PYROLYSATES (P2)

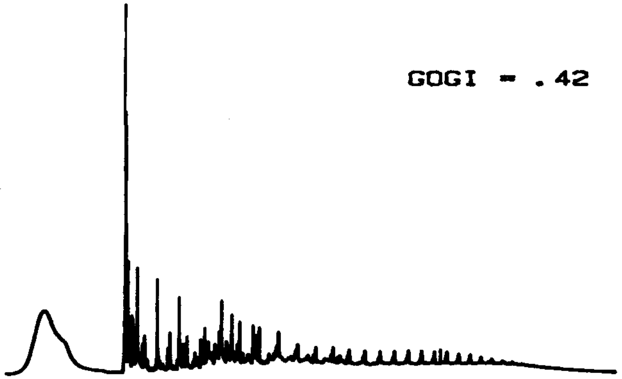
fig. i



GEOCHEMISTRY BRANCH, BP SUNBURY

KEROGEN PYROLYSATES (P2)

fig. ii

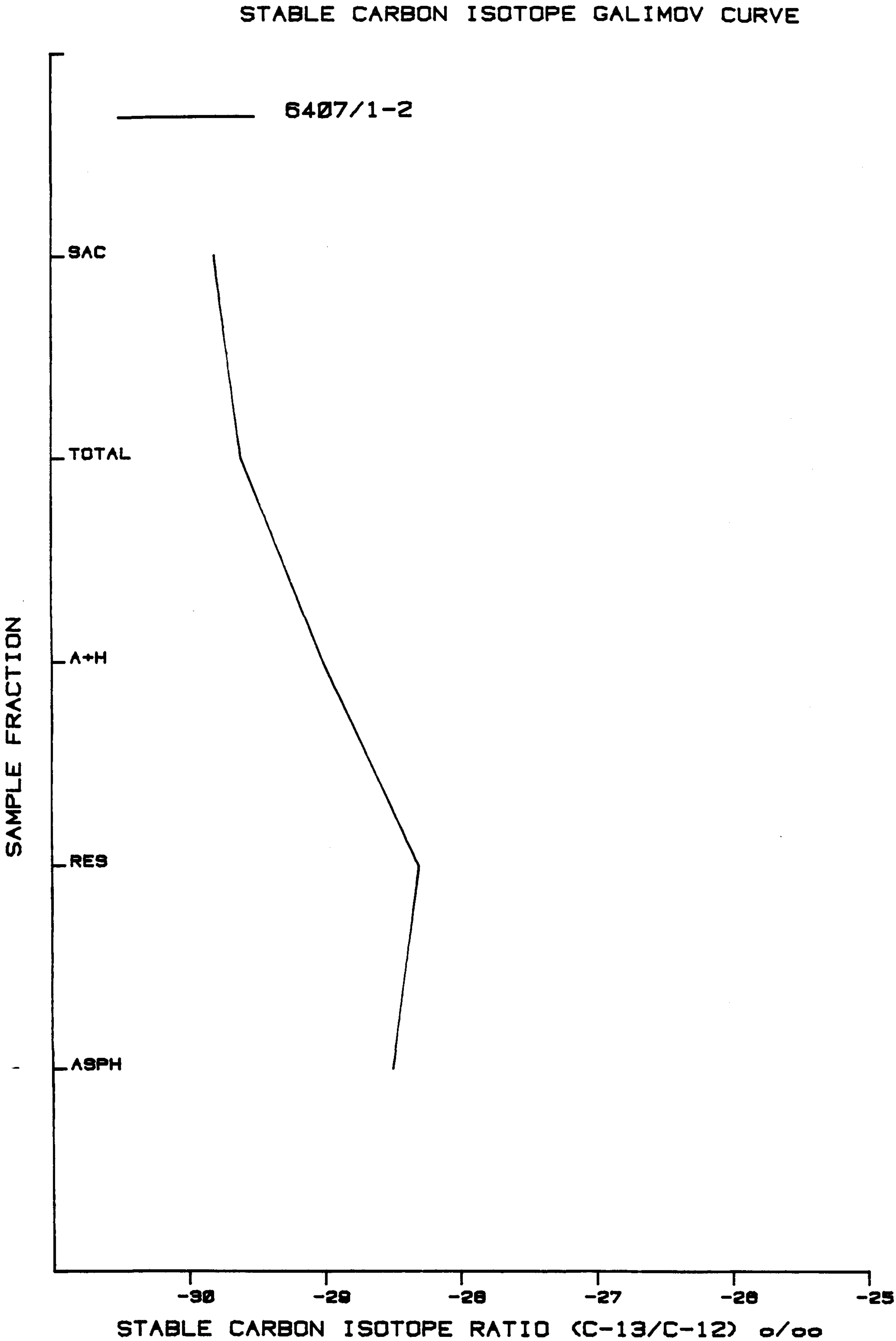


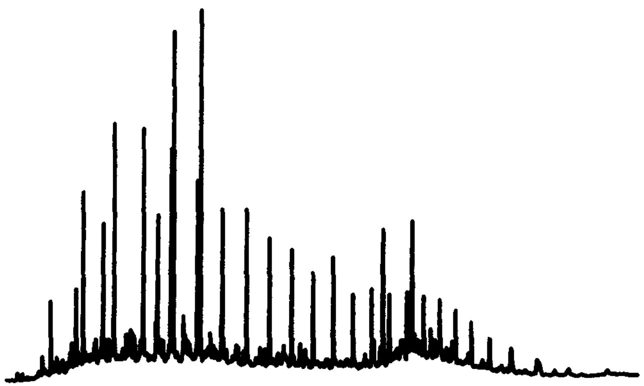
SAMPLE #6507/12-1 2910

GEOCHEMISTRY BRANCH, BP SUNBURY

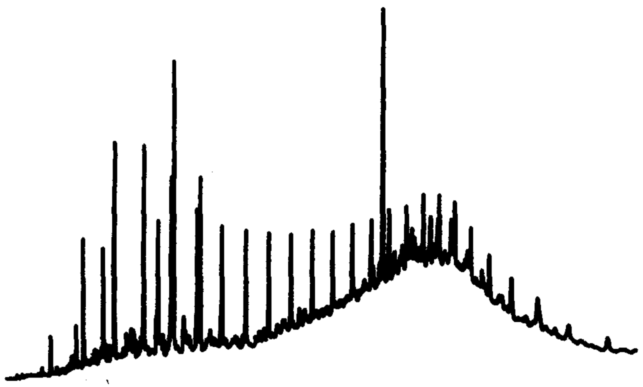
KEROGEN PYROLYSATES (P2)

fig. iii

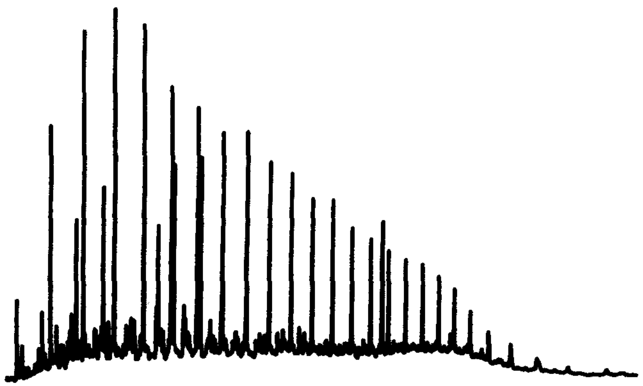

STABLE CARBON ISOTOPE GALIMOV CURVE
6407/1-2
SAMPLE FRACTION
SAC
TOTAL
A+H
RES
ASPH
-30
-29
-28
-27
-26
-25
STABLE CARBON ISOTOPE RATIO (C-13/C-12) o/oo
[fig.iv]



SAMPLE : 6407/2-1 2899



SAMPLE : 6507/10-1 2804

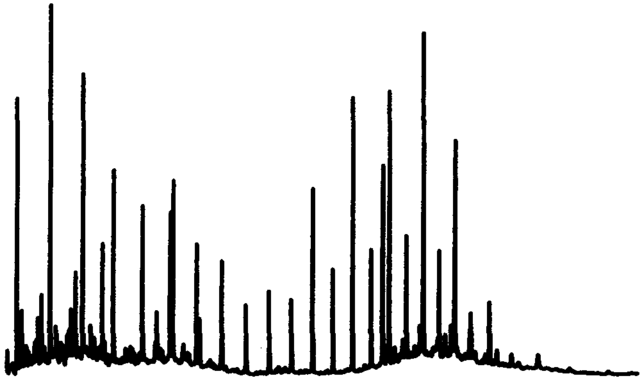


SAMPLE : 6407/1-2 3540

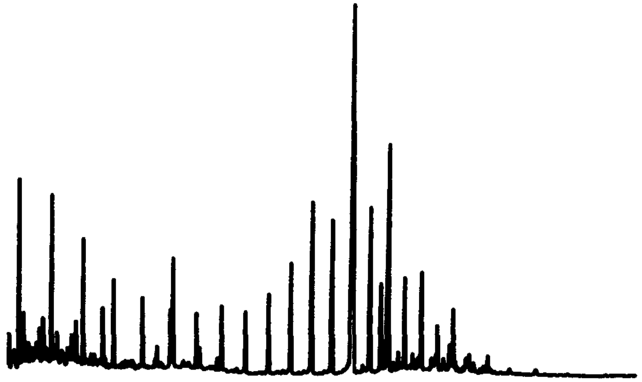
GEOCHEMISTRY BRANCH, BP SUNBURY

SAC FRACTION GAS CHROMATOGRAMS

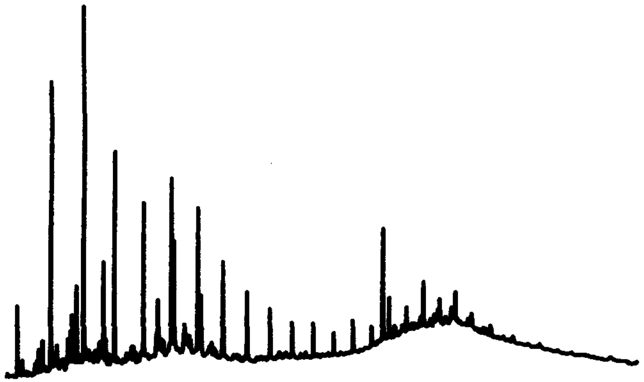
fig. V



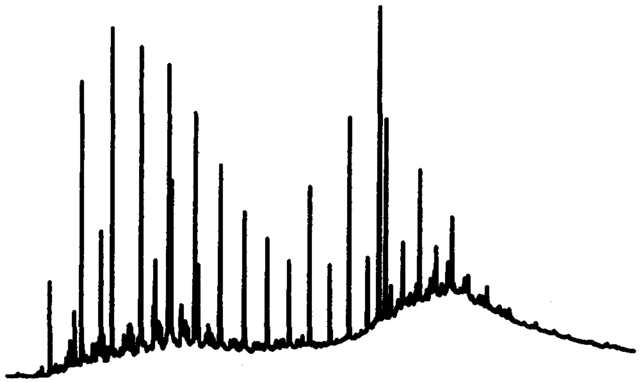
SAMPLE : 6507/12-1 2601



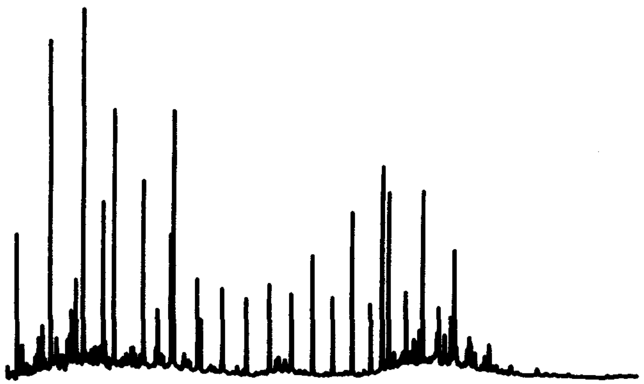
SAMPLE : 6507/12-1 2814



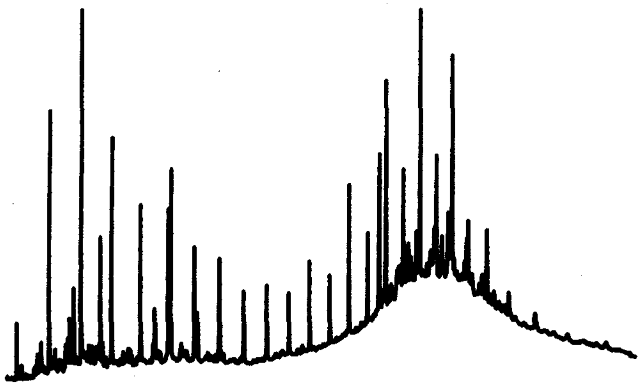
SAMPLE : 6507/12-1 2709



SAMPLE : 6507/12-1



SAMPLE : 6507/12-1 2745



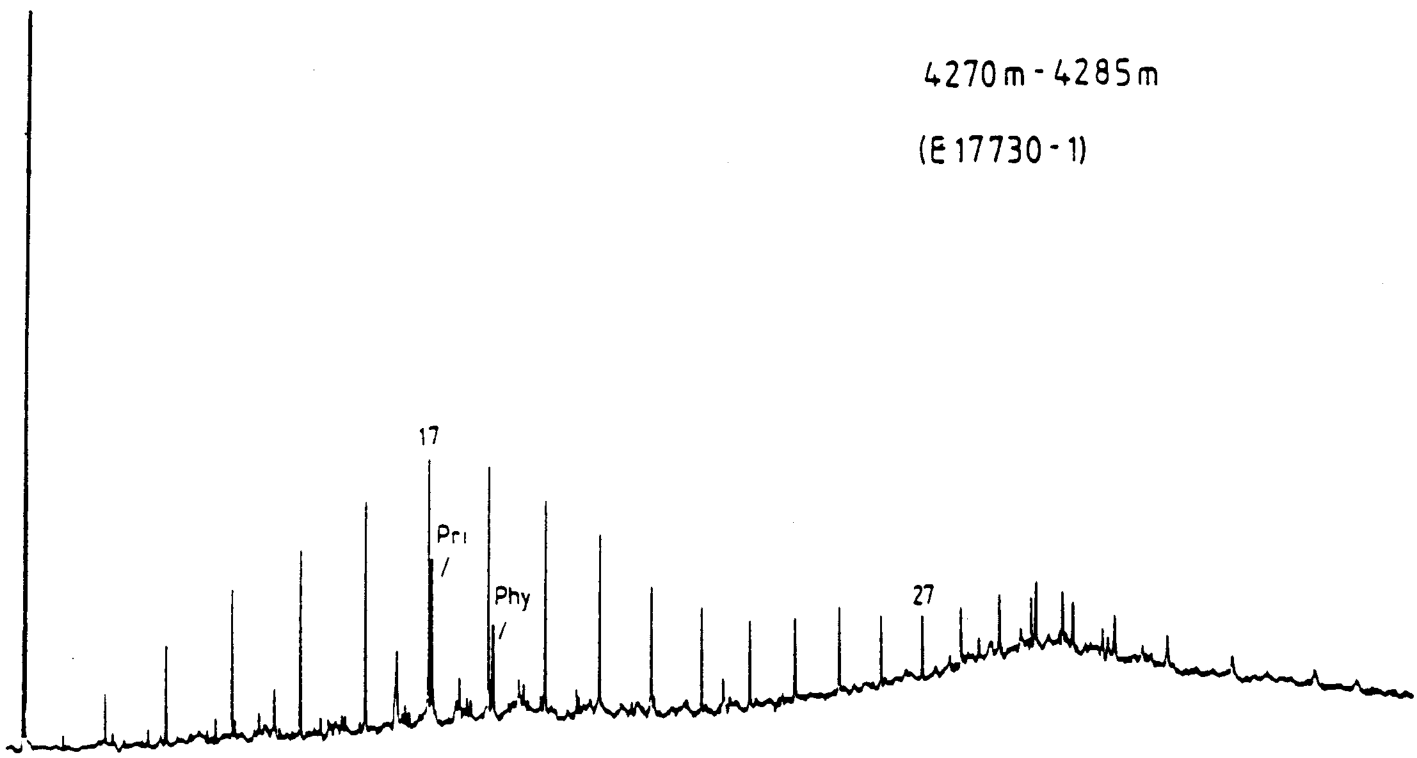
SAMPLE : 6507-12-1

GEOCHEMISTRY BRANCH, BP SUNBURY

SAC FRACTION GAS CHROMATOGRAMS

fig. vi

SATURATES GC FOR THE COAL UNIT (AFTER KFA, 1983)



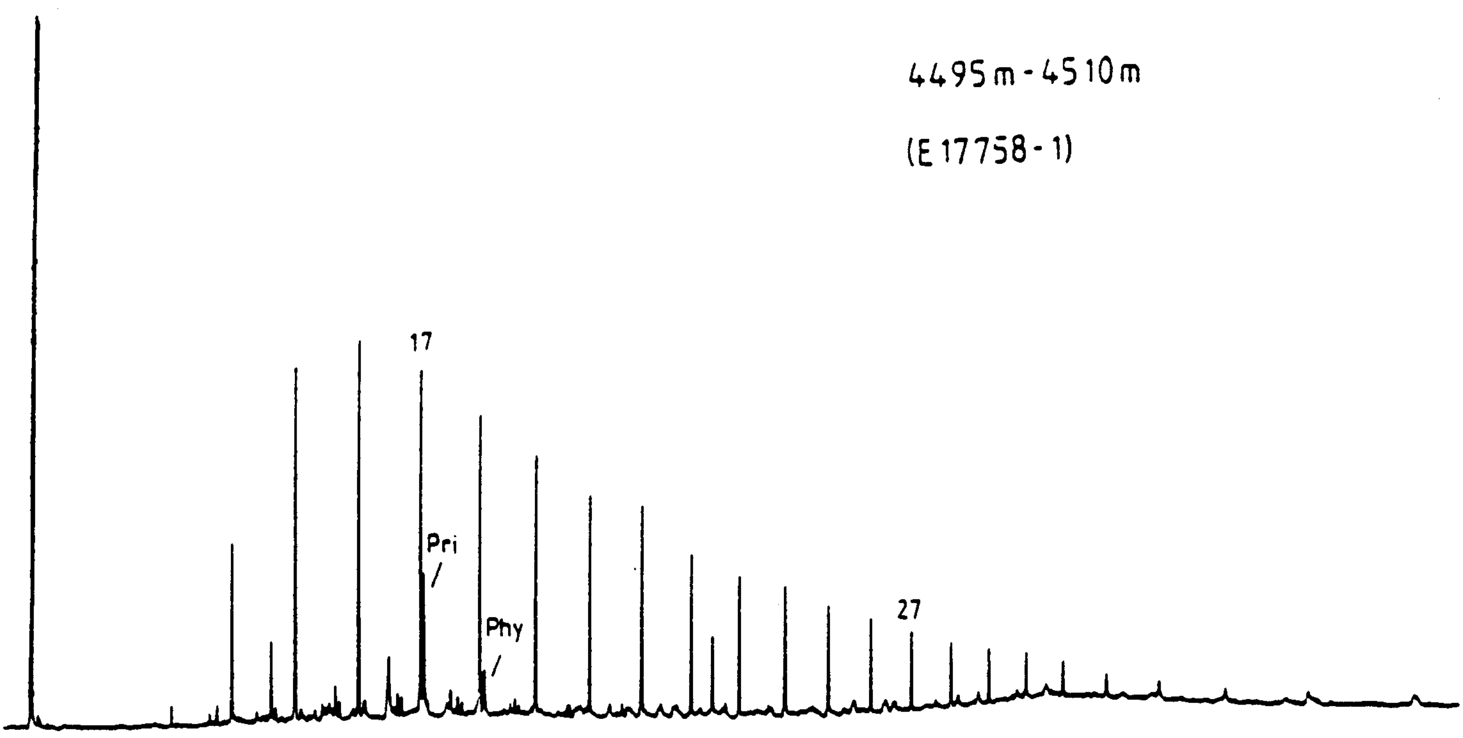
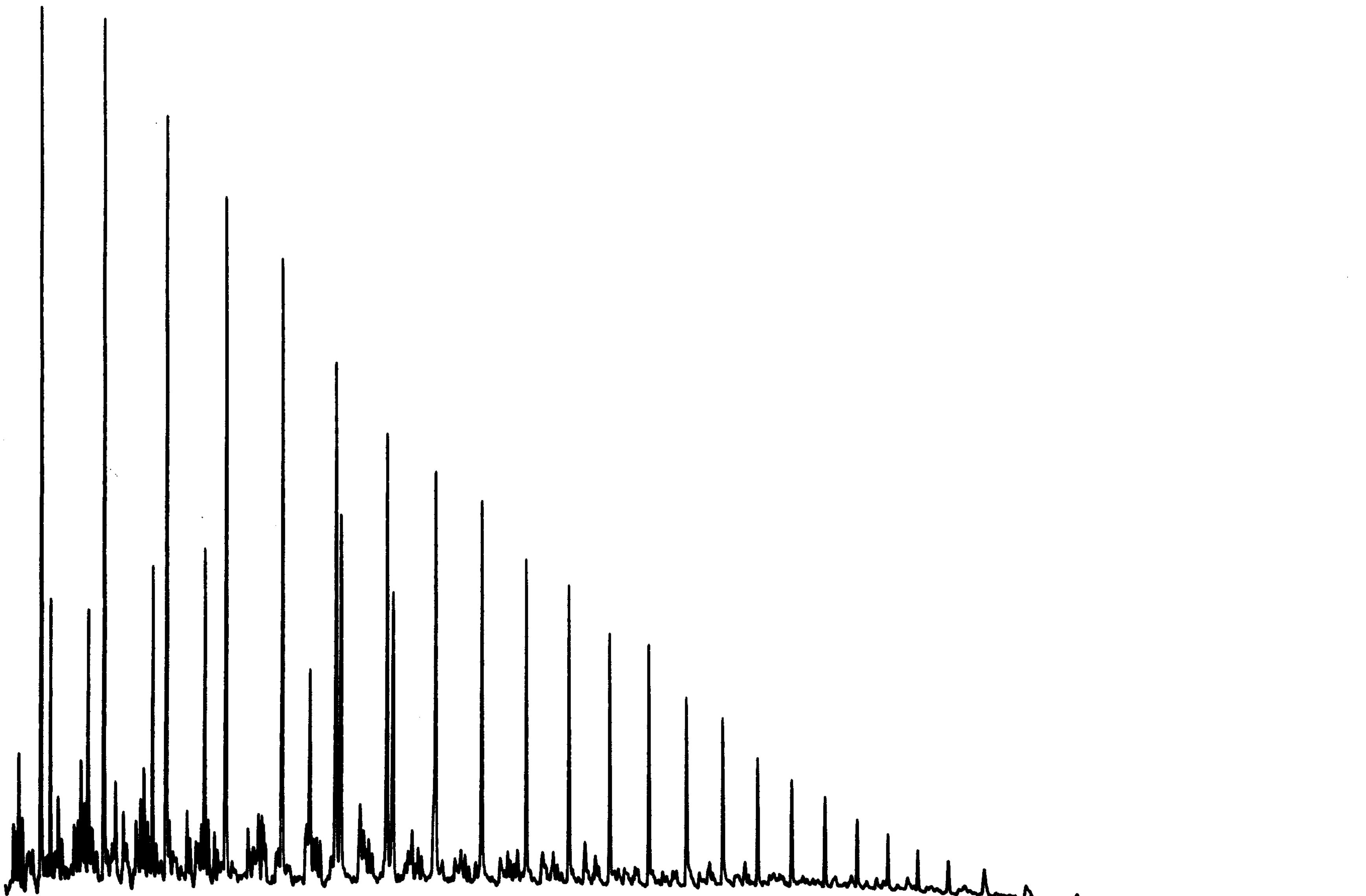
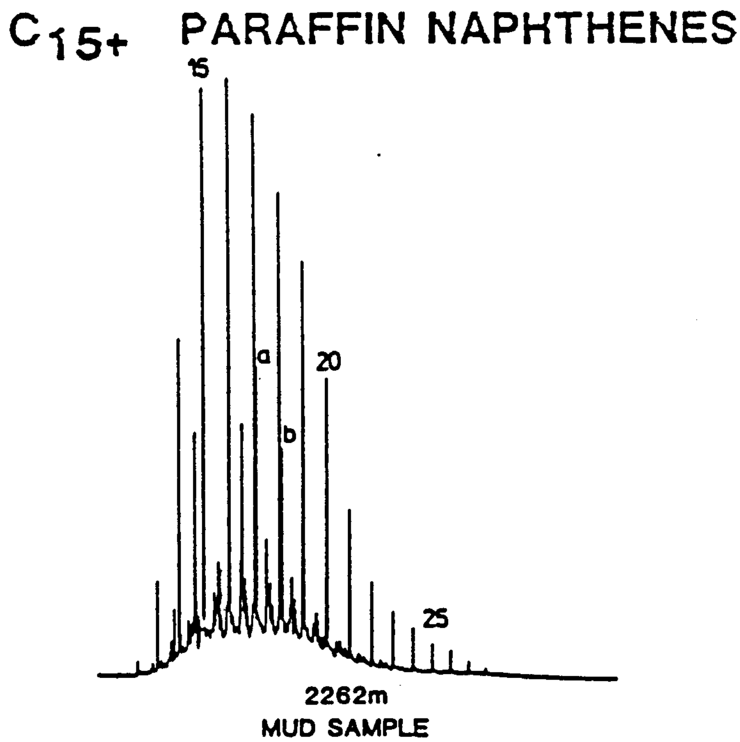


Fig.vii



SAMPLE: 6407/1-2 SATURATES FRACTION



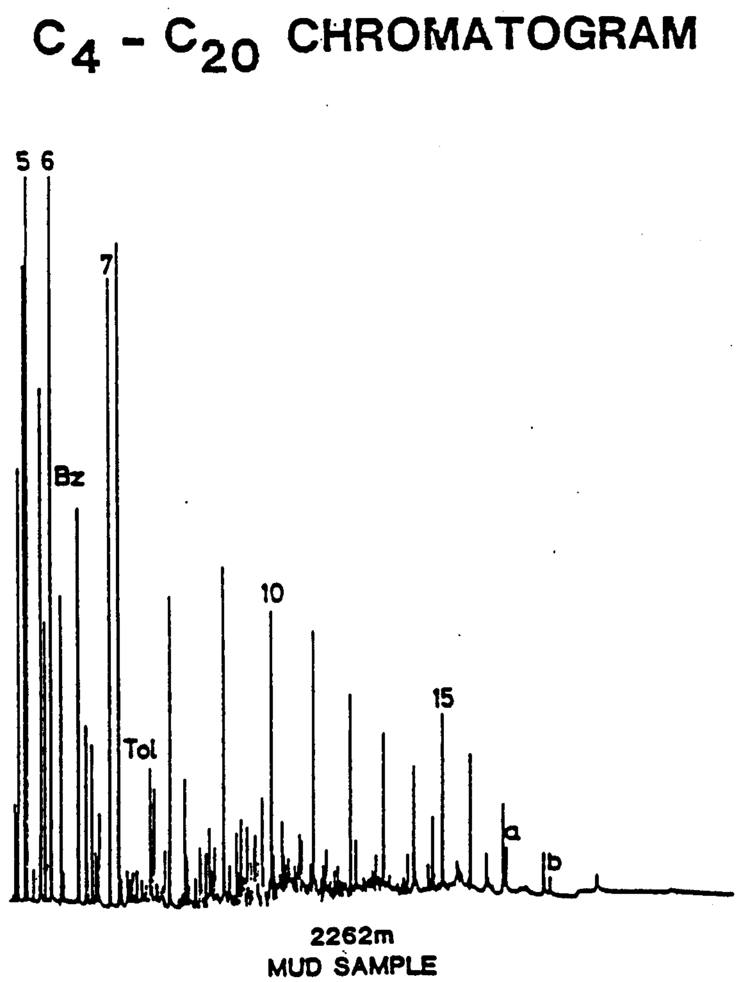
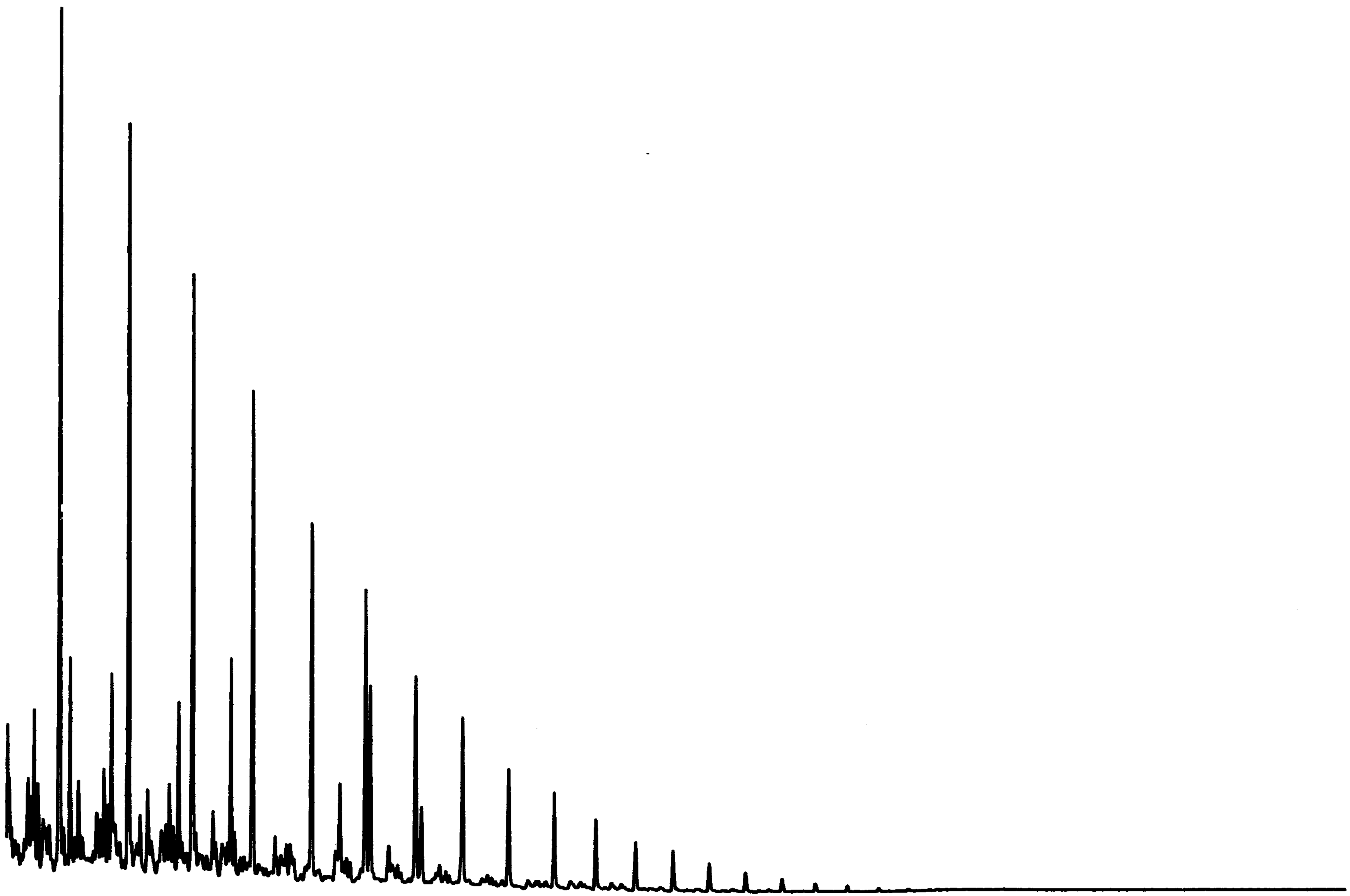


Figure ix 6407/2-1 Oil : GC traces
(after Geochem Labs, 1982)



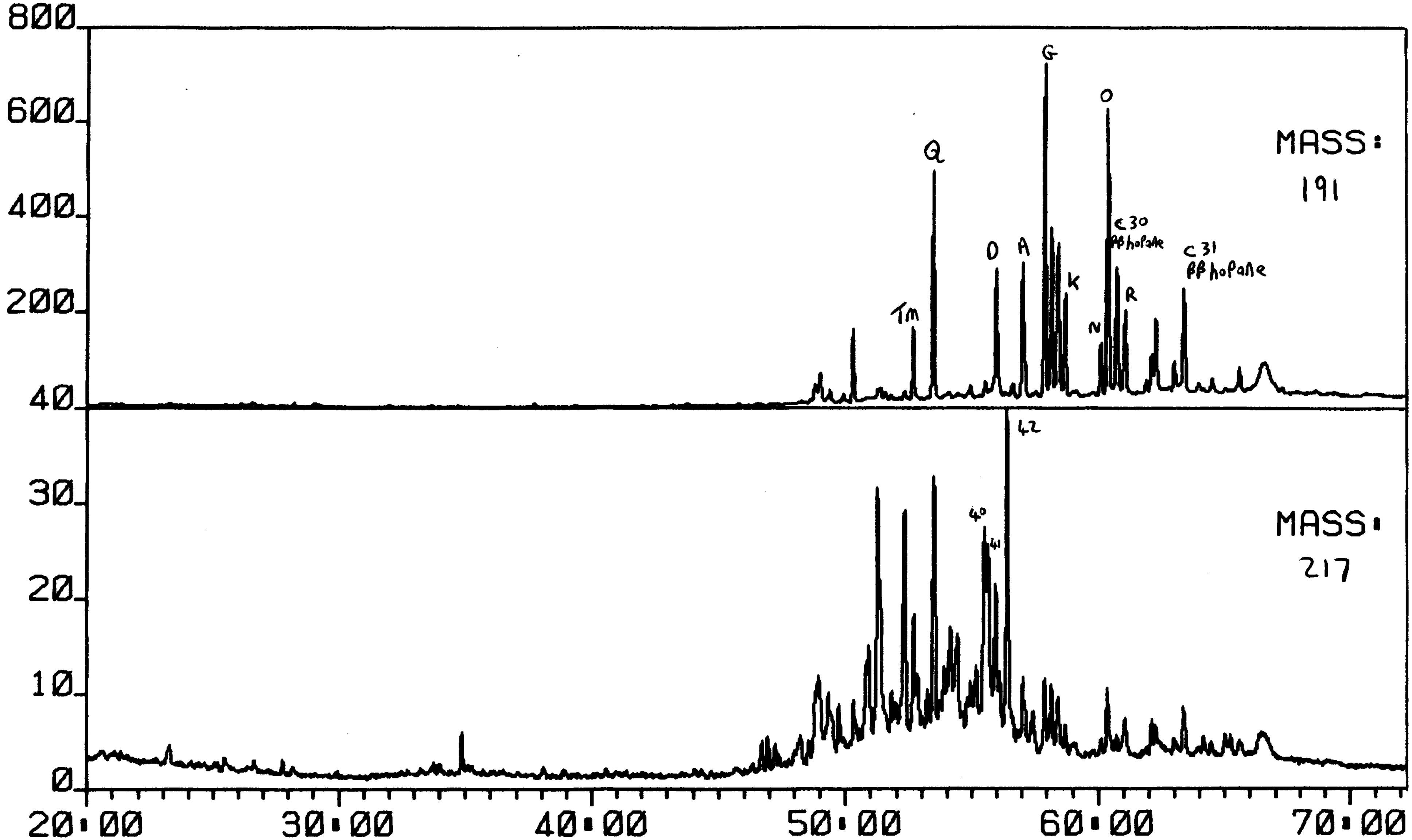
[fig.x]

6507/11-1 CONDENSATE - SATURATES FRACTION GC

ANALYSIS NAME: DM00:[300,301]N506.MIS;1 V04.0 WINDOW

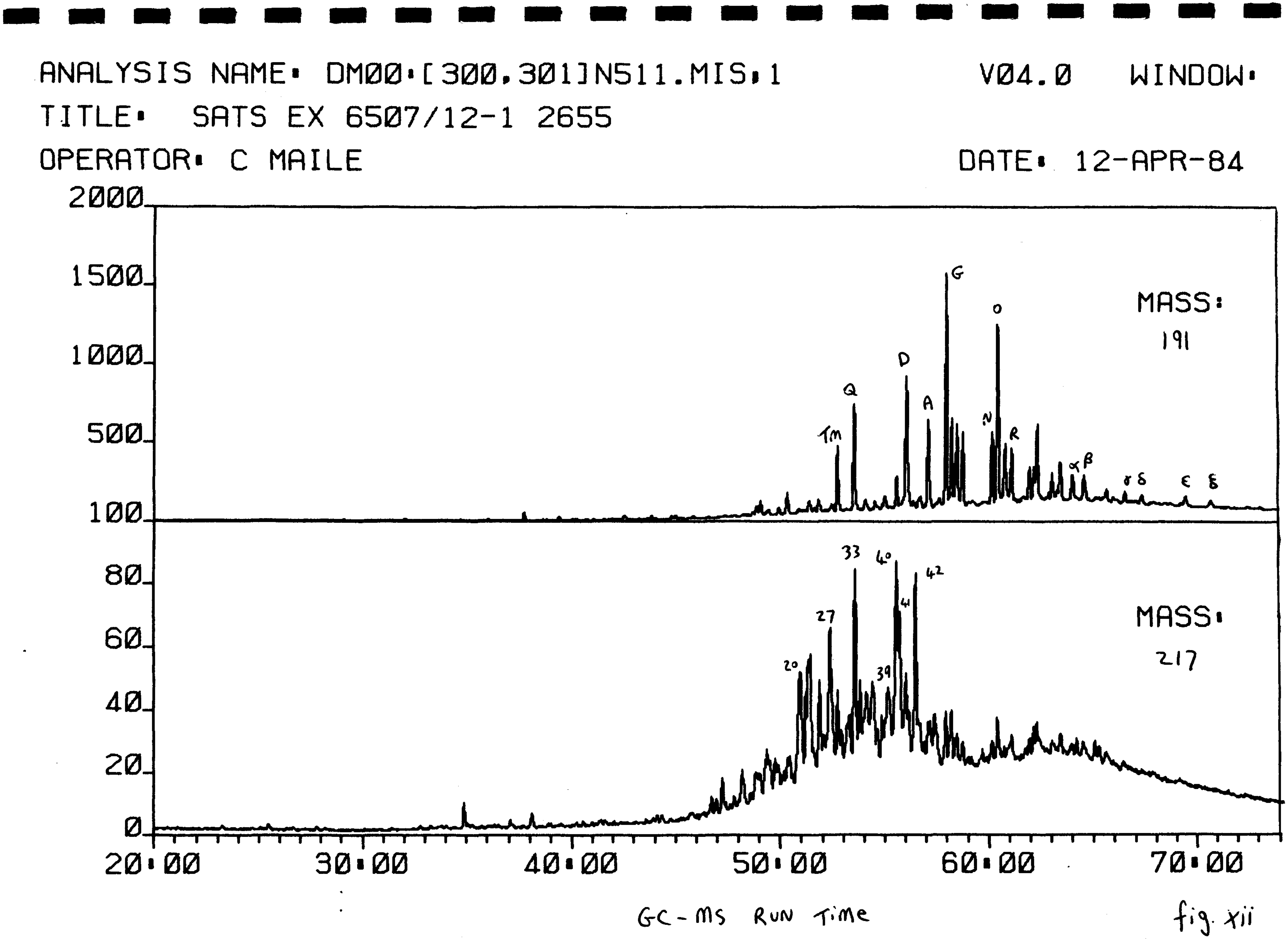
TITLE: SATS EX 6507/12-1 2601M

OPERATOR: C MAILE DATE: 11-APR-84



GC-MS RUN TIME

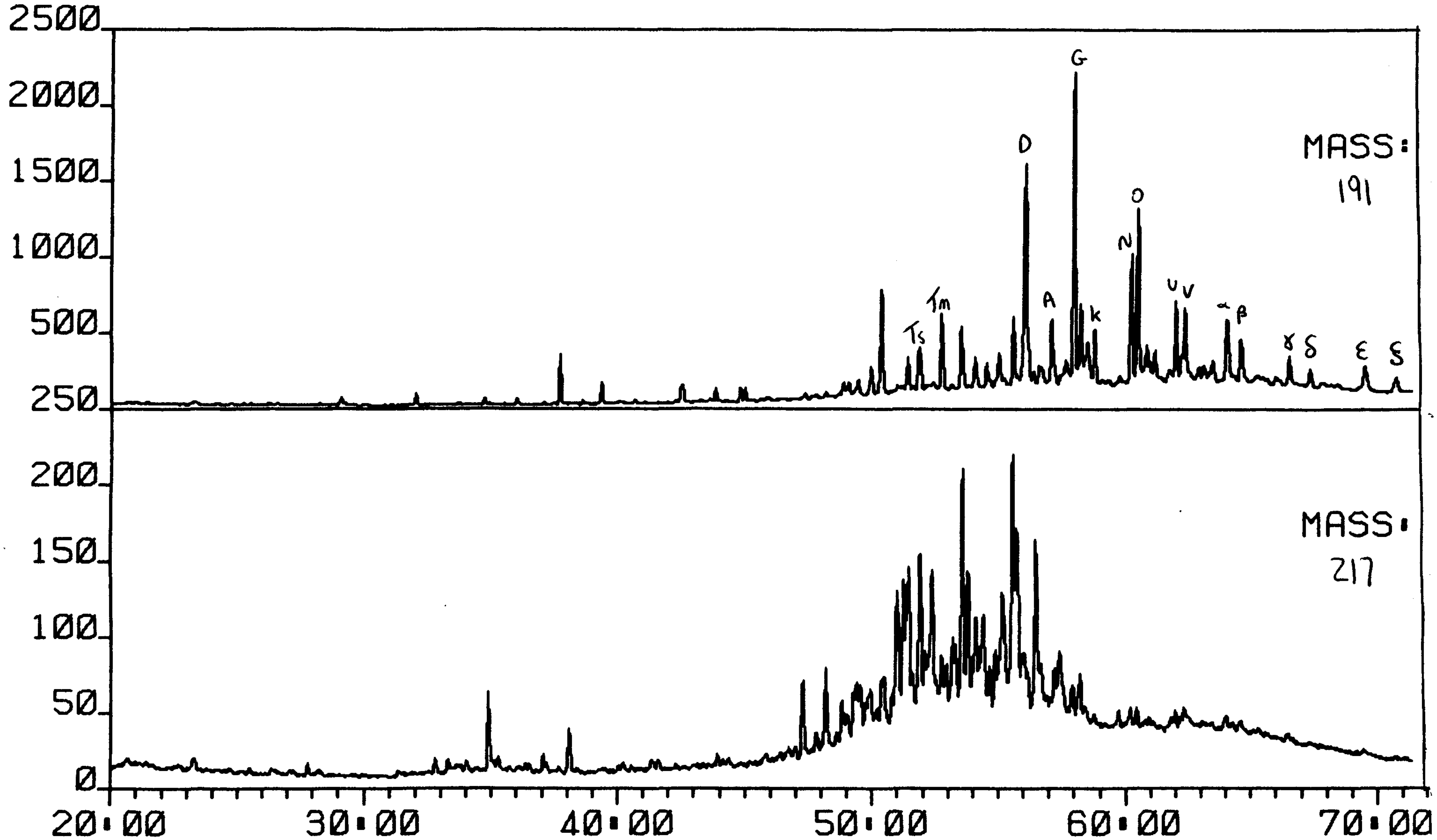
fig. xi


ANALYSIS NAME: DM00:[300,301]N511.MIS;1
V04.0 WINDOW:
TITLE: SATS EX 6507/12-1 2655
OPERATOR: C MAILE
DATE: 12-APR-84
MASS: 191
MASS: 217
Tm
Q
D
A
G
O
N
R
20
27
33
39
40
41
42
20:00
30:00
40:00
50:00
60:00
70:00
GC-MS RUN TIME
fig. xii

ANALYSIS NAME: DM00:[300.301]N507.MIS;2 V04.0 WINDOW

TITLE: SATS EX 6507/12-1 2709

OPERATOR: C MAILE DATE: 12-APR-84



GC - MS RUN TIME

fig. xiii

ANALYSIS NAME: DM00:[300,301]N508.MIS;1 V04.0 WINDOW

TITLE: SATS EX 6507/12-1 2745

OPERATOR: C MAILE DATE: 12-APR-84

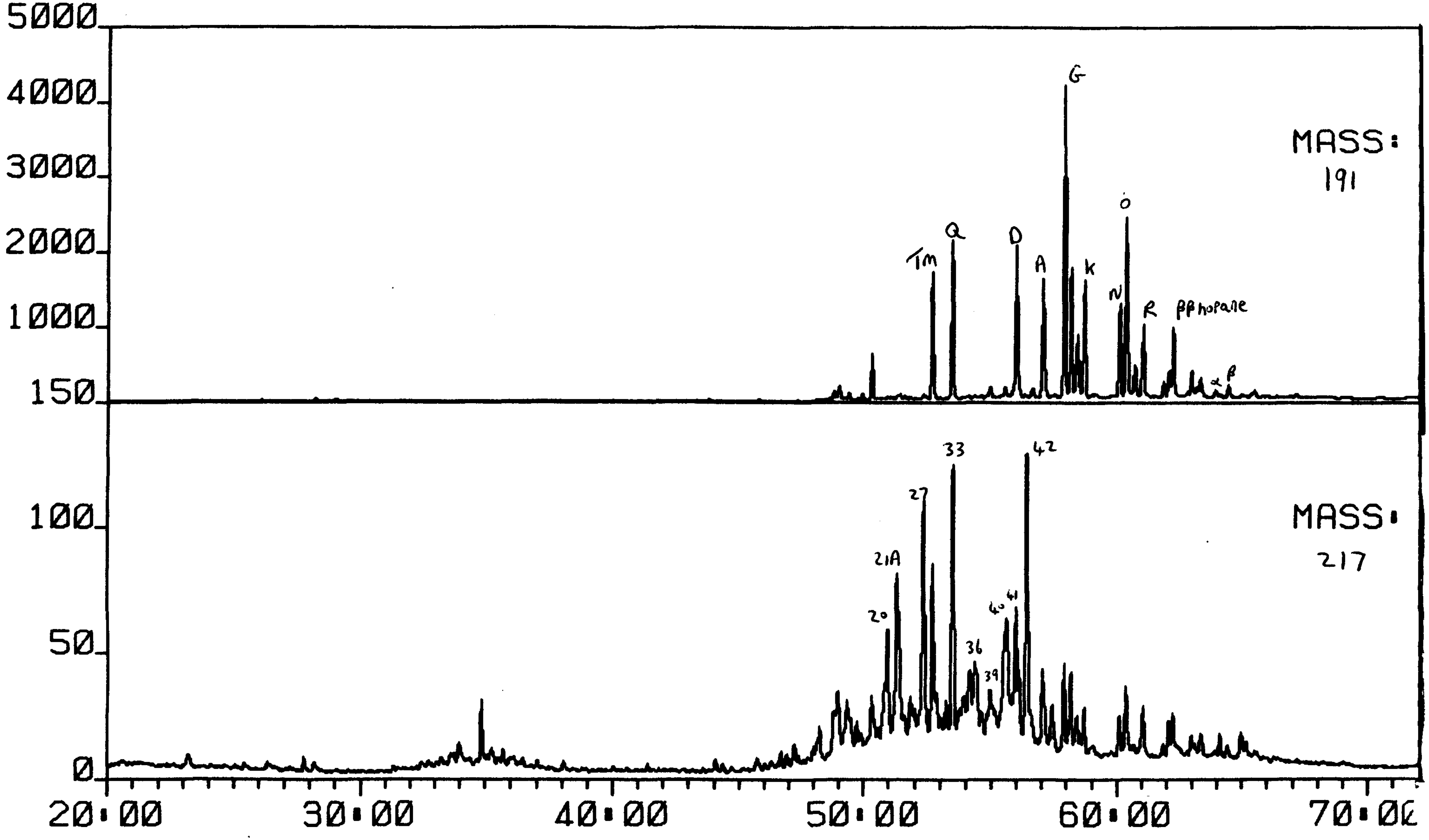


fig. xiv

ANALYSIS NAME: DM00:[300,301]N509.MIS;1 V04.0 WINDOW:

TITLE: SATS EX 6507/12-1 2814

OPERATOR: C MAILE DATE: 12-APR-84

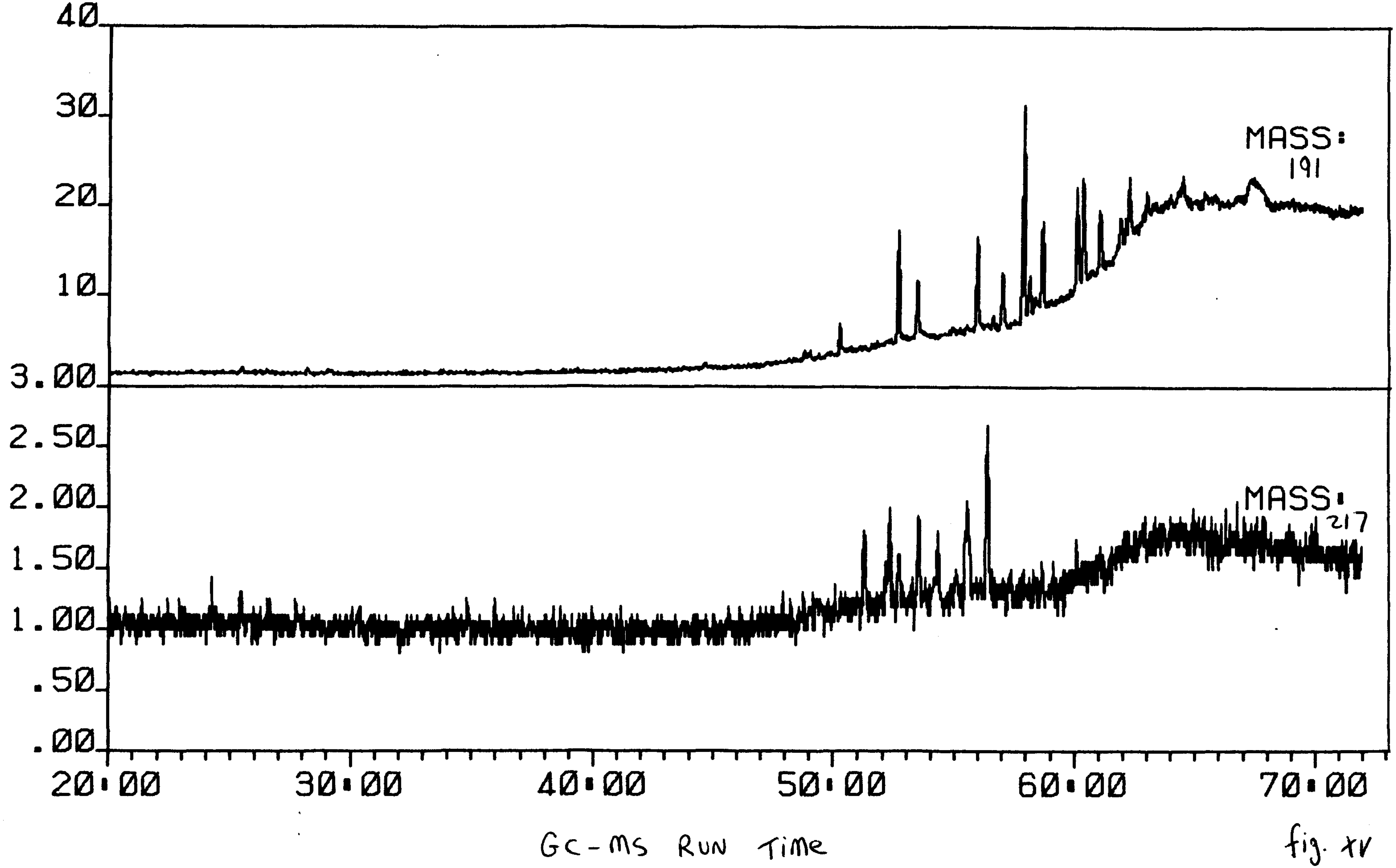


fig. xv

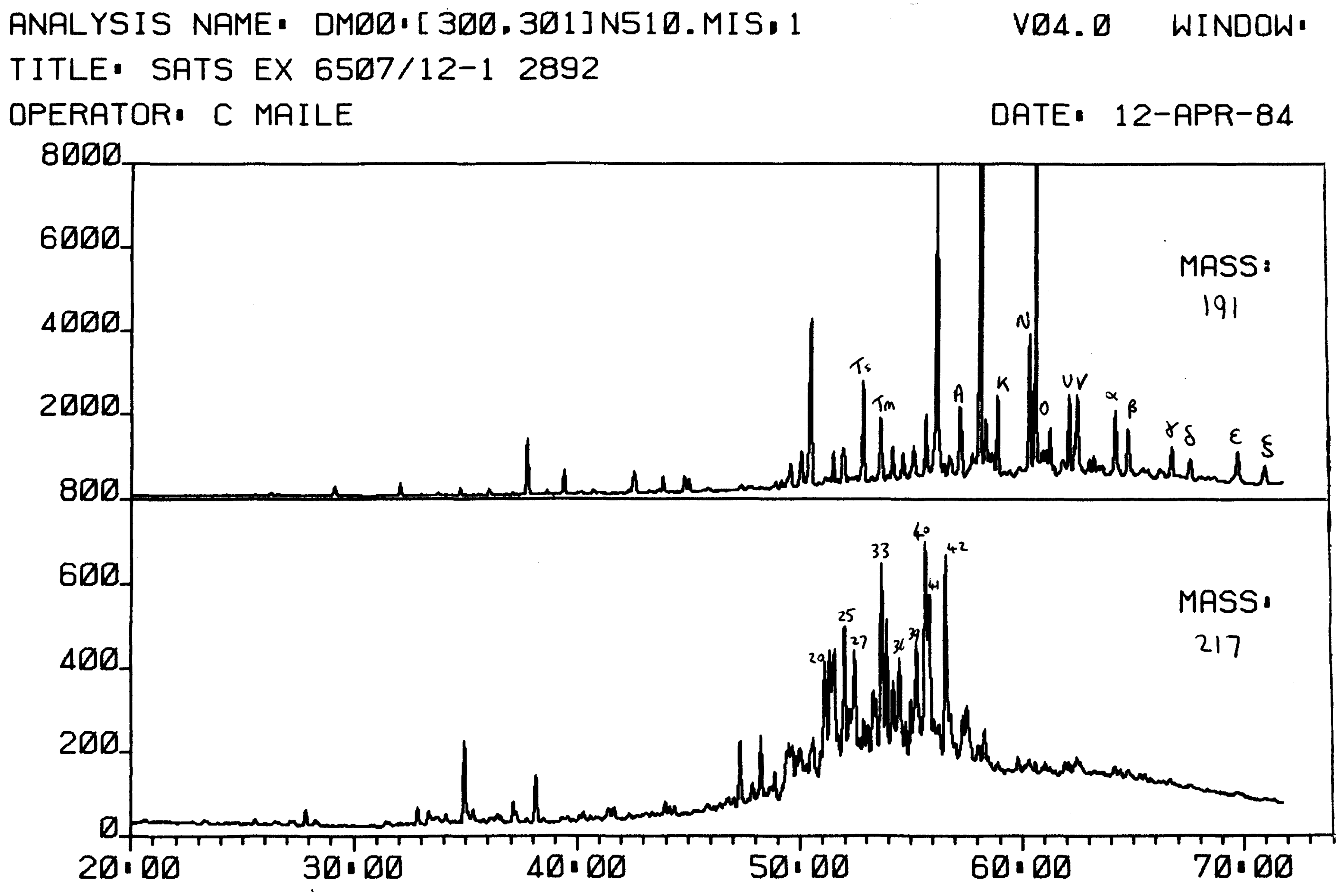

ANALYSIS NAME: DM00:[300,301]N510.MIS;1
V04.0 WINDOW:
TITLE: SATS EX 6507/12-1 2892
OPERATOR: C MAILE
DATE: 12-APR-84
8000
6000
4000
2000
800
MASS: 191
Ts
Tm
A
K
N
O
V V
α
β
γ
δ
ε
ξ
600
400
200
0
MASS: 217
20
25
27
33
36
39
40
41
42
20:00
30:00
40:00
50:00
60:00
70:00
GC-MS RUN TIME

fig. xvi

ANALYSIS NAME: DM00:[300,301]N505.MIS;1 V04.0 WINDOW

TITLE: SATS EX 6507/10-1 2804

OPERATOR: C MAILE DATE: 11-APR-84

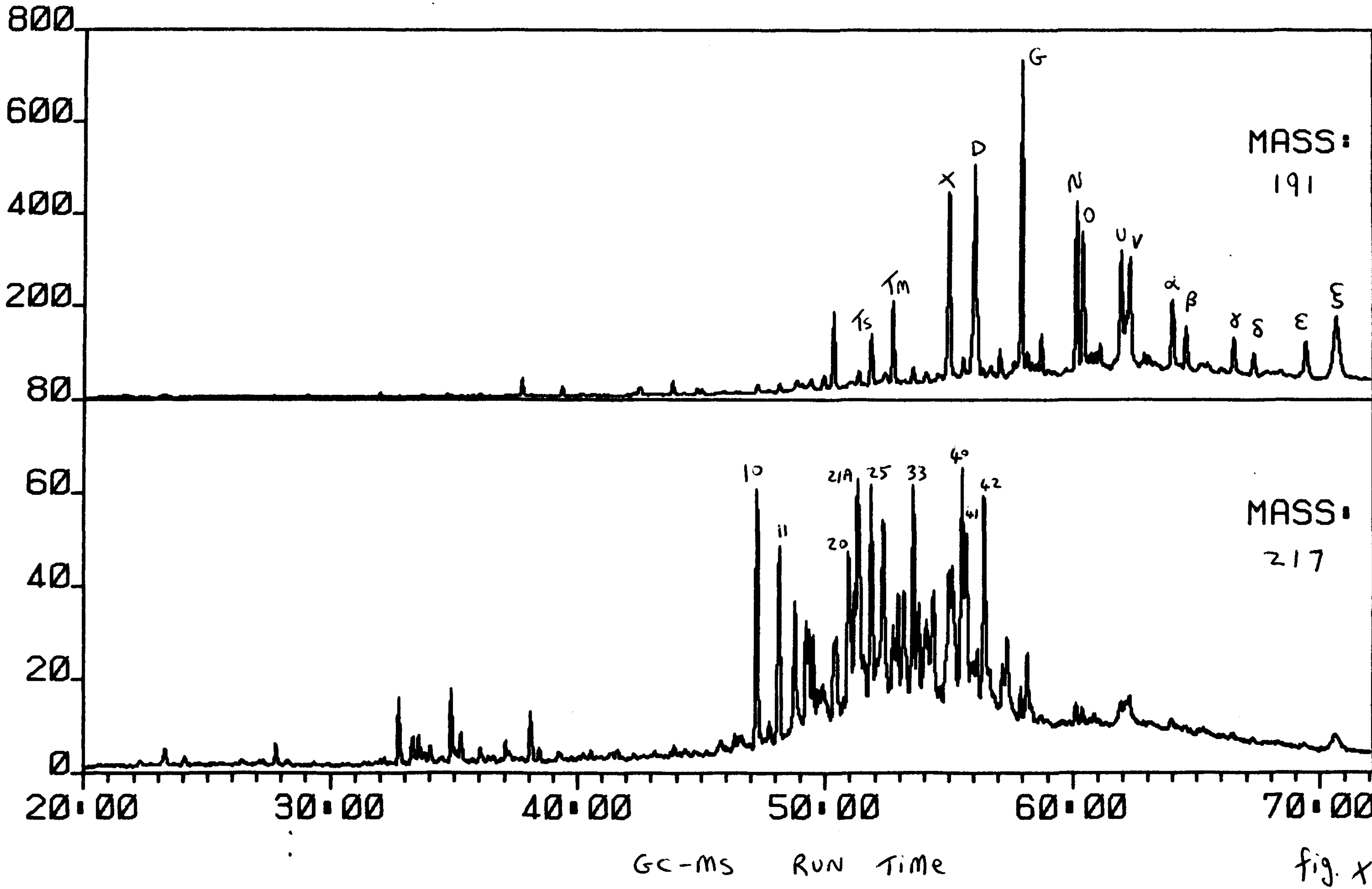


fig. xvii

ANALYSIS NAME: DM00:[300,301]N503.MIS;1 V04.0 WINDOW

TITLE: SATS EX 6407/2-1 2899M

OPERATOR: C MAILE DATE: 11-APR-84

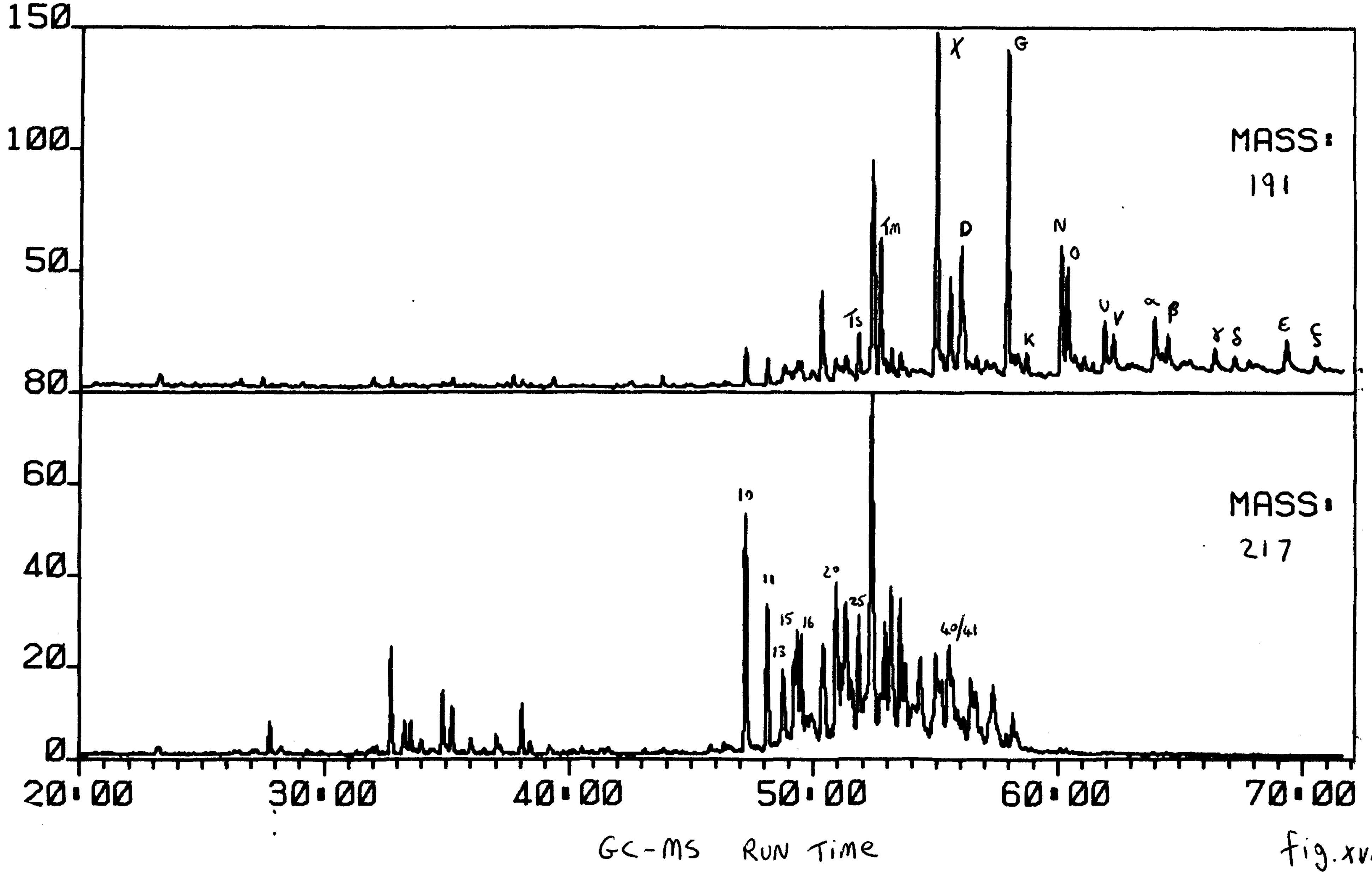


fig. xviii

ANALYSIS NAME: DM00:[300,301]N504.MIS;1 V04.0 WINDOW

TITLE: SATS EX 6407/1-2 3540

OPERATOR: C MAILE DATE: 11-APR-84

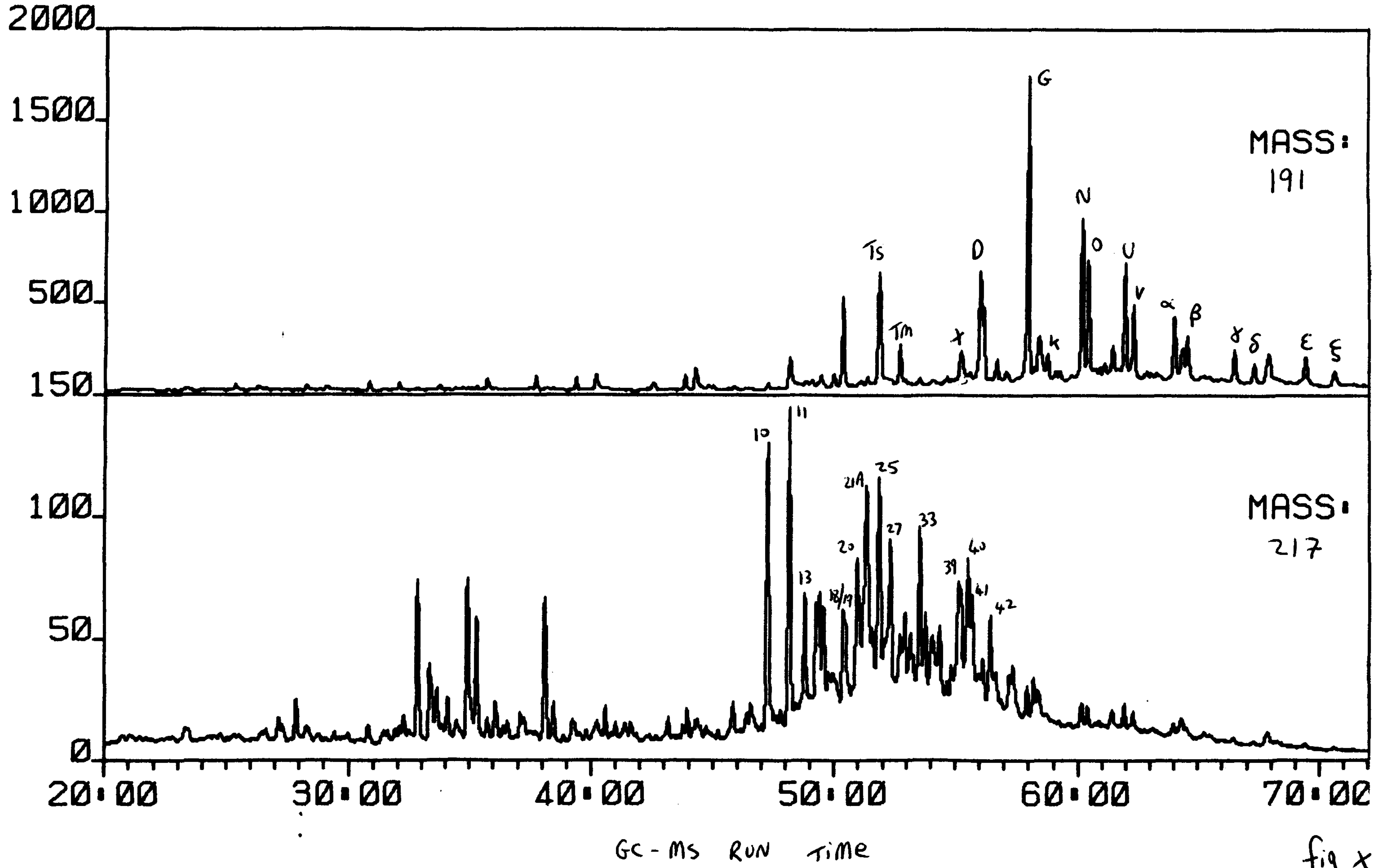


fig. xix

ANALYSIS NAME: DM00:[300,301]N520.MIS;1 V04.0 WINDOW:

TITLE: AROMATICS EX 6507/10-1 2804M

OPERATOR: C MAILE DATE: 25-APR-84

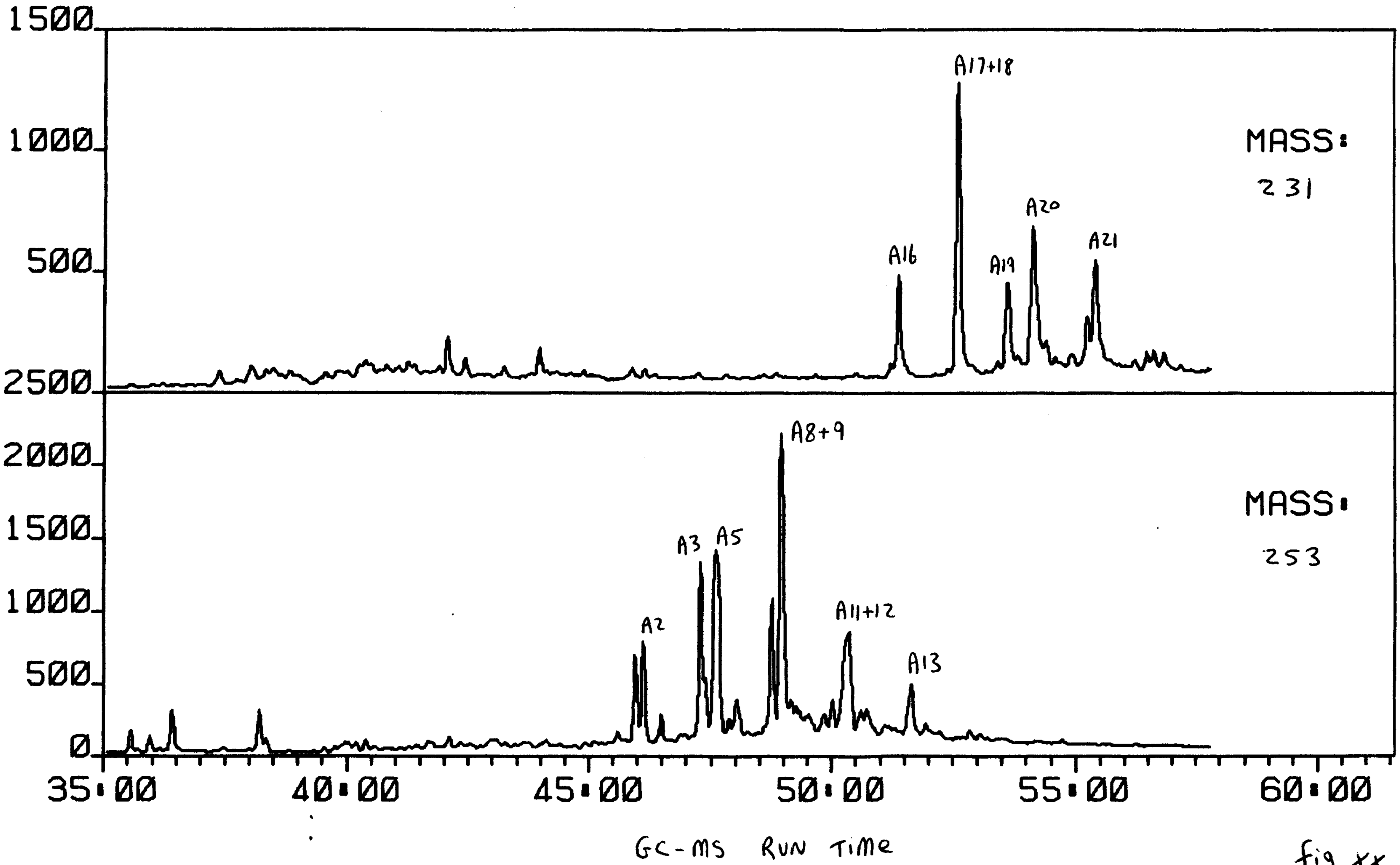


fig xx

ANALYSIS NAME: DM00:[300,301]N517.MIS;4 V04.0 WINDOW:

TITLE: AROMATICS EX 6407/2-1 2899

OPERATOR: C MAILE DATE: 16-APR-84 1

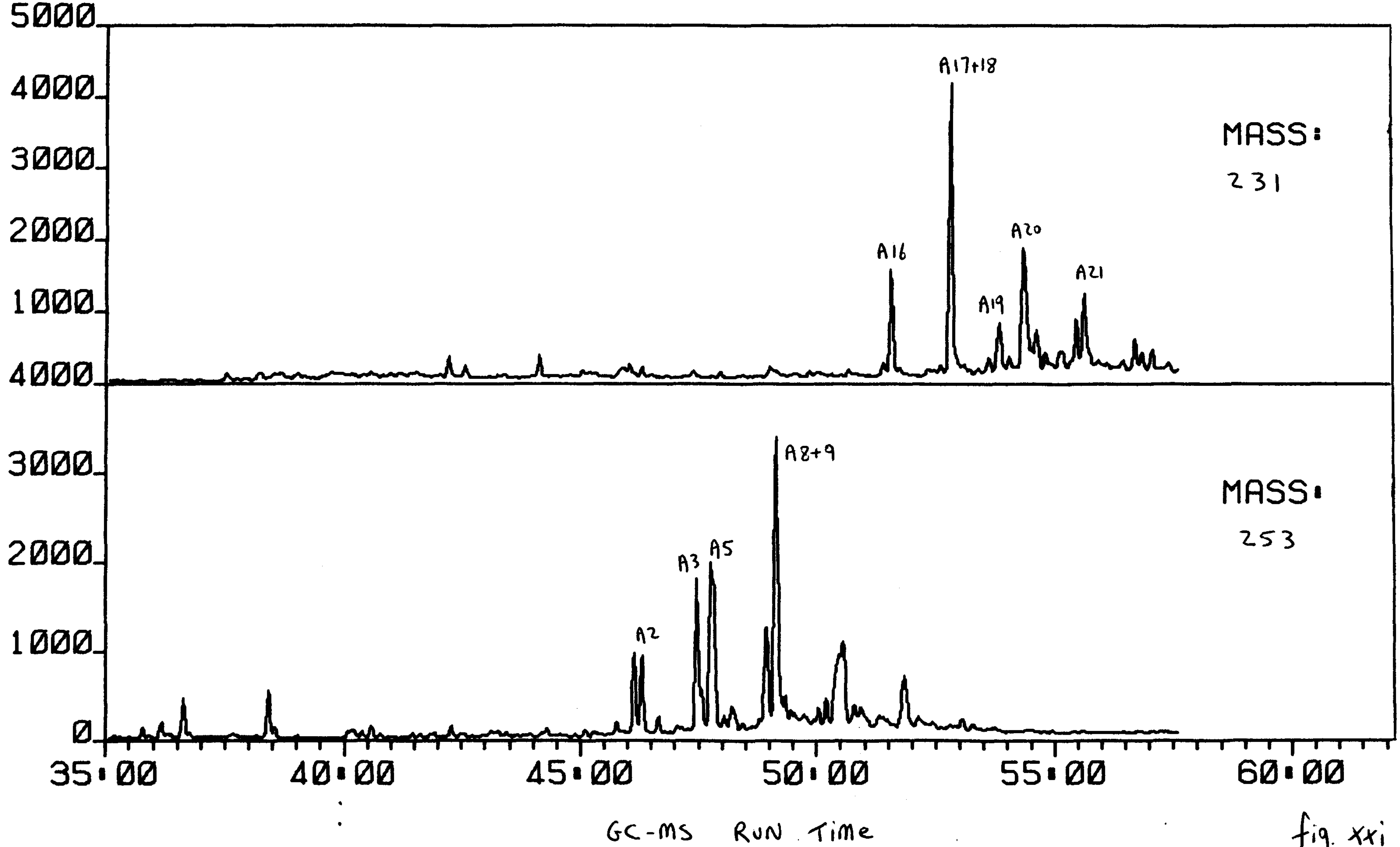


fig. xxi

ANALYSIS NAME: DM00:[300,301]N518.MIS;1 V04.0 WINDOW:

TITLE: AROMATICS EX 6407/1-2 3540M

OPERATOR: C MAILE DATE: 16-APR-84 1

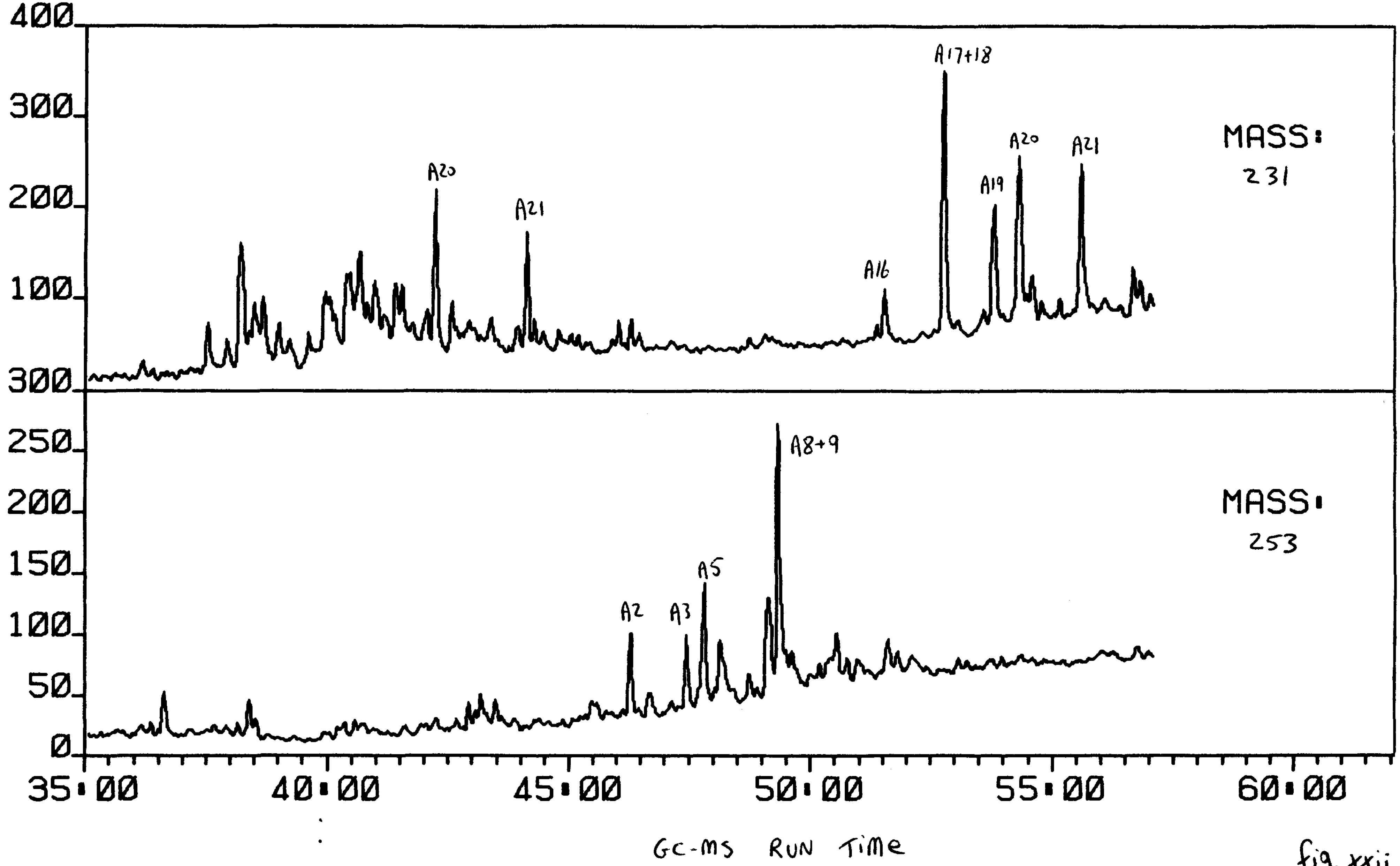


fig. xxii

AI YSIS NAMF: DM00:[300.301]N271.MIS;2 V04.0 WINDOW: 1

TLE: SNTS EX 6407/1-2 OIL

ERATOR: C MAILE DATE: 17-NOV-83 16:22:17

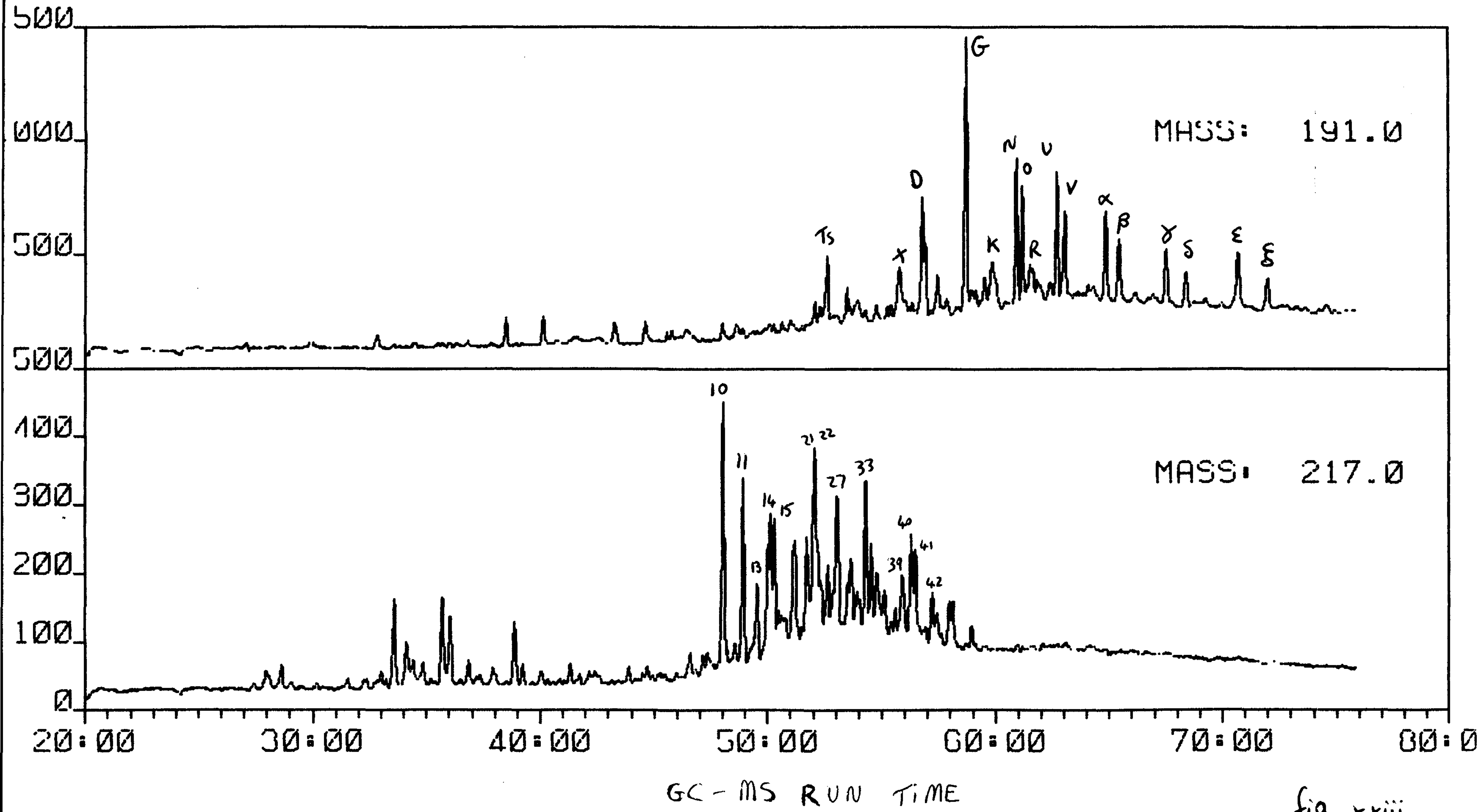
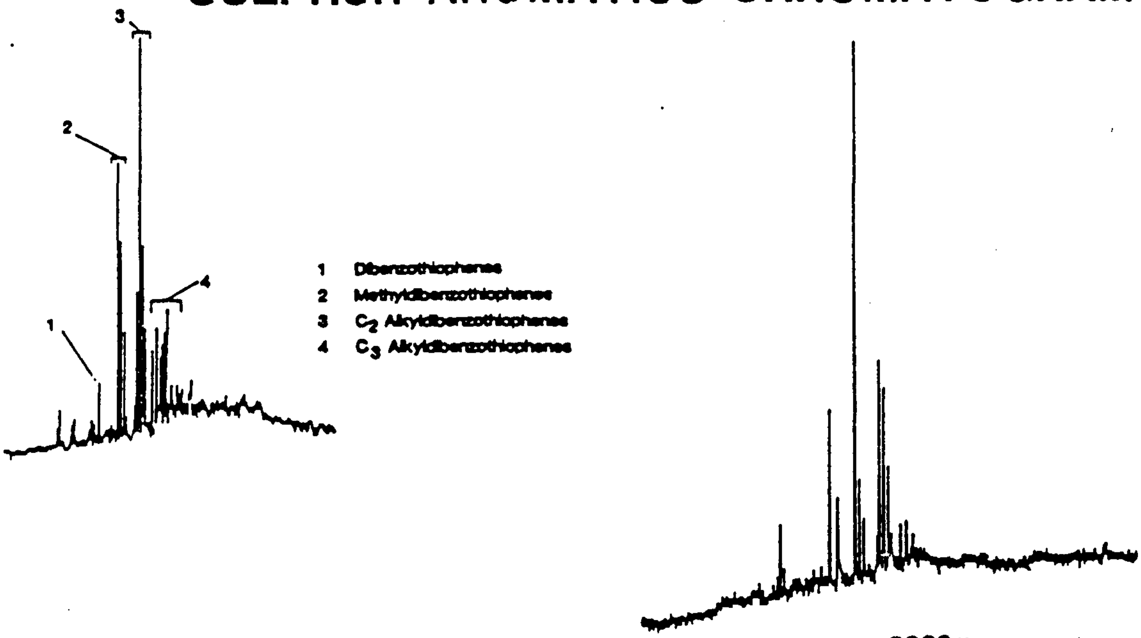


fig. xxiii

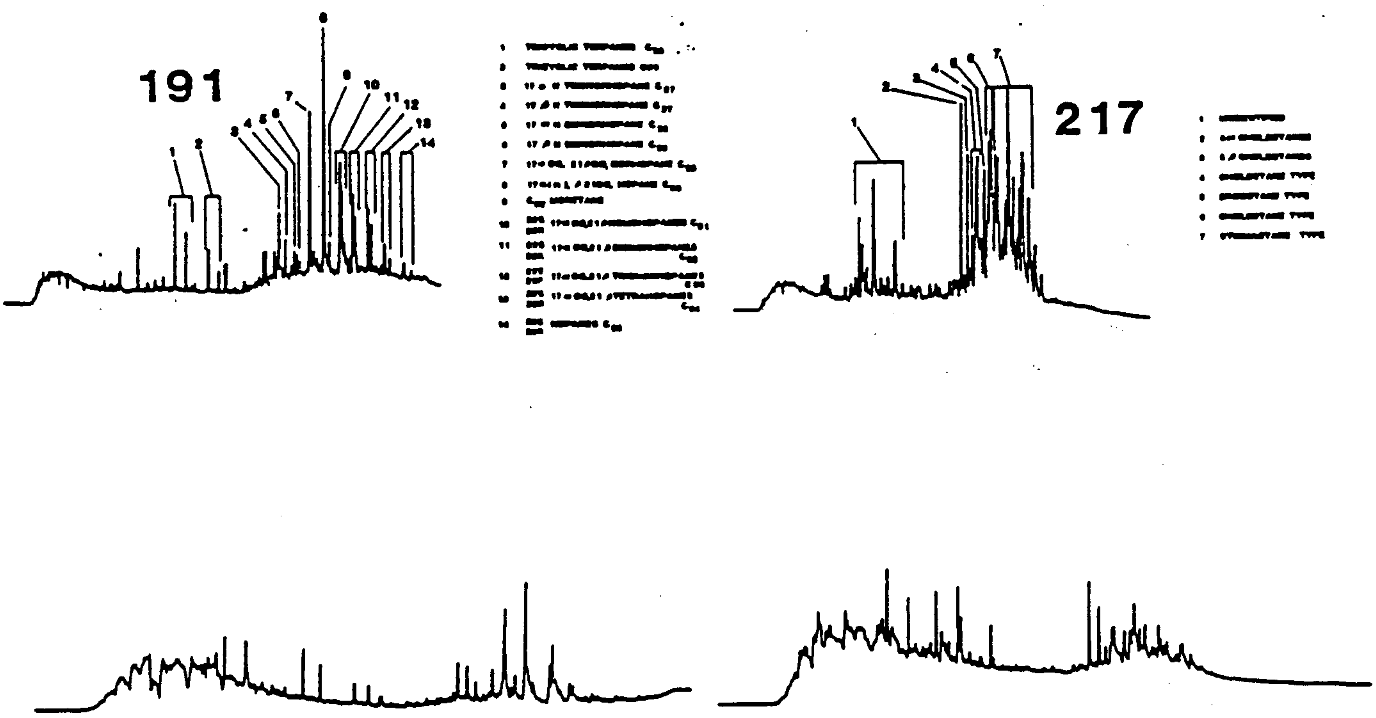
SULPHUR-AROMATICS CHROMATOGRAM



2262m
MUD SAMPLE

MASSFRAGMENTOGRAMS

TERPANES & STERANES



2262m
MUD SAMPLE

Figure *xxiv* 6407/2-1 Oil : Sulphur profile and GC-MS data (after Geochem Labs, 1982)

ANALYSIS NAME: DM00:[300,301]N025.MIS;2 V04.0 WINDOW: 1

TITLE: 6507/11-1 SATS COND

OPERATOR: C MAILE DATE: 27-JUL-83 09:49:31

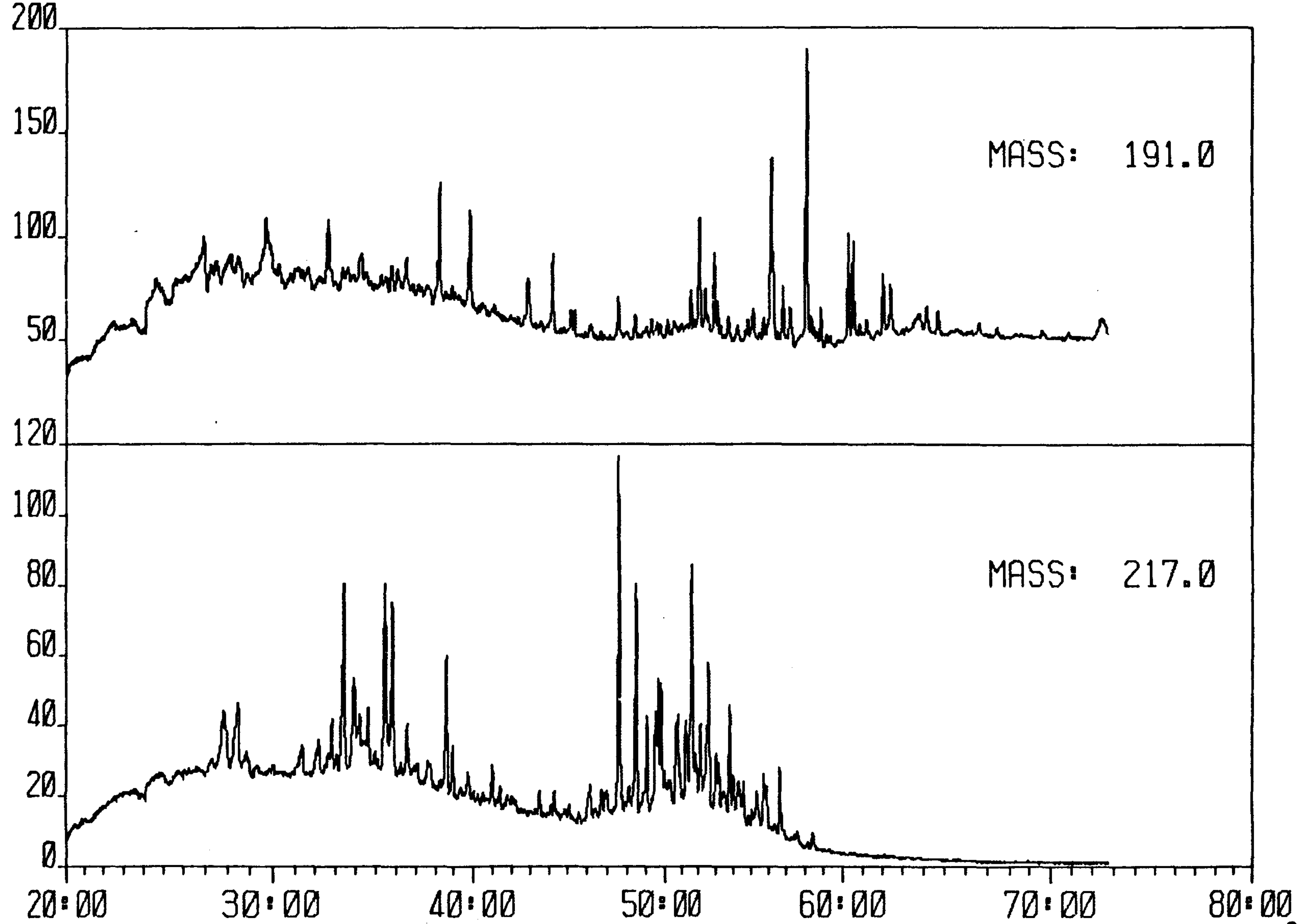


fig. XXV

S3 RATIOS FOR THE KIMMERIDGE CLAY, COAL UNIT AND 6407/1-2 OIL SAMPLE IN HALTENBANKEN

KEY

- X COAL UNIT
- ◆ KIMMERIDGE CLAY
- ● 6407/1-2 OIL

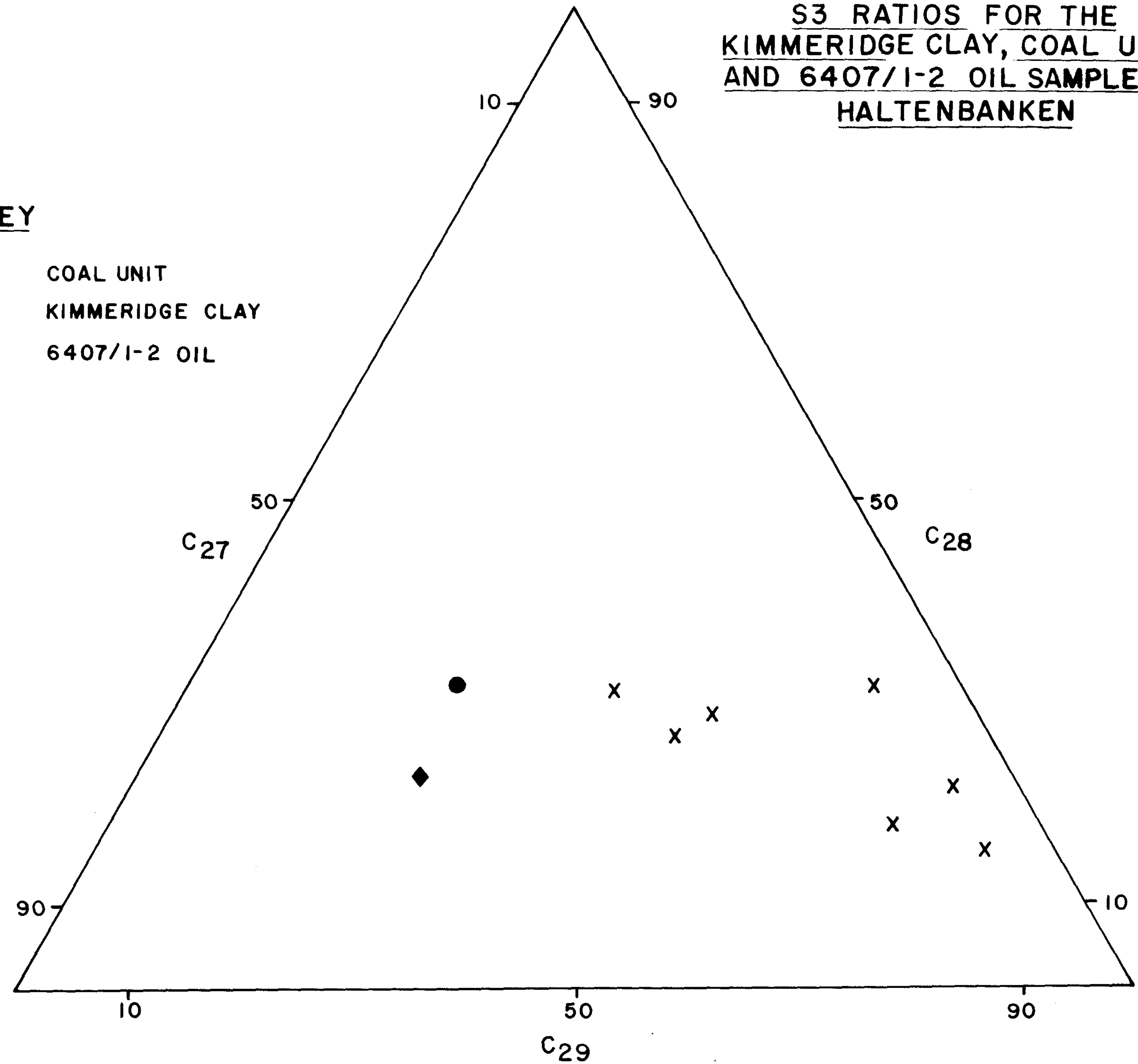


Fig. XXVi