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Report

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Title/Author(s)

SOURCE ROCK STUDY BLOCK 7/11

by

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For Norsk Hydro, Exploration. Licence Group

Sign.

Summary/Conclusion/Recommendation

* The Upper Jurassic Kimmeridge Caly Fm. is regarded to be the source rock.

* Sterane distributions and $\delta^{13}C$ analysis indicate a good correlation between the Kimmeridge Clay Fm. in Well 7/11-5 and 6, and the crude oil from Well 7/11-5.

Key words

Source rock
Oil/source rock correlation

Subject category

Geochemistry

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Research Centre, Geology Dept., Bergen

Field/Block/Well

7/11-5, 7/11-6

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Report ☒ Note ☐

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CONCLUSION

SOURCE ROCK POTENTIAL OF THE WELLS 7/11-5 AND 7/11-6.

* The Tertiary and Upper Cretaceous sediments in the area are immature to early mature and are regarded to have negligible source potential.

* The Lower Cretaceous (Well 7/11-5 and 6) contain mature source rocks which have only a gas potential today.

* The Upper Jurassic Kimmeridge Clay Fm. has reached a late mature stage in Wells 7/11-5 and 6. Several of the horizons mainly in the upper part of the Formation, are regarded to be good source rocks for oil. However, the low Hydrogen Indices show that the sediments at present are only gas/condensate prone due to past generation and migration.

* Sediments in the Triassic sections in Well 7/11-5 are mature to overmature, and the hydrocarbon source potential is moderate to good. Again, the present generation potential is considered to be low because of previous generation and migration.

SOURCE ROCK/OIL CORRELATION

* Sterane distributions indicate a good correlation between the Kimmeridge Clay Fm. in Well 7/11-5 and 6 and in the crude oil from Well 7/11-5.

* $\delta^{13}C$ analysis of the crude oil and a sediment sample from the Kimmeridge Clay Fm. in 7/11-5 generally support the sterane indication.

* The results also suggest that the Upper Triassic sediments in 7/11-5 are stained by Kimmeridgian crude oil.

* $\delta^{13}C$ analysis indicate that the Kimmeridge Clay Fm. in 7/11-5 and 6 is not contaminated by the crude oil found in 7/11-5.

* Biomarker analyses suggest that there is a slight difference in maturity between the crude oil and the sediments of the Kimmeridge Clay Fm. (7/11-5).

* The lithology (and the organic facies) of the Kimmeridge Clay Fm. varies both stratigraphically and laterally. This can affect source rock/oil correlations, and because of the observed differences in maturity between the oil and source rock studied, it is likely that the oil in 7/11-5 has migrated from other parts of the basin.

INTRODUCTION

This report comprise a study of two reports (ref. 1-2) on petroleum geochemistry on Wells 7/11-5, 7/11-6.

The optical geochemical data are evaluated, and additional studies on available material from 7/11-5 and 6 were undertaken.

The possible source rocks and the crude oil in Well 7/11-5 were compared. This study includes:

1. GC/MS analysis for determination of the distribution of certain biomarkers in bitumens extracted from sediments and in the crude oil.

2. Light isotope MS analysis for comparison of the $\delta^{13}C$ isotopic quantities in a selected organic rich shale and the crude oil.

SOURCE ROCK POTENTIAL

WELL 7/11-5

Teritiary and Upper Cretaceous sediments are immature and have negligible source potentials.

The Lower Cretaceous and the Upper Jurassic (Kimmeridge Clay Fm.) sediments contain mature organic matter, and are considered to be poor to good source rocks. Low Hydrogen Indices most likely reflect the presence of inertinitic material which is observed by reflected light microscopy. However, Paleochem work and the present light microscopy studies of the kerogen (Figs.3,4), show that woody material is present, and that in general, amorpohus material is dominant. Only one of the samples (Rødby Fm.) contained a small amount of inertinite. On the basis of pyrolysis data and the low Hydrogen Indices, these sediments are considered to be late mature source rocks.

The shaly intervals in the Triassic section contain both terrestrially derived organic matter and amorphous material. Palynomorph colouration indicates that the sediments have reached anover-mature (D.Batten Scale, 5/6; SCI 8: late mature) level. The Total Organic Carbon contents are good, and the hydrocarbon source potential is moderate. The Hydrogen Indices are, however, low. The Triassic shales are considered to be highly mature source rocks, with some remaining gas potential. In addition, because of the relatively small volume of organic-rich sediments in the Triassic, this unit would have only a limited source potential.

Vitrinite reflectance

Determinations indicate that organic material in the sediments stratigraphically above the Kimmeridge Clay Fm. has reached an early mature stage (Ro%: 0.3-0.5). Below Base Cretaceous,values indicate a middle to late mature stage.

Fig.1 shows a plot of samples (12-21 separate readings for samples above the Kimmeridge Clay Fm., and only 4-6 for deeper samples) from a Paleochem report (ref.1, Table 1). To achieve reliable results it is desirable that at least 20 separate readings should be made. The trend above the Lower Cretaceous seems reasonable. However, below this depth the small number of determinations together with bitumen staining and the presence of cavings, makes the deeper trend much less reliable.

Additional vitrinite reflectance measurements were therefore performed on one fine-grained sand sample from the Ula Fm. containing terrestrial plant material (Fig. 2). A Ro value of 0.74% indicated a moderately mature level for the vitrinite content of this sample.

The unconformity above the Kimmeridge Clay Fm. could possibly be a factor in accounting for the increase to higher readings in the lower section of this well.

Visual kerogen

Table 2 in a Paleochem report (ref.1) suggests that organic matter in the sediments from Lower Cretaceous to Triassic have reached a mature to late mature stage (scale readings 4/5-5/6). Paleochem (ref.1, p.11) suggest that the inertinite content of the lower part of Upper Cretaceous (Hidra Fm.) and the Upper Jurassic is significant. However, in Table 2 (ibid.) only traces of woody material and intertinite are recorded. This is in accordance with present studies of the kerogen types of these intervals (Figs.3,4).

Fig.4 and (ref. 2, Table 2) show, in general, abundant to common amounts of amorphous material. All samples (except one in the lowermost Valhall Fm. which is barren) contain minor amounts of woody material (Fig.3). All samples contain type II kerogen, except a sample from 3970 m (Rødby Fm.) which is of type III.

WELL 7/11-6

In a Paleochem report (ref.2) it is pointed out that Lower Cretaceous sediments contain aboundant amorphous algal material, and are classed as oil prone sediments based on visual kerogen descriptions. This is in contrast to the results from pyrolysis measurements which show that the sediments are gas/condensate prone. It is possible that a variation in the content of amorphous and woody material from one horizon to another exists. A sample from the Valhall Fm. (3990 m, Fig. 7) has practically no amorphous material, but woody fragments only, whereas in a sample from 4000 m, amorphous material is common.

It is suggested that the Lower Cretaceous contain mature source rocks which still have some gas potential.

The same conclusion as for the Cretaceous also pertains to the Upper Jurassic sediments. At some stage the Kimmeridge Clay Fm. most likely had the capability of generating oil (contains abundant amounts of amorphous material). Based on pyrolysis measurements it is demonstrated that the sediments are at present gas/condensate prone.

Vitrinite reflectance

Most of the samples contained few vitrinite particles. Only one sample (from the Tertiary) has more than 20 readings. An evaluation of the readings in a Paleochem report, (ref. 2, Table 1) was undertaken, and Fig.5 shows a selection of the most reliable R_o data. According to this trend, only the Upper Jurassic sediments have reached a middle mature stage, whilst the shallower sediments are early mature.

Visual kerogen

Analyses were performed on kerogen extracts from the Lower Cretaceous/Kimmeridge Clay Fm. transition throughout Upper Jurassic (ref. 2, Table 2),

DISTRIBUTION OF MATURITY LEVELS IN THE AREA AROUND BLOCK 7/11

Based on averaged vitrinite reflectivity determinations for the Kimmeridge Clay Fm., an isoline R_o% map of the area was constructed (Fig.10). This shows both middle mature (0.55 - 0.75), and late mature (0.75 - 1.2) zones.

The R_o 0.5 % isoline transverses blocks 7/8, 7/9 and 8/10. The maturity gradient increases in a SSW direction, and has a marked increase towards blocks 7/11 and 7/12 (R_o 0.8 %). This is not in complete agreement with Robertson Research Studies (e.g. "Southern Offshore Norway, phase II Study"). The R_o = 0.8 isoline crosses the south-western corner of block 7/11.

The data from vitrinite reflectivity measurements show that south of Well 7/11-5 and 6, the possible source rocks of the Kimmeridge Clay Fm. would yield major amounts of oil and/or condensate and gas. In the area to the north the possible hydrocarbon product would be oil plus minor amounts of gas.

The extention of zone (R_o 0.75-1.2 %) into the southern parts of Block 7/11 and 7/12 is uncertain because of lack of available data. The R_o % in this area could be lower if some blocks have been uplifted due to differential movements after the deposition of Upper Jurassic sediments. Some areas might also have been located higher than others in certain time intervals, and subsequently subsided. This would result in a lower maturity of the sediments in some areas.

To satisfactorily evaluate the maturity zones south of block 7/11, information from wells in blocks 1/2 and 1/3 located in the deeper part of the Viking Graben area is desirable.

SOURCE ROCK POTENTIAL AND SOURCE ROCK/OIL CORRELATION

Based on the source rock evaluations of the Wells (7/11-5, 7/11-6) and the source rock/oil correlation performed for this study (Figs. 9-15, Table 1), the Upper Jurassic Kimmeridge Clay Fm. is regarded to be the most likely source rock of the area.

In general the Tertiary and Upper Cretaceous sediments are immature to early mature (Figs. 1,5). The lower Cretaceous and Upper Jurassic have reached a mature stage (Figs. 1,5) and the shaly intervals in the Triassic are late mature (Figs. 1,5).

However, the sediments are considered to be gas/-condensate prone at present due to previous generation and migration.

Regionally, the maturity increases towards SSW (Fig. 8). Based on the present distribution of maturity levels in the area (Fig. 8), and the observed differences in maturity between the oil and source rock, it is likely that the hydrocarbons in the past would have migrated towards NNE from the deeper part of the basin.

Visual kerogen analyses of the type of kerogen present in the Kimmeridge Clay Fm. show that there are, in general, an insignificant amount of inertinite particles in the sediments. Because of the low amount of terrestrial organic contents, and a relatively high content of amorphous material (Figs. 3-4, 6-7) it is suggested that the sediments in the past mainly would have been oil prone.

DISTRIBUTION OF MATURITY LEVELS: SOUTHERN PART OF BLOCK 7 AND 8.

Based on averaged vitrinite reflectivity determinations for the Kimmeridge Clay Fm., an isoline R_o% map of the area was constructed (Fig. 8). This shows both middle mature (0.55 - 0.75), and late mature (0.75 - 1.2) zones.

The R_o 0.5 % isoline transverses blocks 7/8, 7/9 and 8/10. The maturity gradient increases in a SSW direction, and has a marked increase towards blocks 7/11 and 7/12 (R_o 0.8 %). This is not in complete agreement with Robertson Research Studies (e.g. "Southern Offshore Norway, phase II Study"). The 0.8 isoline crosses the south-western corner of block 7/11.

The data from vitrinite reflectivity measurements show that south of Well 7/11-5 and 6, the possible source rocks of the Kimmeridge Clay Fm. would yield major amounts of oil and/or condensate and gas. In the area north of a line through Well 7/12-5. The possible hydrocarbon product would be oil plus minor amounts of gas.

The extention of zone (R_o 0.75-1.2 %) into the southern parts of Block 7/11 and 7/12 is uncertain because of lack of available data. The R_o % in this area could be lower if some blocks have been uplifted due to differential movements after the deposition of Upper Jurassic sediments. Some areas might also have been located higher than others in certain time intervals, and subsequently subsided. This would result in a lower maturity of the sediments in some areas.

To satisfactorily evaluate the maturity zones south of block 7, information from wells in blocks 1/2 and 1/3 located in the deeper part of the Viking Graben area is desirable.

SOURCE ROCK/OIL CORRELATION

A correlation study between crude oil from the Ula Fm. in Well 7/11-5 and possible source rocks from the Upper Jurassic Kimmeridge Clay Fm. and shaly horizons in the Upper Triassic was undertaken.

Comparisons were besed on biomarker analysis and stable isotopic ($\delta^{13}C$) compositions of oil and sediment extracts.

The following sediment samples (cuttings) were used for analysis:

7/11-5:	4038 m	Kimmeridge Clay Fm.
	4053 m	- " -
	4135 m	- " -
	4265 m	Triassic
7/11-6:	4010 m	Kimmeridge Clay Fm.
	4040 m	- " -

Biomarkers

Both the rock extracts and crude oil contained a very low consentration of steranes and triterpanes. The triterpanes were present in such low abundance that they could not be used as a reliable correlation parameter, without further consentration.

On high resolution Selected Ion Monitoring (SIM) the steranes abundance is also too low to get a good mass fragmentogram . However, the new SMIM method separates the steranes well and this is shown in Fig. 9 - 14. The advantage of the SMIM method is that mass chromatograms of C_{27}, C_{28}, C_{29} and C_{30} steranes are obtained separately.

In the normal SIM mode the various sterane isomers are displayed superimposed on each other and this results in a highly complex pattern with many overlapping peaks.

Correlation has been attempted by both visual comparison of the sterane distributions from the oil with that of the sediments and also by Multivariate Statistical Analyses.

Visual comparison shows all of the samples to have appartently very high consentration of diasteranes compared to the non-rearanged sterane components. One sample (7/11-6, 4040 m, Fig. 14) has a particular high consentration of the C_{27}, 13β(H), 17α (H), 20S, diasterane and has a dissimilarity with all of the other samples, (Fig. 11 - 13) including the crude oil sample. (Fig. 9). The relative abundance of the steranes (C_{27}, C_{28} etc.) in these latter samples appears to be approximately the same, indicating a good correlation, between the oil and Kimmeridge Clay Fm., and also between the oil and Triassic (4265 m, Fig. 12). The similarity of the sterane distribution in the Triassic sample and the other samples is, however, probably due to oil staining of these sediments by a Kimmeridgian oil.

Multivariate Statistical Analyses carried out on the oil and sediment extracts from 4038 m, 4053 m, 4265m, and 4010 m shows a strong similarity between all of these samples (O.H.J. Christie pers. comm.) However, the greatest similarity exists between the oil and the extracts from 4038 m. (Fig. 9, 10). Based on this procedure, the samples are ranked in the following decending order of similarity with the oil:

1.	4038 m	7/11-5
2.	4010 m	7/11-6
3.	4265 m	7/11-5
4.	4053 m	7/11-5

δ^{13} C analysis

The results of the $\delta^{13}C$ analysis (Table 1) are plotted as "Galimov-type" curves (ref. 5), see Fig. 15 .

The two curves are approximately parallel. The data point for the asphaltenes in the sediment extract is anomalous and deviates from the general trend. The reason for this is either that the asphaltens have been altered by biodegradation, or that the sample is contimated by traces of solvent.

The SAC fraction of the oil and the rock extract show a marked difference, but are just within the range of variation seen for source rocks and their related oils.

Comparison of $\delta^{13}C$ values between crude oil and the total sediment extract gives a reasonable correlation (difference 0.7 $^{o}/oo$) although the oil is usually isotopically lighter than its source extract. This difference might be due to variation within the source rock and/or slightly difference in maturity between the oil and the sediment.

Alltogether the $\delta^{13}C$ results support some resemblance between the Kimmeridge Clay Fm. and the oil in Well 7/11-5. This is less definite than that indicated by the sterane distribution patterns (see preciding section). The $\delta^{13}C$ analysis also indicate that the Kimmeridge Clay Fm. in 7/11-5 (and 7/11-6) is not stained by reservoir oil. If this had ocurred, then the differences between the $\delta^{13}C$ results for the individual fractions (SAC., A+H., NSO) would have been considerably less than the observed values.

EXPERIMENTAL

Biomarkers: Solvent extraction was undertaken on handpicked consentrates of cutting. Approximately 3-5 g material was crushed and extracted with dichlormethane in a soxhlet apparatus for 48 hours.

Extracts were injected directly into a Hewlett Packard 5710A gas chromatograph connected to a VG 7050 mass spectrometer. The gas chromatographic parameters were: Injection temperature 300°C. Over program 150-300°C at a rate of 4°C/min. The column was a 24 m fused silica column coated with methylsilicone (0.15 µm layer) (Chrompack, CPSil5). With a i.d. of 0,25 mm. Helium was used as carrier gas at a pressure of 1 kp/cm^2. The mass spectrometer was run in a Selective Metastabile Ion Monitoring (SMIM) mode (ref. 3).

$\delta^{13}C$ analysis: The oil was distilled to a cut point of approximately 200°C to remove lower boiling components. The residual oil was divided into two portions. One of the fractions was separated by liquid chromatography into saturates (SAC), aromatics (A+H) and nitrogen-sulfur-oxygen (NSO) fractions. The other fraction was retained for whole oil analysis.

A consentrate (18,1 g), picked from cuttings (7/11-5, 4048 m) was crushed and extracted with dichloromethane in a soxhlet apparatus for 48 hours. The extract was divided into two parts. One portion was used for whole extract analysis and the other portion was, after

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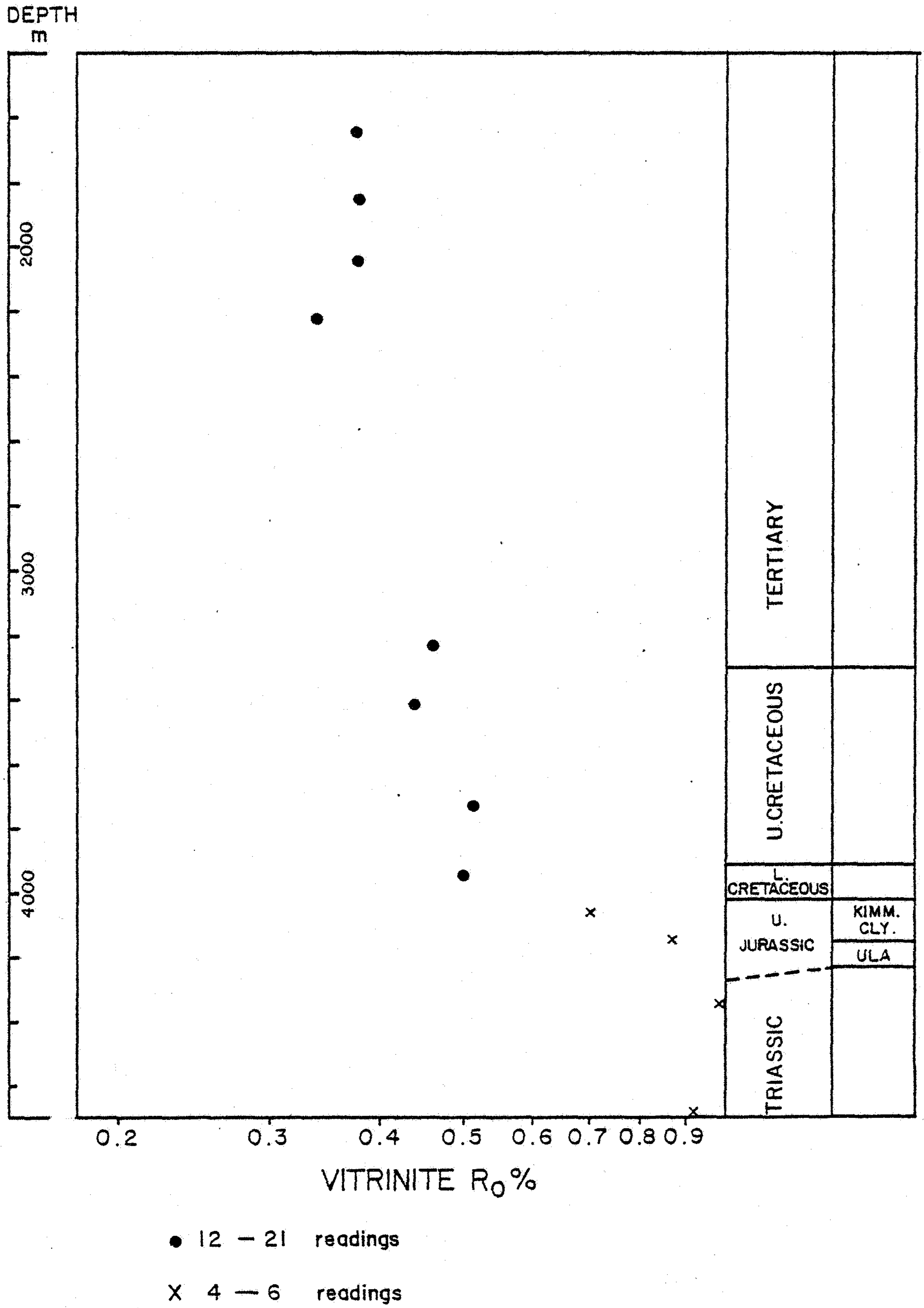
7/11-5



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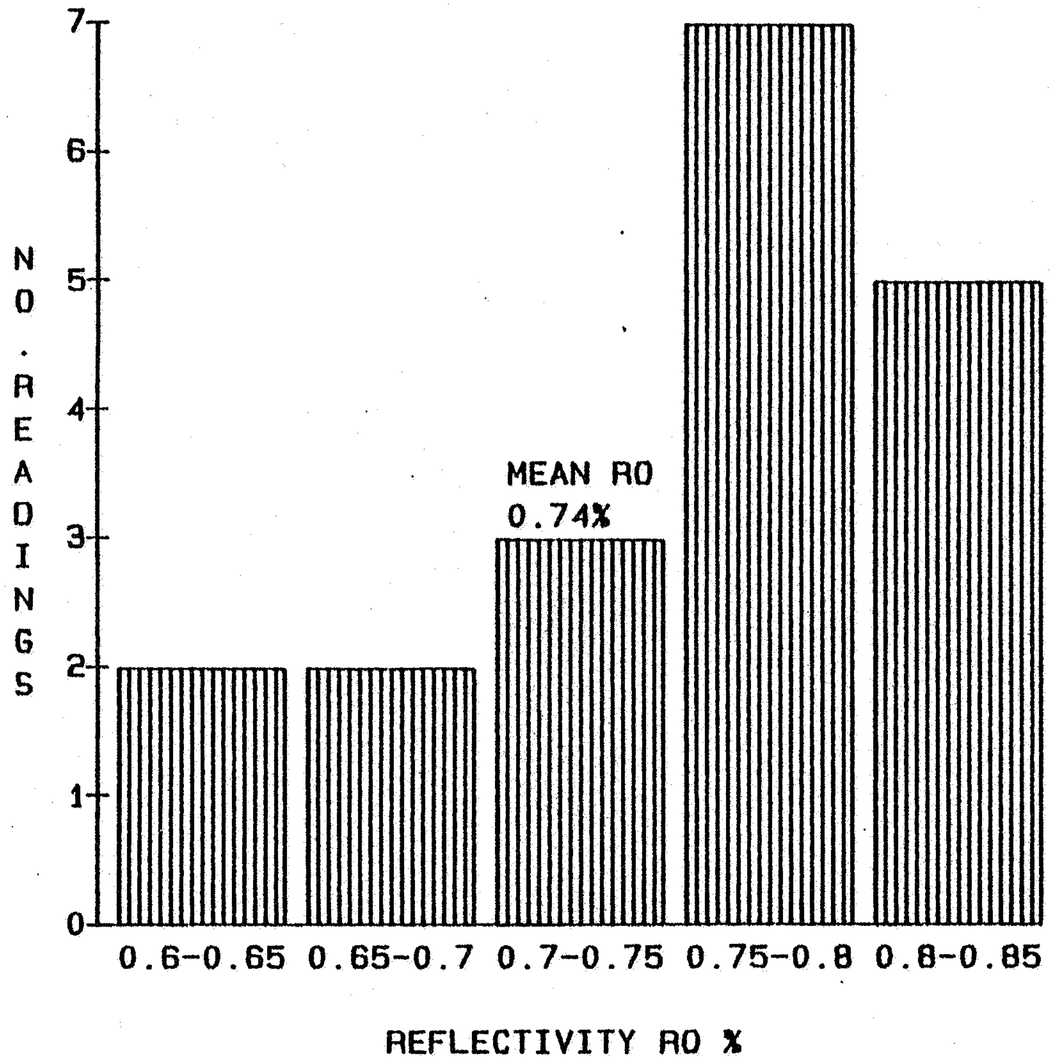
WELL 7/11-5 * ULA FM * 4218 M



Distribution table

0	Intervals	1 COUNT
1	0.6-0.65	2
2	0.65-0.7	2
3	0.7-0.75	3
4	0.75-0.8	7
5	0.8-0.85	5
6	0.85-0.9	0
7	OTHER	0

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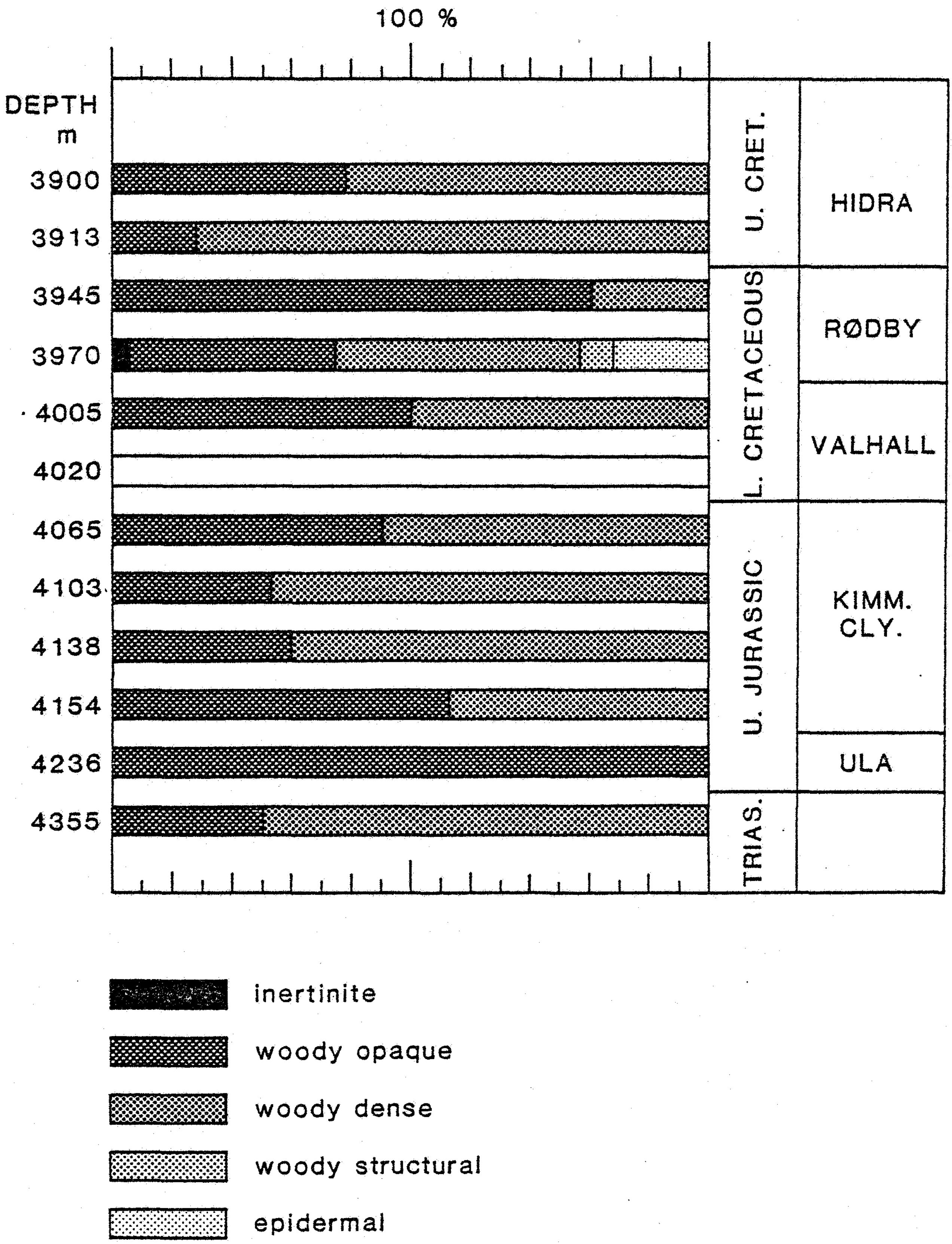
Geology Dept. (TGB)

Fig. 2

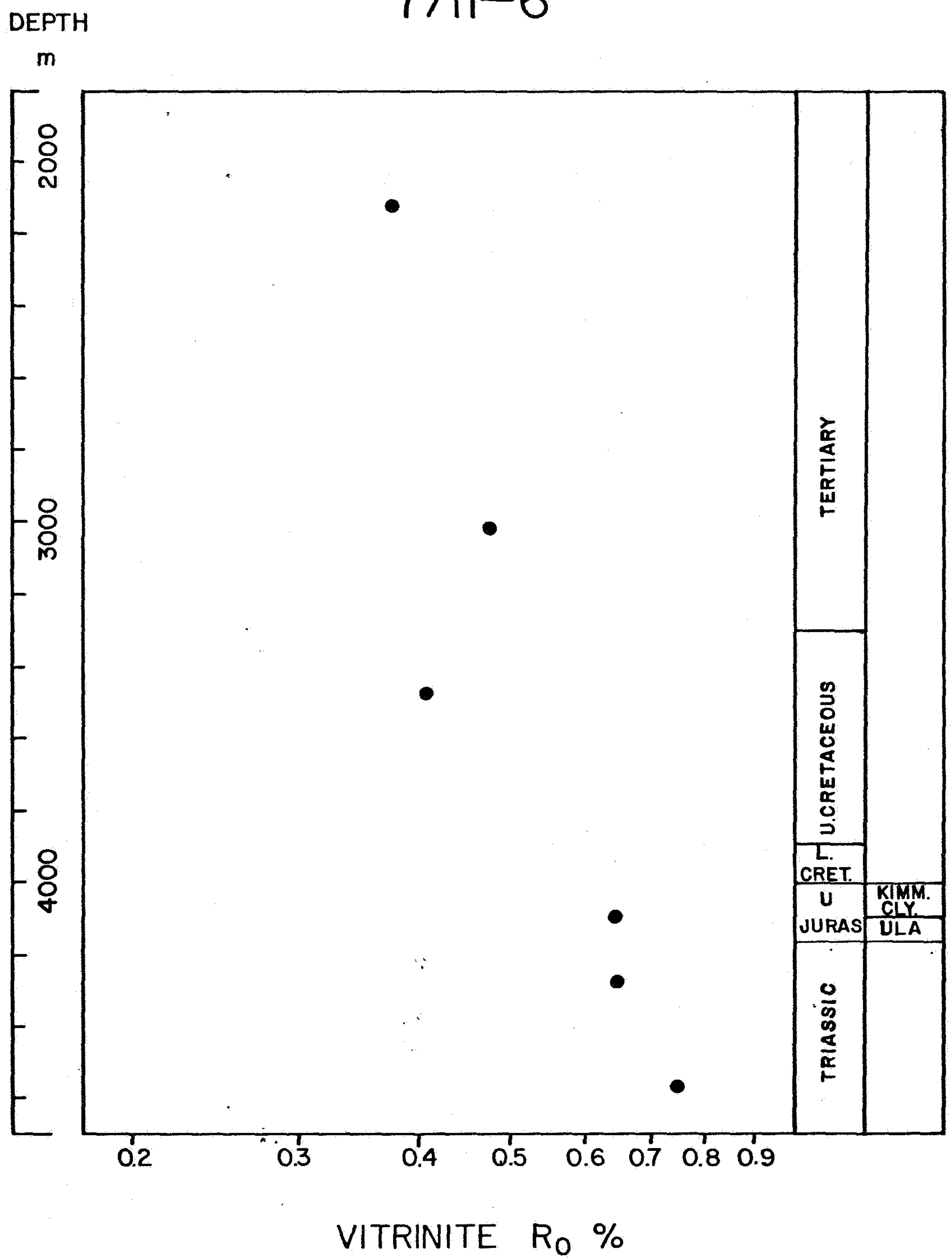
RELATIVE PERCENTAGES OF DIFFERENT TYPES OF TERRESTRIAL ORGANIC MATERIAL IN 12 SAMPLES FROM WELL 7/11 - 5



WELL 7/11-5

		DEPTH M	AMOUNT OF AMORPHOUS MATERIAL
U. CRET.	HIDRA	3900	COMMON
		3913	COMMON
L. CRETACEOUS	RØDBY	3945	SMALL
		3970	TRACE
	VALHALL	4005	ABUNDANT
		4020	TRACE
U. JURASSIC	KIMM. CLY.	4065	ABUNDANT
		4103	ABUNDANT
		4138	COMMON
		4154	COMMON
	ULA	4236	÷
TRIAS.		4355	COMMON

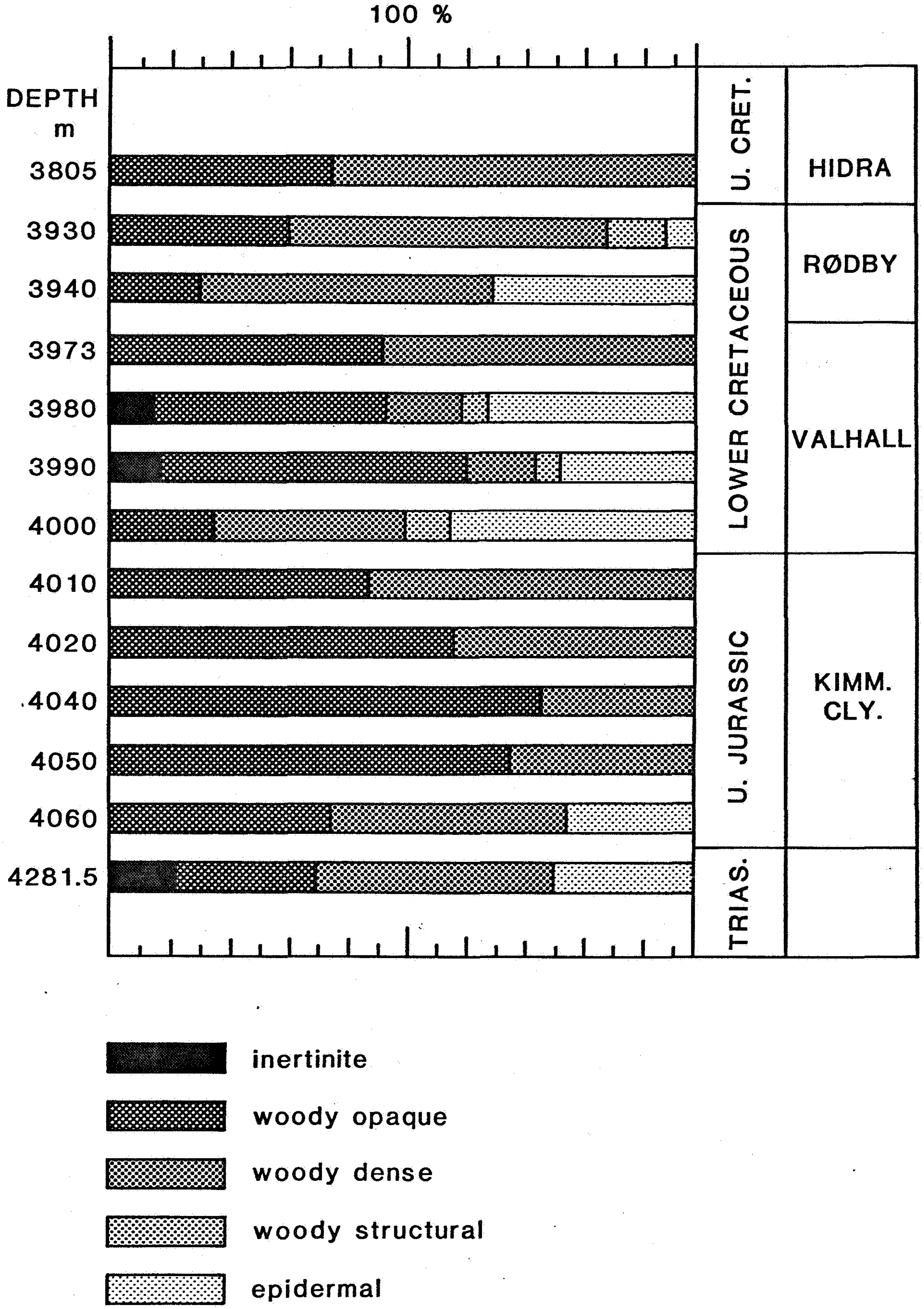
7/11-6



DEPTH
m
2000
3000
4000
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
VITRINITE Ro %
TERTIARY
U.CRETACEOUS
L. CRET.
U JURAS
TRIASSIC
KIMM. CLY.
ULA

FIG. 6

RELATIVE PERCENTAGES OF DIFFERENT TYPES OF TERRESTRIAL ORGANIC MATERIAL IN 13 SAMPLES FROM WELL 7/11 - 6



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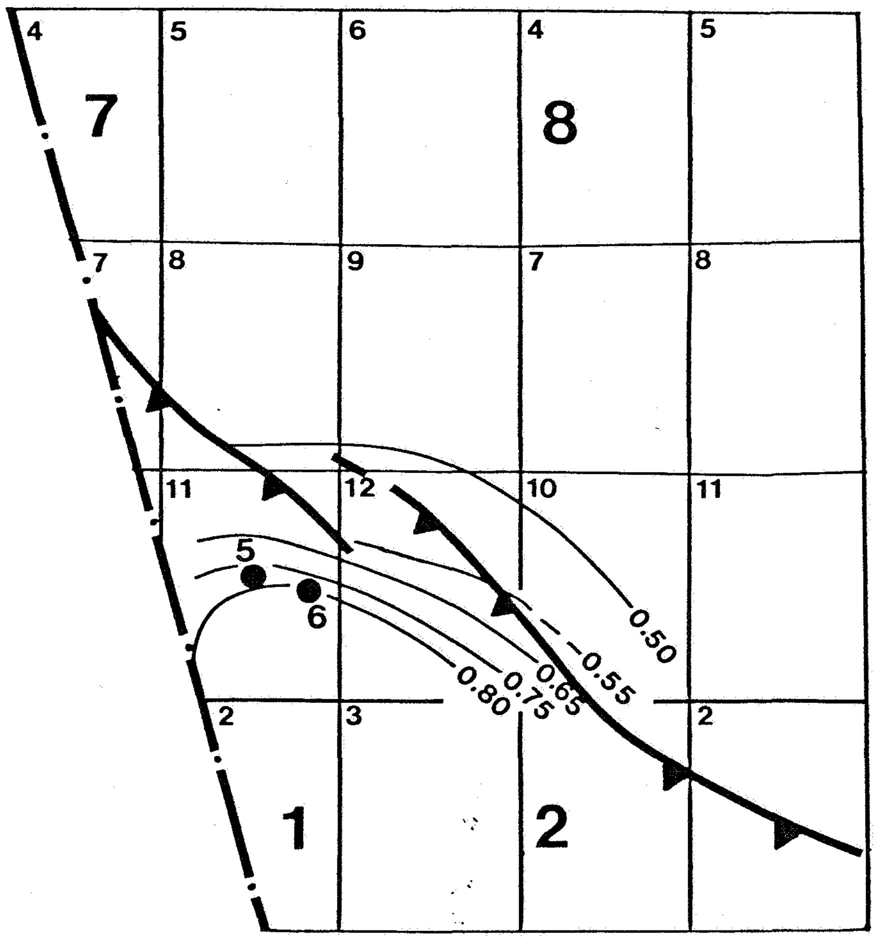
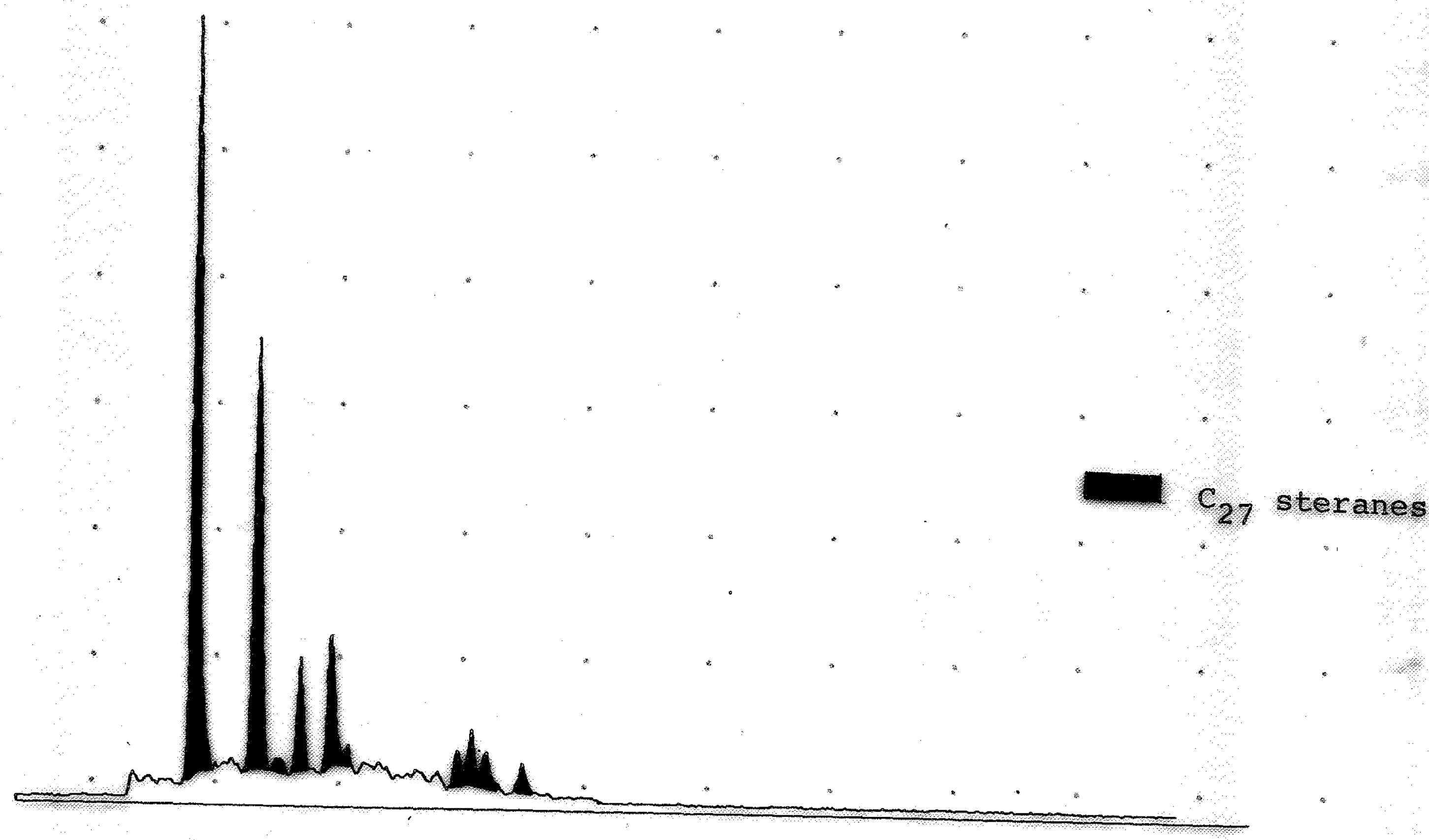
WELL 7/11-6

		DEPTH M	AMOUNT OF AMORPHOUS MATERIAL
U.CRET.	HIDRA	3805	SMALL
LOWER CRETACEOUS	RØDBY	3930	SMALL
		3940	SMALL
	VALHALL	3973	TRACE
		3980	TRACE
		3990	÷
		4000	COMMON
U. JURASSIC	KIMM. CLY.	4010	ABUNDANT
		4020	COMMON
		4040	ABUNDANT
		4050	ABUNDANT
		4060	ABUNDANT
TRIAS.		4281,5	SMALL

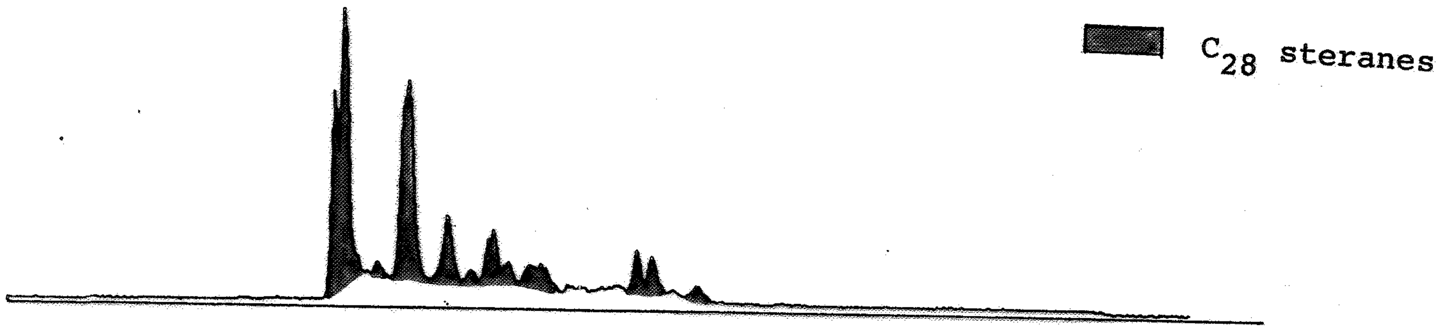
KIMMERIDGE CLAY FM.

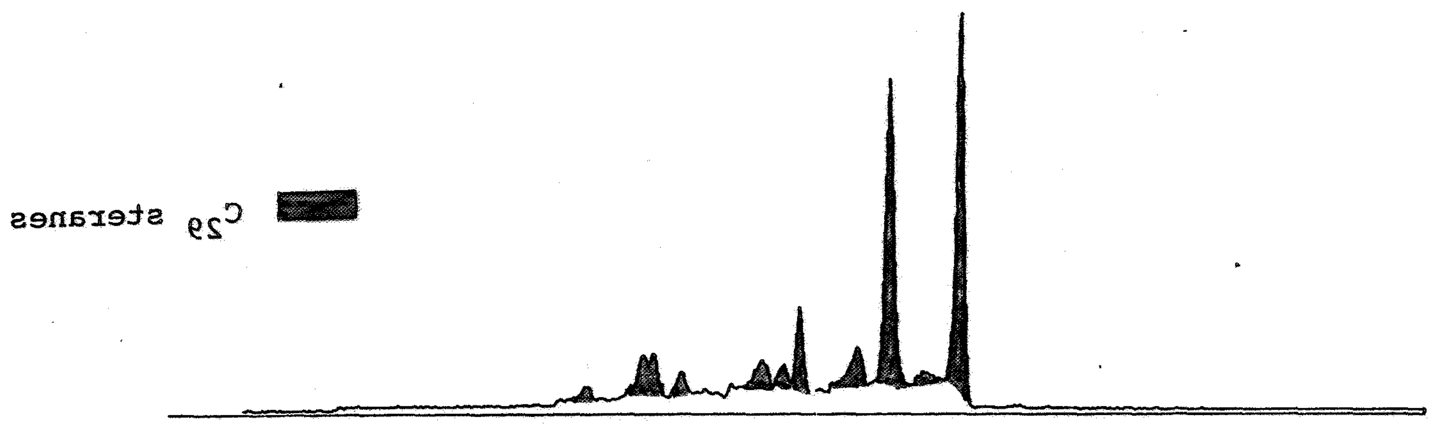


VITRINITE REFLECTANCE $\bar{R}_o$ %



C_{27} steranes


C28 steranes


C29 steranes

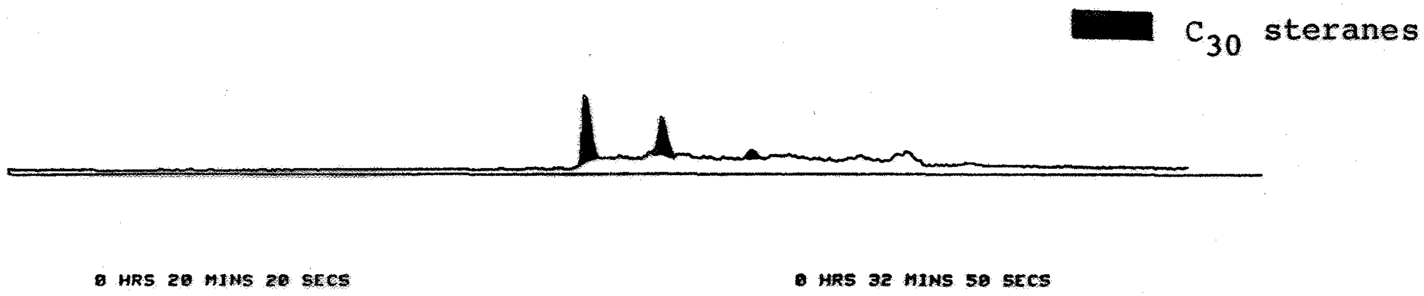
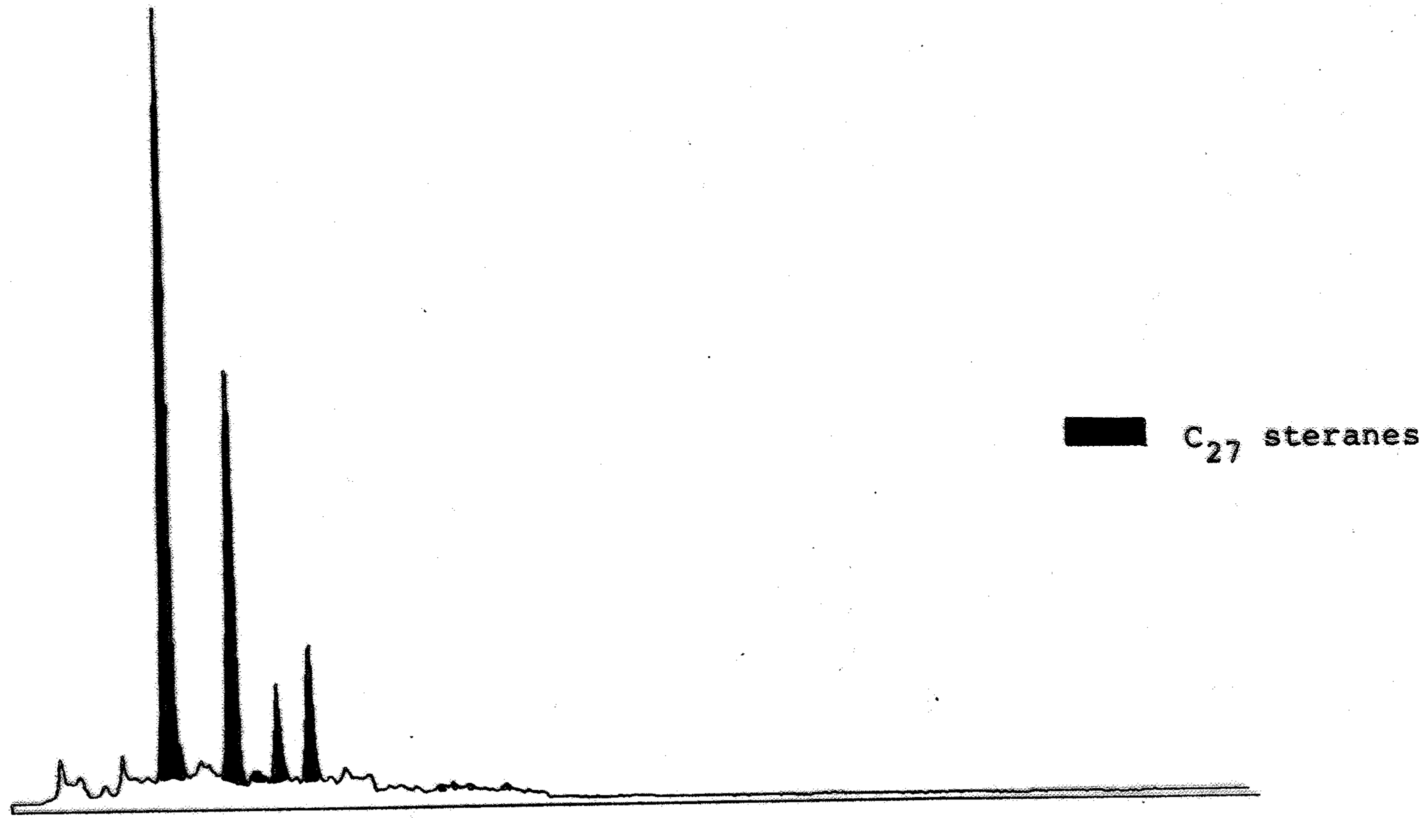
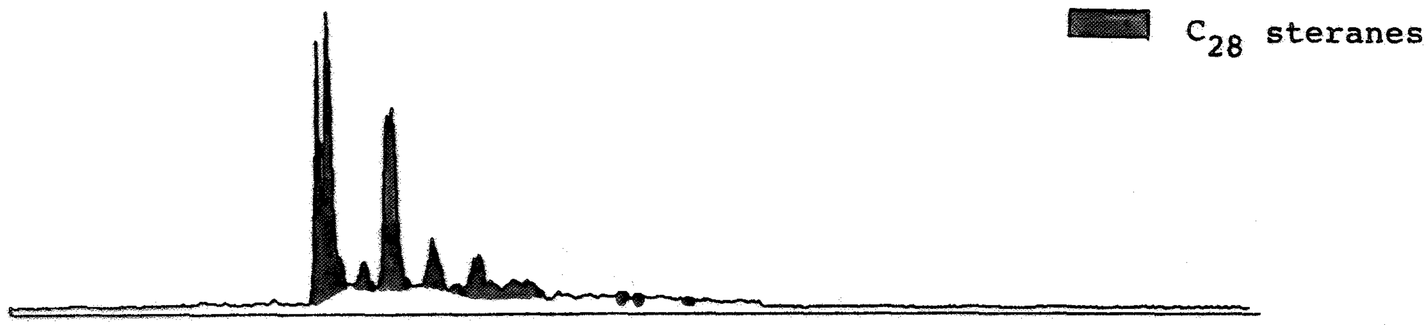
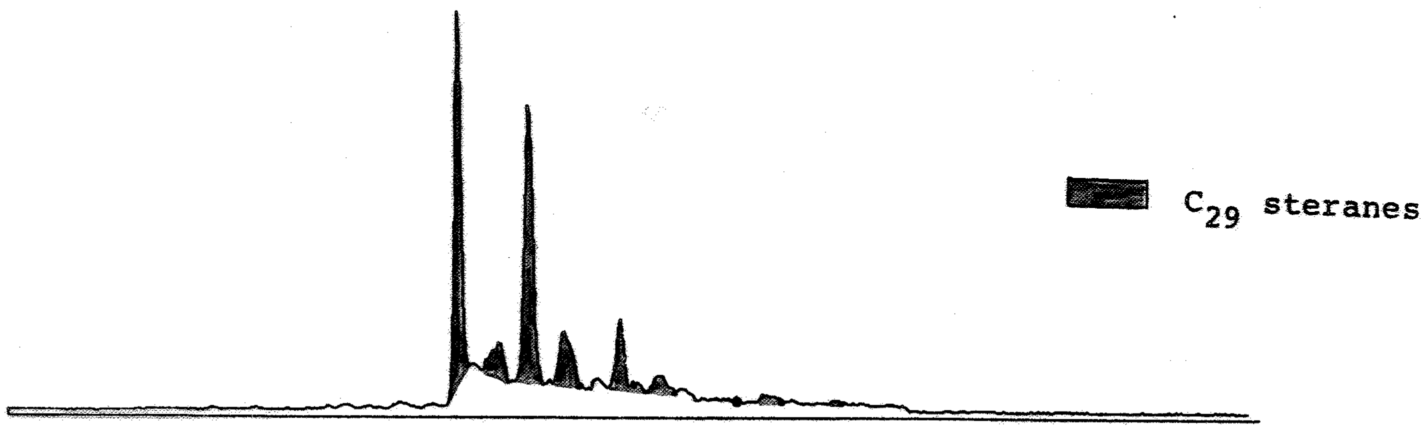


Fig. 9 . Sterane distribution in 7/11 - 5 crude oil, using Selective Metastabile Ion Monitoring (SMIM). To be compared with Figs. 10 - 14.


C_{27} steranes


C_{28} steranes


C29 steranes

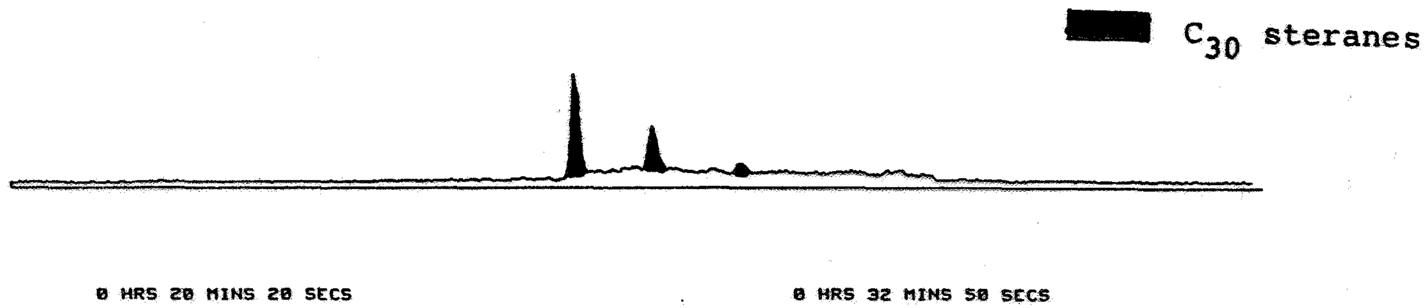


Fig. 10. Sterane distribution in 7/11 - 5, 4038 m, using Selective Metastabile Ion Monitoring (SMIM). To be compared with Fig. 9.

Fig. 11. Sterane distribution in sample 4053 m, 7/11 - 5. (Kimmeridge Clay Fm), using Selective Metastabile Ion Monitoring (SMIM). To be compared with Fig. 9 .

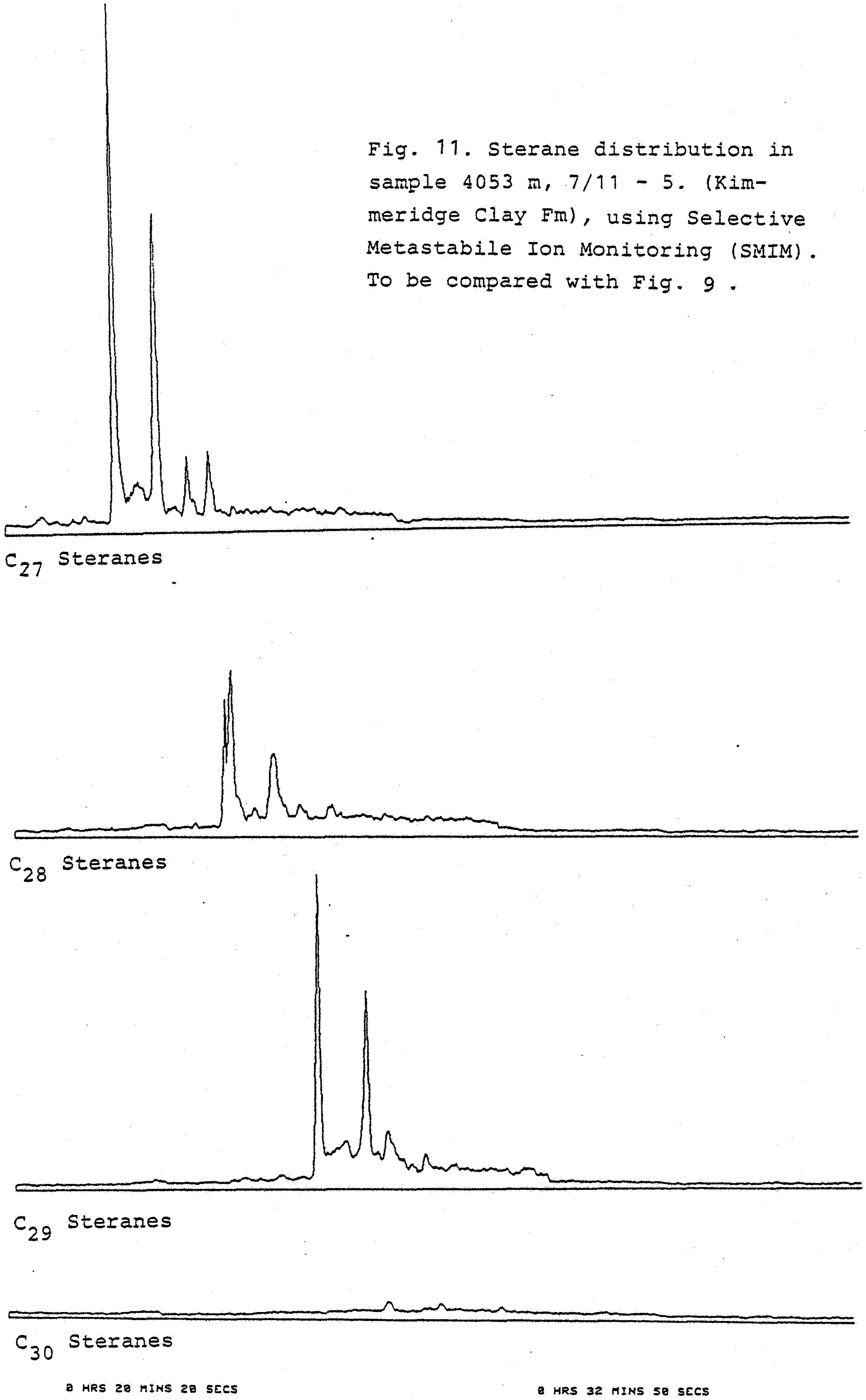
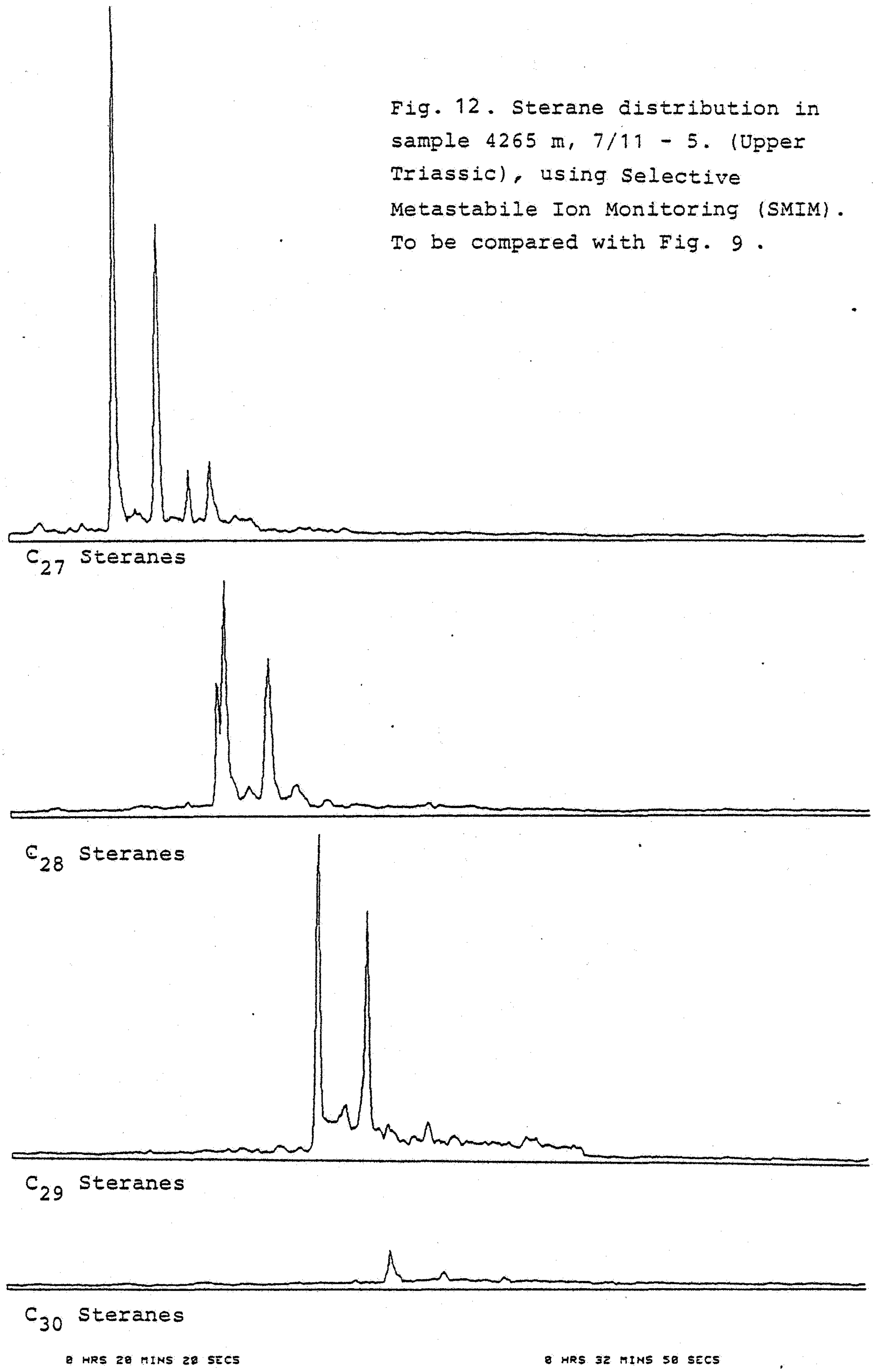


Fig. 12. Sterane distribution in sample 4265 m, 7/11 - 5. (Upper Triassic), using Selective Metastabile Ion Monitoring (SMIM). To be compared with Fig. 9 .



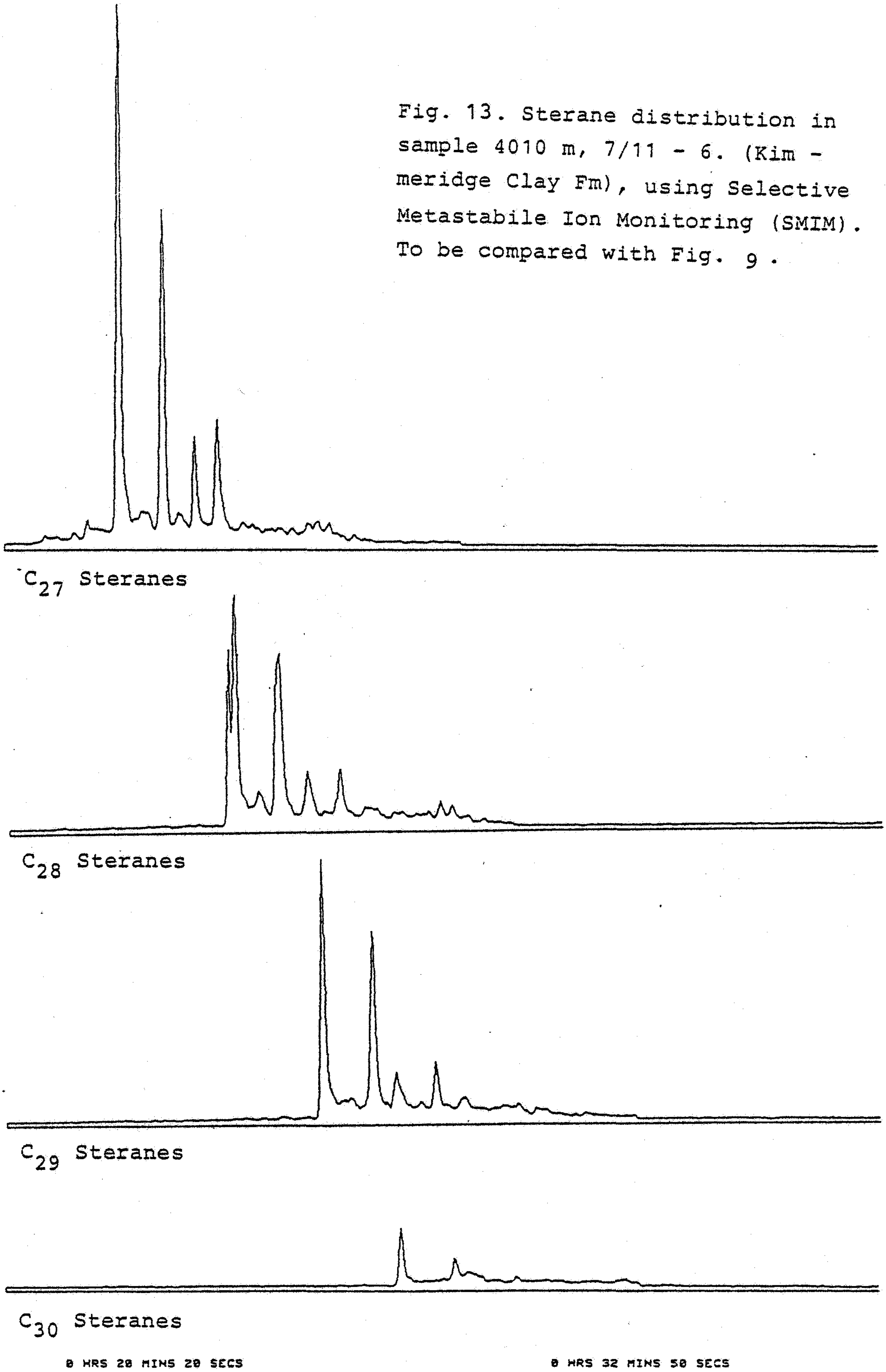
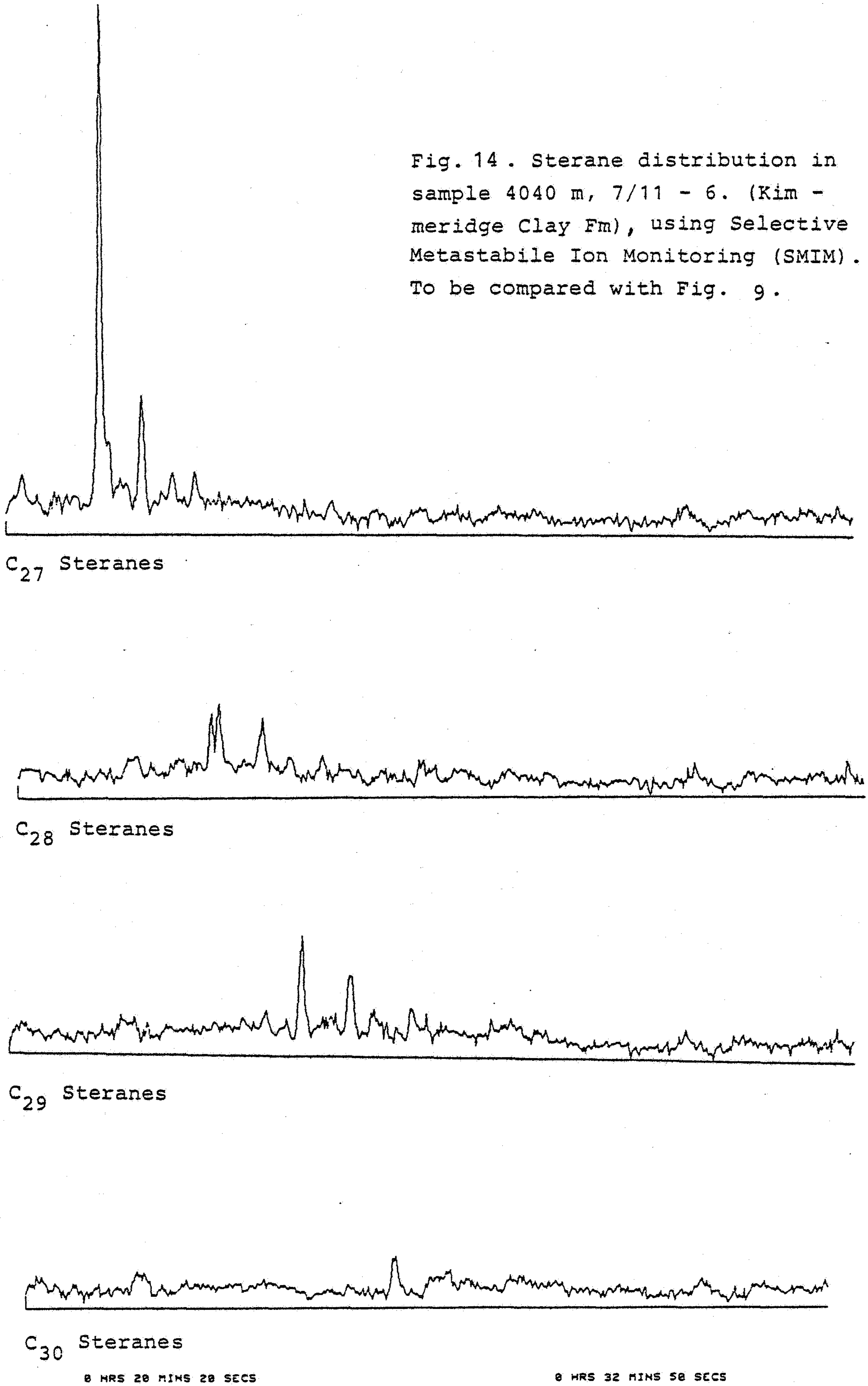
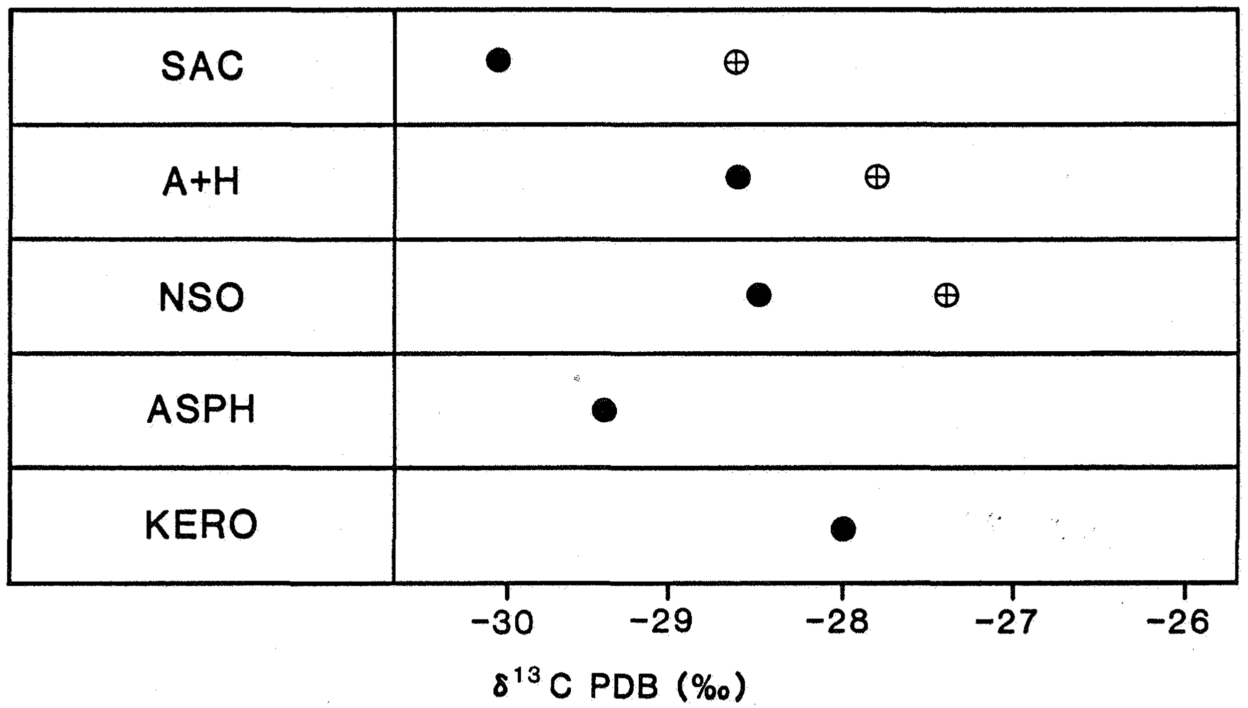


Fig. 13. Sterane distribution in sample 4010 m, 7/11 - 6. (Kim - meridge Clay Fm), using Selective Metastabile Ion Monitoring (SMIM). To be compared with Fig. 9.

Fig. 14 . Sterane distribution in sample 4040 m, 7/11 - 6. (Kimmeridge Clay Fm), using Selective Metastabile Ion Monitoring (SMIM). To be compared with Fig. 9 .





WHOLE OIL	$\delta^{13}C$ = −28.9‰	⊕ Oil, 7/11-5
WHOLE EXTRACT	$\delta^{13}C$ = −29.6‰	● Rock extract, 7/11-5, 4048m
PYROLYSATE	$\delta^{13}C$ = −28.0‰	

TABLE 1

Well 7/11-5:

Sample list and result for $\delta^{13}C$ determinations

SAMPLE	$\delta^{13}C$ (o/oo)
Whole oil	- 28.9
Saturates (SAC), oil	- 28.6
Aromatics (A+H), oil	- 27.8
NSO oil	- 27.4
Whole extract, 4048 m	- 29.6
Saturates (SAC), 4048m	- 30.0
Aromatics (A+H), 4048m	- 28.6
NSO 4048m	- 28.5
Asphaltenes, 4048m	- 29.4
Kerogen pyrolysate, 4048m	- 28.0
Decarbonated Kerogen, 4048m	- 28.0