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ORGANIC GEOCHEMICAL CORRELATION OF NINE OILS AND TEN SOURCE ROCKS FROM THE NORTHERN NORTH SEA AREA

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SUMMARY/ SAMMENDRAG

Ten source rock samples from 3 wells in the Northern North Sea were correlated with nine oils previously analysed at IKU (Bjorøy et al., 1982). Various GC and GC-MS measurements were applied in the correlation. Based on the results the Kimmeridge and Heather formations in well 30/7-7 may have sourced three of the oils, while two of these oils also showed fairly good correlation to the Drake formation in well 30/3-1.

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INTRODUCTION

Ten source rock samples from 3 wells in the Northern North Sea area (Table 1) were analysed by various organic geochemical methods, in order to perform an oil/source rock correlation in this area. Nine oils from 9 wells in the same area (Table 2) were analysed by the same methods in an oil/oil correlation performed at IKU last year (Bjorøy et al, 1982). A location map is shown in Figure 1.

In addition to the methods reported in the oil/oil correlation study, all well established procedures, TOC (Total Organic Carbon) and Rock-Eval analyses were performed to evaluate the source rock potential of the supplied samples. Prior to the analyses the source rocks samples were hand-picked and mixed to give composite samples representing wider depth intervals.

To simplify the correlation, each well will be discussed separately, similarities will be applied to group the various source rocks before the correlation is performed.

EXPERIMENTAL

Ten source rock samples were analysed for correlation purposes. Prior to the correlation analyses the source rock potentials were determined.

Total Organic Carbon

Bulk samples were crushed in a centrifugal mill. Aliquots of the samples were then weighed into Leco crucibles and treated with hot 2N HCl to remove carbonate, and washed twice with distilled water to remove traces of HCl. The crucibles were then placed in a vacuum oven at 50°C and evacuated to 20mm Hg for 12 hrs. The total organic carbon (TOC) content of the dried samples was determined using a Leco EC12 carbon analyser.

Rock-Eval Pyrolysis

Crushed sample (100mg) was weighed into a patinum Crucible the base and cover of which are made of sintered steel, and analysed on a Rock-Eval pyrolyser.

Extractable Organic Matter and Chromatographic Separation

Approximately 50gm of powdered rock was extracted by a ultrasonic probe for 3 minutes using dichloromethane (DCM) as solvent. The DCM used was of organic geochemical grade and blank analyses showed the occurrence of negligible amounts of contaminating hydrocarbons.

Activated copper fillings were used to remove any free sulphur from the samples.

After extraction the solvent was removed on a Buchi Rotavapor and the amount of extractable organic matter (EOM) was determined.

The EOM was separated into a saturated, an aromatic and a non-hydrocarbon fraction using a MPLC system with n-hexane as eluant (Radke et. al, 1980). The various fractions were evaporated on a Buchi Rotavapor and transferred to glass vials and dried in a stream of nitrogen.

Gas Chromatographic Analyses

The saturated and aromatic hydrocarbon fractions were each diluted with n-hexane and analysed on a HP 5730A gas chromatograph, fitted with a 25m OV-101 fused silica capillary column. Hydrogen (0.7ml/min) was used as carrier gas.

The aromatic fractions were also analysed on a Varian Model 3700 GC especially designed for separation of aromatic, fitted with a 100m glass capillary column and a back-flushing system. Hydrogen was used as carrier gas.

Injections on both systems were performed in the split mode (1:20). The temperature program applied was 80°C (2 min) to 260°C at 4°C/min.

The data processing for all the GC analyses was performed on a VG Multichrom System.

GC-MS Analyses

The analyses were performed on a VG 70-70H GC-MS-DS. The Varian Model 3700 GC was fitted with a 30m OV-1 fused silica column, and the injection were performed in split mode (1:20). The GC oven was temperature programmed from 80°C (2 min) to 270°C at 4°C/min, and helium was used as carrier gas.

The saturated hydrocarbon fractions were analysed by multiple ion detection (MID) for steranes and terpanes, with a scan cycle time of approximately two seconds. Full data collection was applied for the aromatic hydrocarbon fractions at a scan time of 1 sec/decade.

The ratios from the mass chromatograms were calculated from the peak heights in the appropriate chromatograms.

RESULTS AND DISCUSSION

Total Organic Carbon (TOC)

Values for the source rock samples are given in Table 3.

Well 30/3-1: Two samples from Drake and Burton/Amundsen formations were found to have TOC values of 1.77 and 1.88%, respectively, indicating both samples to have a good source rock potential based on richness.

Well 30/7-7: The five analysed samples were all found to contain more than 2% organic carbon. The two shallowest samples from Kimmeridge Hot shale and Heather formations were the richest, having more than 3.5%, while the deeper Heather, Drake and Burton/Amundsen samples contained approximately 2.2%.

Well 35/8-1: Of the three samples from this well, the Kimmeridge Hot shale and Heather samples contained more than 3% organic carbon. the deepest sample from the Drake formation was found to have a TOC-value of 1.6%.

Based on the TOC-values all the composite samples could represent source rocks.

Rock-Eval Pyrolysis

Results are reported in Table 3 and Figure 2.

Well 30/3-1: Based on hydrogen and oxygen indices the two samples are believed to be of kerogen type III, indicating a source rock potential for gas only. It is, however, difficult to distinguish between different types of kerogen by Rock-Eval at this high maturity level. From the T_{max}-values the samples were determined to have maturity in the oil window.

Well 30/7-7: The five samples are, from the Rock-Eval data, believed to be of kerogen type III. Similar arguments as above might, however, be applied, and these source rocks might have potential as source rocks for oils. This discrepancy is discussed in more detail in previous reports concerning the evaluation of source rock potential in this well (Bjorøy et al, 1979; Bjorøy 1980).

T_{max}-values assign the three shallowest samples to be of oil window maturity. For the two deepest samples the reported T_{max}-values are far too low and thus misleading. Based on the previous source rock evaluation, these two deeper samples are also in the oil window maturity range.

Well 35/8-1: The two shallowest samples from the Hot shale and Heather formations were found to be the most promising source rocks for oil, having a mixed type II/III kerogen.

The maturity is slightly less than oil window maturity, indicating that production from these source rocks is only in the beginning. This might also be seen from the low production indices, suggesting high amounts of hydrocarbons still bond to the kerogen structure.

The deepest sample from the Drake formation, is of oil window maturity, but the kerogen is a type III, implying source rock potential for gas rather than oil.

Based on the Rock-Eval data the samples in wells 30/3-1 and 30/7-7 are of such high maturity that it is difficult to distinguish between different types of kerogen. This implies that it is still possible for these source rocks, even with the low hydrogen indices, to have potential as source rocks for oil. The maturity of these source rocks is in the oil/condensate window.

Only two samples, from well 35/8-1, were truly found to have mixed type II/III kerogen, and they could thus have potential as source rocks for oils/condensates. These samples, from Kimmeridge Hot shale and Heather formations, were assigned as moderate mature-mature.

Gross Composition from Extraction Data

The gross composition of the source rock samples was determined after extraction with dichloromethane and separation of the extractable organic matter (EOM) by medium pressure liquid chromatography (MPLC). The separation was performed into saturated and aromatic hydrocarbons and heterocomponents (non-hydrocarbons). Results are reported in Table 4. The content of insoluble asphalthenes is less than 1.0mg in all the samples, and this is not discussed further.

Well 30/3-1: The samples from Drake and Burton/Amundsen formations were found to contain approximately 50% $C_{15}+$ hydrocarbons. The percentage of saturated hydrocarbons in the $C_{15}+$ fraction is 35 and 45%, respectively, while the content of aromatic hydrocarbons is approximately 10% in both samples.

Well 30/7-7: All the samples from this well were found to contain 55-65% $C_{15}+$ hydrocarbons. Of this is 45-50% saturated and 10-15% aromatic hydrocarbons.

Well 35/8-1: Approximately similar distribution as discussed above, was seen between the three $C_{15}+$ fractions in this well.

The gross composition in the $C_{15}+$ fraction could not be used to differentiate between certain samples. All the source rock samples were found to have similar characteristics.

Capillary Column Gas Chromatography of $C_{15}+$ Saturated Hydrocarbons

The gas chromatograms of the saturated hydrocarbons are given in Figure 3, while chromatographic data are presented in Table 5 as carbon preference indices (CPI_{14-22} and CPI_{22-34}) and pristane/C_{17} and pristane/-phytane ratios.

Histograms representing absolute concentrations (µg/g rock) of pristane and certain n-alkanes are shown in Figure 4.

Well 30/3-1: The two samples show different n-alkane distributions, the shallowest Drake sample (M-9138) having a unimodal front-end biased distribution with maximum at nC_{16} characteristic of condensate type pattern. The deeper Burton/Amundsen sample (M-9139) exhibits a fairly smooth distribution from C_{15} to C_{35}. As can be seen from Figure 4, the absolute concentration of n-alkanes is significantly lower in M-3139 than in the shallower M-3138. The total amount of saturated hydrocarbons is, however, approximately the same in the two samples. This might indicate that, to a certain extent, the lower molecular weight n-alkanes have migrated out of the shale. CPI-values of 1.0 and the Pr/Ph and Pr/C_{17} ratios being approximately the same for the two samples, indicate that the variation in n-alkane concentrations are not caused by any great difference in maturity.

Well 30/7-7: The three shallowest samples from well 30/7-7 show similar unimodal n-alkane distribution with maximum at nC_{16}, and n-alkanes in the range from C_{15} to C_{35}. A unimodal distribution is also seen for the n-alkanes in the two deepest samples, showing a maximum at nC_{16}. The n-alkane range is, however, only from C_{15} to C_{28}, and a complex pattern of peaks can be seen in the top end of these two chromatograms. A pattern like this is often seen when samples are contaminated by pipe dope. CPI and Pr/C_{17} and Pr/Ph ratios are approximately the same for all five samples, indicating they all to be mature.

One explanation for the different distribution between n-alkanes and the polycyclic geochemical fossils is different maturity. In samples of low maturity the content of the geochemical fossils relative to n-alkanes is higher than in more mature samples. This is both due to less n-alkanes and to higher concentrations of steranes. Since the maturity of all five samples, as discussed above, is approximately the same, it is more likely that the different distribution is an indication of different environments.

Well 35/8-1: The gas chromatograms of these three samples reveal two different groups, the two shallowest samples being of lower maturity than the previously discussed samples. These samples show n-alkane distribution from C_{15} to C_{35} with maximum at nC_{16}, while the deepest sample exhibits unimodal distribution of condensate type and is also of higher maturity. This deepest sample from the Drake formation also contains higher absolute concentration of n-alkanes and n-alkane/total saturated hydrocarbons (Table 6) than the Kimmeridge Hot shale and Heather samples from this well. As discussed previously this could be due to maturity differences. However, the same trend was seen for the Drake sample in well 30/3-1, and might be characteristic of the Drake formation in this area. The Drake sample in well 30/7-7 did not show the same, indicating this horizon is different.

The Kimmeridge Hot shale and Heather samples in well 35/8-1 show n-alkane distributions and absolute amounts that imply either depletion or low maturity. Even though type II/III kerogen will give lower T_{max} values than type III at the same actual maturity, the maturity of these two samples is still too low for the source rocks to have produced enough hydrocarbons to start expulsion.

From the GC data there are evidently differences within the various formations in these wells. The difference is most pronounced for the Drake formation. Figure 5, which plots the ratios of n-alkanes and total saturates versus depth, shows there to be an increase in this ratio with increasing depth for all formations apart from Drake. It is thus likely that the increased ratios are to a great extent due to increased maturity.

Capillary Gas Chromatography of Aromatic Hydrocarbons

The aromatic hydrocarbon fractions were analysed on two different instruments, one GC with single FID and one with dual FID/FPD detection. GC-traces are given in Figure 6 and 7, the numbers in the FID traces in Figure 7 corresponding to those in the chromatograms in the oil/oil correlation (Bjorøy et al, 1982).

Since only low amounts of dimethylphenanthrenes were detected in the FID-traces, the ratios applied in the oil correlation were difficult to obtain. Results are presented in Table 7.

Well 30/3-1: No big difference was revealed from the chromatograms of the aromatic hydrocarbons in the two samples. Aromatic sulphur components were not detected in significant amount in any of the samples. The main difference is the lower intensities of the methylated phenanthrenes relative to the lower molecular weight naphthalenes in the shallowest sample. The methylphenanthrene ratios indicate similar maturity for the two samples.

Well 30/7-7: The shallowest sample, M-9028, shows a distribution with approximately equal amounts of naphthalenes and phenanthrenes. No aromatic sulphur compounds were detected and this sample is not very different from the 30/3-1 samples.

The four deeper samples were all found to contain aromatic sulphur compounds such as benzo-and dibenzothiophenes. Apart from the minor difference that peak number 3 is missing in the two Heather samples, the four samples look fairly similar. The methylphenanthrene ratio indicates increased maturity for the two deepest samples, implying that these two samples are of oil window maturity as suggested from the GC-data. This supports the conclusion about the T_{max}-values being erronous.

Well 35/8-1: No aromatic sulphur compounds were seen in any of the 35/8-1 samples. Only minor differences were seen between the three samples.

No big difference was seen in the aromatic hydrocarbon GC-traces, and an attempted cluster analysis did not give any distinct groupings of the source rocks.

GC-MS Analyses of Saturated C_{15}+ Hydrocarbons (Steranes and Terpanes)

The saturated hydrocarbon fractions were analysed by GC-MS for their content of steranes and terpanes. The terpane distributions, represented by the m/e 191 mass chromatograms, and the sterane distributions, represented by the m/e 217 chromatograms, are monitored in Figure 8 and 9, respectively.

Molecular ratios given in Tables 8 and 9 are both maturity and source characteristic parameters, which will be discussed separately.

Maturity

Four of the five maturity ratios are based on isomerization reactions in the sterane and terpane ring structure. The $\alpha\beta/\alpha\beta+\beta\alpha$ approaches unity in highly mature samples, and represents the conversion of $17\beta(H),21\alpha(H)$-hopanes to the more stable $17\alpha(H)$, $21\beta(H)$-structure. While the %22S reaches the approximately 60/40 equilibrium mixture of the biological preferred 22S and the thermodynamically more stable 22R configuration in the extended $17\alpha(H),21\beta(H)$-hopanes ($>C_{31}$). The sterane ratios approaches equilibrium mixture of 50/50 of the biological preferred 20S and 20R configuration in $14\alpha(H)$, $17\alpha(H)$. C_{29} steranes, and 75/25 of the more stable $14\beta(H)$, $17\beta(H)$-C_{29} steranes and the $14\alpha(H)$, $17\alpha(H)$-steranes, respectively. The sterane ratios reach the equilibrium at a slightly lower maturity than do the hopane ratios. The T_m/T_s-ratio is applied by Seifert et al (1978) in maturity assignments, the values are reduced when maturity increases for the same type of organic matter.

Well 30/3-1: Both samples were found to be of oil window maturity. the difference in absolute amount of the 17α(H),21β(H)-hopane, as seen in Table 9, is thought to be due to different source characteristics rather than to maturity variations.

Well 30/7-7: Oil window maturity was also found for all the five samples in this well. Again the four ratios represent equilibrium for the various reaction. The Tm/Ts ratio varies quite considerably in this well. This is probably due to a source difference rather than to maturity, since a pure maturity effect would imply that the maturity decreases downwards in the well, a conclusion that would contradict the other maturity ratios.

Well 35/8-1: The same conclusion as was reached from T_{max}- and GC-data was found from GC-MS maturity ratios. The three samples in this well were of lower maturity than the other samples, but still relatively mature since the hopane ratios show equilibrium mixture. From the sterane data a slight increase in maturity is seen with increasing depth.

Similar conclusions concerning the maturity were reached from GC-MS data as from the other previously discussed maturity parameters. The GC-MS data also supported the theory about the T_{max}-values for the two deepest samples being far too low.

Type of Organic Matter

Different absolute concentrations as well as appearance of certain components in the mass chromatograms are believed to be source characteristic parameters. The abundance of four different components in the terpane mass chromatograms (m/e 191, Figure 8) relative to the 17α(H),21β(H)-hopane is considered. In addition to the ratios applied in the oil correlation (Bjorøy et al, 1982) the relative amounts of an unidentified C_{30} triterpane (X) and of tricyclic terpanes were calculated. The bisnorhopane (Z) found in some of the oils could not be detected in significant amount in any of the source rock samples and will not be further considered.

Well 30/3-1: All the parameters show different values for the two samples. The most pronounced difference is seen from the relative amount of tricyclics (Table 8) and in the absolute concentrations (Table 9). A difference is also seen from the sterane distribution in that the C_{29} sterane seen to be more prominent relative to the C_{27} steranes in the deepest Burton/Amundsen sample.

Well 30/7-7: The five samples in this well may clearly be separated into two different groups according to these source parameters. The main differences between the two groups are the lack of component Z and the low relative amounts of tricyclics in addition to the significant higher concentrations of the hopanes, in the two deepest samples. Certain variations are seen within the three shallowest samples, particularly in the relative amount of the unidentified component (X), and this might be due to maturity variations. The sterane distribution shows the same two groups as the other parameters, the two deepest samples having much more abundant C_{29} steranes than the lower molecular weight steranes.

There are certain problems connected with the use of the relative amount of the norhopane (C). It is known that an unidentified component is nearly coeluting with the norhopane (C), causing the broad peak in the chromatograms, and the ratio (C/E) is also believed to change with maturity. This is probably the reason for the variations in this ratio.

Well 35/8-1: Only small differences are seen from the terpane ratios and the sterane distributions for these three samples. The absolute amounts do, however, show two groups, the two shallow Kimmeridge Hot shale and Heather samples being one group and the deeper Drake sample the other. The Drake sample was found to have similar characteristics to the 30/3-1 Drake sample, but different to the 30/7-7 Drake sample.

GC-MS Analyses of Aromatic Hydrocarbons

A number of mass chromatograms typical of various types of aromatic compounds were recorded, and some of the chromatograms are presented in Figure 10. Since only minor discrepancies were seen from some of the mass chromatograms, only traces representative of various groups of samples are given. The groups are presented in Table 10. Due to the low abundance of dibenzothiophenes in the GC-traces, the corresponding ratios together with the methylphenanthrene ratio were calculated from the mass chromatograms and are given in Table 11. Taking the maturity variations into consideration, these GC-MS data do not distinguish clearly among groups of samples, and they will not be discussed in detail. The main difference is the lack of any homologous alkylbenzenes in the 30/3-1 Burton/Amundsen sample.

CONCLUSION ON THE SOURCE ROCKS

Based on the previous discussion a subdivision of the source rocks is done before the correlation with the oils is attempted. One sample, M-9137, was assigned as a type III kerogen, and is not considered in the further correlation, since this rock is not likely to have produced any oil or condensate. The rest of the samples are all of oil window maturity and at best consisting of a mixed type II/III kerogen (Figure 2).

The five groups that were assigned and applied in the correlation are thus:

Group I: M-9135, M-9136 (35/8-1)
Group II: M-9028, M-9029, M-9030 (30/7-7)
Group III: M-9031, M-9032 (30/7-7)
Group IV: M-9138 (30/3-1)
Group V: M-9139 (30/3-1)

OIL/OIL CORRELATION

This correlation was discussed in detail in a previous report (Bjorøy et al, 1982), and only results that will make the oil/source rock correlation simpler to follow will be repeated or added here.

The conclusion on the oil correlation was that four groups of oils could be rationalized from the various analyses:

Group A: M-49 (31/2-2), M-51 (31/2-5), M-52 (31/4-5), M-54 (30/6-4,
M-56 (30/6-3)

Group B: M-57 (30/3-2)

Group C: M-50 (30/4-2), M-53 (35/8-1)

Group D: M-55 (34/10-2)

In addition to the sterane/triterpane ratios applied in the oil/oil correlation, one new ratio, the relative amount of the unidentified C_{30} triterpane (X) was calculated. This ratio and a summary of the previously calculated ratios are given in Table 12. The additional ratio supports the previous group division, assigning oils M-50 and M-53 (Group C) as being different from the rest.

OIL/SOURCE ROCK CORRELATION

Based on the previous source rock discussion, sample M-9137 will not be considered as a possible source rock for the oils and condensates in this correlation, and is therefore not discussed.

In Figure 11 is shown a triangular plot of the gross composition of all the samples. The difference between the source rock and oil samples is probably mainly due to the expected lower amount of polar components in the oils as compared to the sediments. The results thus imply that none of the sediment samples can be excluded as source rocks for these oils based on the gross composition.

The GC-traces did not give very much information as to the correlation. One oil, M-51 (31/2-5) was biodegraded and can not be correlated to the other samples by the saturated hydrocarbon profile. The two condensates, M-49 (31/2-2) and M-56 (30/6-3), show n-alkane distributions most similar to the Group III source rocks. The relative amount of steranes and triterpanes were, however, much more pronounced in the Group III source rocks than in the condensates. As discussed previously this might be due to pipe dope.

None of the samples can be excluded as sources based on the aromatic hydrocarbon profiles, but attempts to perform clustering analyses did not give any clear positive correlation even with a correlation coefficient of 0.85.

Since the internal standard for use in the GC-MS analyses was not available at the time the oil analyses were performed, absolute concentrations were not applied in the final correlation. We feel that this could be useful in future work, however, in this report the quantitative data were only applied in performing distinction between groups of the source rocks. Thus, for the oil/source rock correlation only the qualitative distributions from the GC-MS analyses are applied.

Only minor dissimilarities were seen from the sterane traces of the oils (Figure 9), they all seem to contain relatively high amounts of diasteranes (*), and exhibit a fairly even distribution of the C_{27}-C_{29} steranes. These sterane molecular weight distributions are presented in a triangular diagram together with the distributions in the source rock samples

(Figure 12). Only minor variations were revealed also in the source rock samples, even if the scatter within the source rock samples is more pronounced. None of the sediment samples can be positively ruled out as source rocks for these oil. However, the Group III and one of the Group I sediment seem to be the least similar.

Only three samples (Group II and IV) were found to contain approximately the same relative amounts of rearranged and regular steranes as were seen in the oils.

Based on the sterane distribution it is probable that the most promising source rocks for the oils are the Group II and IV samples, representing the Kimmeridge and Heather formations in well 30/7-7 and the Drake formation in well 30/3-1, respectively. This ratio should, however, not be trusted as the only parameter since different maturity is known to affect the relative amount of rearranged steranes.

The terpane mass chromatograms (Figure 8) give more information to be applied in the correlation. All the oil samples, except for two (M-50, 30/4-2 and M-53, 35/8-1), contained significant amounts of bisnorhopane (Z). This compound was not detected in any of the source rocks. This would suggest that the analysed source rocks can only have sourced the two oils put together in Group C in the oil correlation, representing the oils from wells 30/4-2 and 35/8-1. Based on the lack of bisnorhopane all the rocks are possible sources.

The unidentified C_{30} component (X) was seen in all the sediment samples in varying relative concentrations, but in significant amount in only three of the oil samples. It is not known how maturation and migration effects will change the relative amount of this compound. Variations are seen within the Group II source rock samples, indicating some effect due to maturation. We do, however, believe that significant amount of the C_{30} compound is related to specific source characteristics. This would imply that the group I, III and V source rock samples can be excluded as sources for the two Group C oil samples and M-49 (31/2-2) from the Group A oils. Based on this parameter these same source rocks (Group I, III and V) might have sourced the rest of the oils.

The relative amount of tricyclic terpanes (represented by the ratio of peak T to the 17α(H),21β(H)-hopane (E)) is two in all the oil samples apart from M-49 from the Group A oils (31/2-2). This indicates that the Group II and V sediments are the most likely sources for this oil. The almost complete absence of these components in the other samples suggests that Group I and III might have been the source for the rest of the oils, with the possible exception of M-50, M-55 and M-56, which all show somewhat intermediate concentrations.

Correlation based on this actual distribution of the various components in the sterane and terpane mass chromatograms are summarised in Table 13. The x indicates correlation either by lack of the actual component or component class or by approximately the same amount in the oil and source rock sample.

The best correlation was seen between the Group II source rocks and Group C oils and M-49 of the Group A oils. The Group C oils also show a relatively good correlation with the Drake sample from well 30/3-1 (Group IV). It is unlikely that these rocks have sourced the other oils.

Only poor correlation was found for the Group I, III and V source rocks and the oils, and it is thus doubtful if these rocks have been the only source of any of the oils. However, considering the possibility of mixed sources, none of the sediments should be excluded as a contributor to the oils.

One should also bear in mind the possible effects on the applied ratios from migration and maturation processes. This may cause variations in the applied ratios.

CONCLUSION

In conclusion we can thus say that there is a fairly good correlation between the oils from wells 31/2-2 (M-49), 30/4-2 (M-50) and 35/8-1 (M-53) and the Kimmeridge and Heather formations in well 30/7-7. There are also indications of positive correlation between the Drake formation in well 30/3-1 and the oils from 31/2-2 and 30/4-2.

Since we do not have any information about the depth intervals where the oils were taken, it is not possible to consider if the migration pathways acquired in these cases are geological feasible.

The data discussed in this report should also be considered in connection with the stable isotope analyses performed on these same samples. These data were unfortunately not available at the time when this report was written.

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Table 1: Source rock samples analysed

IKU No.	Well	Depth Interval	Formation
M-9138	30/3-1	3873-3950	Drake
M-9139	30/3-1	4128-4227	Burton/Amundsen
M-9028	30/7-7	3900-3925	Kimmeridge Hot shale
M-9029	30/7-7	3925-4200	Heather
M-9030	30/7-7	4200-4500	Heather
M-9031	30/7-7	4500-4730	Drake
M-9032	30/7-7	4790-4910	Burton/Amundsen
M-9135	35/8-1	3180-3350	Kimmeridge Hot shale
M-9136	35/8-1	3350-3500	Heather
M-9137	35/8-1	3700-3800	Drake

Table 2: Oil samples analysed in the previous oil/oil correlation (Bjorøy et al, 1982)

IKU No.	Well No.
M-49	31/2-2
M-50	30/4-2
M-51	31/2-5
M-52	31/4-5, DST 3
M-53	35/8-1, DST 4
M-54	30/6-4, DST 2
M-55	34/10-2, DST 2
M-56	30/6-3, DST 2
M-57	30/3-2, 2C

TABLE 3

ROCK EVAL PYROLYSES

IKU No.	DEPTH m/ft	S1	S2	S3	TOC (%)	HYDR. INDEX	OXYGEN INDEX	OIL OF GAS CONTENT S1+S2	PROD. INDEX S1 / S1+S2	TEMP. MAX (C)
30/3-1										
M 9138	3950	0.79	1.17	0.37	1.77	66	21	1.96	0.40	446
M 9139	4227	0.96	0.75	0.63	1.88	40	34	1.71	0.56	453
30/7-7										
M 9028	3924	3.71	3.31	0.67	4.32	77	16	7.02	0.53	441
M 9029	4200	3.52	1.90	0.60	3.86	49	16	5.42	0.65	447
M 9030	4502	2.02	0.84	0.58	2.30	37	25	2.86	0.71	453
M 9031	4730	2.05	1.58	0.42	2.21	71	19	3.63	0.56	370
M 9032	4910	2.19	0.94	0.45	2.24	42	20	3.13	0.70	357
35/8-1										
M 9135	3350	1.81	8.29	0.76	3.57	232	21	10.10	0.18	431
M 9136	3500	2.46	6.73	0.90	3.06	220	29	9.19	0.27	433
M 9137	3800	1.41	1.42	1.86	1.60	89	116	2.83	0.50	436

DATE : 22 - 4 - 83.

TABLE : 4.1

CONCENTRATION OF EOM AND CHROMATOGRAPHIC FRACTIONS

IKU-No	DEPTH (m)	Rock Extr. (g)	EOM (mg)	Sat. (mg)	Aro. (mg)	HC (mg)	Non HC (mg)	TOC (%)
30/3-1								
M 9138	3950	26.8	39.8	14.6	4.8	19.4	20.4	1.77
M 9139	4227	41.0	82.0	36.1	7.2	43.3	38.7	1.88
30/7-7								
M 9028	3924	18.7	87.8	39.6	12.5	52.1	35.7	4.32
M 9029	4200	36.6	146.0	63.6	16.2	79.8	66.2	3.86
M 9030	4502	49.6	122.0	58.4	14.6	73.0	49.0	2.30
M 9031	4730	41.2	124.7	60.3	19.4	79.7	45.0	2.21
M 9032	4910	36.7	97.7	49.4	14.9	64.3	33.4	2.24
35/8-1								
M 9135	3350	29.7	58.4	18.4	9.1	27.5	30.9	3.57
M 9136	3500	18.1	50.5	24.7	7.3	32.0	18.5	3.06
M 9137	3800	19.0	34.5	13.3	4.1	17.4	17.1	1.60

DATE : 22 - 4 - 83.

TABLE : 4.2

CONCENTRATION OF EOM AND CHROMATOGRAPHIC FRACTIONS

(mg/g TOC)

IKU-No	DEPTH (m)	EOM	Sat.	Aro.	HC	Non HC
30/3-1						
M 9138	3950	83.9	30.8	10.1	40.9	43.0
M 9139	4227	106.4	46.8	9.3	56.2	50.2
30/7-7						
M 9028	3924	108.7	49.0	15.5	64.5	44.2
M 9029	4200	103.3	45.0	11.5	56.5	46.9
M 9030	4502	106.9	51.2	12.8	64.0	43.0
M 9031	4730	137.0	66.2	21.3	87.5	49.4
M 9032	4910	118.8	60.1	18.1	78.2	40.6
35/8-1						
M 9135	3350	55.1	17.4	8.6	25.9	29.1
M 9136	3500	91.2	44.6	13.2	57.8	33.4
M 9137	3800	113.5	43.7	13.5	57.2	56.3

DATE : 22 - 4 - 83.

TABLE : 4.3

WEIGHT OF EOM AND CHROMATOGRAPHIC FRACTIONS

(Weight ppm OF rock)

IKU-No	DEPTH (m)	EOM	Sat.	Aro.	HC	Non HC
30/3-1						
M 9138	3950	1485	545	179	724	761
M 9139	4227	2000	880	176	1056	944
30/7-7						
M 9028	3924	4695	2118	668	2786	1909
M 9029	4200	3989	1738	443	2180	1809
M 9030	4502	2460	1177	294	1472	988
M 9031	4730	3027	1464	471	1934	1092
M 9032	4910	2662	1346	406	1752	910
35/8-1						
M 9135	3350	1966	620	306	926	1040
M 9136	3500	2790	1365	403	1768	1022
M 9137	3800	1816	700	216	916	900

DATE : 22 - 4 - 83.

TABLE : 4.4

COMPOSITION IN % OF MATERIAL EXTRACTED FROM THE ROCK

IKU-No	DEPTH (m)	Sat / EOM	Aro / EOM	HC / EOM	SAT / Aro	Non HC / EOM	HC / Non HC
30/3-1							
M 9138	3950	36.7	12.1	48.7	304.2	51.3	95.1
M 9139	4227	44.0	8.8	52.8	501.4	47.2	111.9
30/7-7							
M 9028	3924	45.1	14.2	59.3	316.8	40.7	145.9
M 9029	4200	43.6	11.1	54.7	392.6	45.3	120.5
M 9030	4502	47.9	12.0	59.8	400.0	40.2	149.0
M 9031	4730	48.4	15.6	63.9	310.8	36.1	177.1
M 9032	4910	50.6	15.3	65.8	331.5	34.2	192.5
35/8-1							
M 9135	3350	31.5	15.6	47.1	202.2	52.9	89.0
M 9136	3500	48.9	14.5	63.4	338.4	36.6	173.0
M 9137	3800	38.6	11.9	50.4	324.4	49.6	101.8

DATE : 22 - 4 - 83.

TABLE 5

TABULATION OF DATAS FROM THE GASCHROMATOGRAMS

IKU No.	DEPTH (m)	PRISTANE / n-C17	PRISTANE / PHYTANE	CPI
30/3-1				
M 9138	3950	0.5	1.6	1.0
M 9139	4227	0.6	1.7	1.0
30/7-7				
M 9028	3924	0.4	1.0	1.0
M 9029	4200	0.5	1.2	1.0
M 9030	4502	0.4	1.0	1.0
M 9031	4730	0.4	1.0	1.1
M 9032	4910	0.4	1.0	1.1
35/8-1				
M 9135	3350	0.9	2.4	1.2
M 9136	3500	0.6	2.6	1.1
M 9137	3800	0.4	2.2	1.0

DATE : 22 - 4 - 83.

Table 6: Absolute amounts of total saturated hydrocarbon fractions (mg/g rock) and of certain n-alkanes (µg/g rock)

	Total SAT (mg/g rock)	n-alkanes* µg/g rock)	n-alkanes/SAT
30/3-1			
M-9138	545	224	0.41
M-9139	880	37	0.04
30/7-7			
M-9028	2118	210	0.10
M-9029	1738	167	0.10
M-9030	1177	133	0.11
M-9031	1464	65	0.04
M-9032	1346	94	0.07
35/8-1			
M-9135	620	51	0.08
M-9136	1365	128	0.09
M-9137	700	281	0.40

*n-alkanes represent the same n-alkanes as plotted in the histograms (Figure 4)

Table 7: Ratios calculated from GC traces of aromatic hydrocarbons

	MP (peaks 49+50/51+52)	DMP (peaks 57/56)	DMP_2 (peaks 58/56)
30/3-1			
M-9138	0.61	0.63	-
M-9139	0.71	0.63	0.49
30/7-7			
M-9028	0.87	0.45	0.33
M-9029	0.90	-	-
M-9030	1.00	0.68	0.50
M-9031	1.44	-	-
M-9032			
35/8-1			
M-9135	0.64	-	-
M-9136	0.63	-	-
M-9137	0.72	-	-

Table 8: Molecular ratios calculated from GC-MS analyses

		m/e191		m/e 217			m/e 191	
Sample No.	Tm/Ts (A/B)	$\alpha\beta/\alpha\beta+\beta\alpha$ (E/E+F)	%22S (G/G+H)	%20S (q/q+t)	%$\beta\beta$ (r+s/q+r+s+t)	C/E	X/E	TRI/E
30/3-1								
M-9138	0.50	0.92	63.9	52.1	76.6	0.64	0.31	0.17
M-9139	0.58	0.89	61.7	44.6	78.3	0.71	0.12	0.27
30/7-7								
M-9028	0.20	0.96	62.1	48.0	79.8	0.52	0.79	0.23
M-9029	0.28	0.92	59.6	45,7	74.4	0.65	0.43	0.26
M-9030	0.74	0.89	61.1	50.9	76.2	0.87	0.12	0.23
M-9031	1.04	0.82	60.0	45.8	73.6	0.62	-	0.06
M-9032	1.15	0.91	64.7	49.4	72.5	1.05	-	0.08
35/8-1								
M-9135	1.39	0.88	61.4	39.6	54.4	0.44	0.04	0.05
M-9136	0.93	0.89	59.7	45.9	63.2	0.50	0.06	0.08
M-9137	1.96	0.89	58.2	46.2	68.5	0.80	0.17	0.10

Letters refer to Figures 8 and 9.

Table 9 Absolute and relative amount of steranes and hopanes.

	αβ-hopane (μg/g rock)	αβ-$C_{30}/\Sigma C_{29}$-steranes
30/3-1		
M-9138	0.19	2.2
M-9139	0.85	1.6
30/7-7		
M-9028	0.25	1.5
M-9029	0.31	1.4
M-9030	0.29	1.7
M-9031	3.25	1.9
M-9032	2.38	2.1
35/8-1		
M-9135	1.93	3.1
M-9136	2.56	3.9
M-9137	0.30	2.2

Table 10. Different groups based on GC-MS of aromatic hydrocarbons (see Figure 10)

m/e 91, 105, 106	Alkylbenzenes	
M-9139		
M-9032	represents the rest of the samples	
m/e 141	Alkylbenzenes	
M-9139		
M-9032	represents the rest of the samples	
m/e 192	Methylphenanthrenes	
M-9137	represents least mature	(see Table 10)
M-9032	represents most mature	
m/e 206		
M-9137	represents M-9136 and M-9135	
M-9032	represents the rest of the samples	
m/e 198	Methyldibenzothiophenes (see table 11 for the different distribution)	

Table 11. Calculated ratios from GC-MS of aromatic hydrocarbons (similar to the GC-ratios in Table 7)

	MP (m/e 192)	DMP (m/e 198)	DMP_2 (m/e 198)
30/3-1			
M-9138	0.53	0.29	0.21
M-9139	0.71	0.24	0.12
30/7-7			
M-9028	0.81	0.28	0.24
M-9029	0.72	0.24	0.19
M-9030	1.14	0.41	0.19
M-9031	1.05	0.32	0.22
M-9032	1.26	0.27	0.24
35/8-1			
M-9135	0.56	0.47	0.45
M-9136	0.57	0.47	0.55
M-9137	0.46	0.45	0.21

Table 12. Ratios from GC-MS analyses of saturated hyrocarbons in the oils

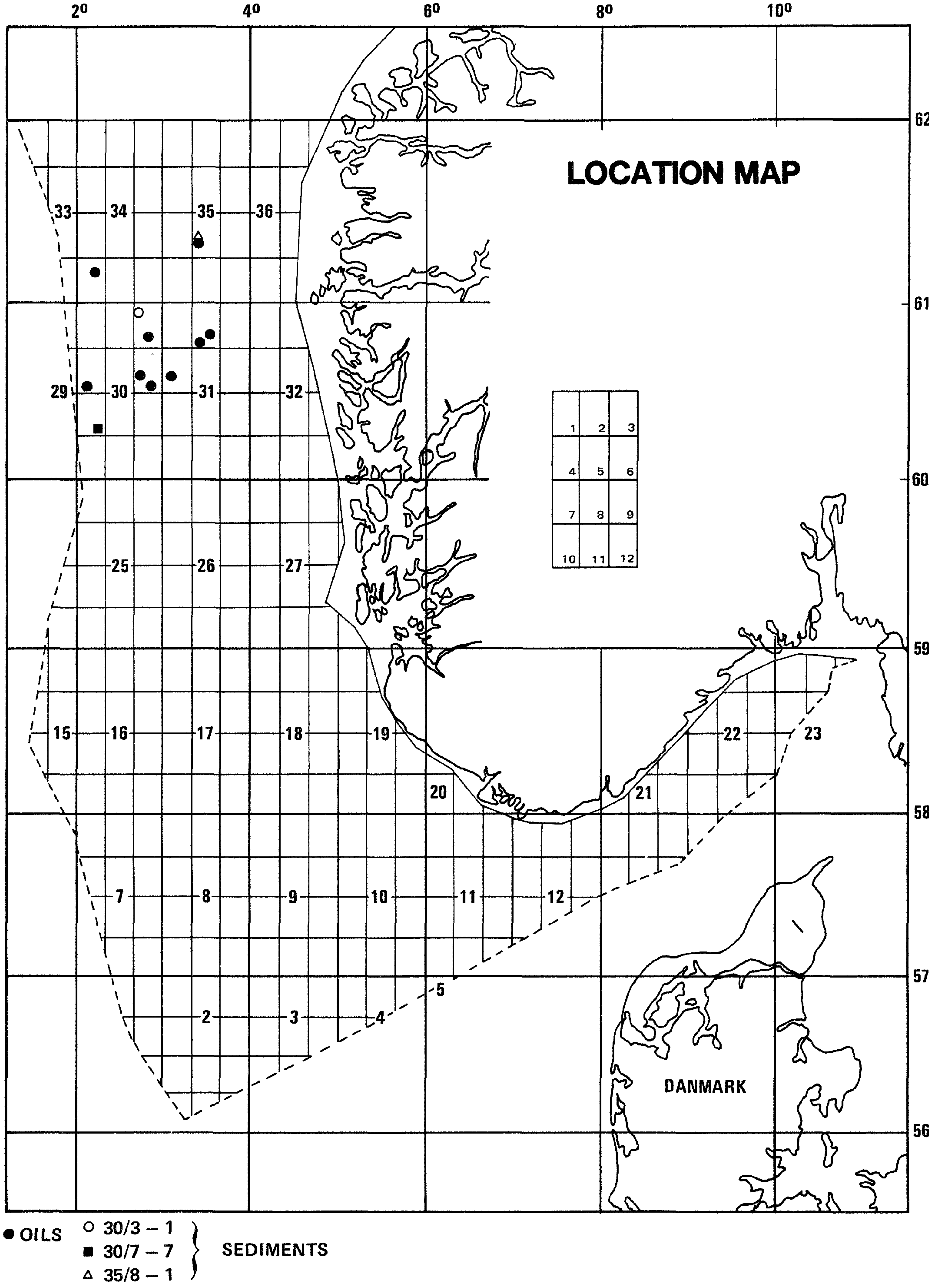
		m/e 191			
	Tm/Ts	Z/E	C/E	X/E	TRI/E
M-49	0.52	0.26	0.54	0.29	0.41
M-50	0.31	-	0.60	0.54	0.11
M-51	1.00	0.29	0.58	0.10	0.05
M-52	1.00	0.27	0.48	0.07	0.04
M-53	0.77	-	0.48	0.40	0.04
M-54	0.72	0.26	0.46	0.07	0.04
M-55	0.71	0.10	0.63	0.10	0.10
M-56	0.72	0.29	0.59	0.10	0.14
M-57	0.65	0.15	0.57	0.10	0.06

Table 13. Correlation of oils and source rocks by GC-MS parameters *
x indicates correlation

OILS	M-49 (31/2-2)				M-50 (30/4-2)				M-51 (31/2-5)				M-52 (31/4-5)				M-53 (35/8-1)				M-54 (30/6-4)				M-55 (34/10-2)				M-56 (30/6-3)				M-57 (30/3-2)			
Source rocks	S	Z	X	T	S	Z	X	T	S	Z	X	T	S	Z	X	T	S	Z	X	T	S	Z	X	T	S	Z	X	T	S	Z	X	T	S	Z	X	T
30/3-1																																				
M-9138 (II)	x				x	x	x		x				x				x	x	x		x				x				x				x			
M-9139 (V)			x	x		x					x				x			x					x				x				x				x	
30/7-7																																				
M-9028 (II)	x		x	x	x	x	x		x				x				x	x	x		x				x				x				x			
M-9029	x		x	x	x	x	x		x				x				x	x	x		x				x				x				x			
M-9030	x		x	x	x	x	x		x				x				x	x	x		x				x				x				x			
M-9031 (III)						x					x	x			x	x		x		x			x	x			x				x				x	x
M-9032 III)						x					x	x			x	x		x		x			x	x			x				x				x	x
35/8-1																																				
M-9135 (I)						x					x	x			x	x		x		x			x	x			x				x				x	x
M-9136 (I)						x					x	x			x	x		x		x			x	x			x				x				x	x
M-9137	-				-				-				-				-				-				-				-				-			

* S - steranes, Z - bisnorhopane, X - unidentified C_{30} component (triterpane), T - tricyclic terpanes, - no source rock for oil.

Fig. 1


LOCATION MAP
2⁰
4⁰
6⁰
8⁰
10⁰
62⁰
61⁰
60⁰
59⁰
58⁰
57⁰
56⁰
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11
12
DANMARK
● OILS
○ 30/3 – 1
■ 30/7 – 7
△ 35/8 – 1
SEDIMENTS

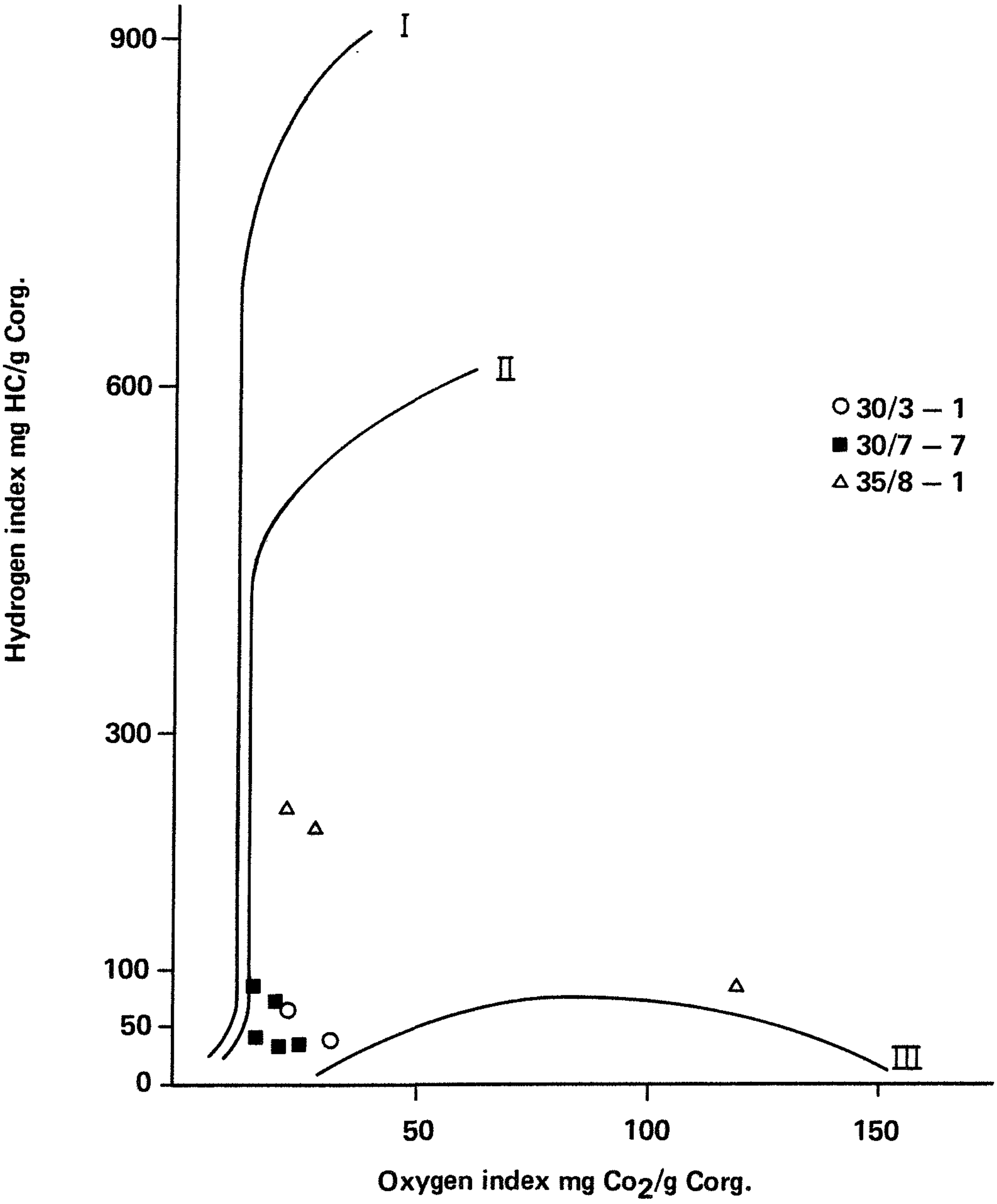


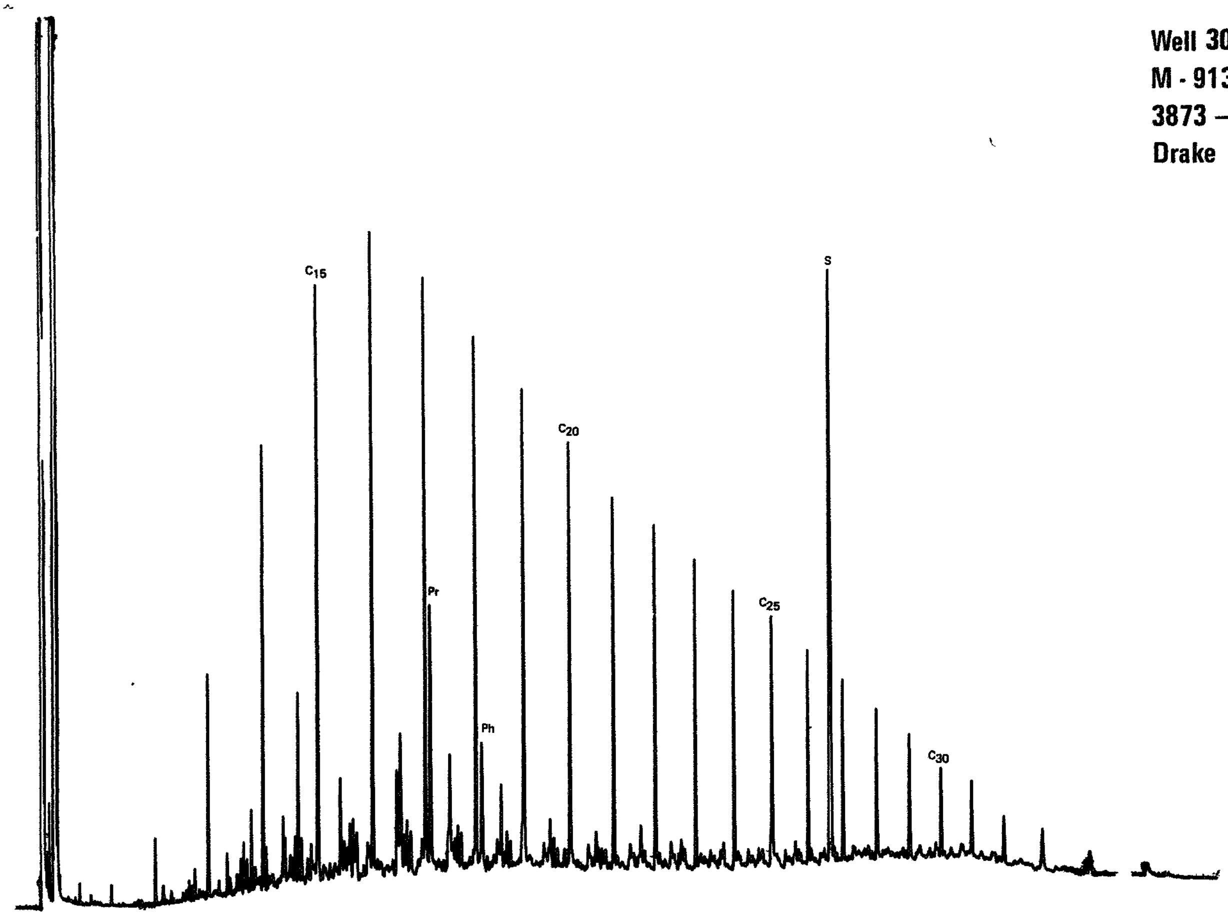
Figure 2 Rock – Eval hydrogen index versus oksygen index.

Figure 3

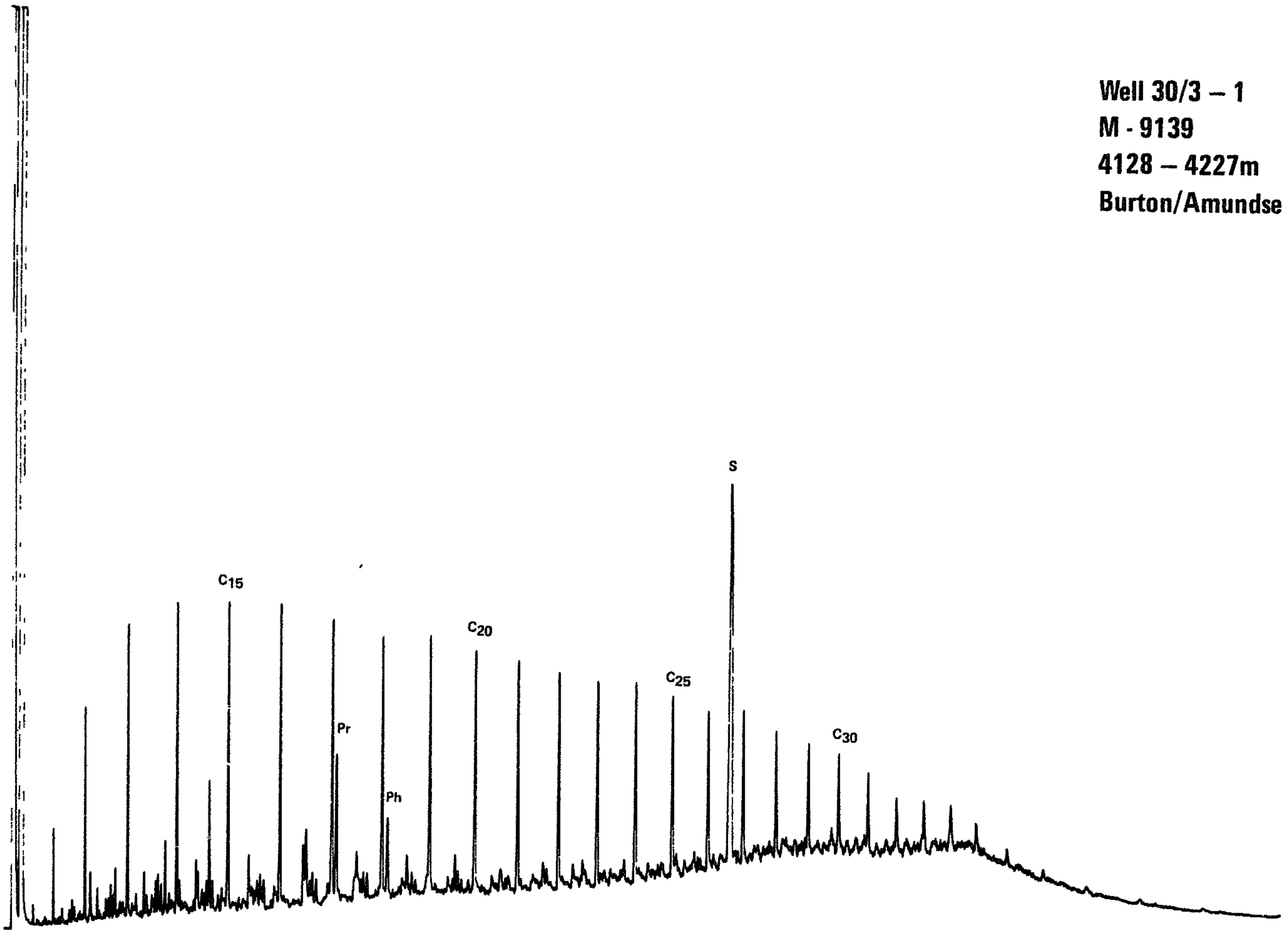
GAS CHROMATOGRAPHIC ANALYSIS SATURATED HYDROCARBONS

Key:

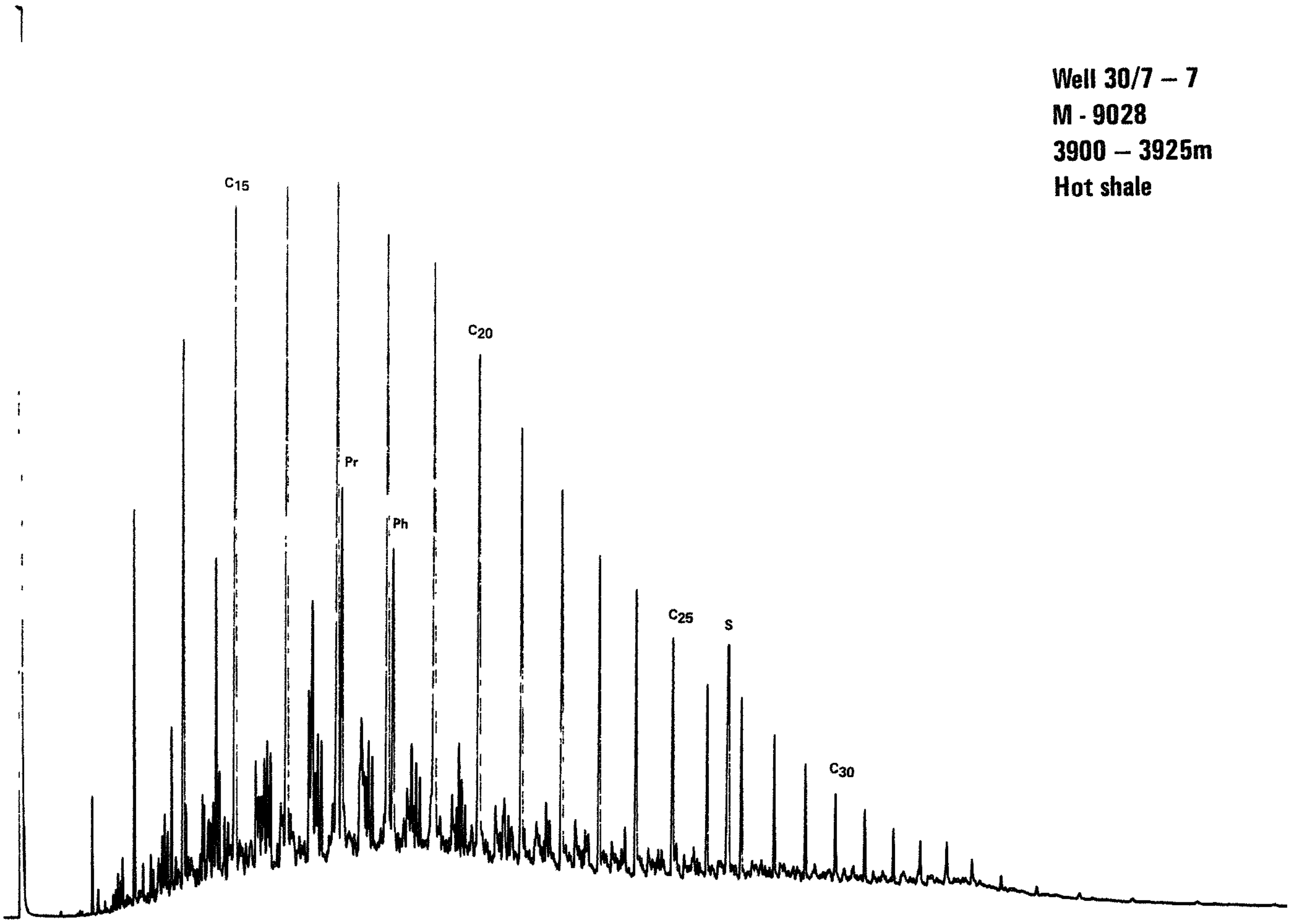
C_{15}, C_{20}, ... = n-alkanes
Pr = pristane
Ph = phytane
S = squalane (internal standard)



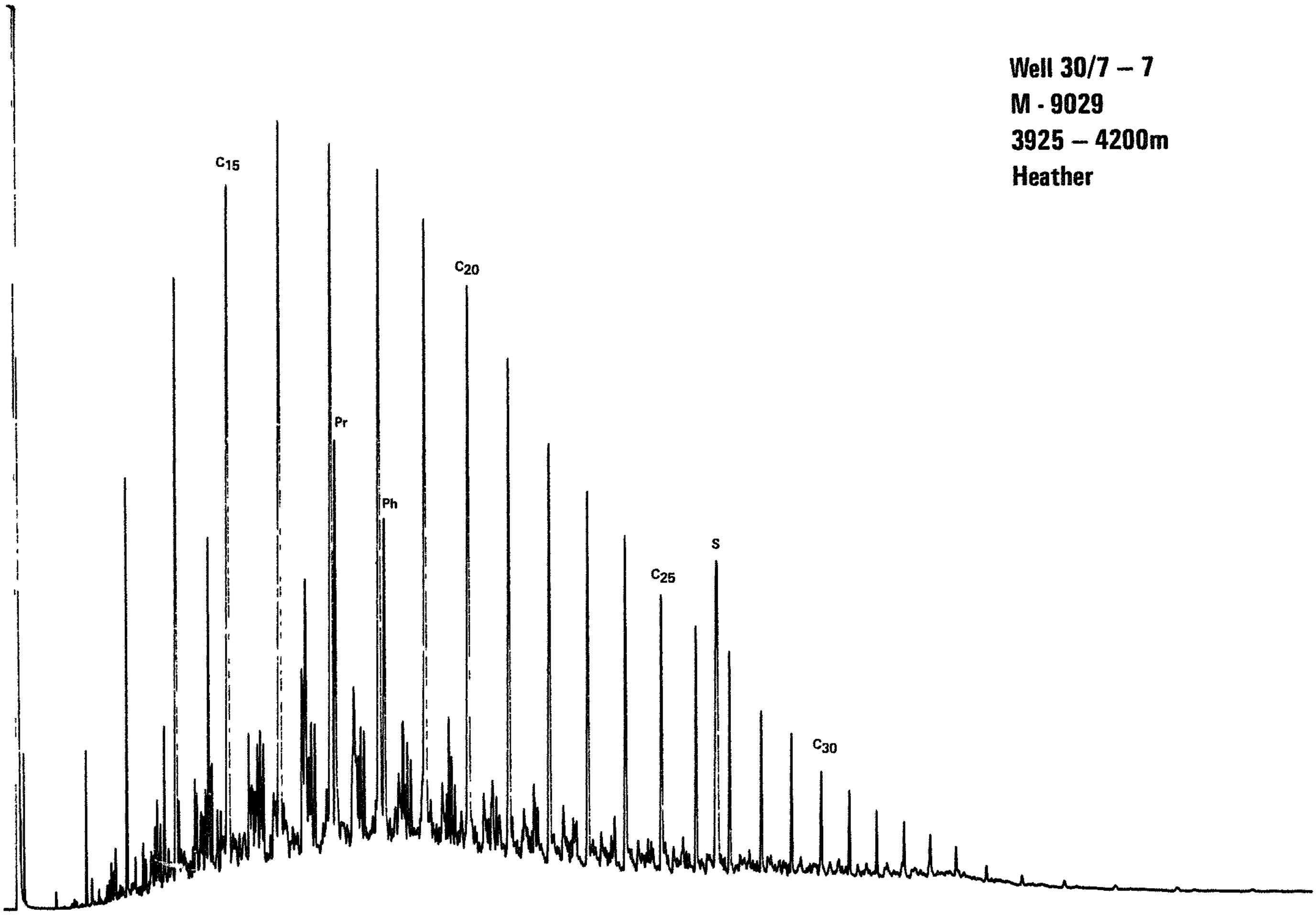
Well 30/3 – 1
M - 9138
3873 – 3950m
Drake



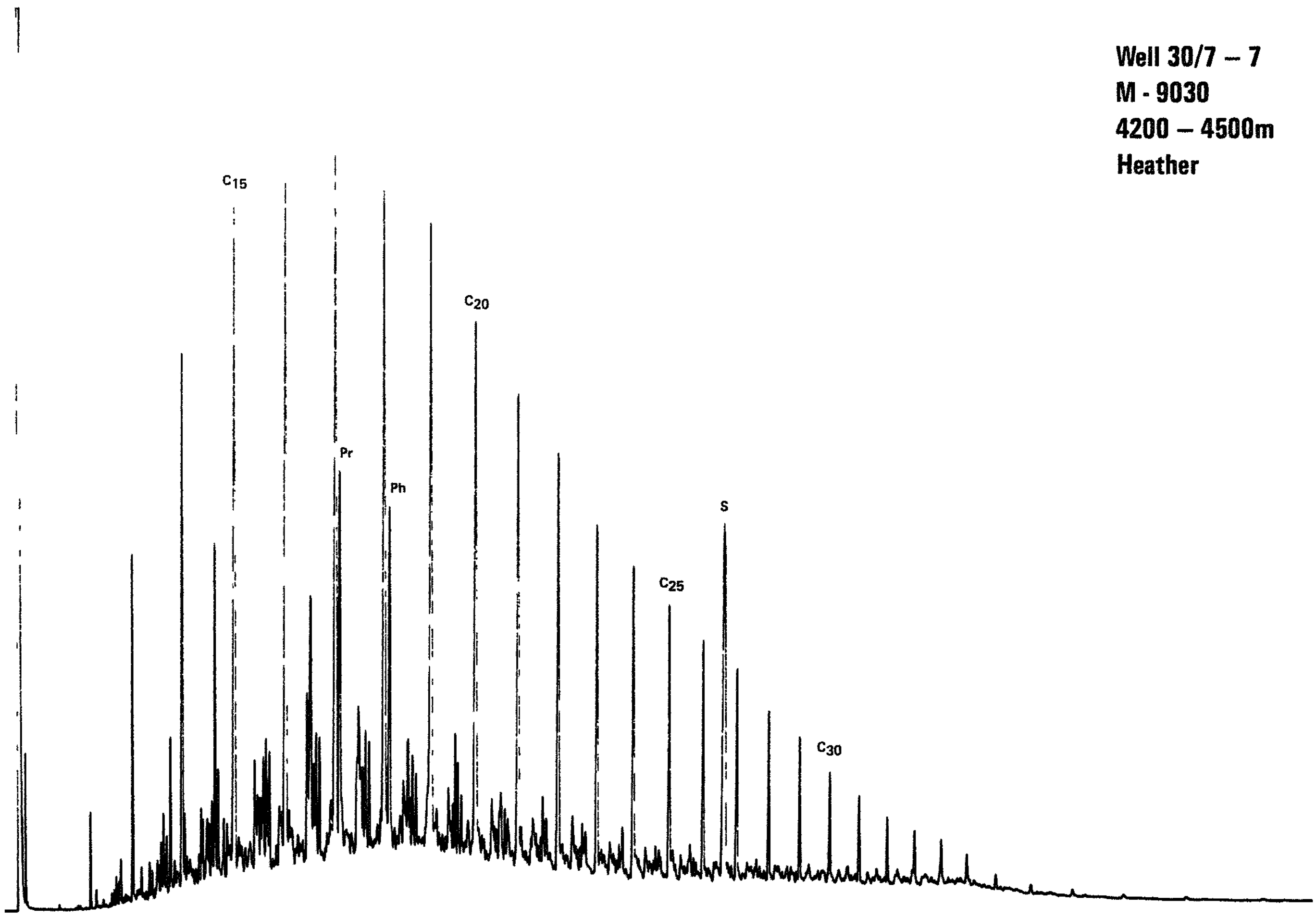
Well 30/3 – 1
M - 9139
4128 – 4227m
Burton/Amundsen

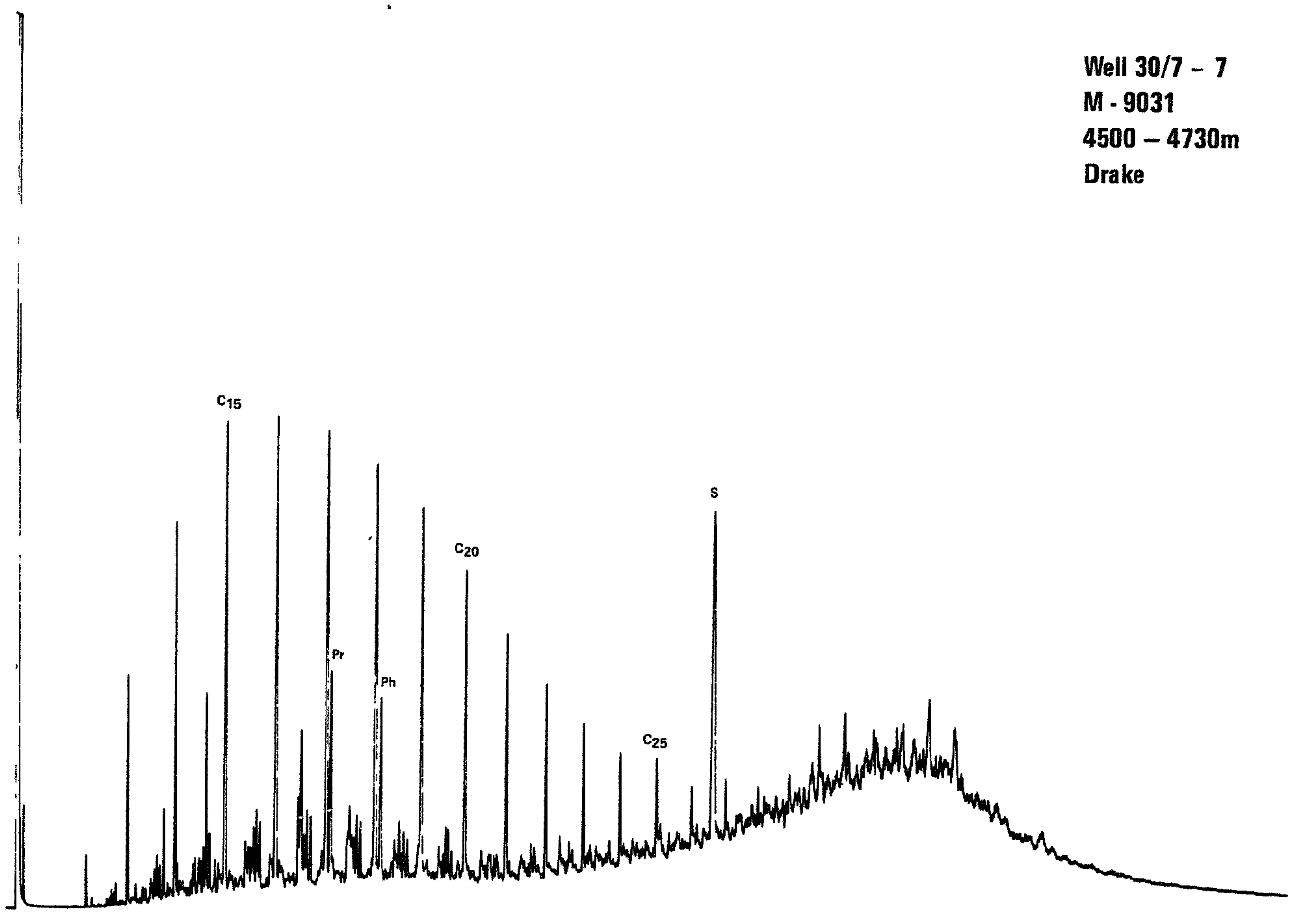


Well 30/7 – 7
M - 9028
3900 – 3925m
Hot shale
C_{15}
C_{20}
Pr
Ph
C_{25}
S
C_{30}

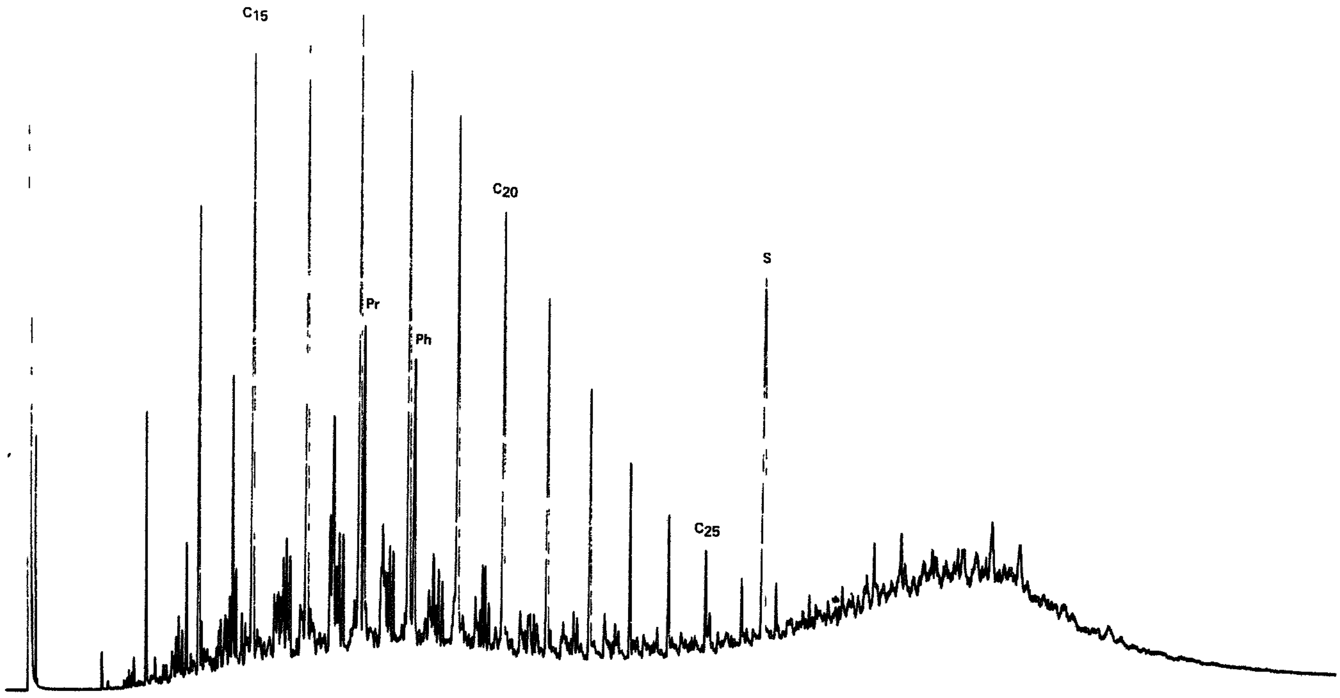


Well 30/7 – 7
M - 9029
3925 – 4200m
Heather
C_{15}
C_{20}
Pr
Ph
C_{25}
S
C_{30}

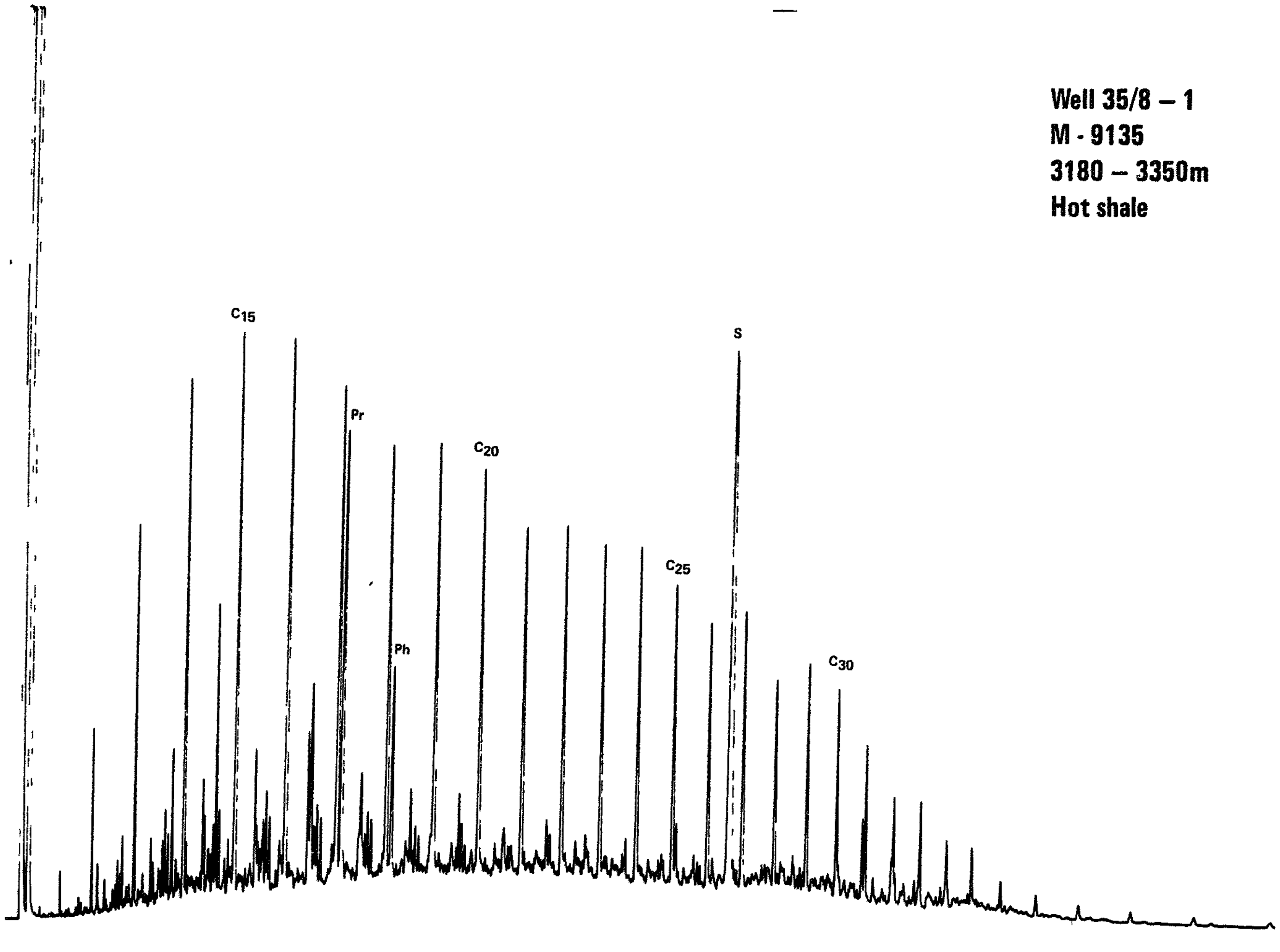

Well 30/7 – 7
M - 9030
4200 – 4500m
Heather
C15
Pr
Ph
C20
S
C25
C30

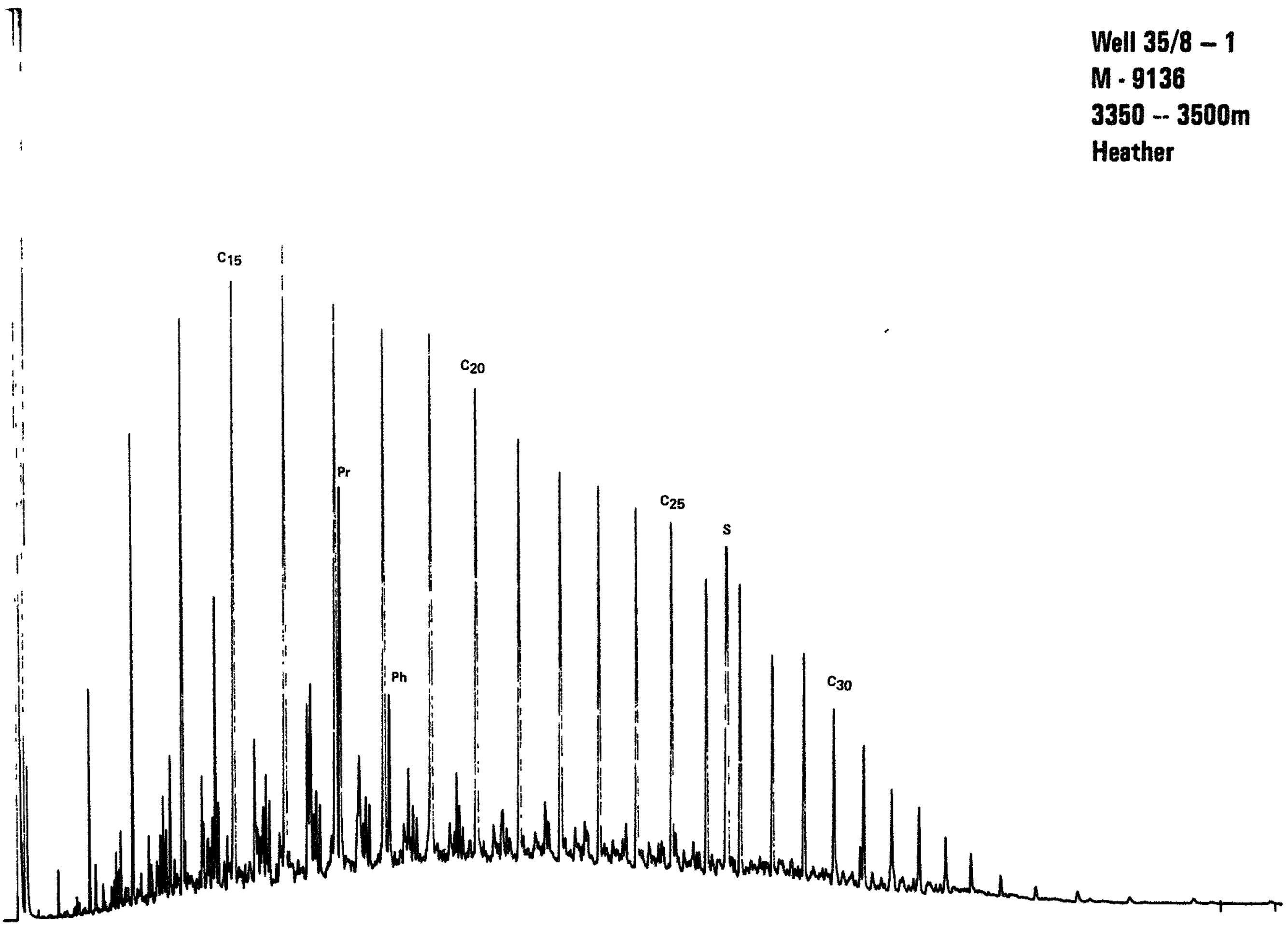

Well 30/7 – 7
M - 9031
4500 – 4730m
Drake
C15
Pr
Ph
C20
S
C25

Well 30/7 – 7
M - 9032
4790 – 4910m
Burton/Amundsen

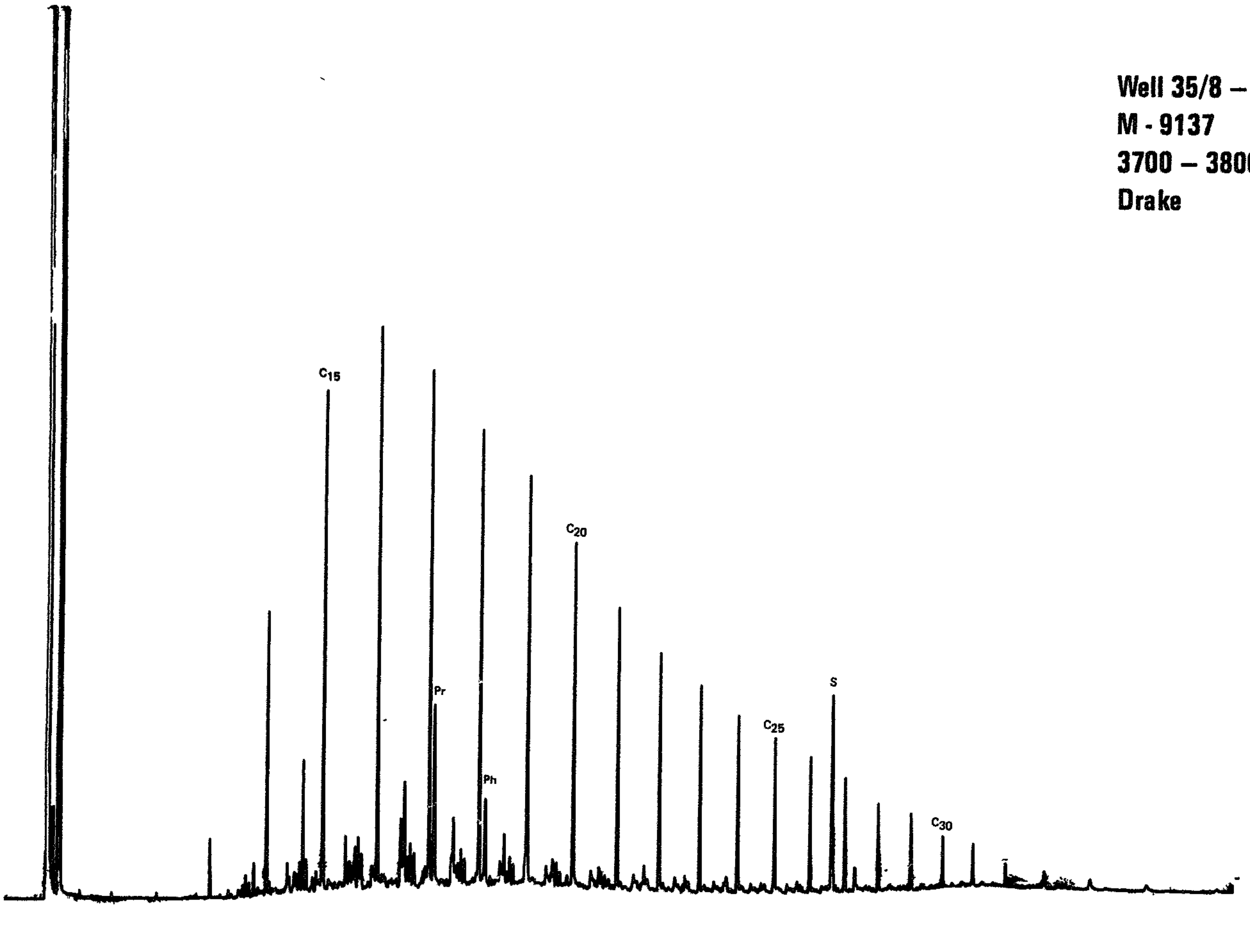


Well 35/8 – 1
M - 9135
3180 – 3350m
Hot shale





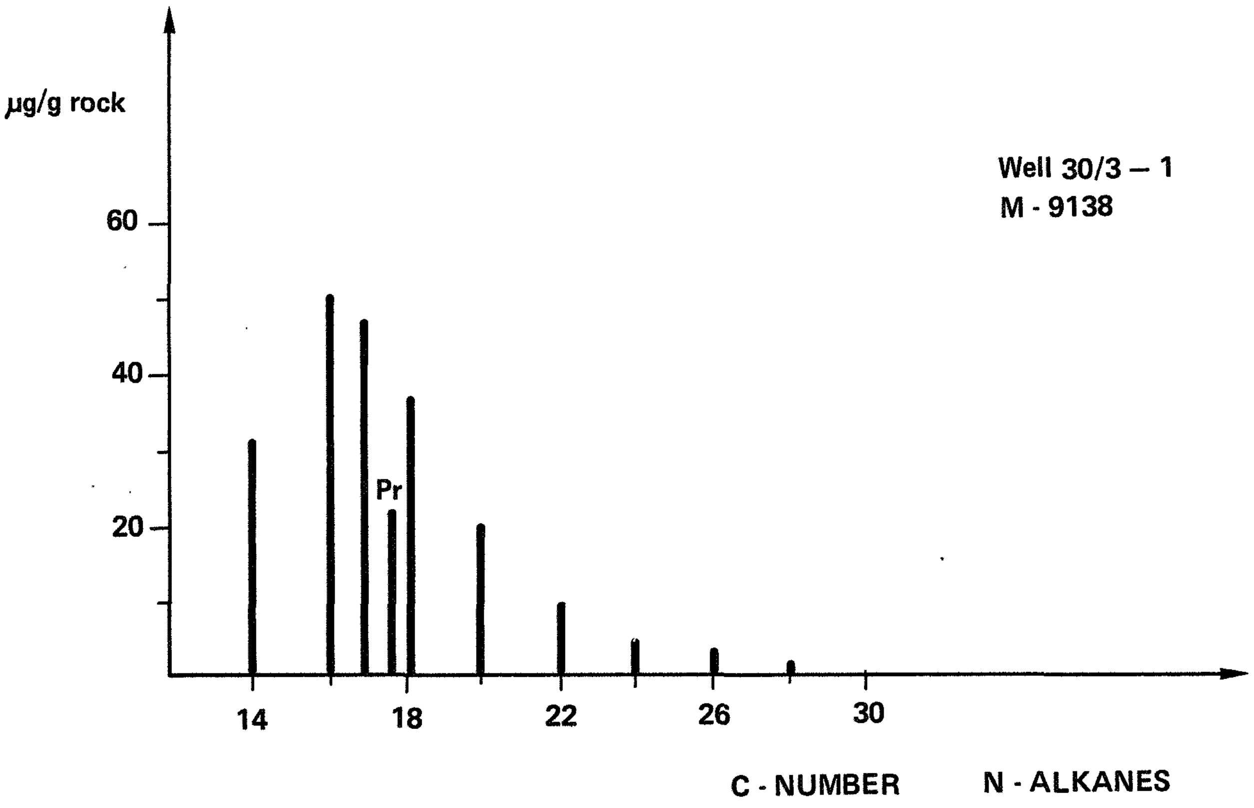
Well 35/8 – 1
M - 9136
3350 -- 3500m
Heather

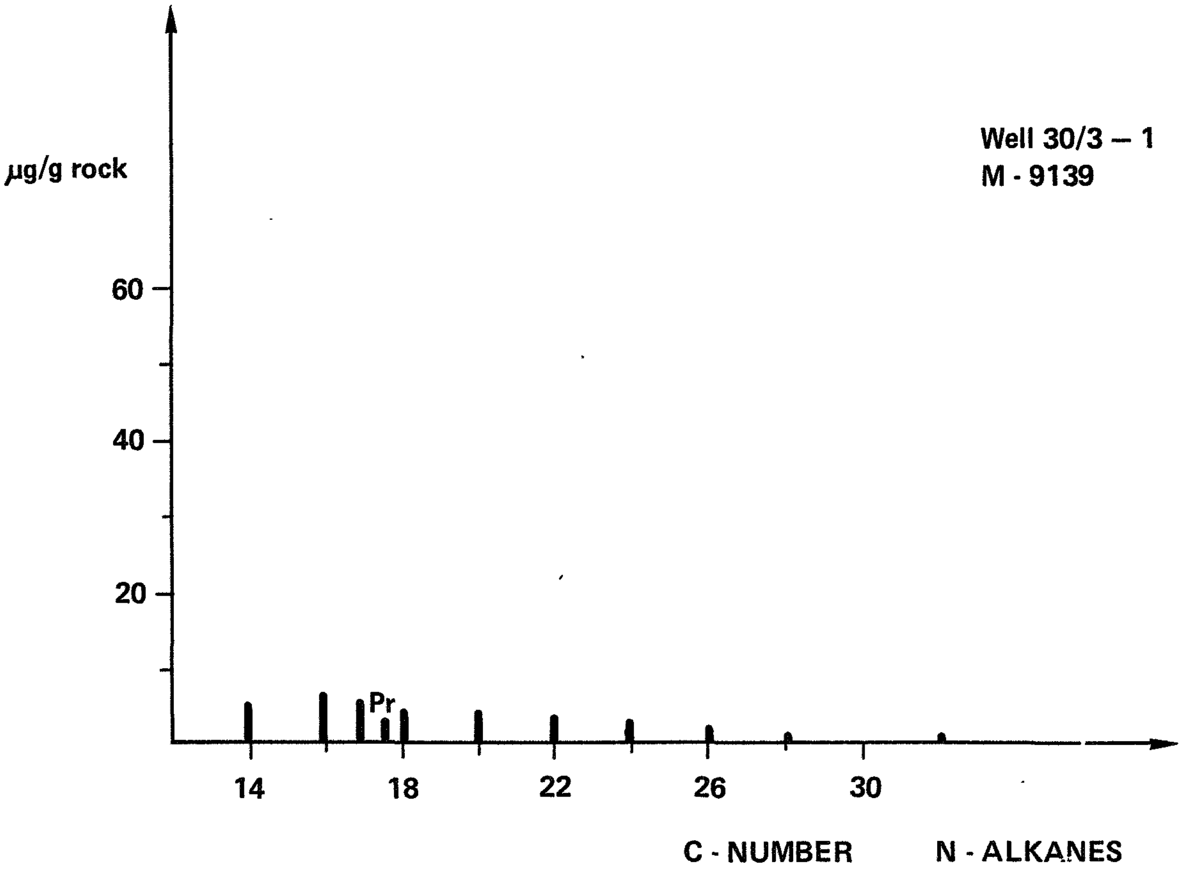


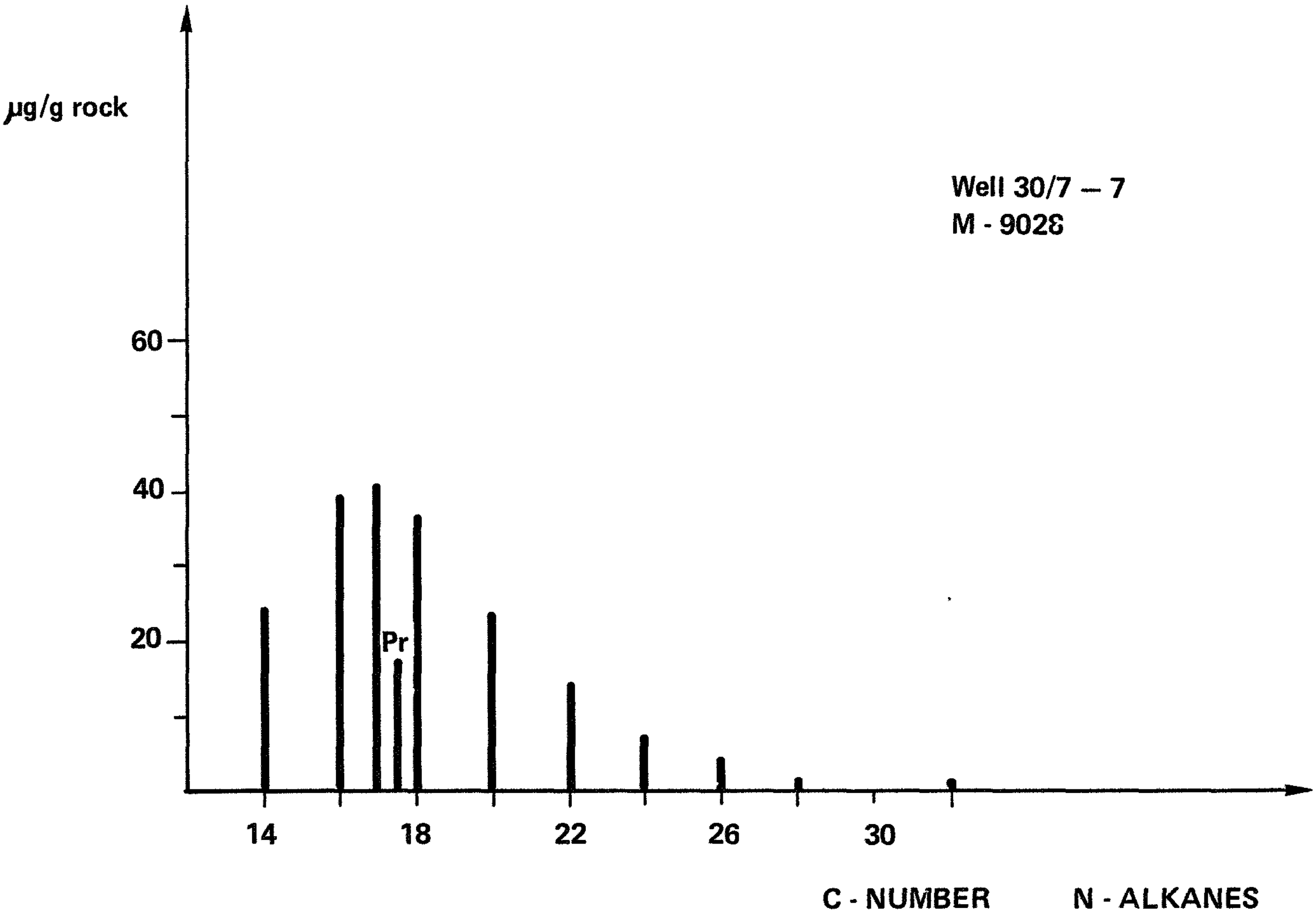
Well 35/8 – 1
M - 9137
3700 – 3800m
Drake

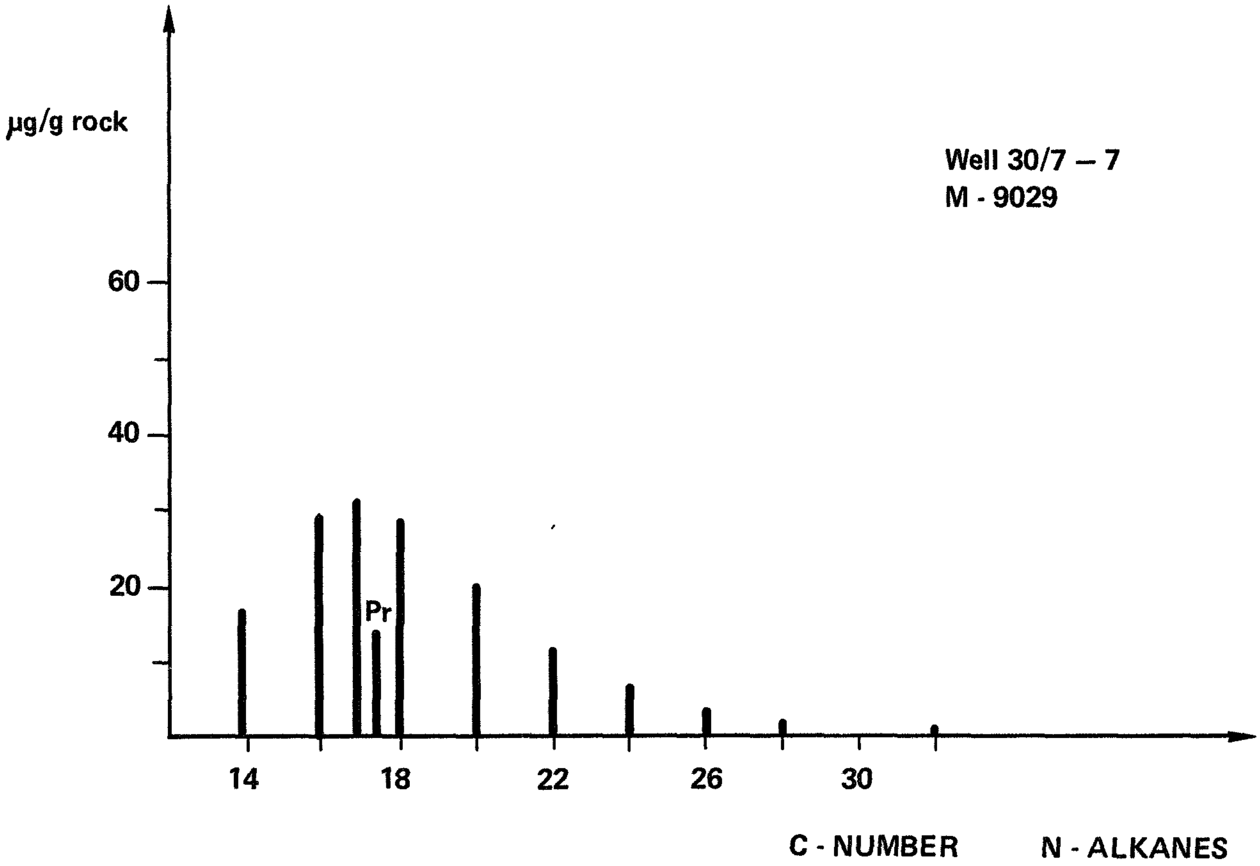
Figure 4

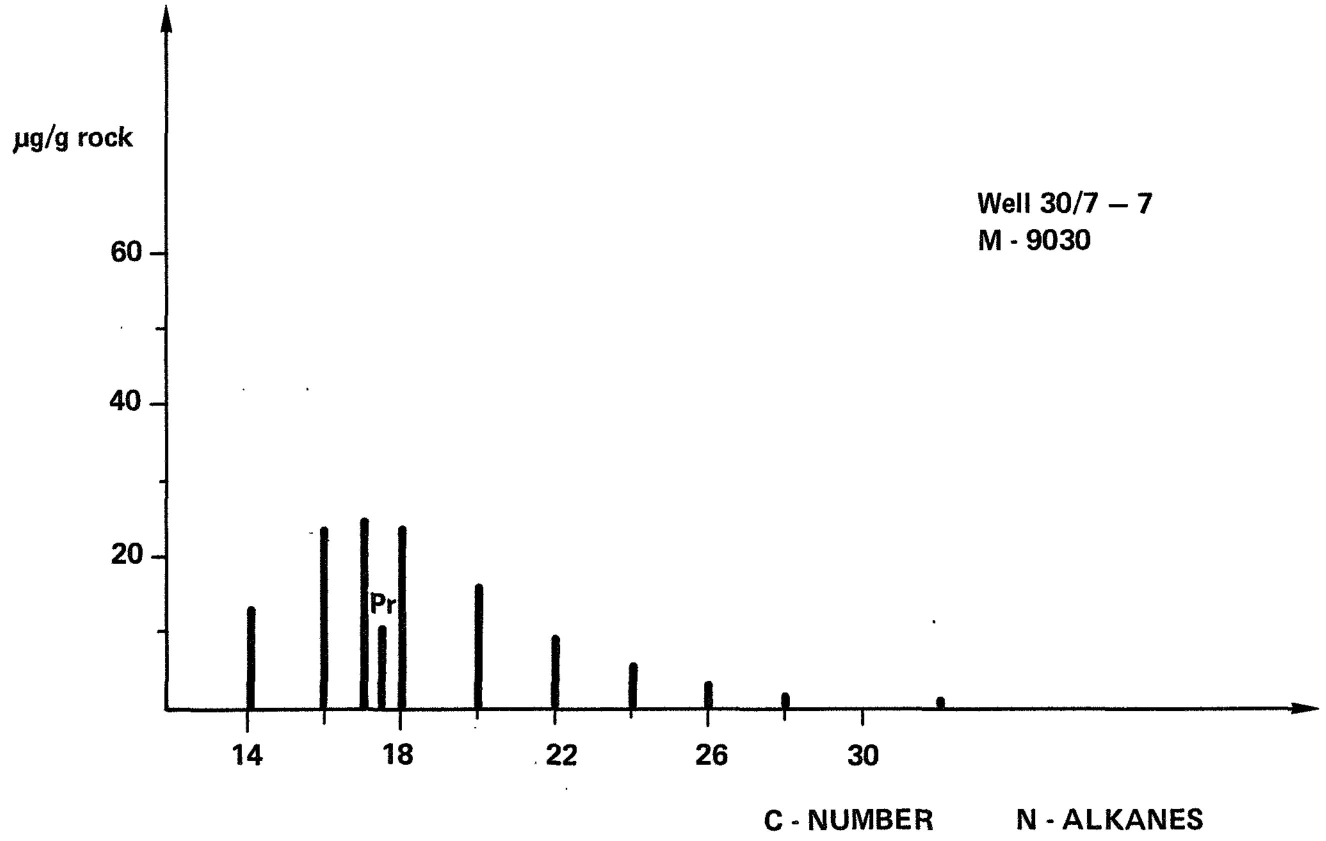
HISTOGRAMS REPRESENTING ABSOLUTE CONCENTRATIONS (μg/g ROCK) OF PRISTANE AND CERTAIN N-ALKANES

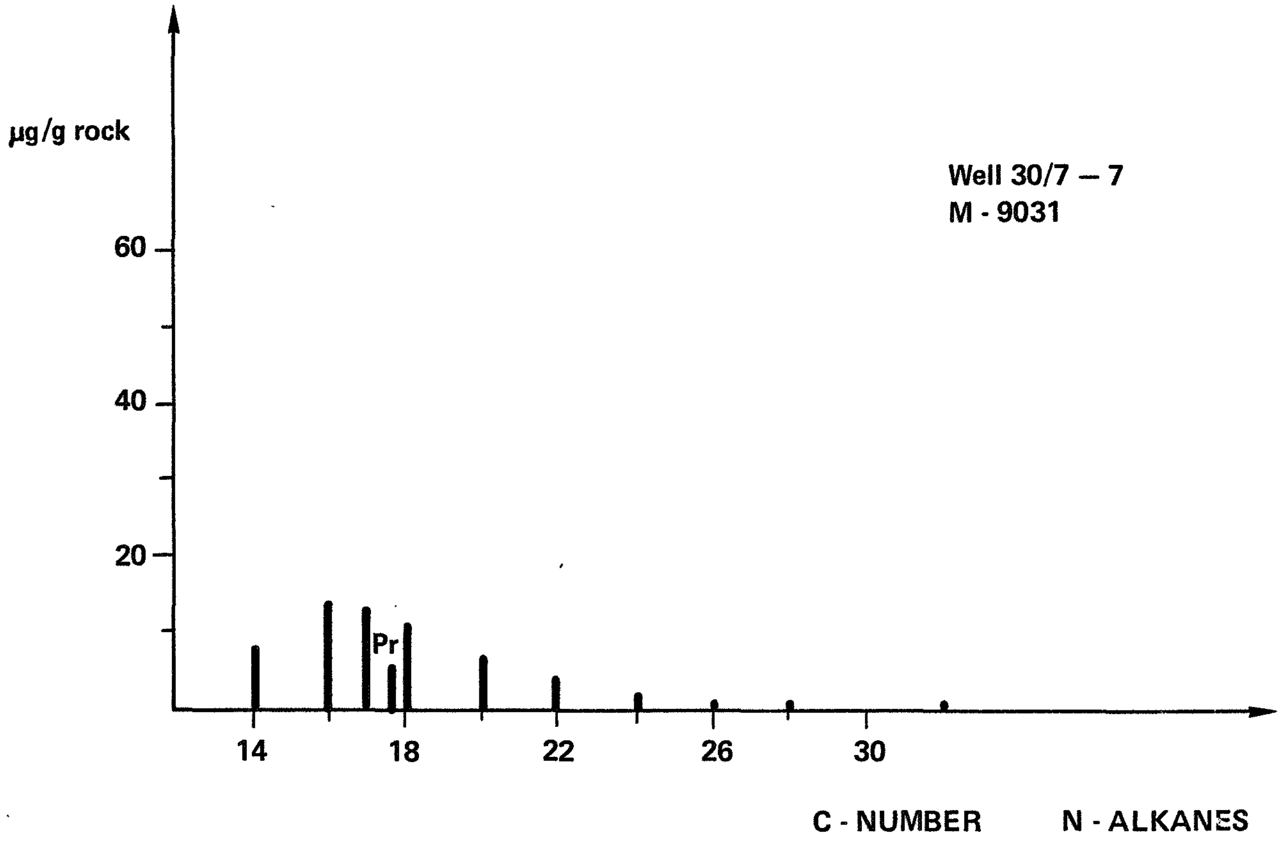

µg/g rock
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES
Well 30/3 – 1
M - 9138

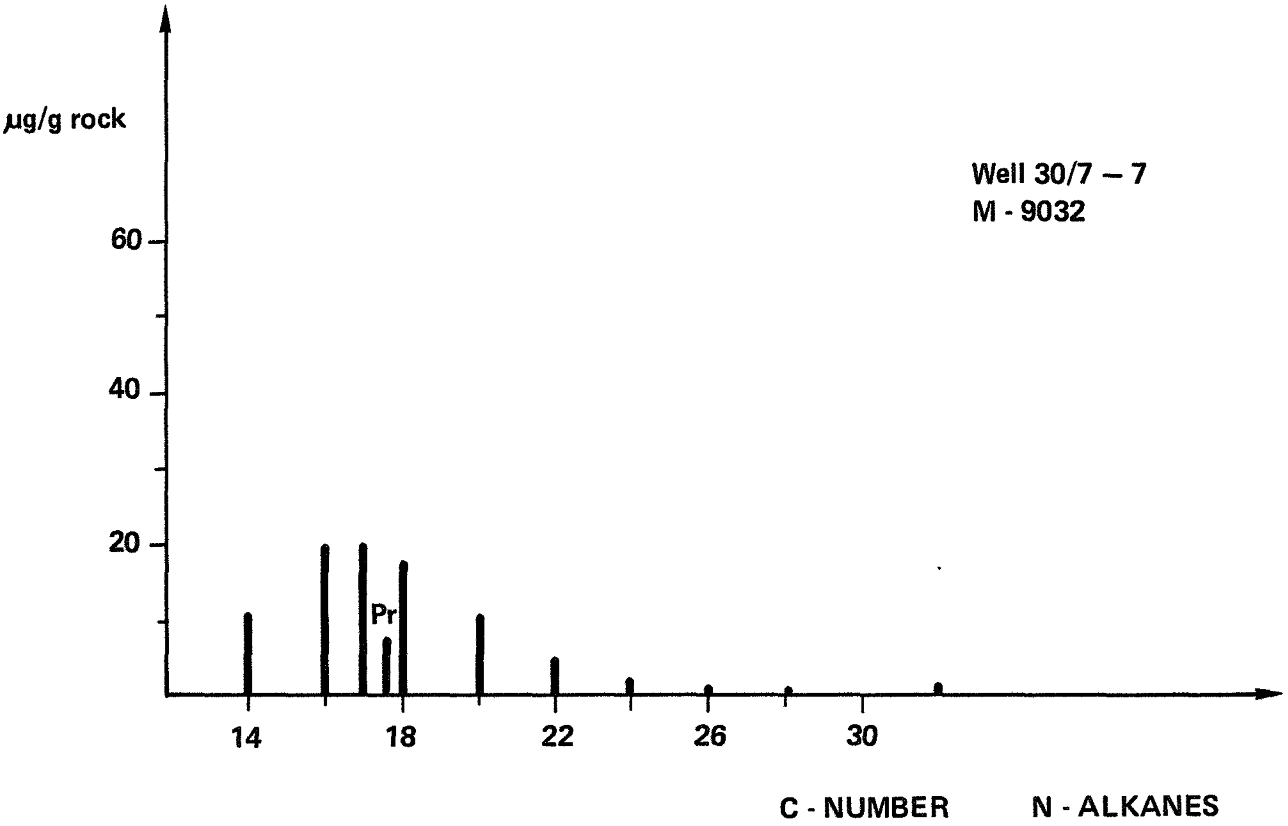

µg/g rock
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES
Well 30/3 – 1
M - 9139

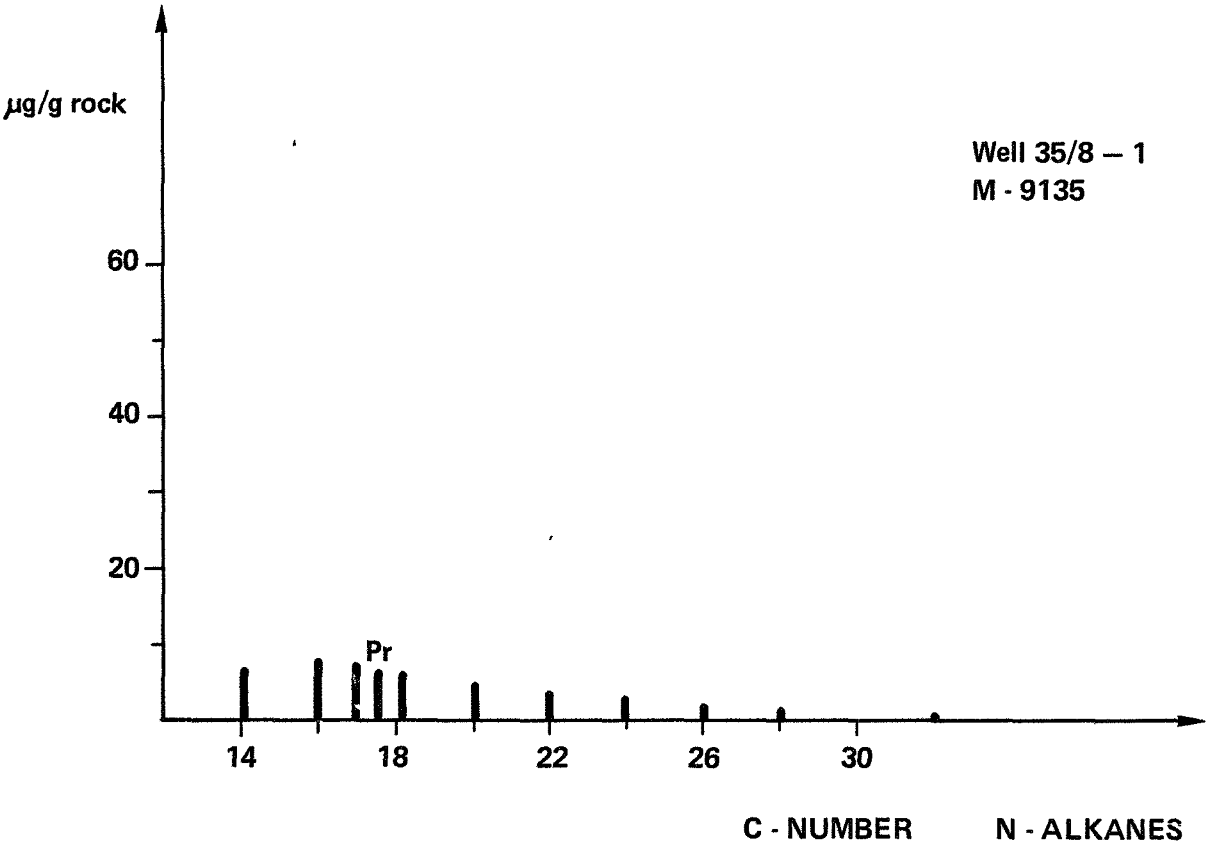

µg/g rock
Well 30/7 – 7
M - 9028
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES

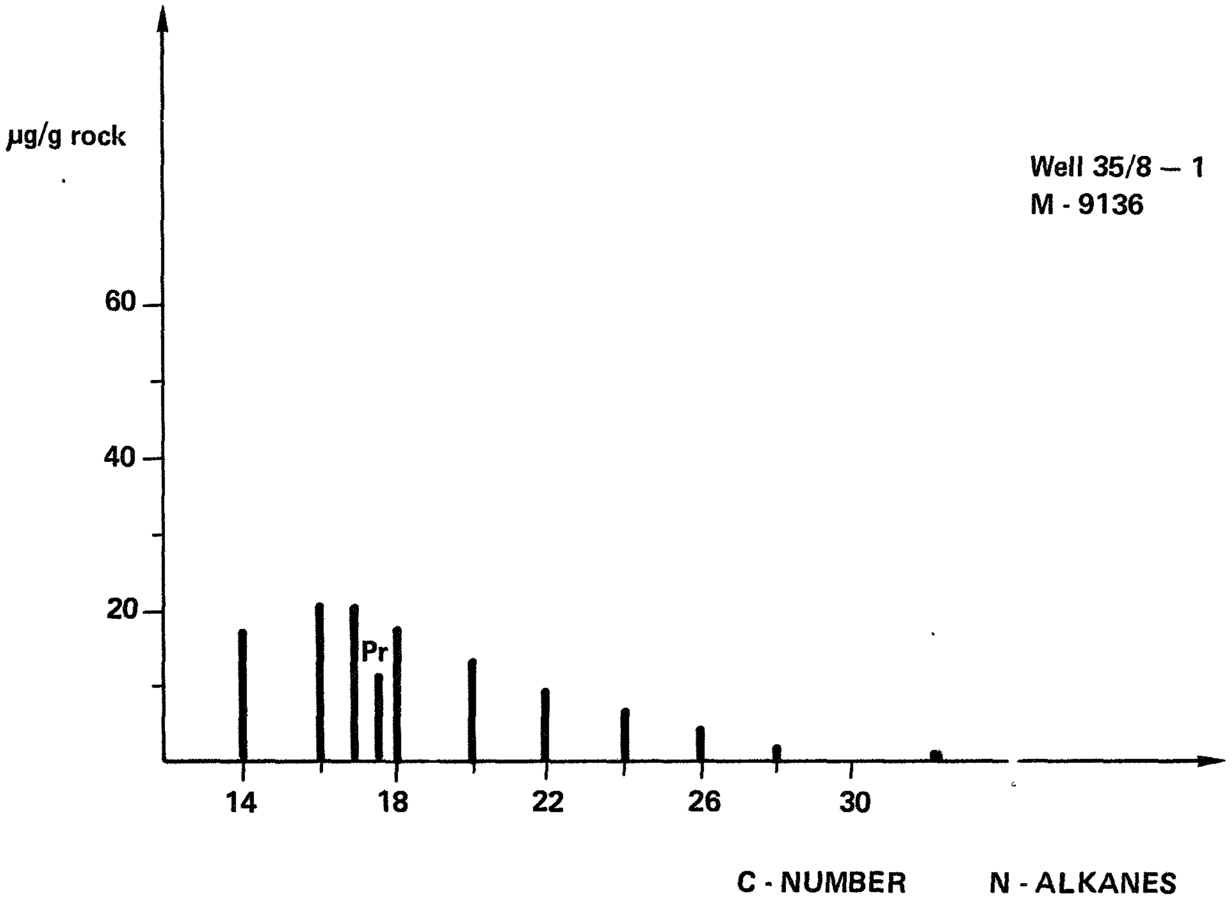

µg/g rock
Well 30/7 – 7
M - 9029
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES

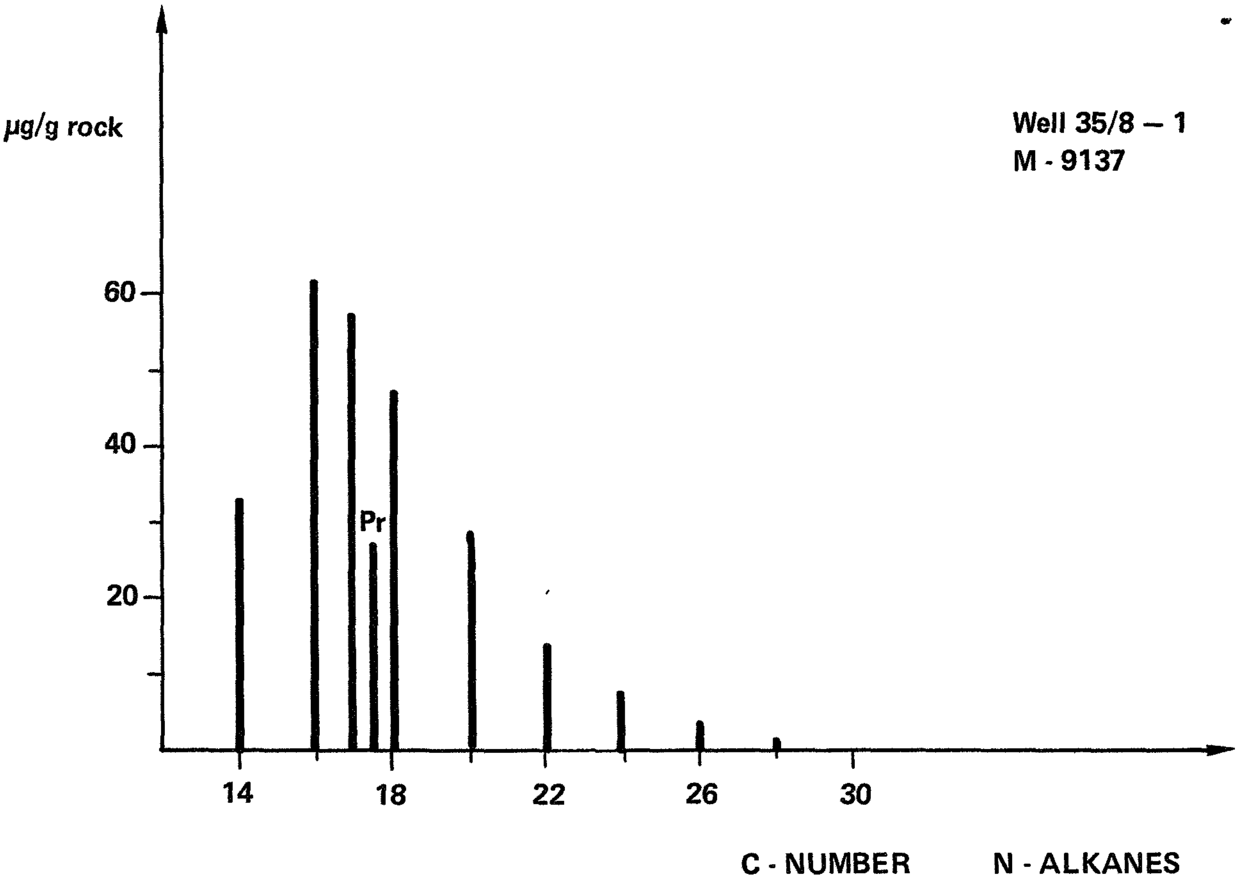

µg/g rock
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES
Well 30/7 – 7
M - 9030


µg/g rock
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES
Well 30/7 – 7
M - 9031


µg/g rock
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES
Well 30/7 – 7
M - 9032


µg/g rock
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES
Well 35/8 – 1
M - 9135


µg/g rock
Well 35/8 – 1
M - 9136
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES


µg/g rock
Well 35/8 – 1
M - 9137
60
40
20
Pr
14
18
22
26
30
C - NUMBER
N - ALKANES

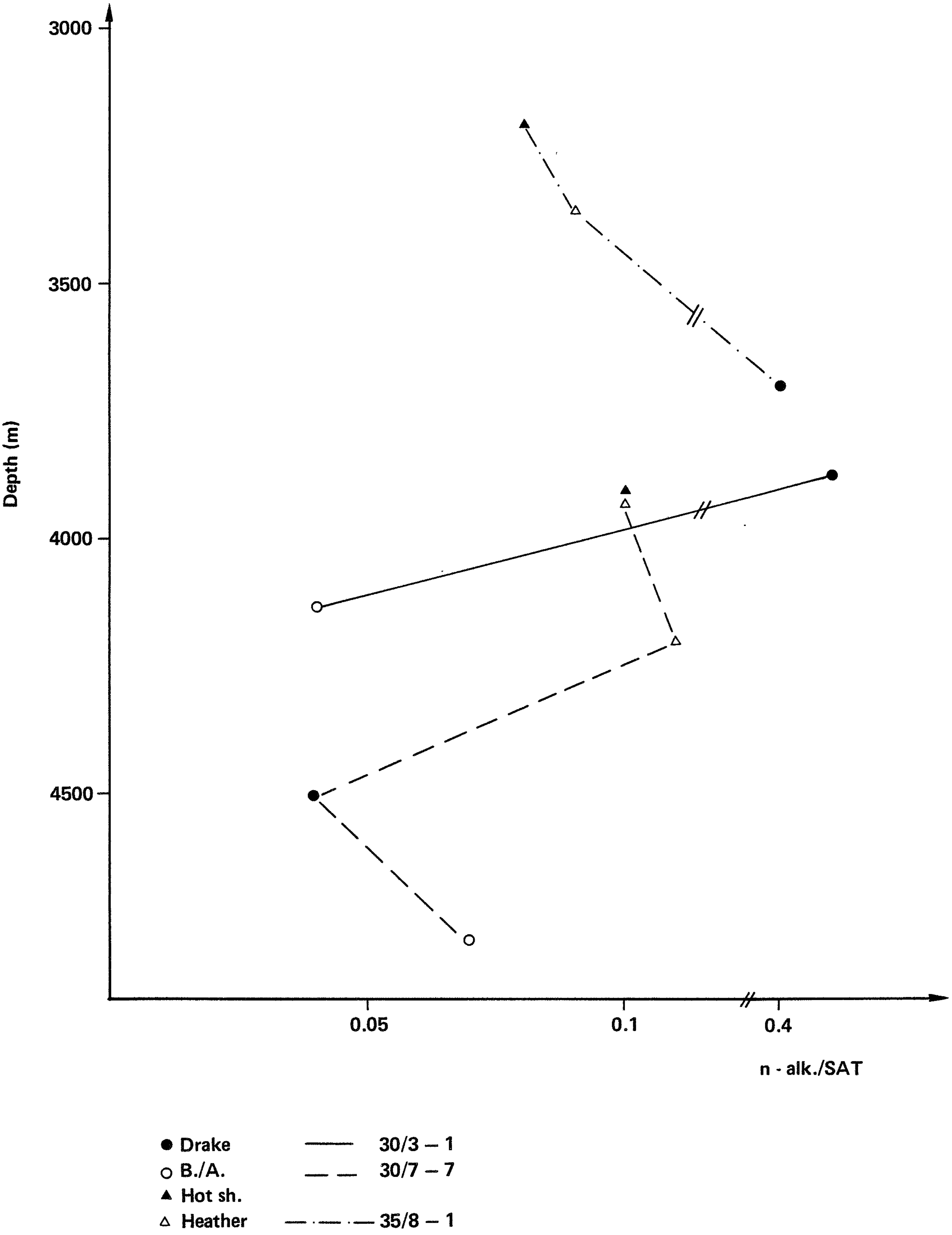


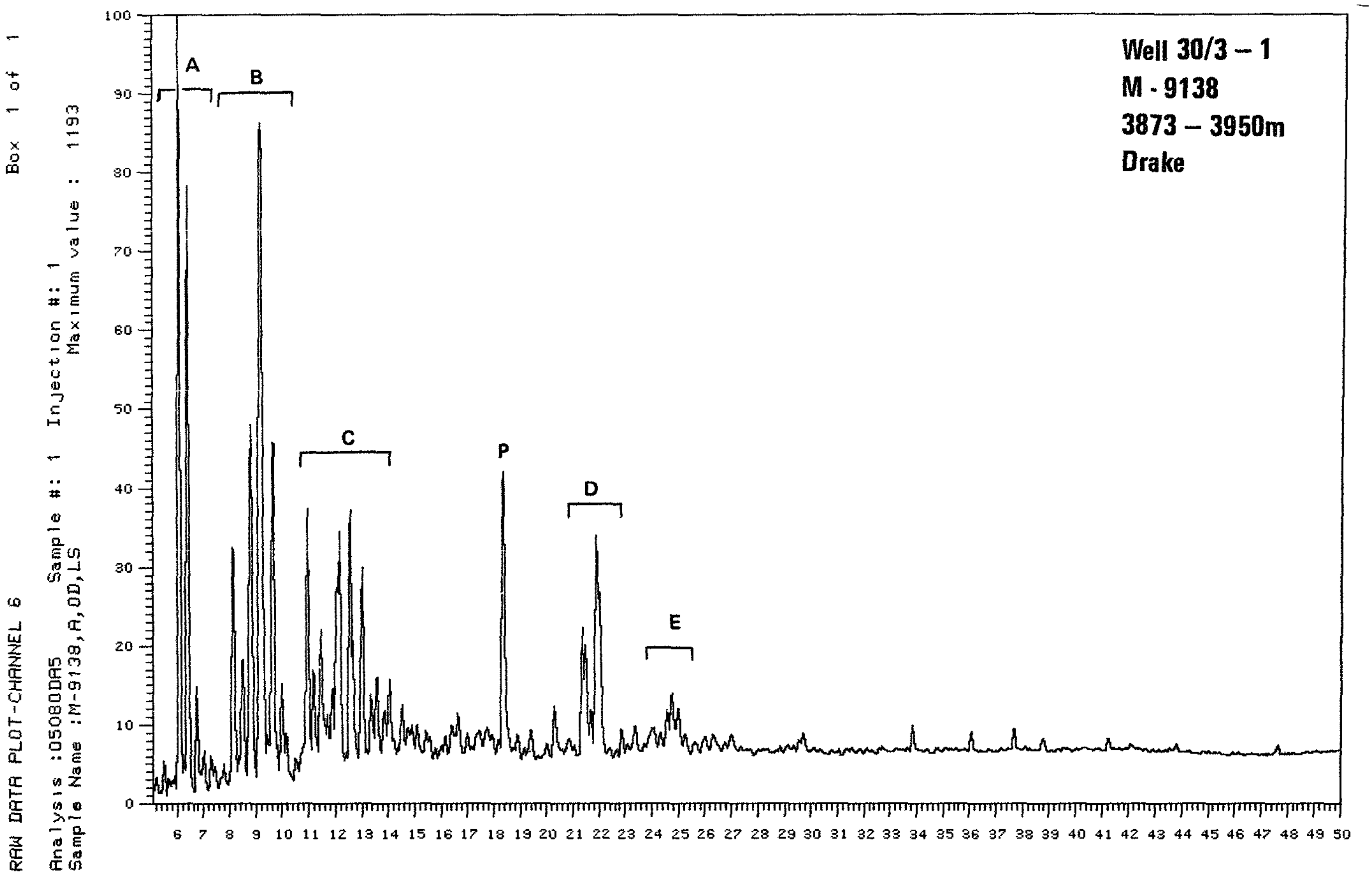
Fig. 5 The variations with depth of the ratio of n - alkanes and the total saturates.

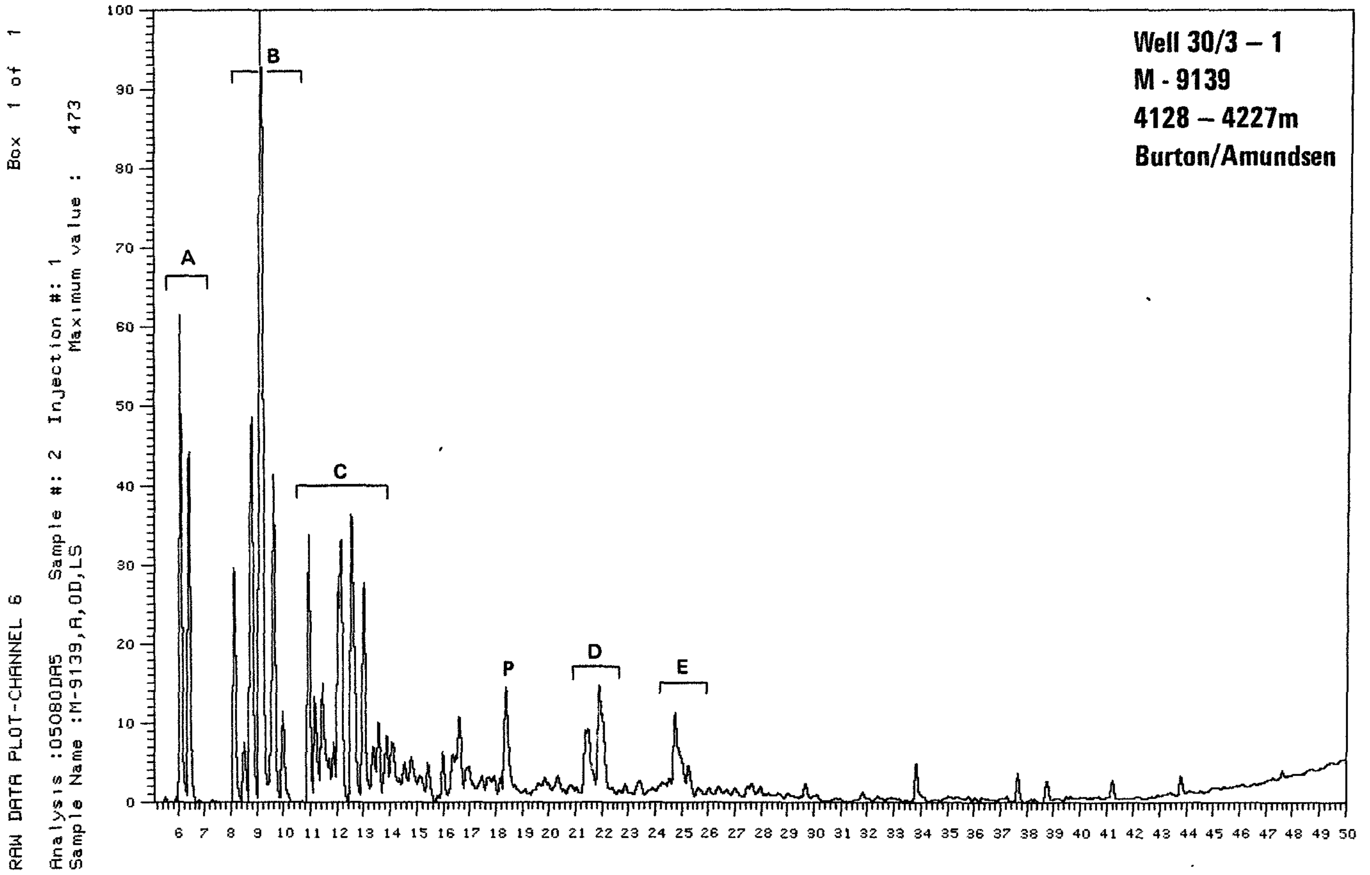
Figure 6, 7

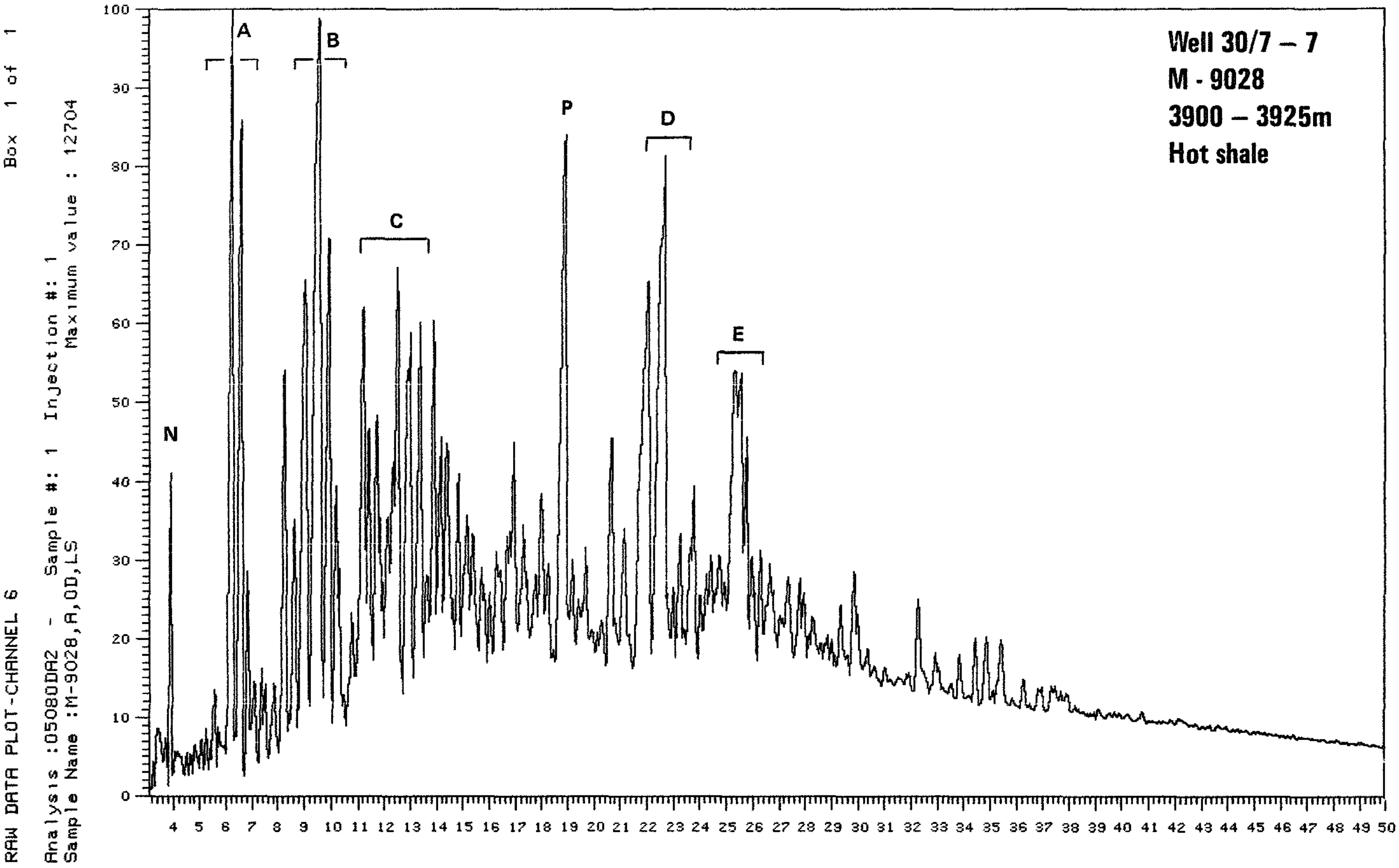
GAS CHROMATOGRAPHIC ANALYSES
AROMATIC HYDROCARBONS

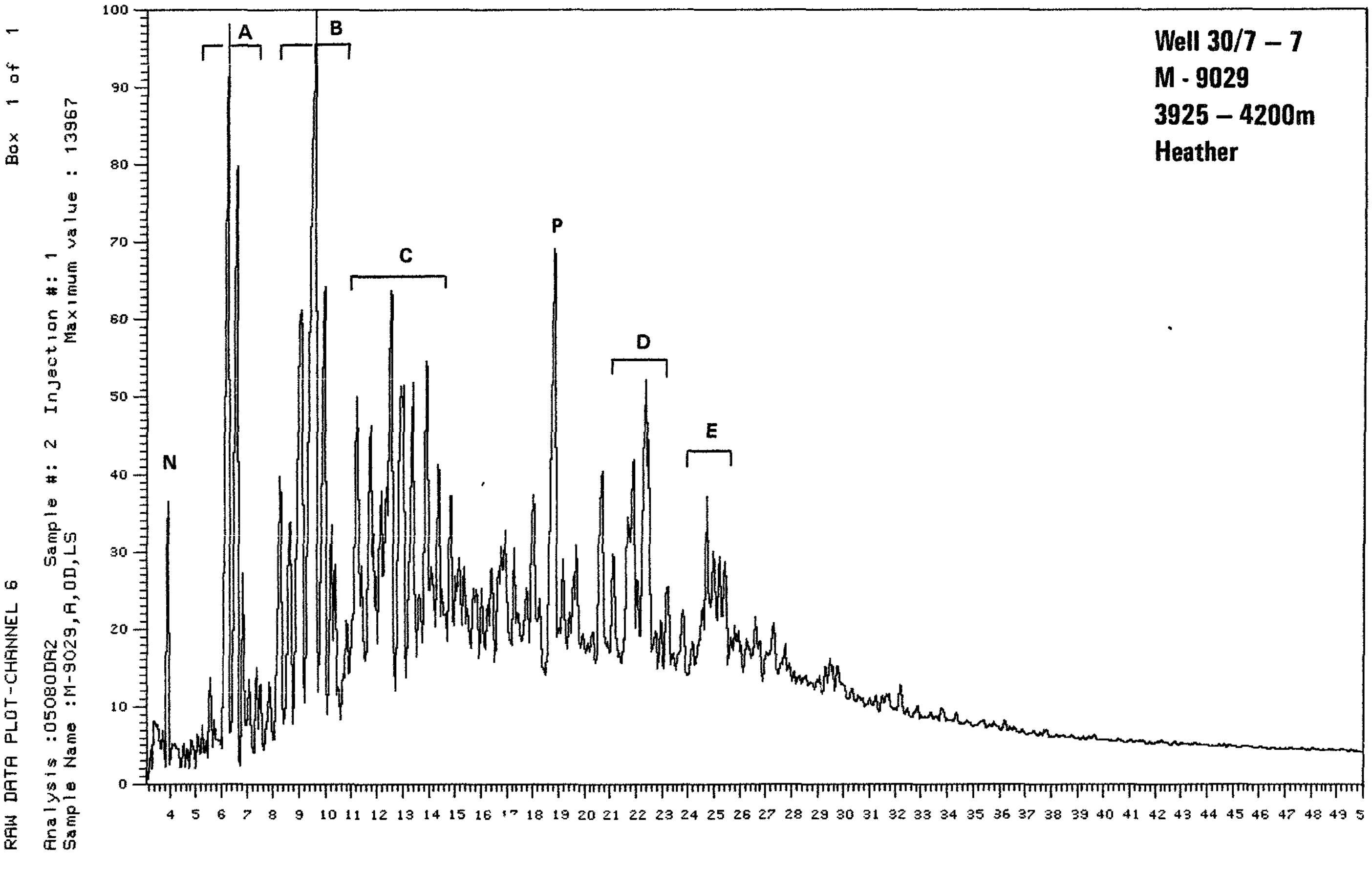
Key:

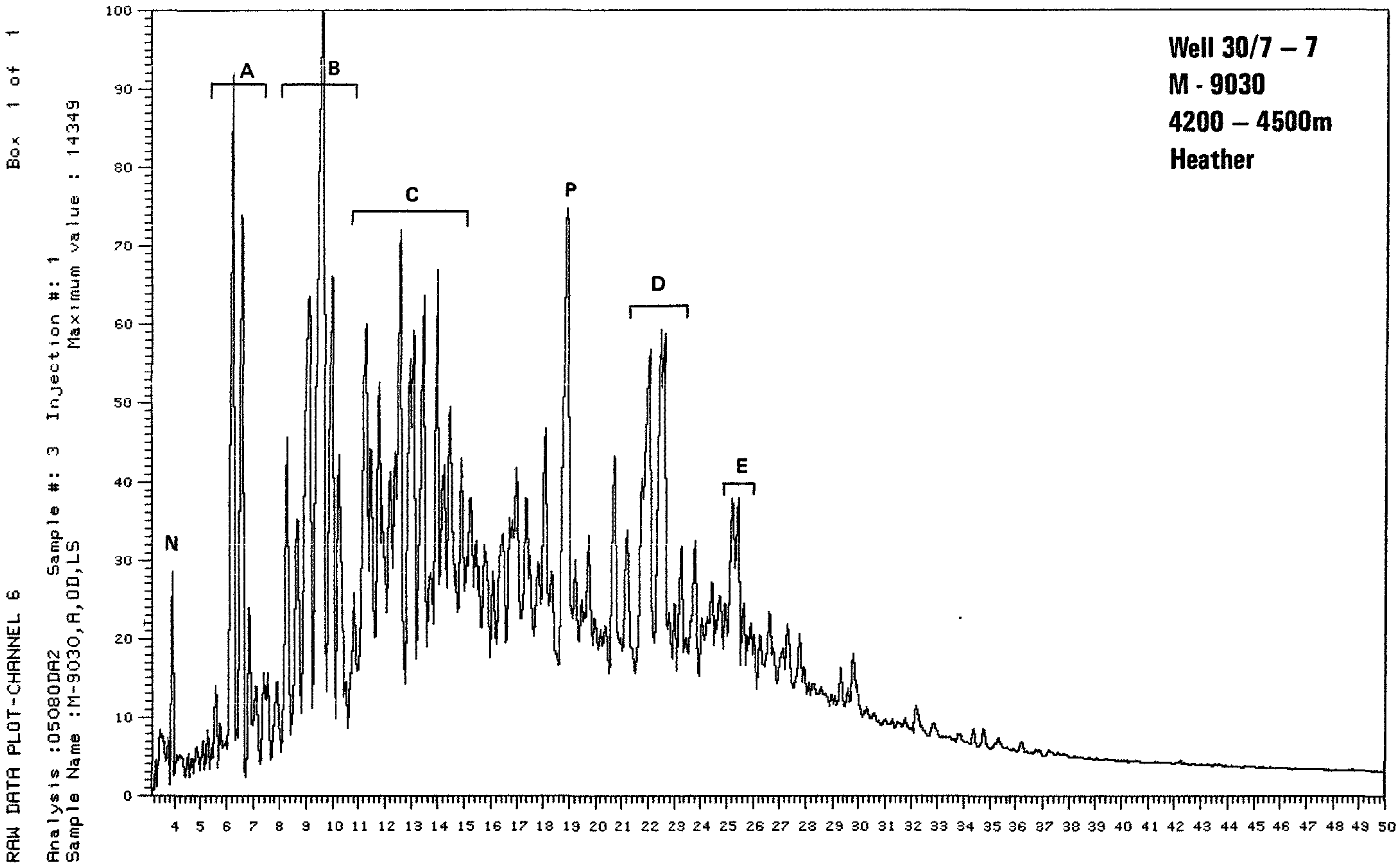
N = naphthalene
A = methyl napthalene
B = dimethyl napthalenes
C = trimethyl napthalene
P = phenanthrene
D = methyl phenanthrenes
E = dimethyl phenanthrenes

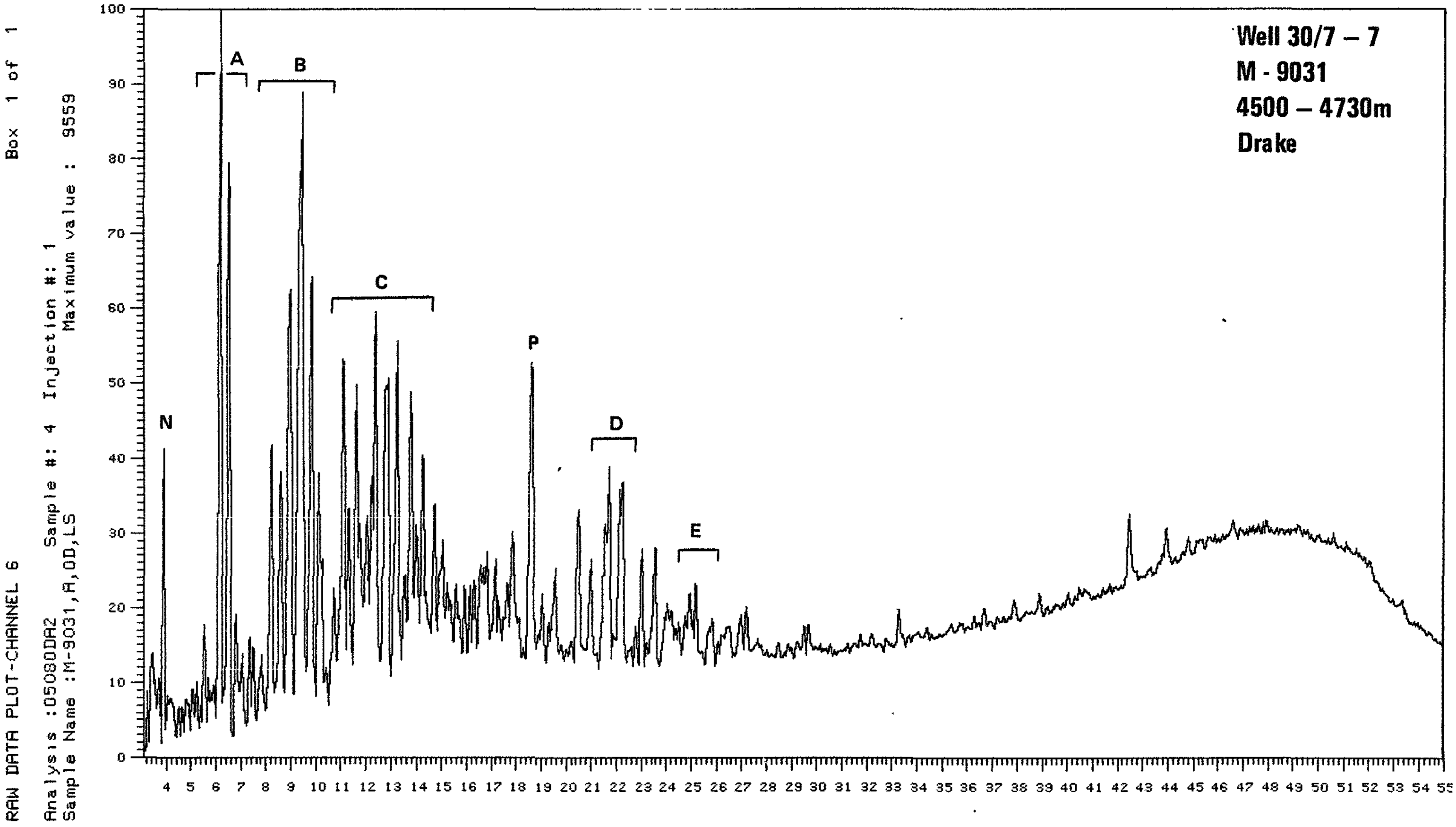

RAW DATA PLOT-CHANNEL 6
Box 1 of 1
Analysis :05080DA5 Sample #: 1 Injection #: 1
Sample Name :M-9138,A,OD,LS Maximum value : 1193
Well 30/3 – 1
M - 9138
3873 – 3950m
Drake
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

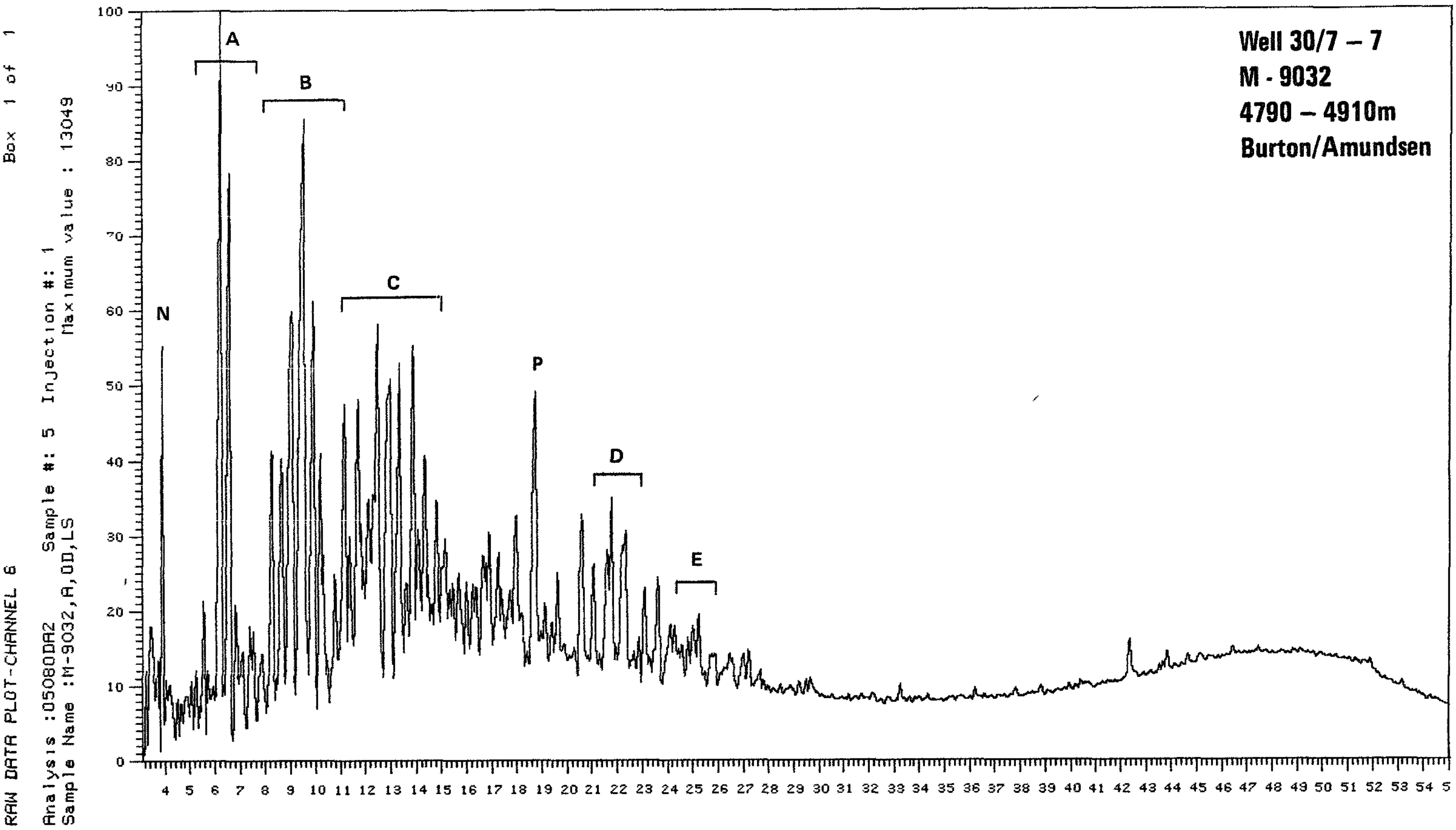

RAW DATA PLOT-CHANNEL 6
Box 1 of 1
Analysis :05080DA5 Sample #: 2 Injection #: 1
Sample Name :M-9139,A,OD,LS Maximum value : 473
Well 30/3 – 1
M - 9139
4128 – 4227m
Burton/Amundsen
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

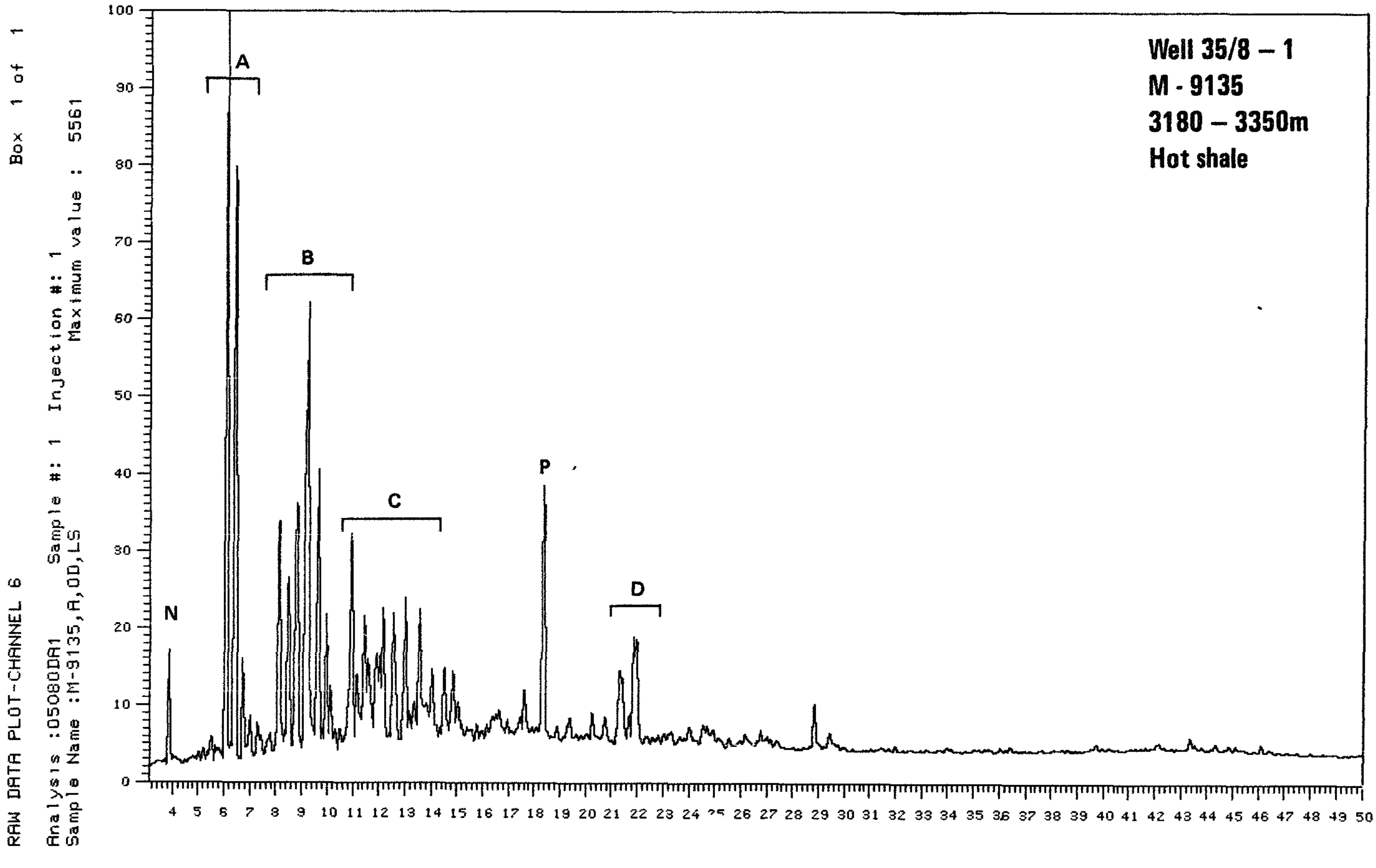

RAW DATA PLOT-CHANNEL 6
Analysis :05080DA2 - Sample #: 1 Injection #: 1
Sample Name :M-9028,A,OD,LS Maximum value : 12704
Box 1 of 1
Well 30/7 – 7
M - 9028
3900 – 3925m
Hot shale
N
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

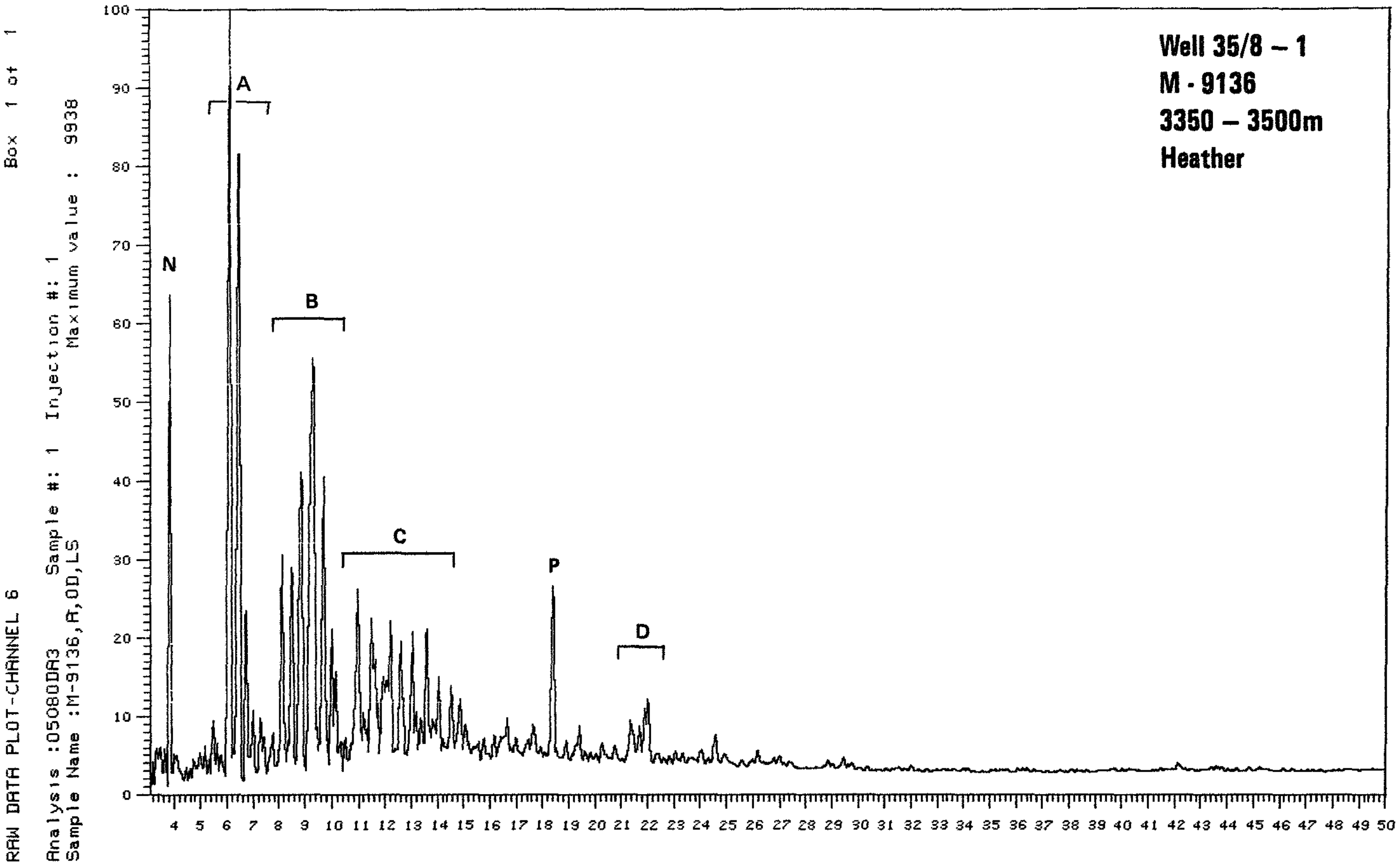

RAW DATA PLOT-CHANNEL 6
Analysis :05080DA2 Sample #: 2 Injection #: 1
Sample Name :M-9029,A,OD,LS Maximum value : 13967
Box 1 of 1
Well 30/7 – 7
M - 9029
3925 – 4200m
Heather
N
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 5

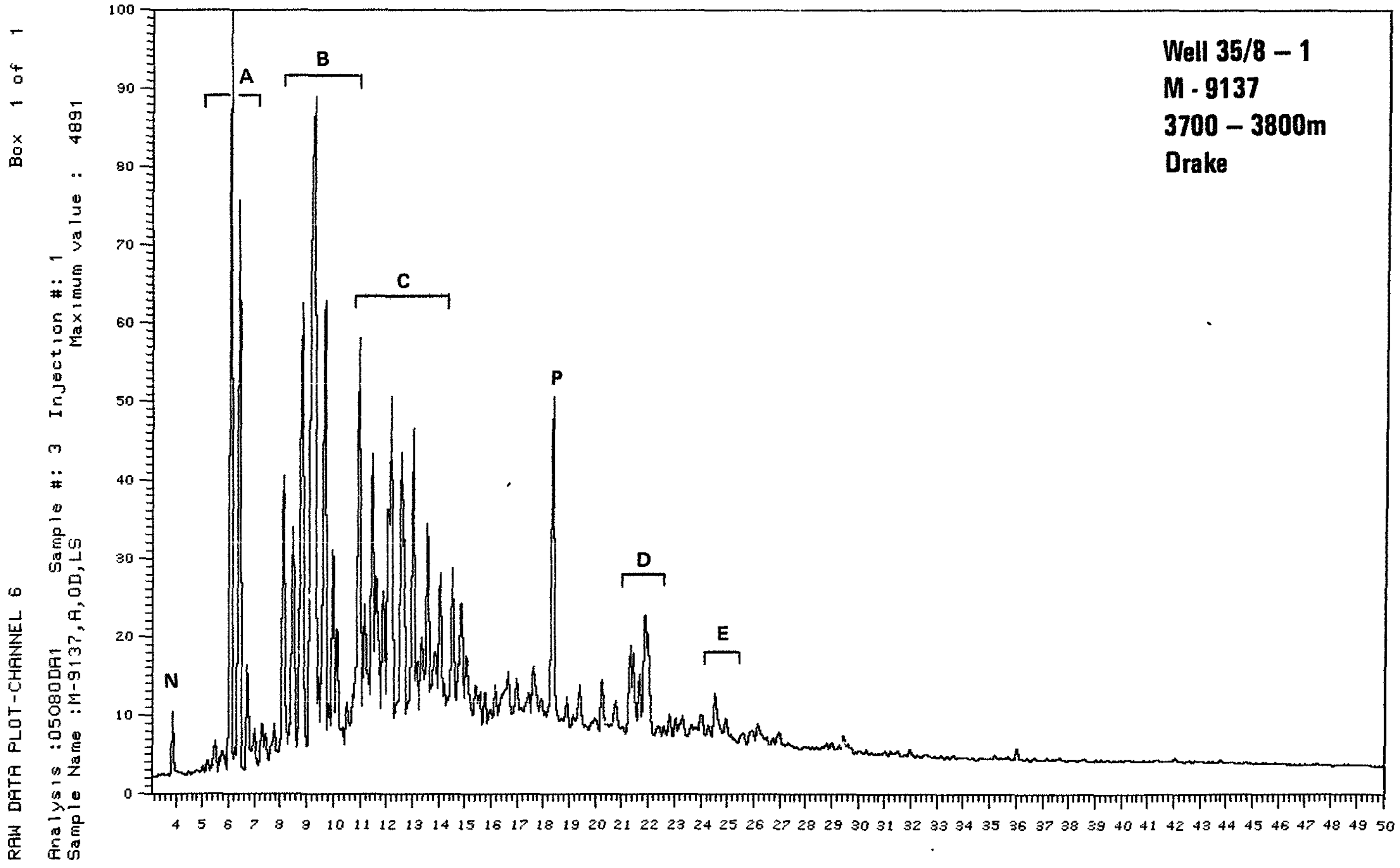

RAW DATA PLOT-CHANNEL 6
Analysis :05080DA2 Sample #: 3 Injection #: 1
Sample Name :M-9030,A,OD,LS Maximum value : 14349
Box 1 of 1
Well 30/7 – 7
M - 9030
4200 – 4500m
Heather
N
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

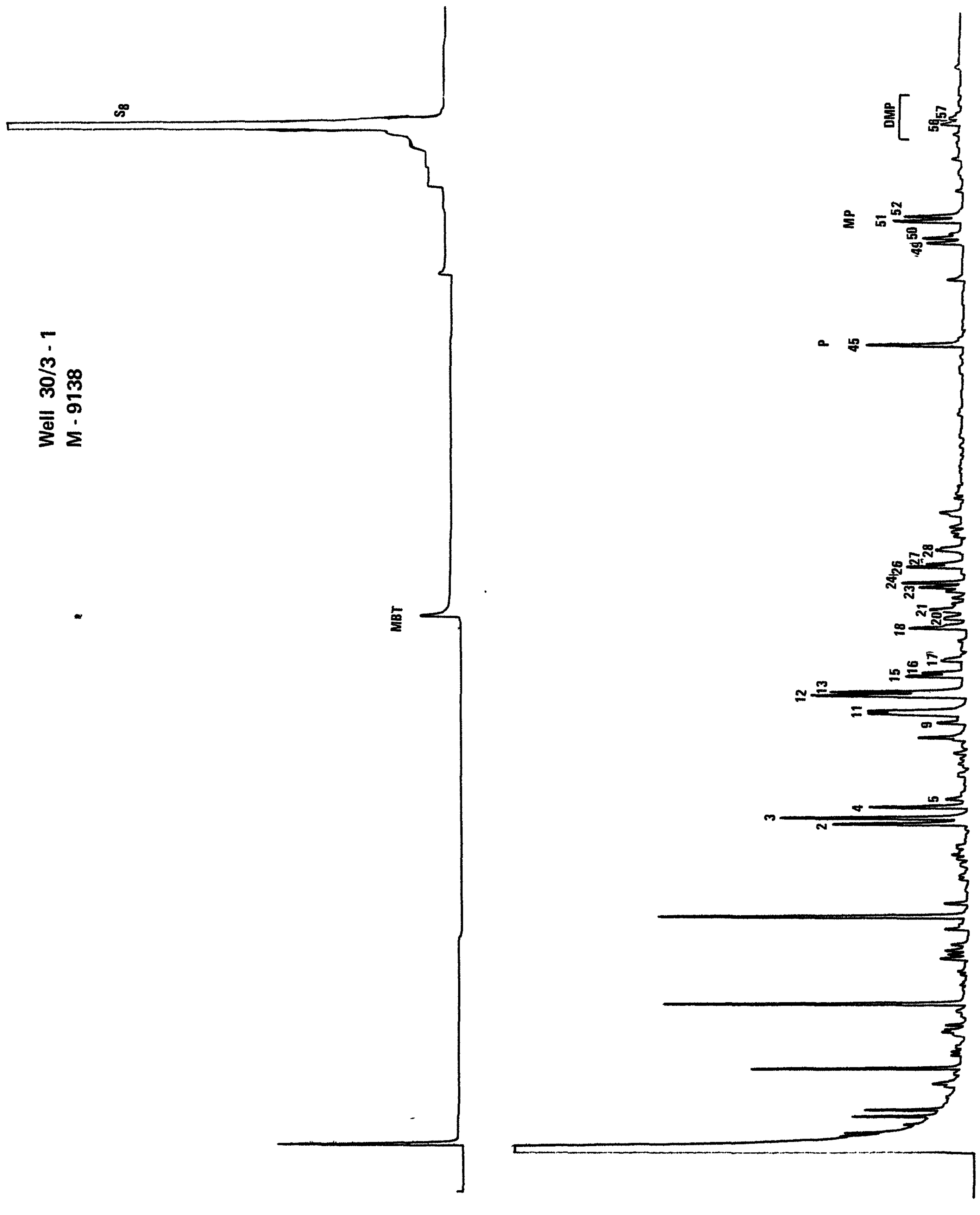

RAW DATA PLOT-CHANNEL 6
Analysis :05080DA2 Sample #: 4 Injection #: 1
Sample Name :M-9031,A,OD,LS Maximum value : 9559
Box 1 of 1
Well 30/7 – 7
M - 9031
4500 – 4730m
Drake
N
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55


Well 30/7 – 7
M - 9032
4790 – 4910m
Burton/Amundsen
N
A
B
C
P
D
E
RAW DATA PLOT-CHANNEL 6
Analysis :05080DA2 Sample #: 5 Injection #: 1
Sample Name :M-9032,A,OD,LS Maximum value : 13049
Box 1 of 1
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 5

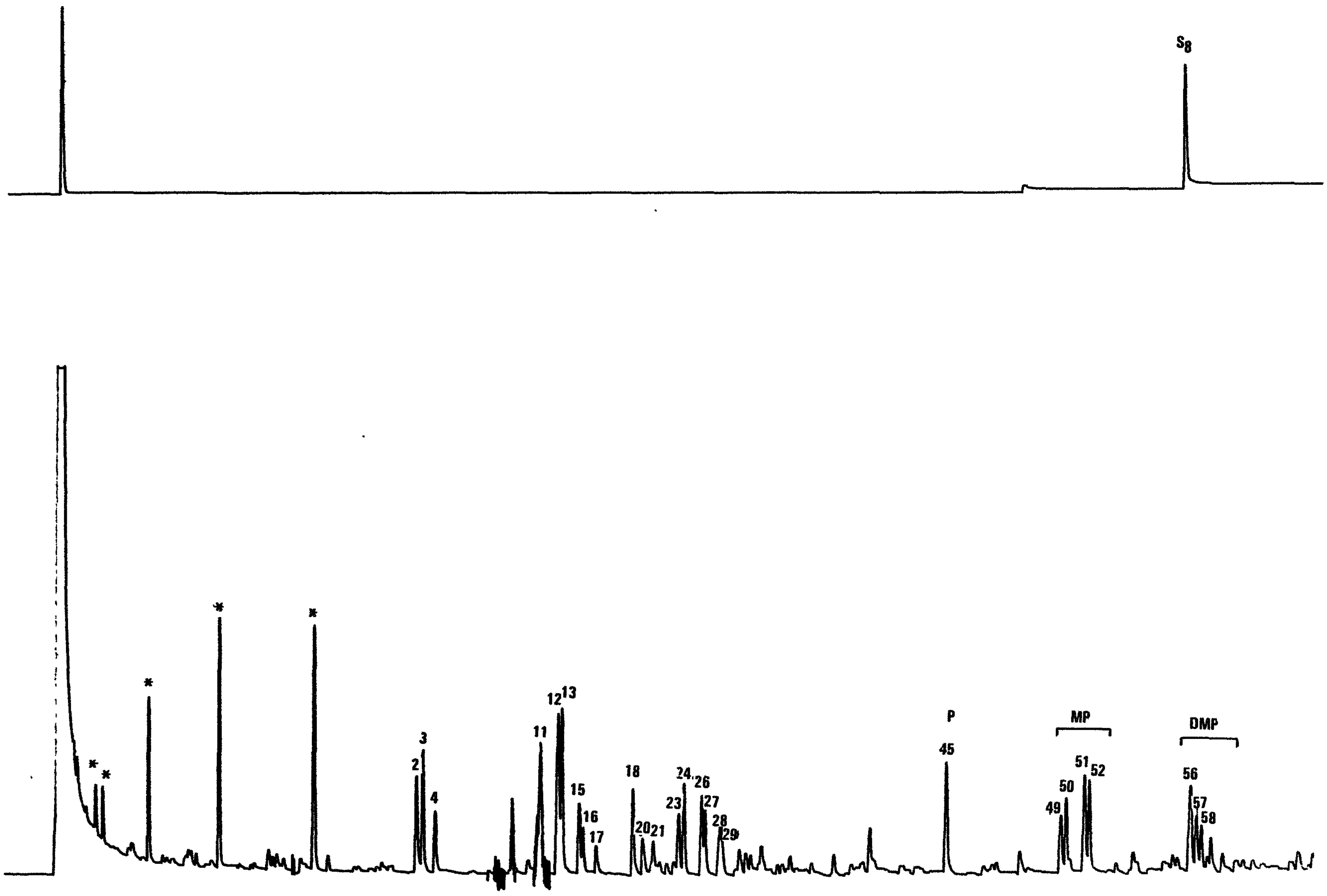

Well 35/8 – 1
M - 9135
3180 – 3350m
Hot shale
N
A
B
C
P
D
RAW DATA PLOT-CHANNEL 6
Analysis :05080DA1 Sample #: 1 Injection #: 1
Sample Name :M-9135,A,OD,LS Maximum value : 5561
Box 1 of 1
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50


Well 35/8 – 1
M - 9136
3350 – 3500m
Heather
RAW DATA PLOT-CHANNEL 6
Analysis :05080DA3 Sample #: 1 Injection #: 1
Sample Name :M-9136,A,OD,LS Maximum value : 9938
Box 1 of 1
N
A
B
C
P
D
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

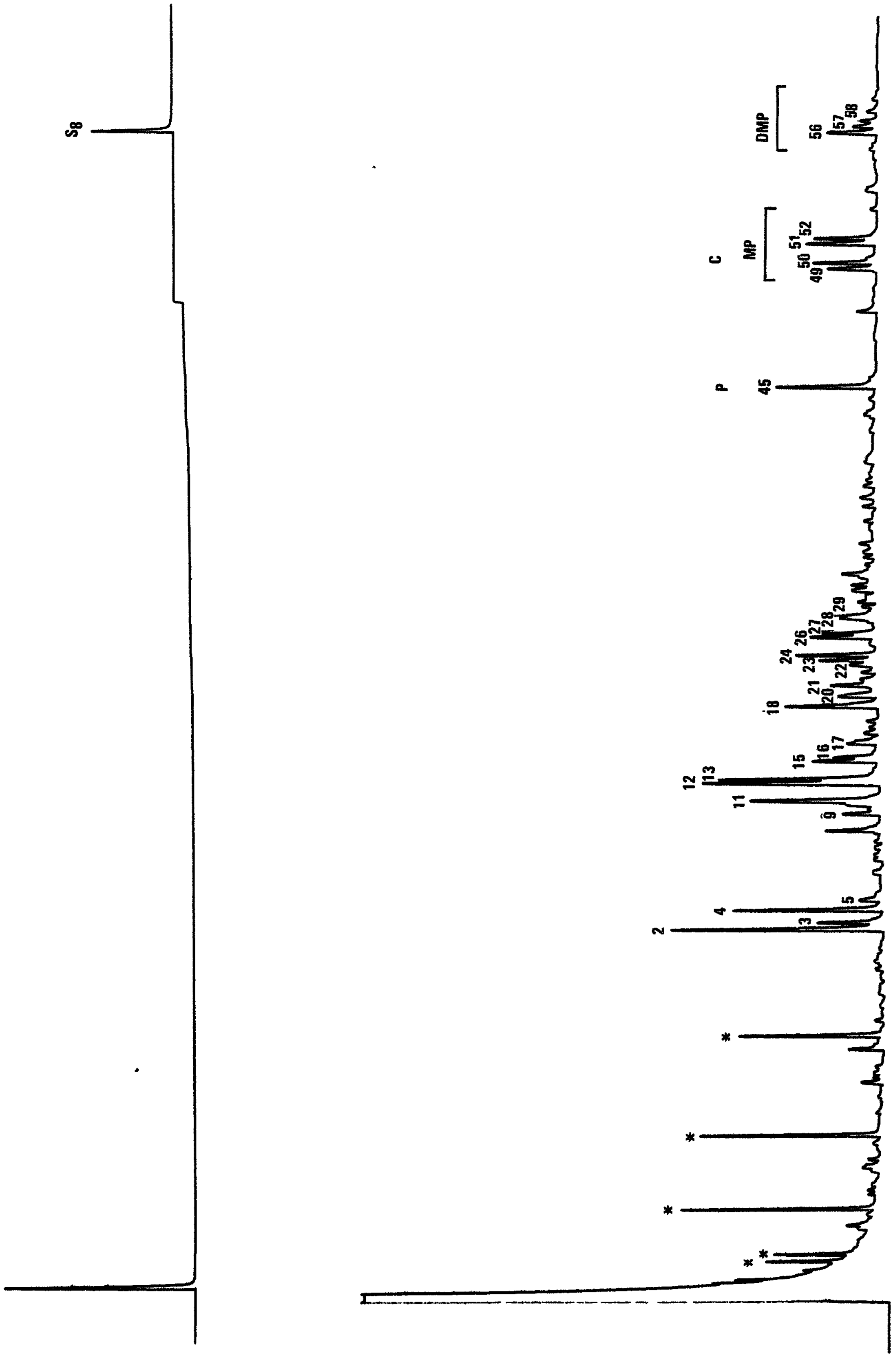

Well 35/8 – 1
M - 9137
3700 – 3800m
Drake
RAW DATA PLOT-CHANNEL 6
Analysis :05080DA1 Sample #: 3 Injection #: 1
Sample Name :M-9137,A,OD,LS Maximum value : 4891
Box 1 of 1
N
A
B
C
P
D
E
0
10
20
30
40
50
60
70
80
90
100
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

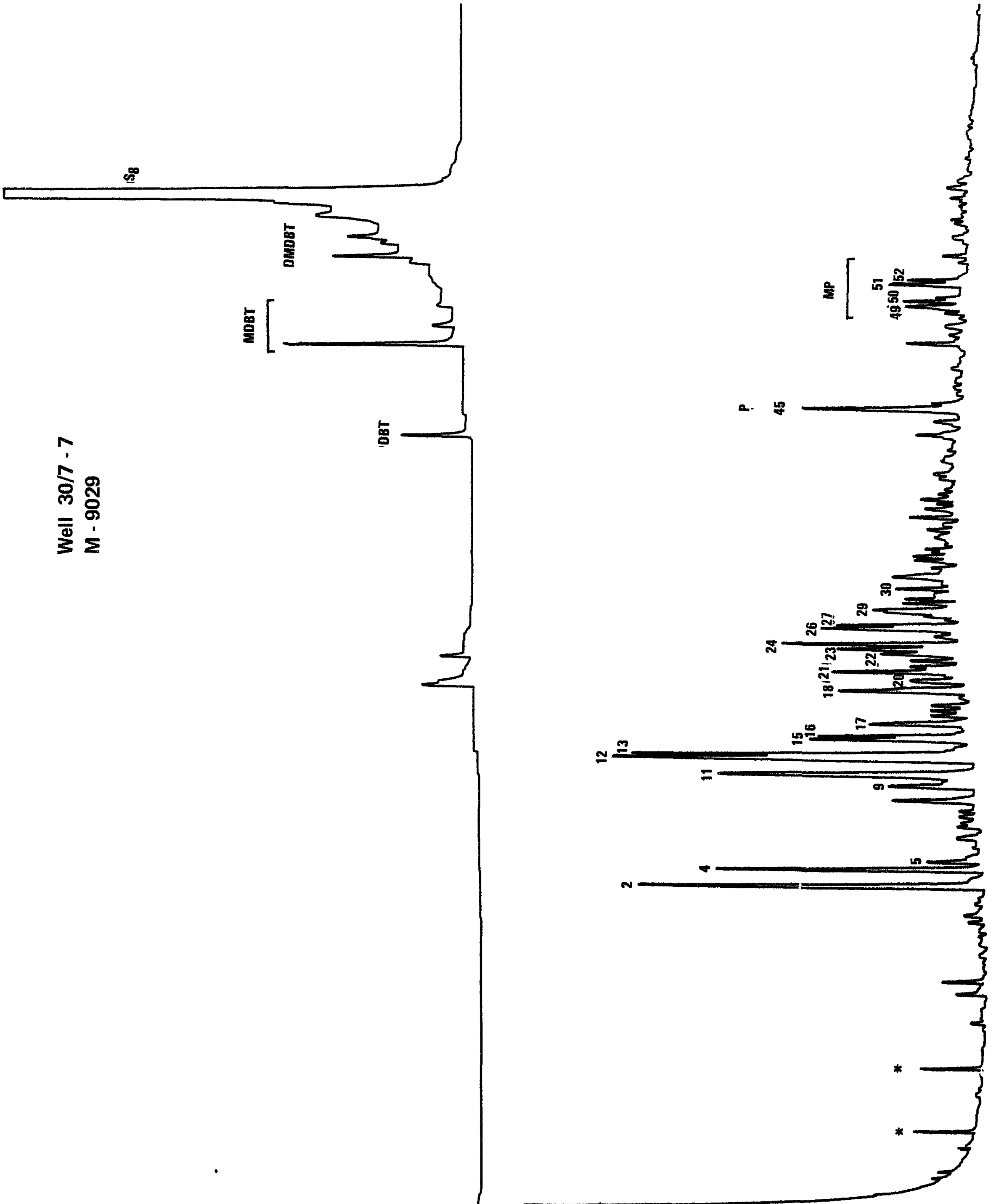

Well 30/3 - 1
M - 9138

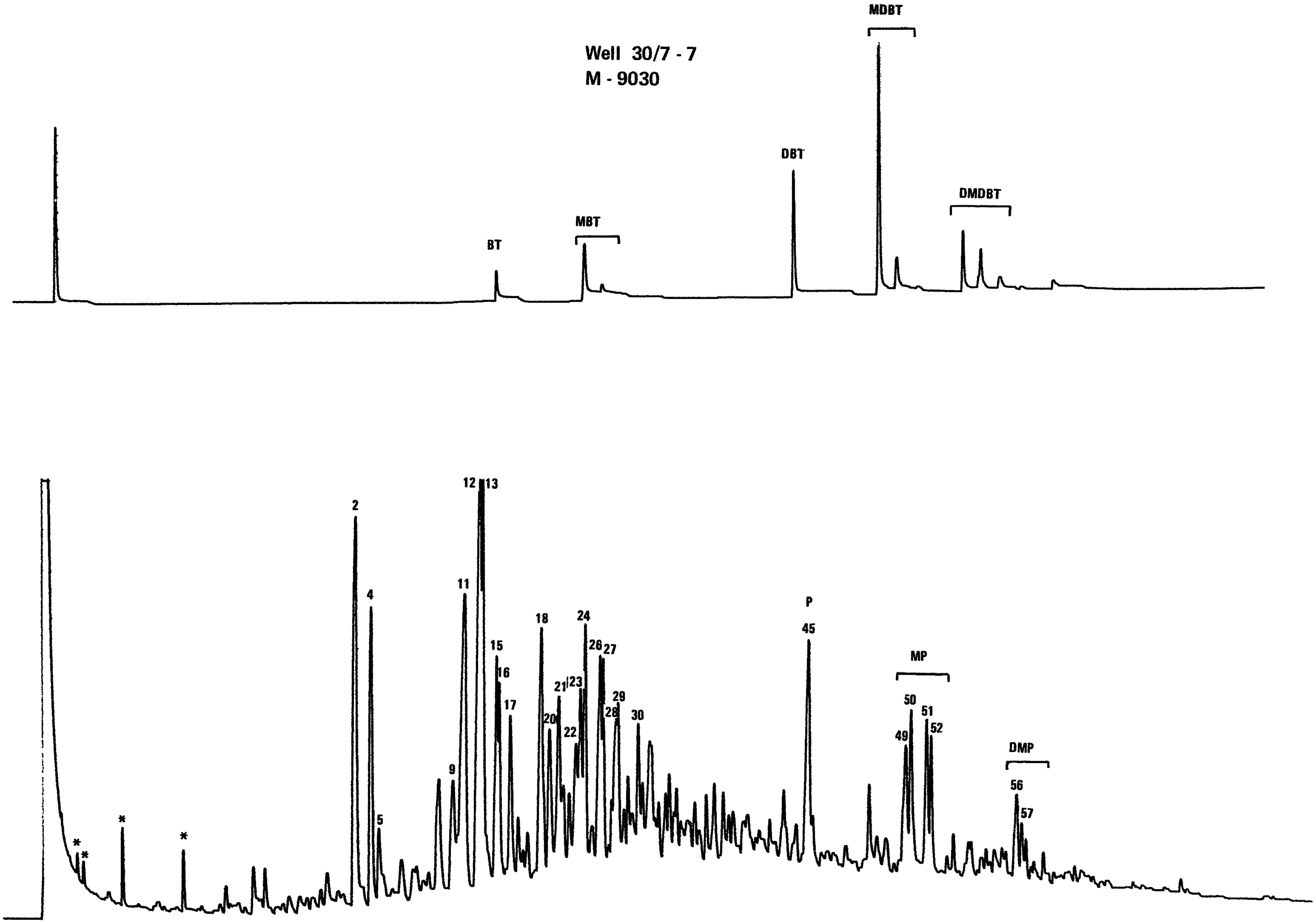
Well 30/3 - 1
M - 9139



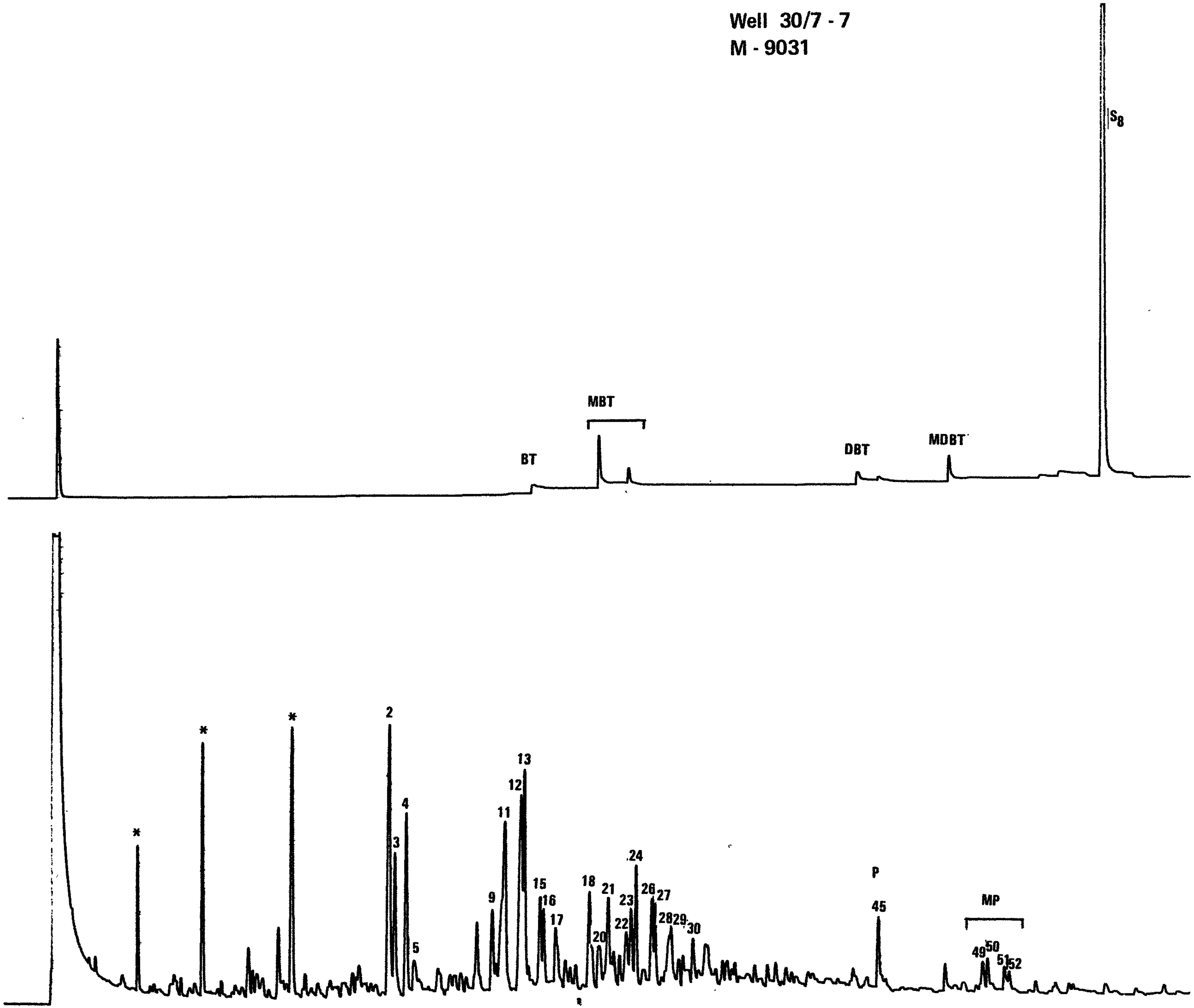
Well 30/7 - 7
M - 9028

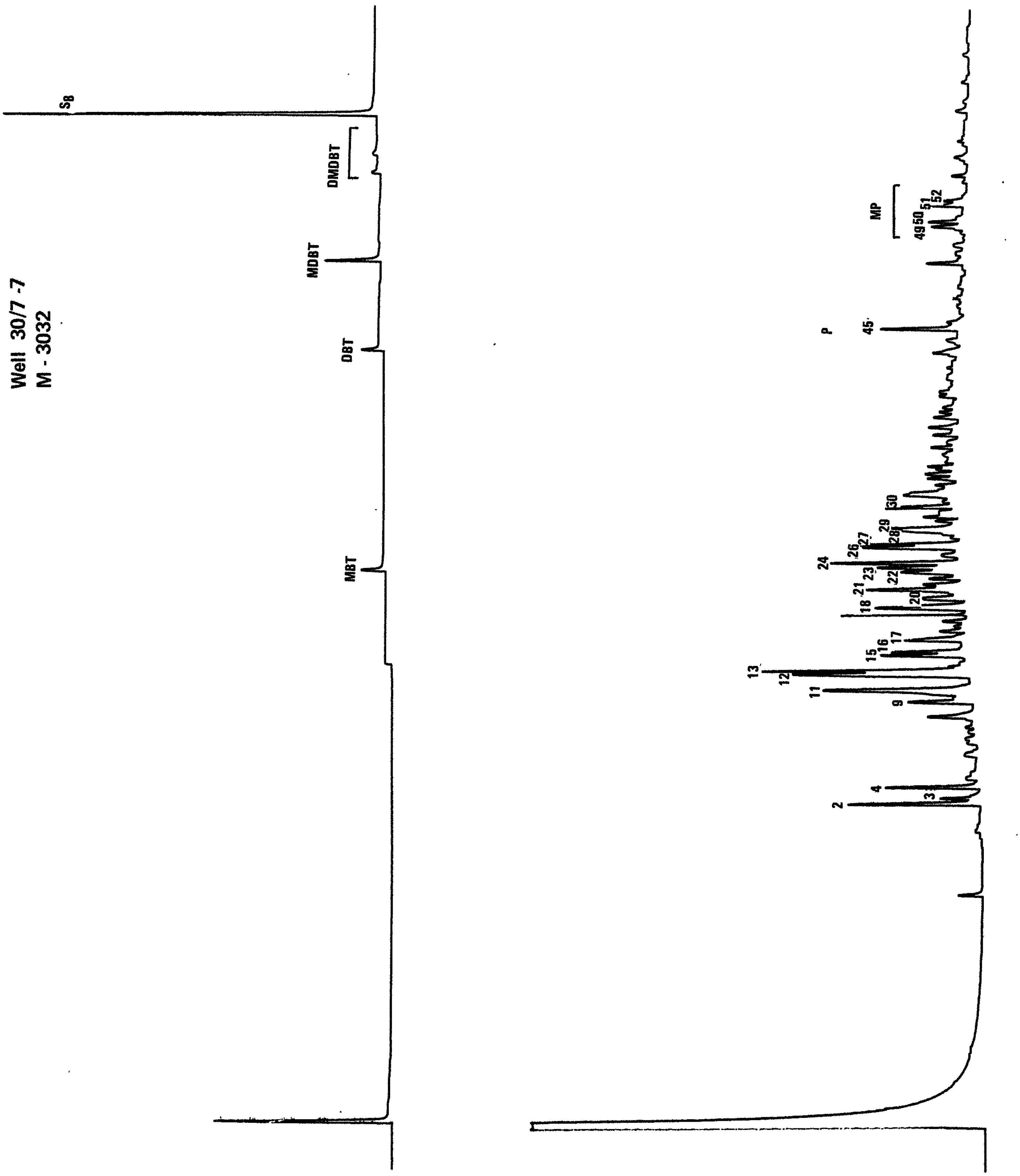



Well 30/7 - 7
M - 9029
S8
DMDBT
MDBT
DBT
MP
P
45
49
50
51
52
30
29
27
26
24
23
22
21
20
18
17
16
15
13
12
11
9
5
4
2
*
*

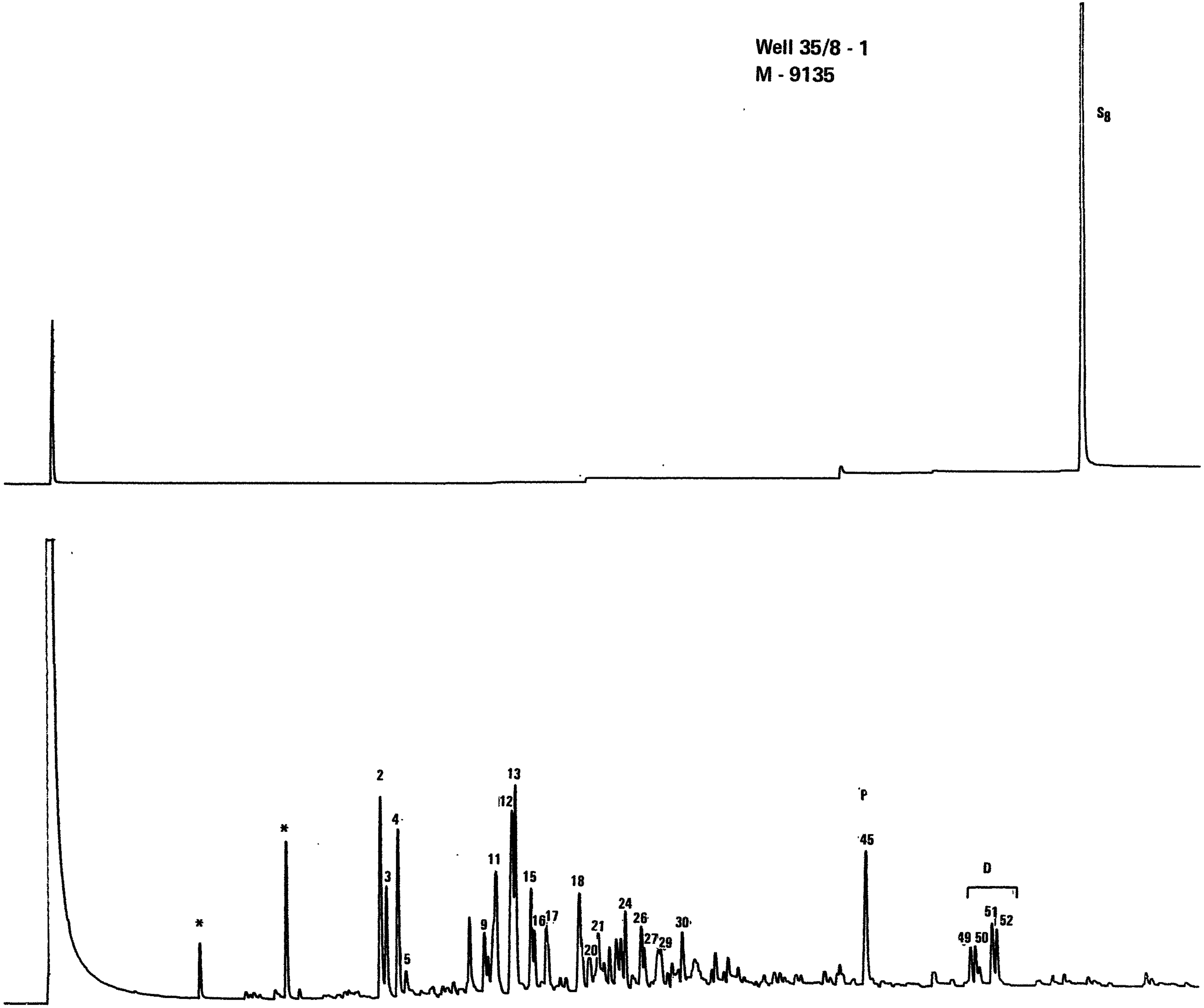

Well 30/7 - 7
M - 9030
BT
MBT
DBT
MDBT
DMDBT
*
*
*
*
2
4
5
9
11
12
13
15
16
17
18
20
21
22
23
24
26
27
28
29
30
P
45
MP
49
50
51
52
DMP
56
57

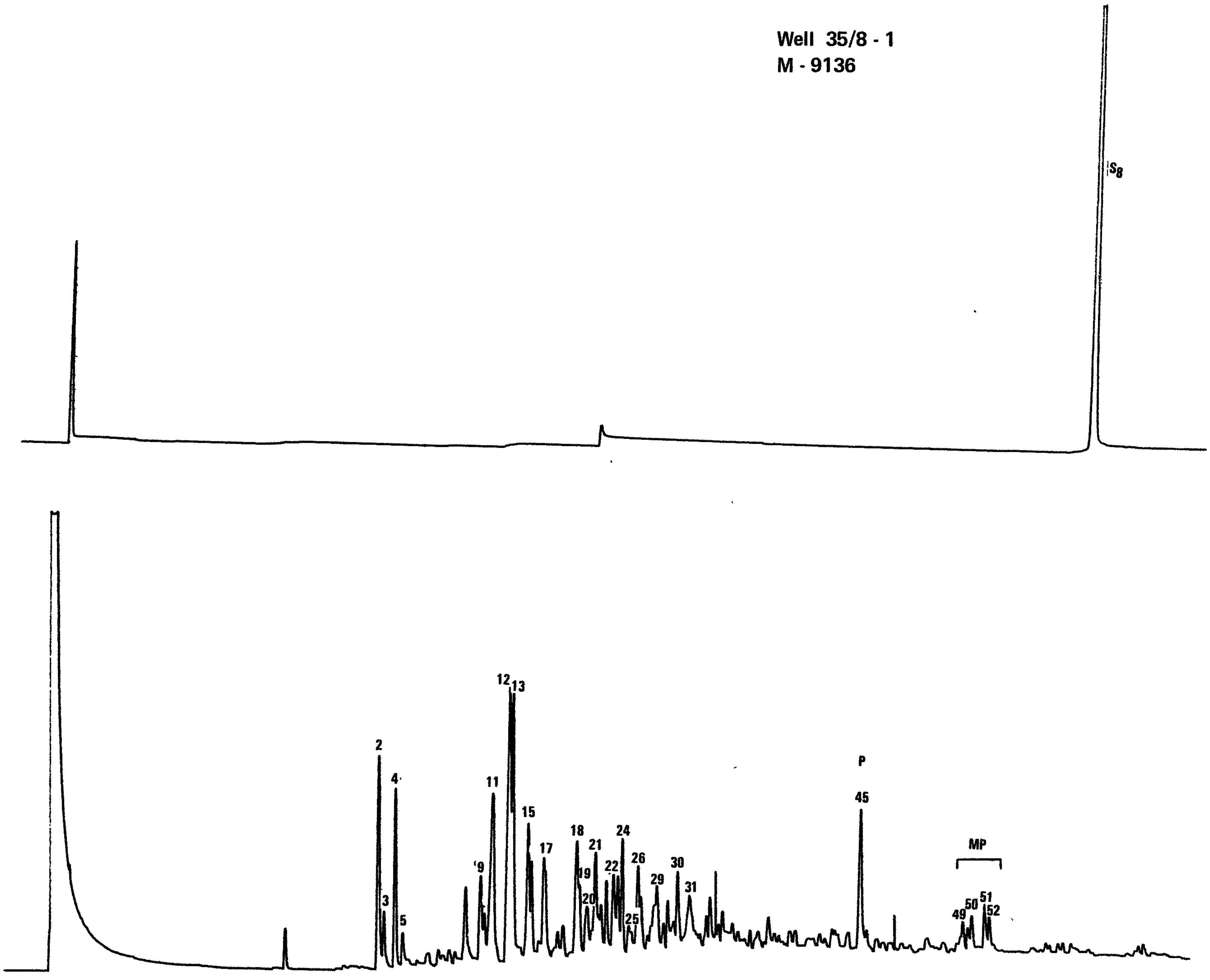
Well 30/7 - 7
M - 9031



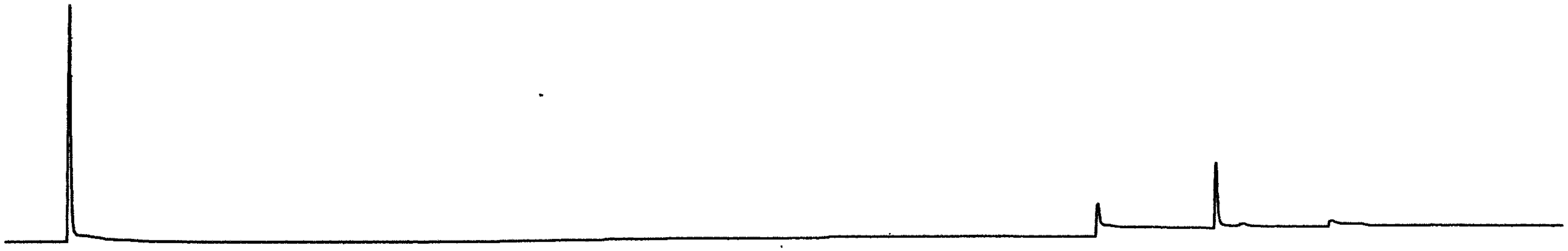


Well 30/7 -7
M - 3032


Well 35/8 - 1
M - 9135
S8
*
*
2
3
4
5
9
11
12
13
15
16
17
18
20
21
24
26
27
29
30
P
45
D
49
50
51
52


Well 35/8 - 1
M - 9136
S_8
2
3
4
5
9
11
12
13
15
17
18
19
20
21
22
24
25
26
29
30
31
P
45
MP
49
50
51
52

Well 35/8 - 1
M - 9137



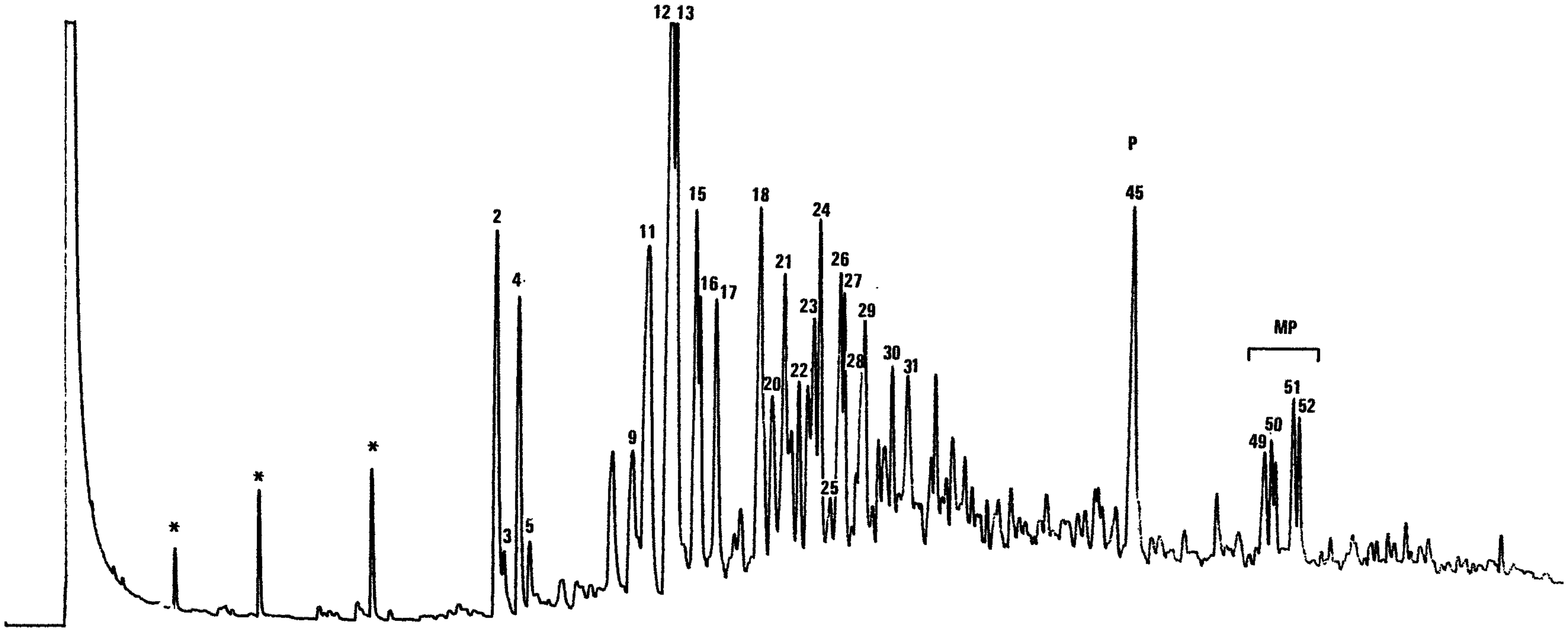


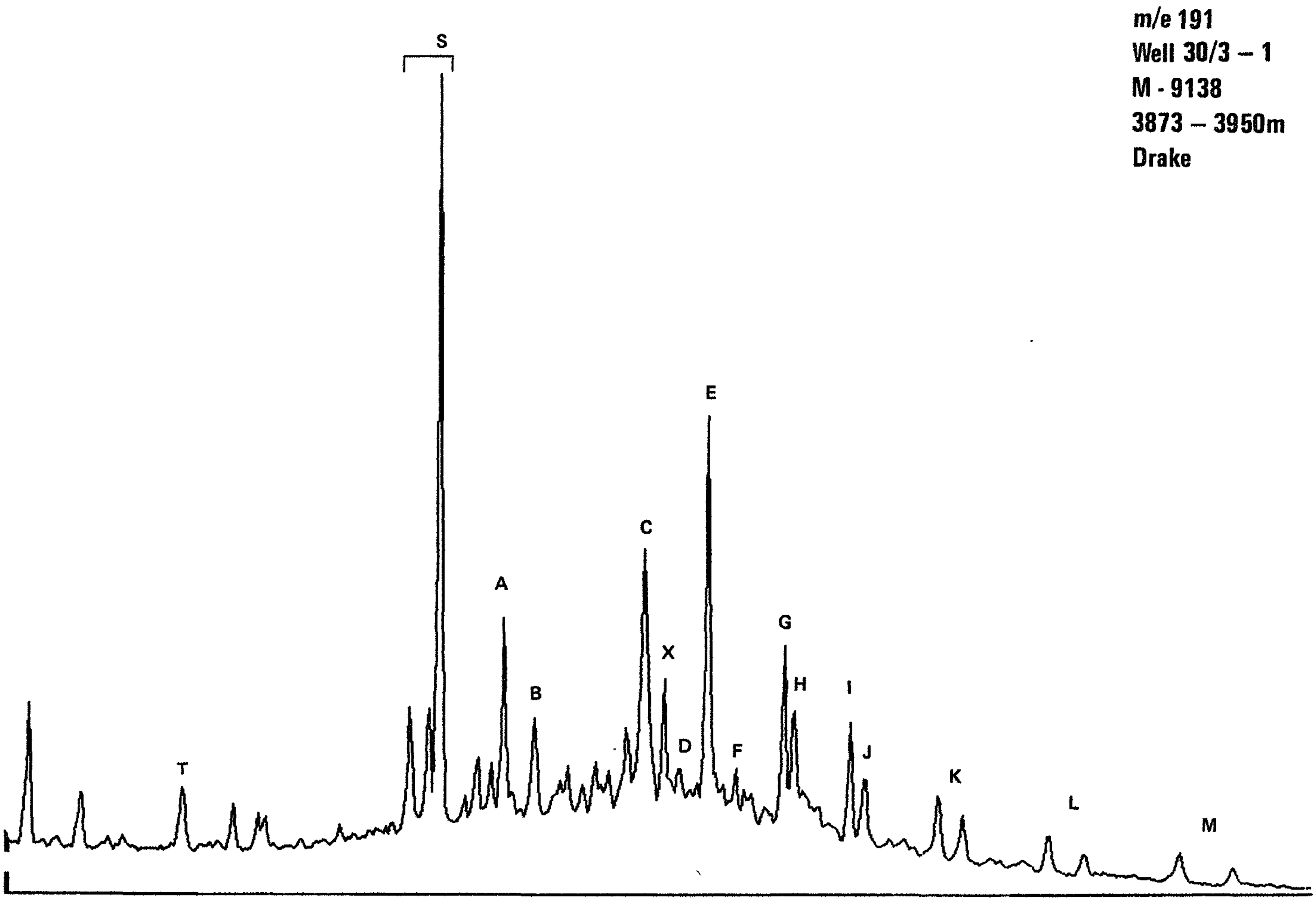
Figure 8

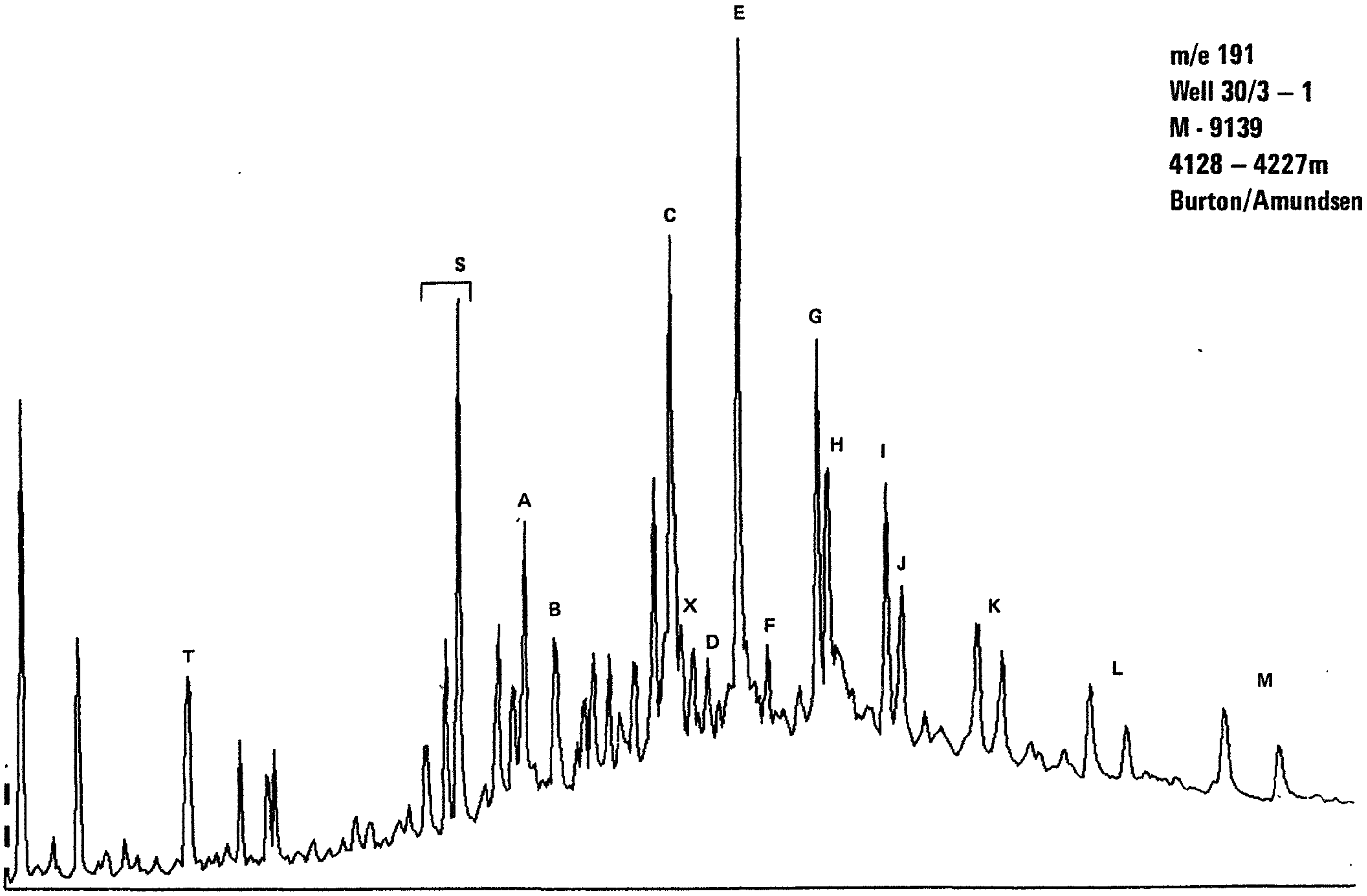
GC-MS ANALYSIS
TERPANE (m/e 191) MASS CHROMATOGRAMS

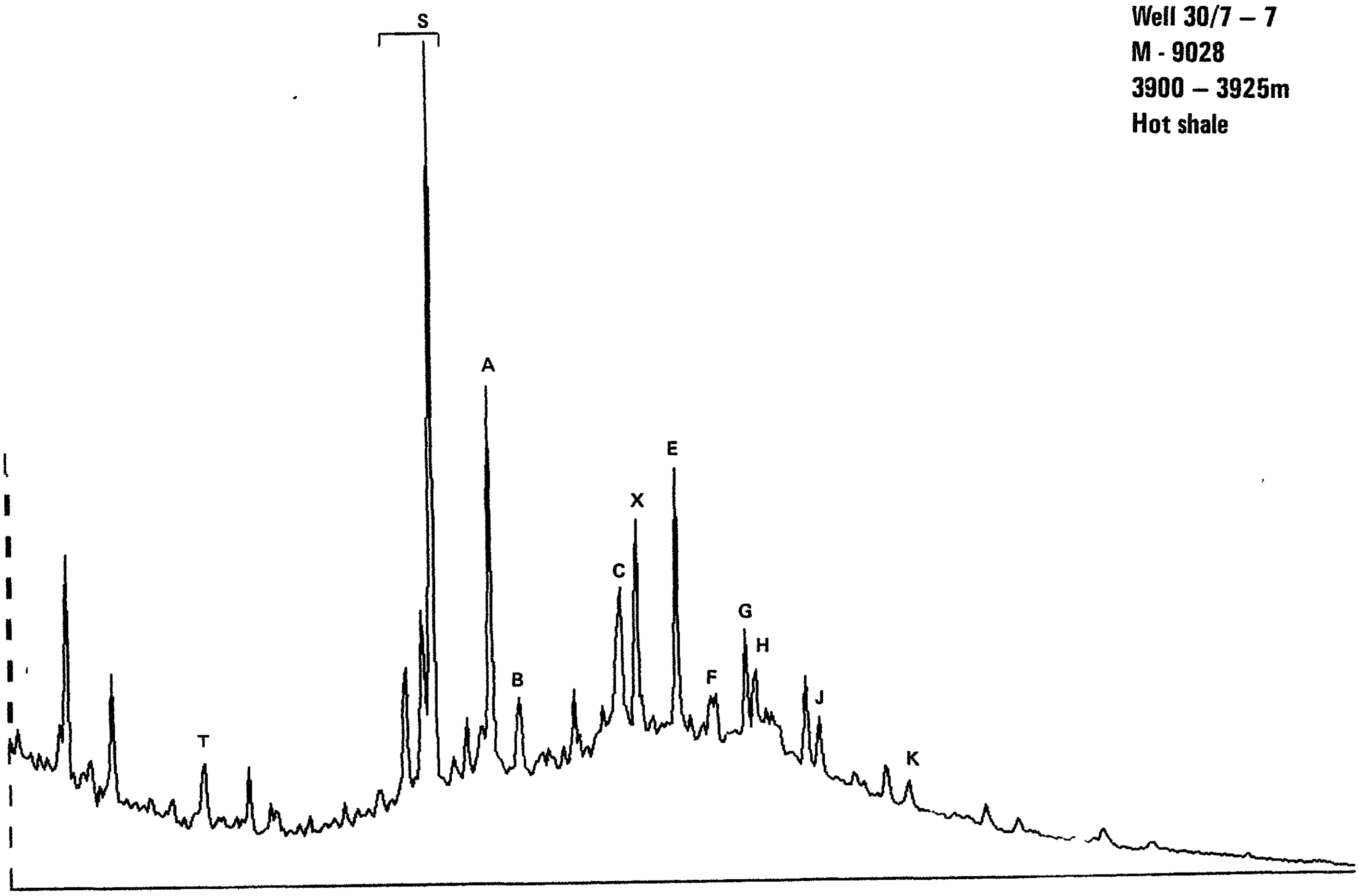
Key:

A = Ts, 18α(H)-trisnorneohopane
B = Tm, 17α(H)-trisnorneohopane
C = 17α(H)-norhopane
D = normoretane
E = 17α(H)-hopane
F = moretane
G = 17α(H)-homohopane (22S)
H = " " (22R)
I = homohopane
J = 17α(H)-bishomohopane (22S, 22R)
K = 17α(H)-trishomomopane (22S, 22R)
L = 17α(H)-tetrakishomohopanes (22S, 22R)
M = 17α(H)-pentakishomohopanes (22S, 22R)
S = internal standard
X = unidentified C_{30} compound

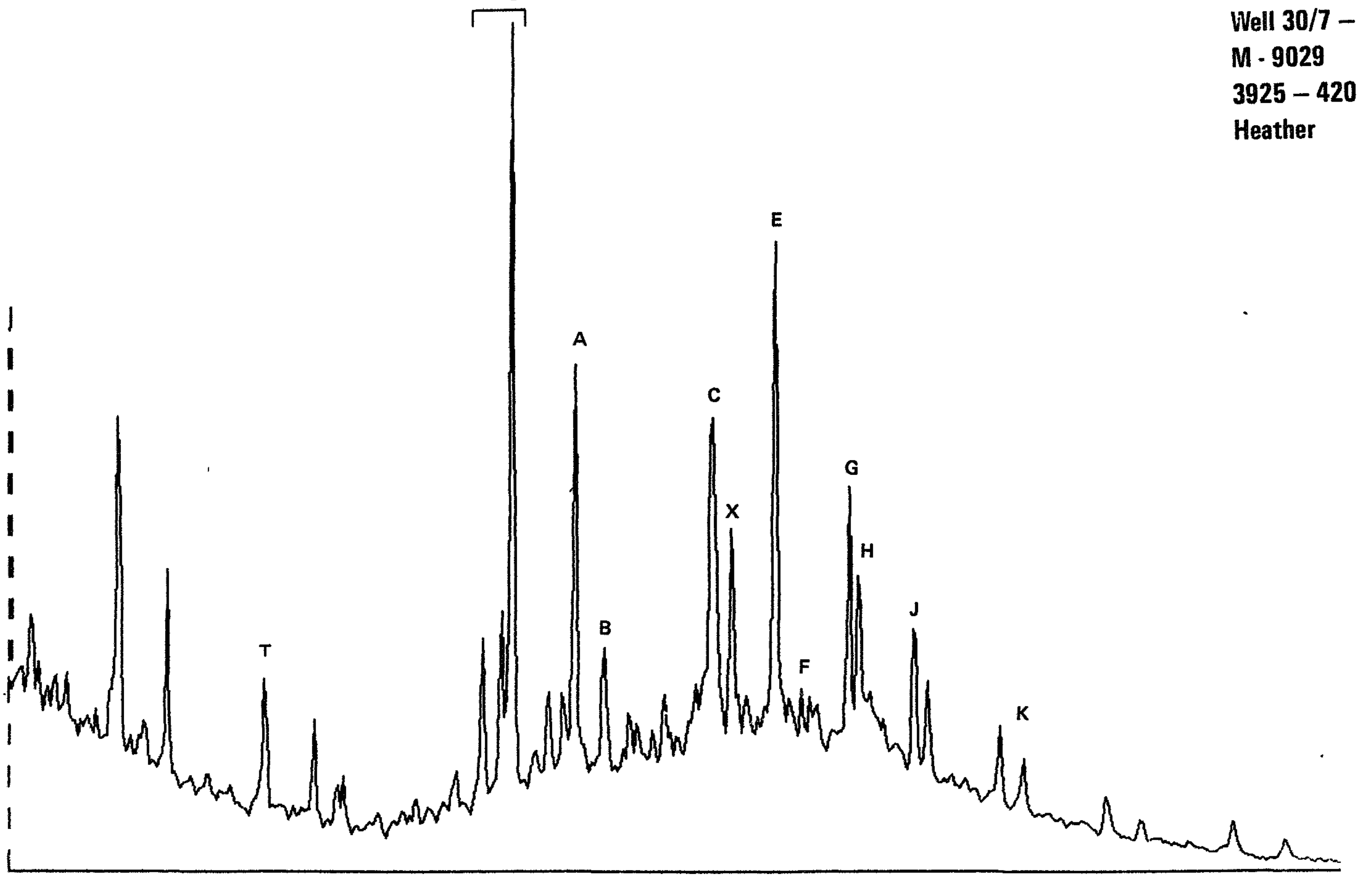
T = tricyclic terpane


m/e 191
Well 30/3 – 1
M - 9138
3873 – 3950m
Drake

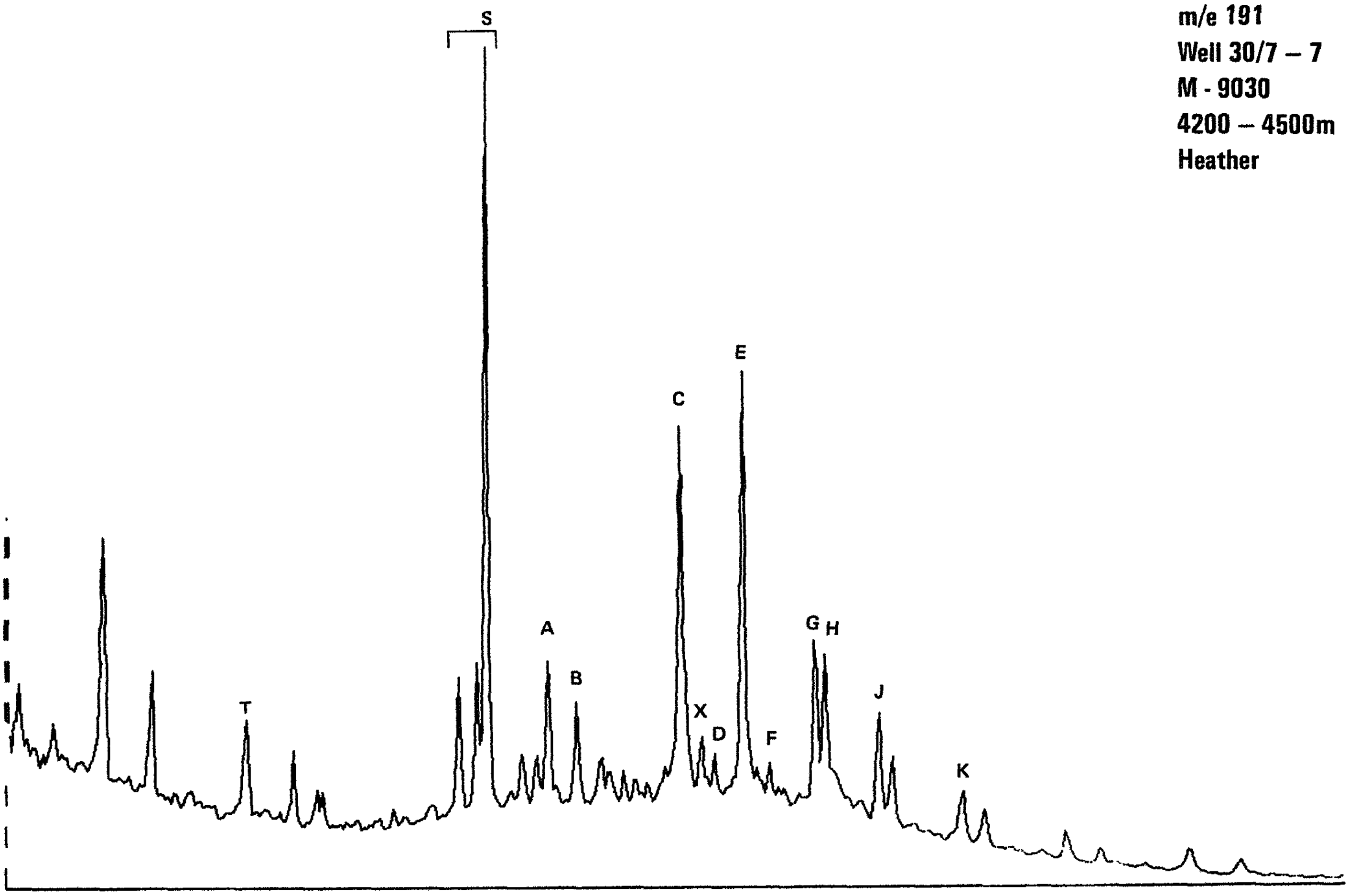

m/e 191
Well 30/3 – 1
M - 9139
4128 – 4227m
Burton/Amundsen

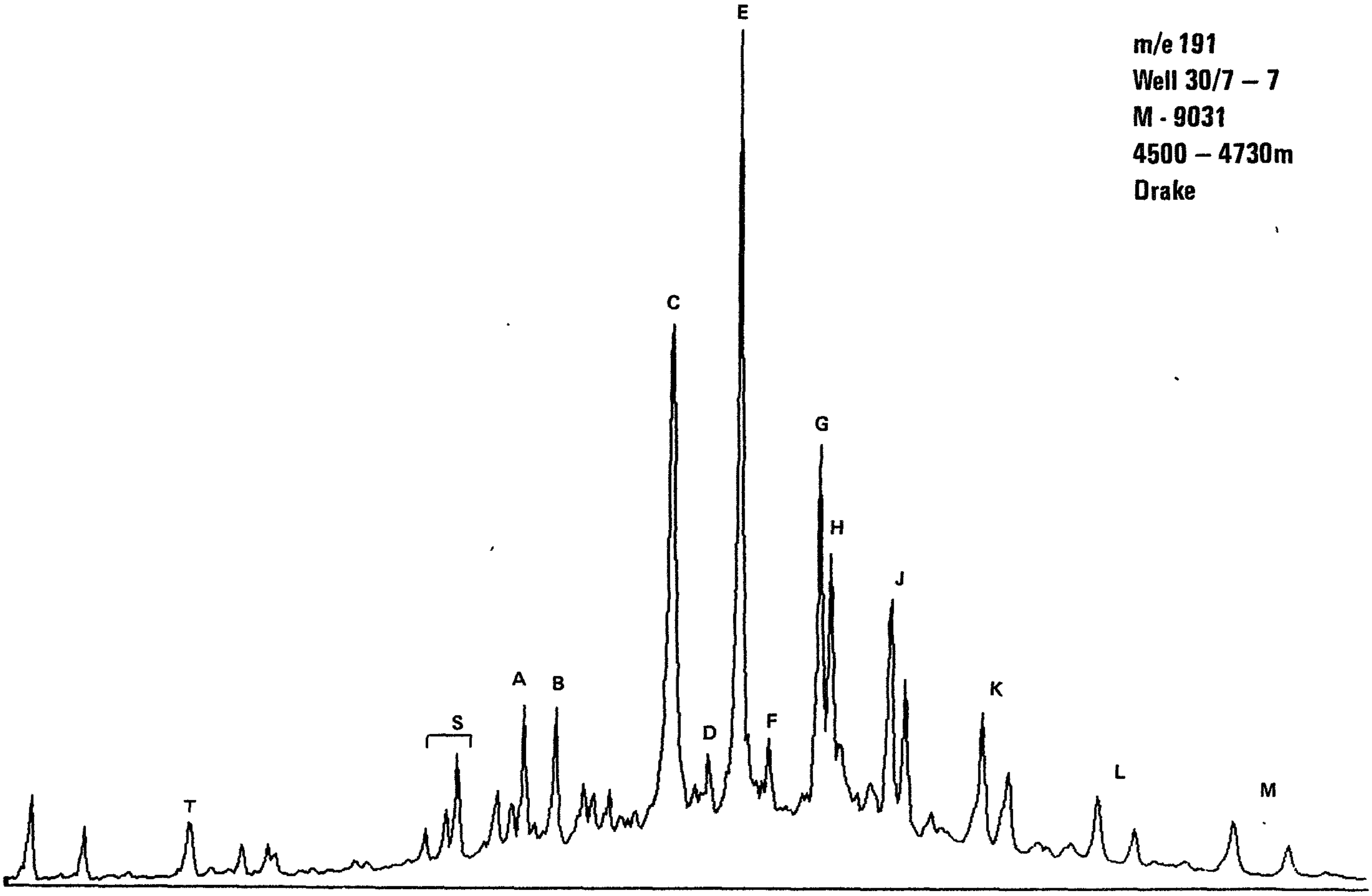


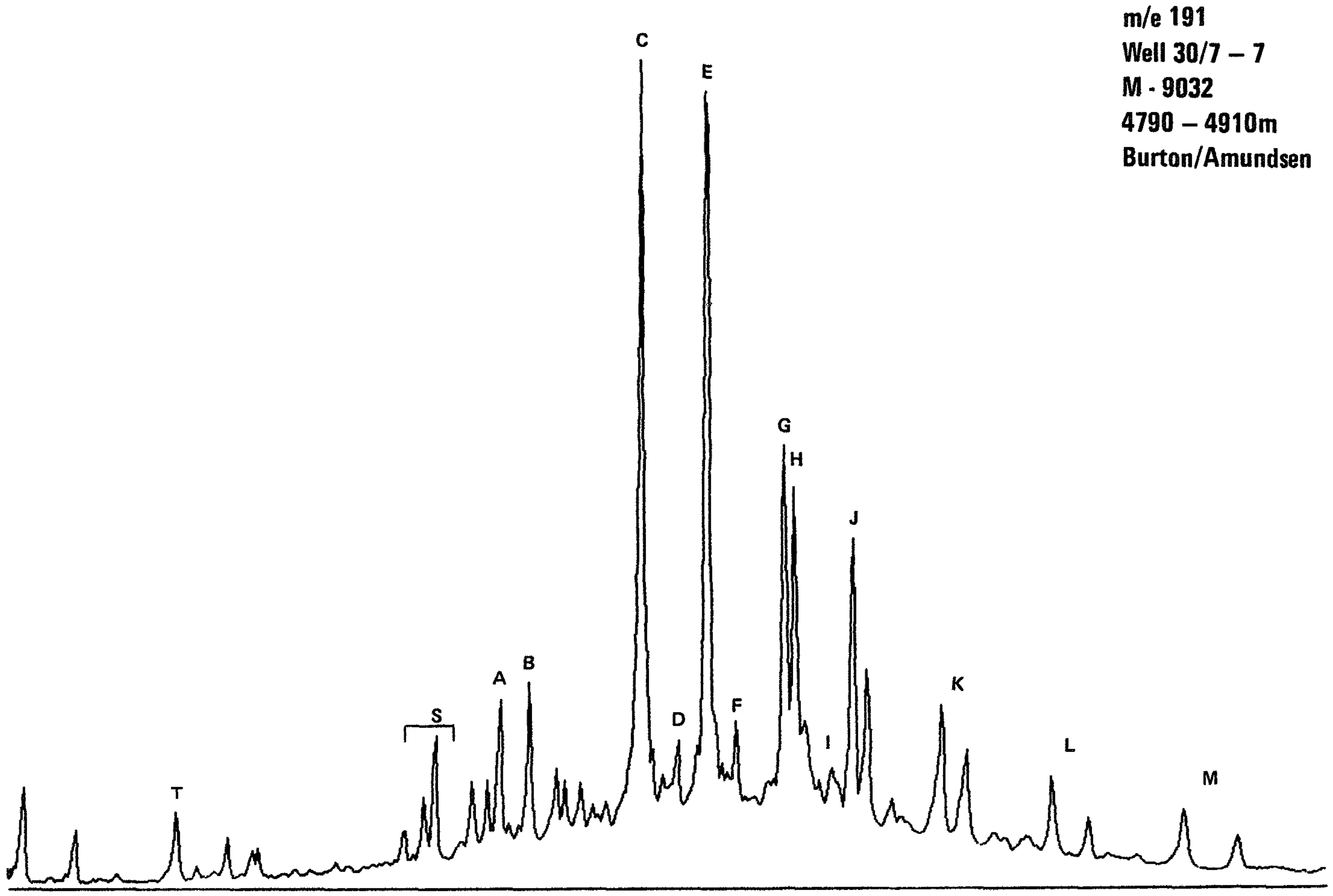
m/e 191
Well 30/7 – 7
M - 9028
3900 – 3925m
Hot shale

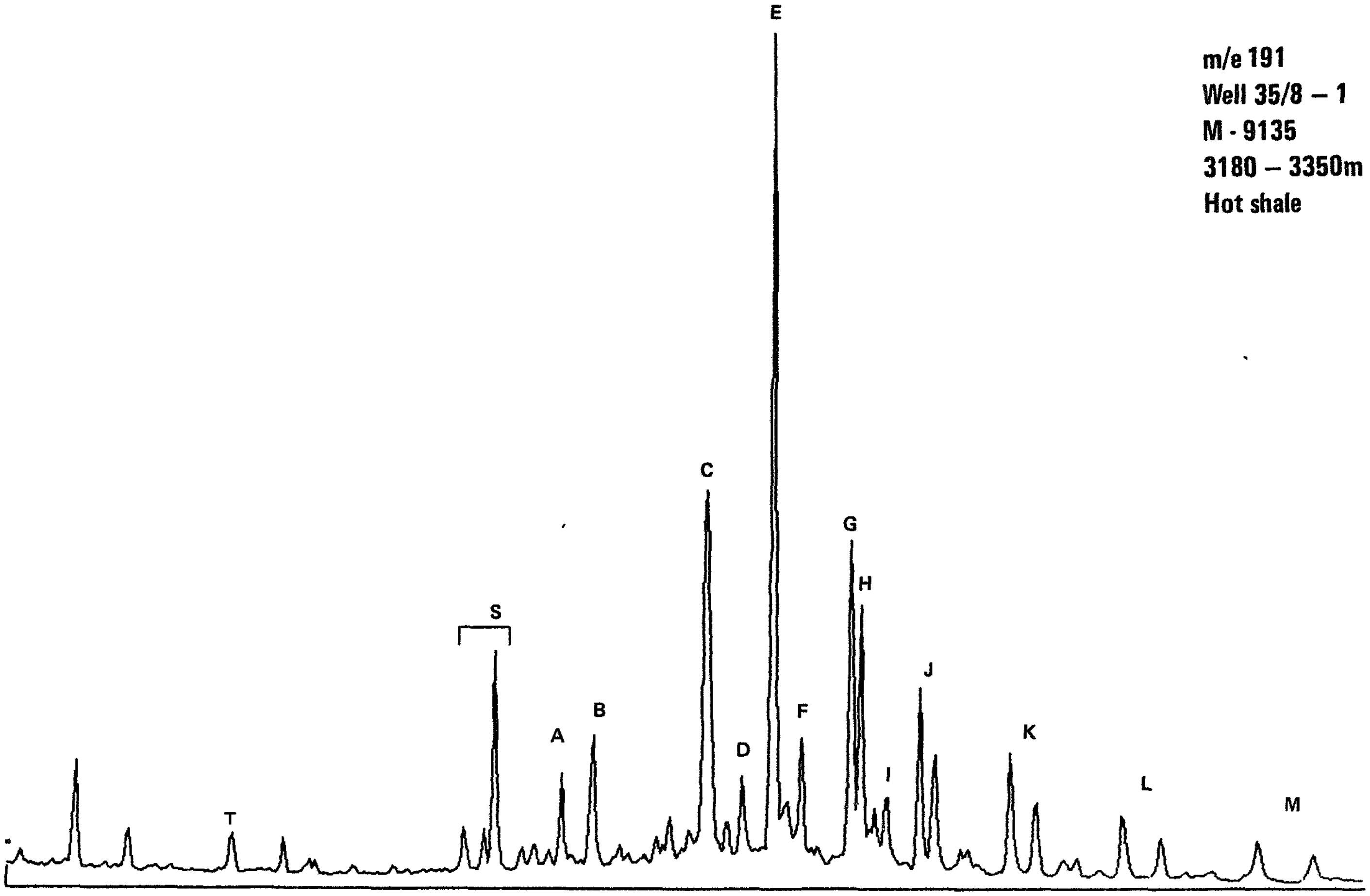


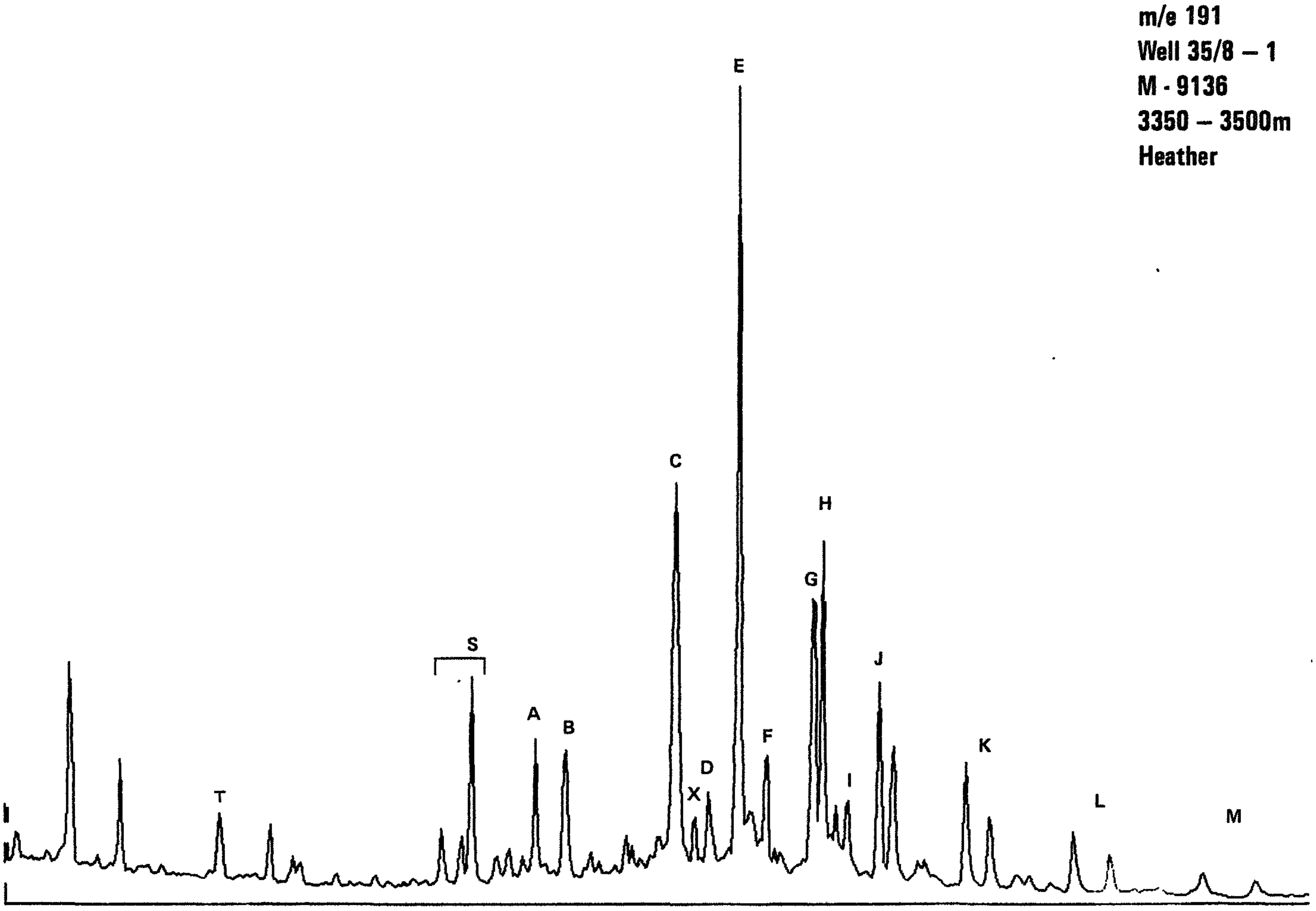
m/e 191
Well 30/7 – 7
M - 9029
3925 – 4200m
Heather


S
A
B
T
C
E
X
D
F
G H
J
K
m/e 191
Well 30/7 – 7
M - 9030
4200 – 4500m
Heather


E
m/e 191
Well 30/7 – 7
M - 9031
4500 – 4730m
Drake
C
G
H
J
A
B
S
D
F
K
T
L
M


m/e 191
Well 30/7 – 7
M - 9032
4790 – 4910m
Burton/Amundsen
C
E
G
H
J
A
B
K
S
F
D
I
L
M
T


E
m/e 191
Well 35/8 – 1
M - 9135
3180 – 3350m
Hot shale
C
G
H
S
J
B
F
A
K
D
I
L
M
T


m/e 191
Well 35/8 – 1
M - 9136
3350 – 3500m
Heather
E
C
H
G
S
J
A
B
F
K
D
X
I
T
L
M

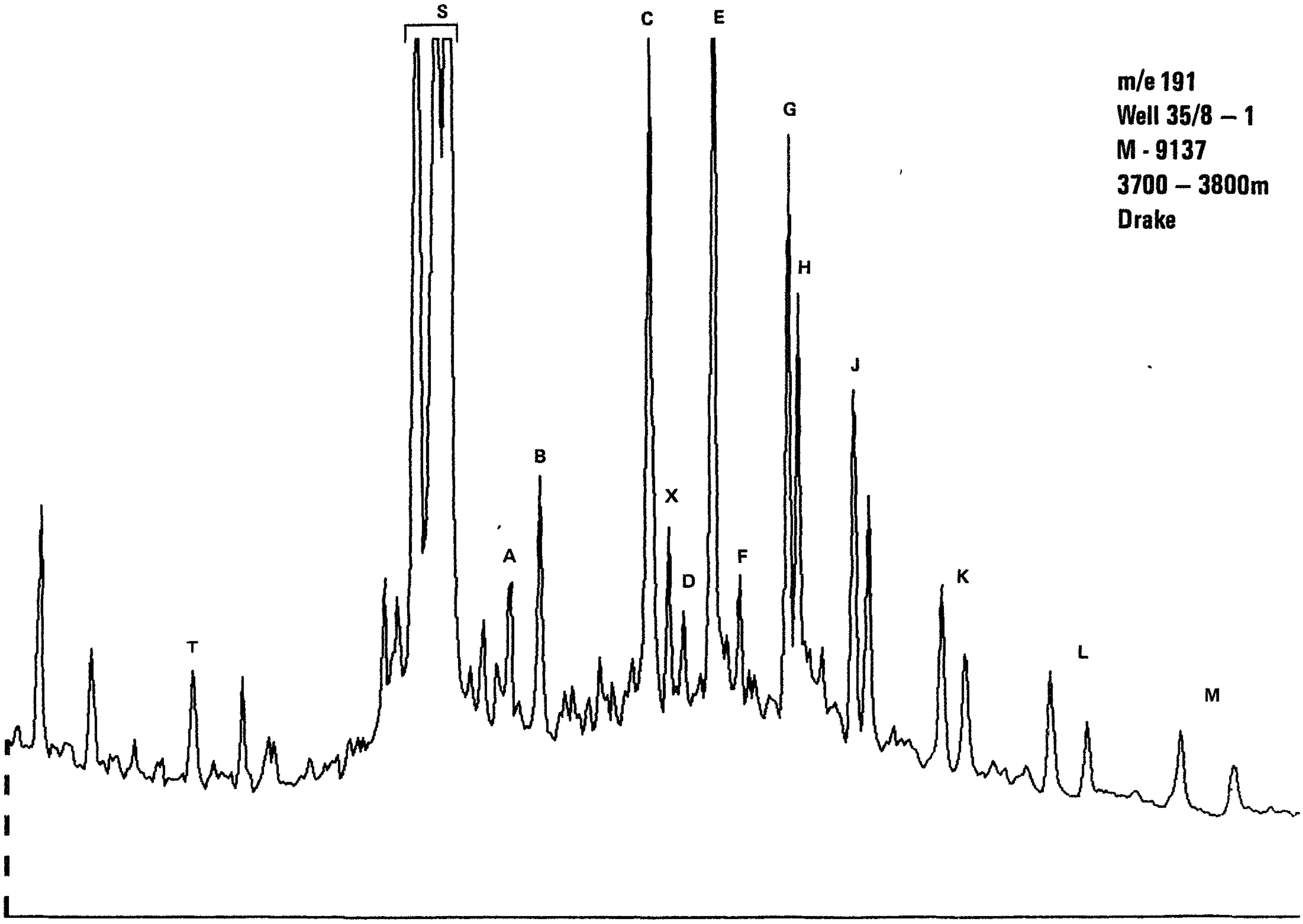
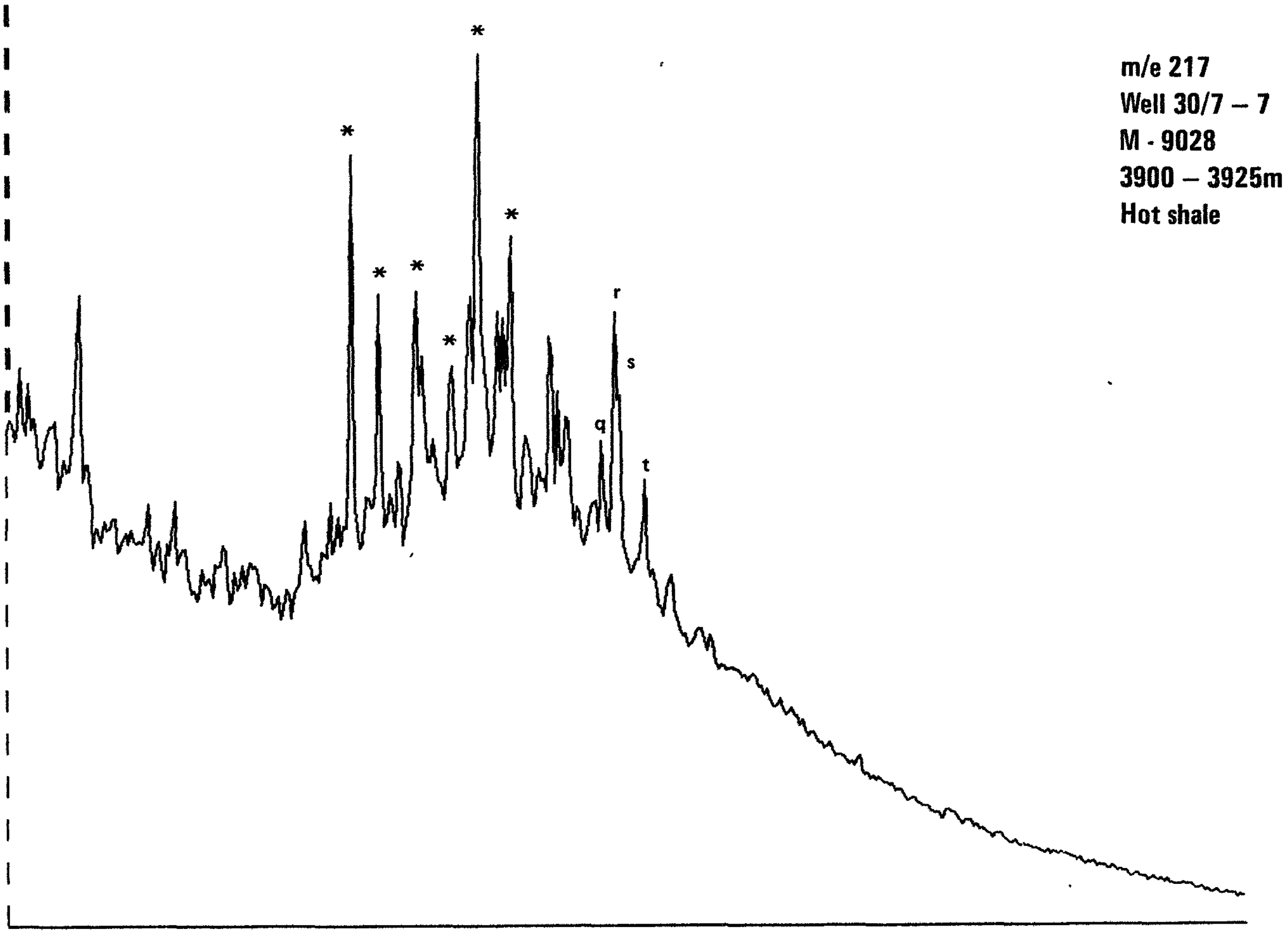

S
C
E
m/e 191
Well 35/8 – 1
M - 9137
3700 – 3800m
Drake
G
H
J
B
X
A
D
F
K
T
L
M

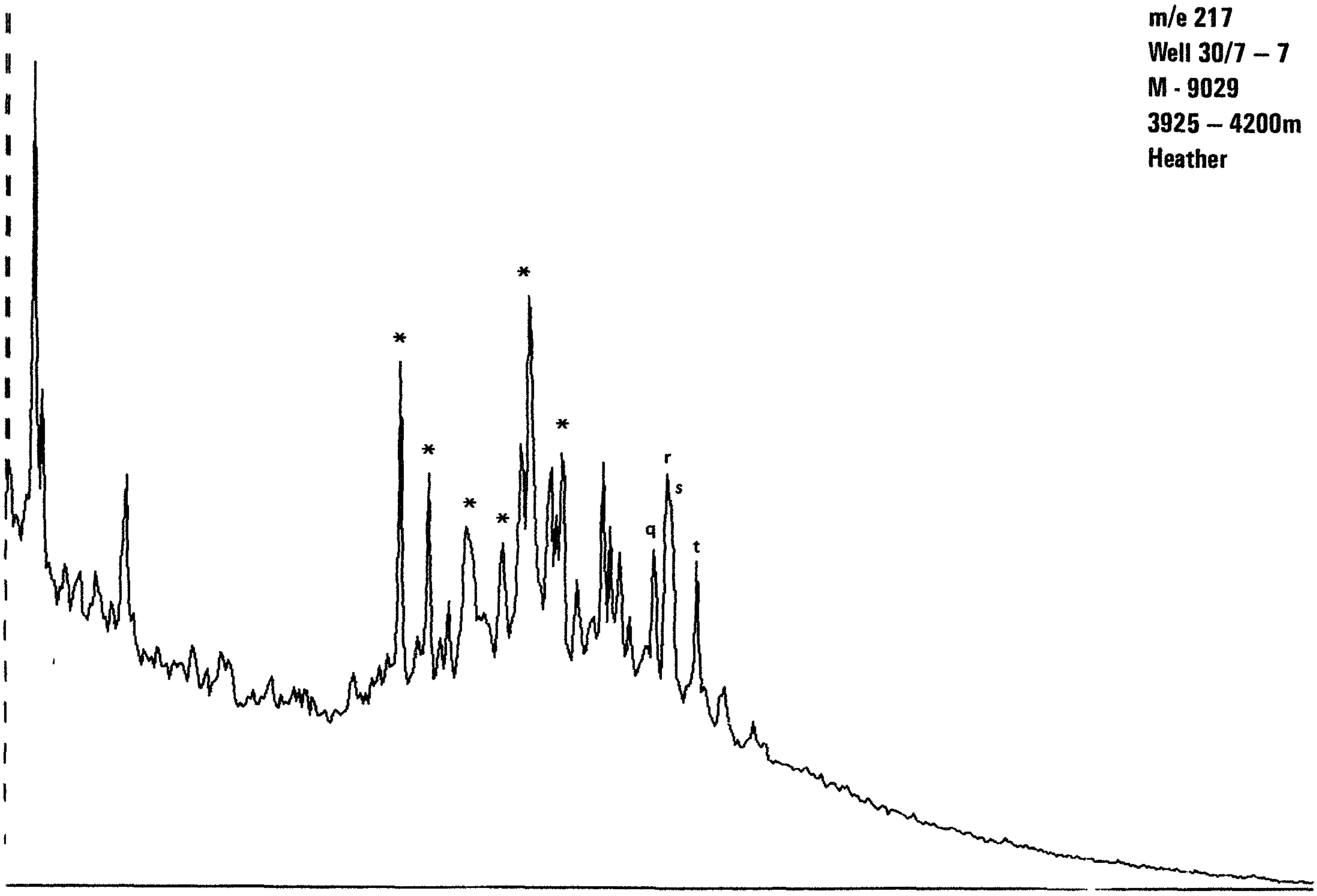
Figure 9

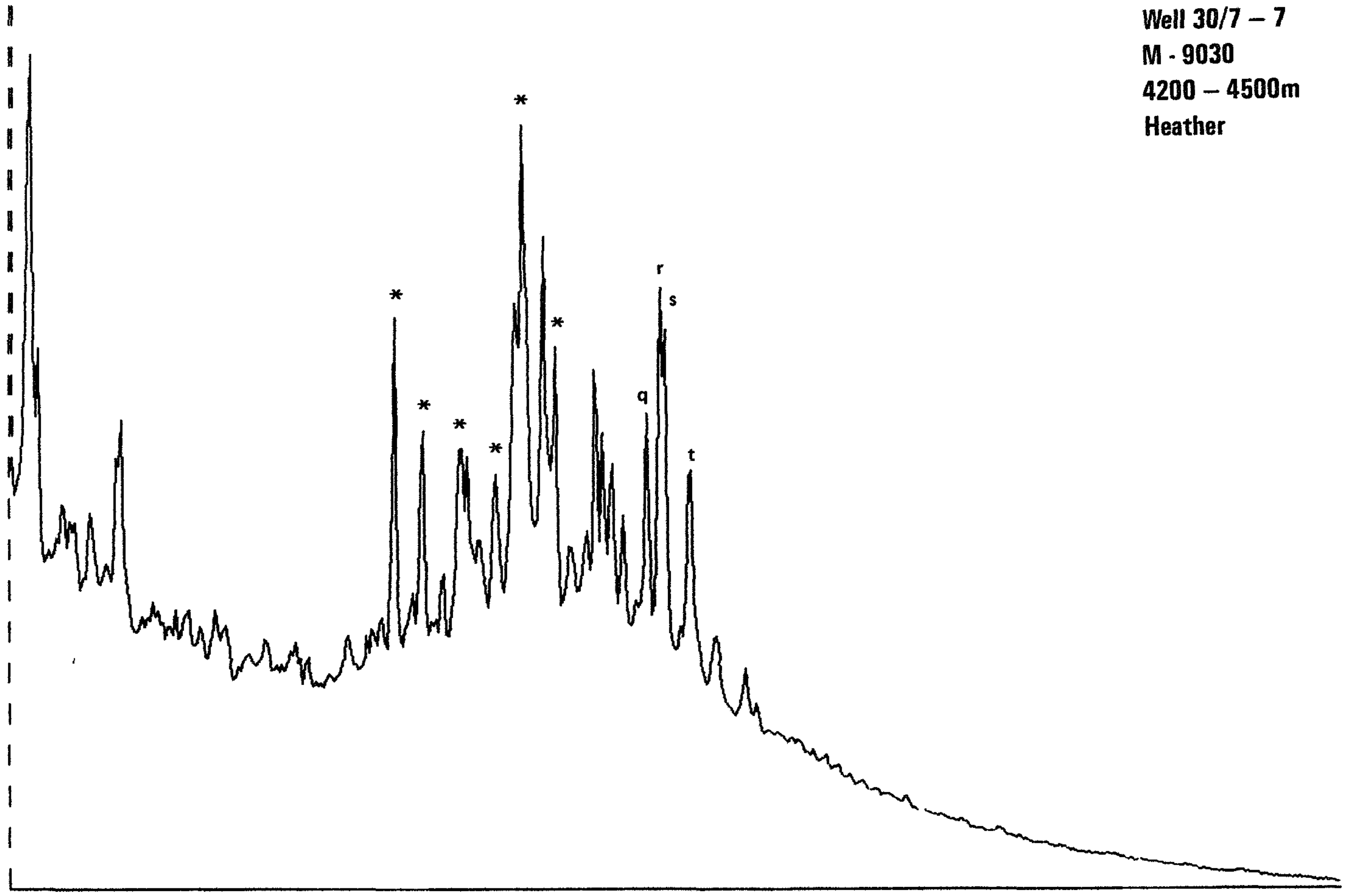
GC-MS ANALYSIS
STERANE (m/e 217) MASS CHROMATOGRAMS

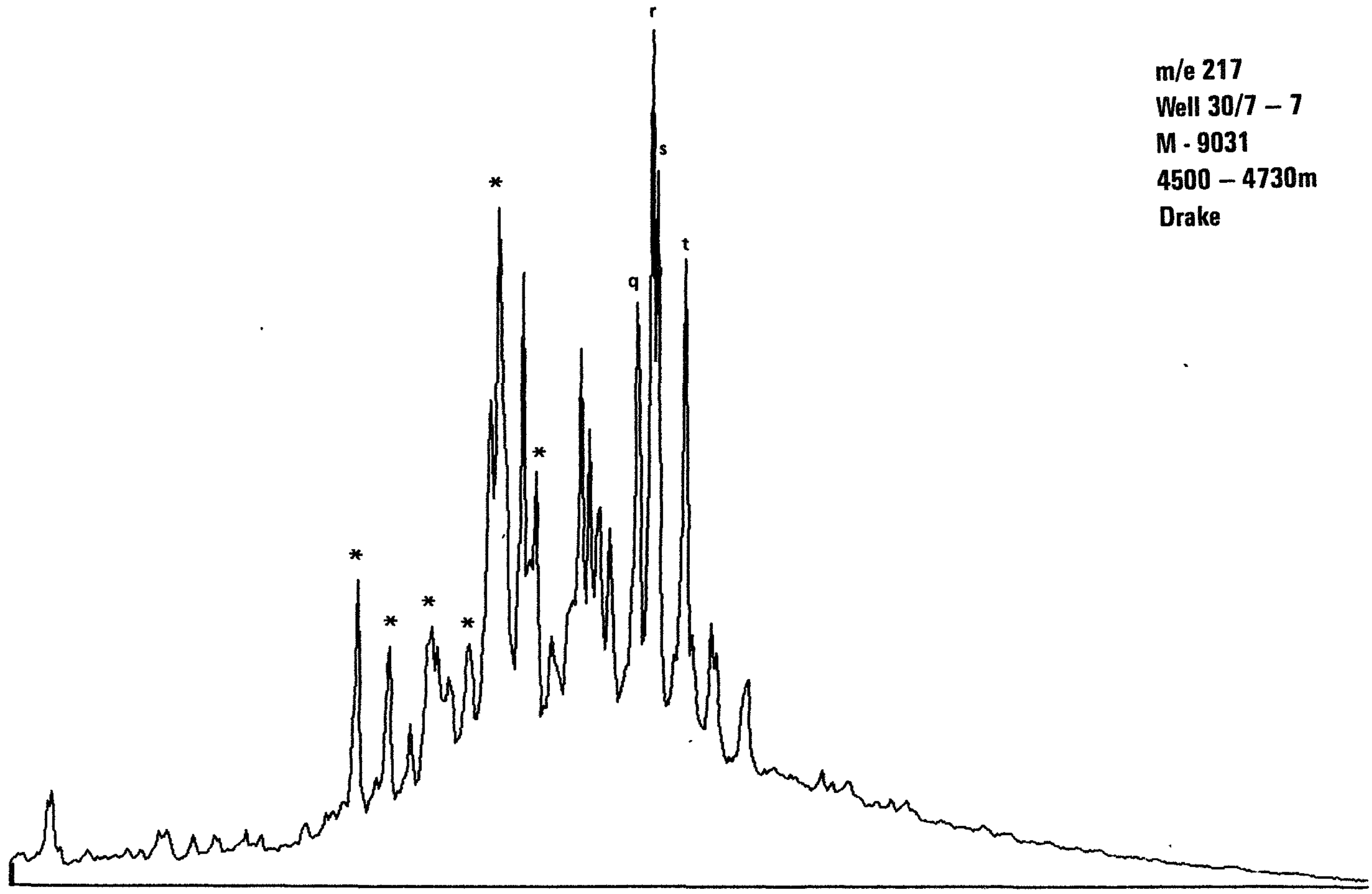
Key:

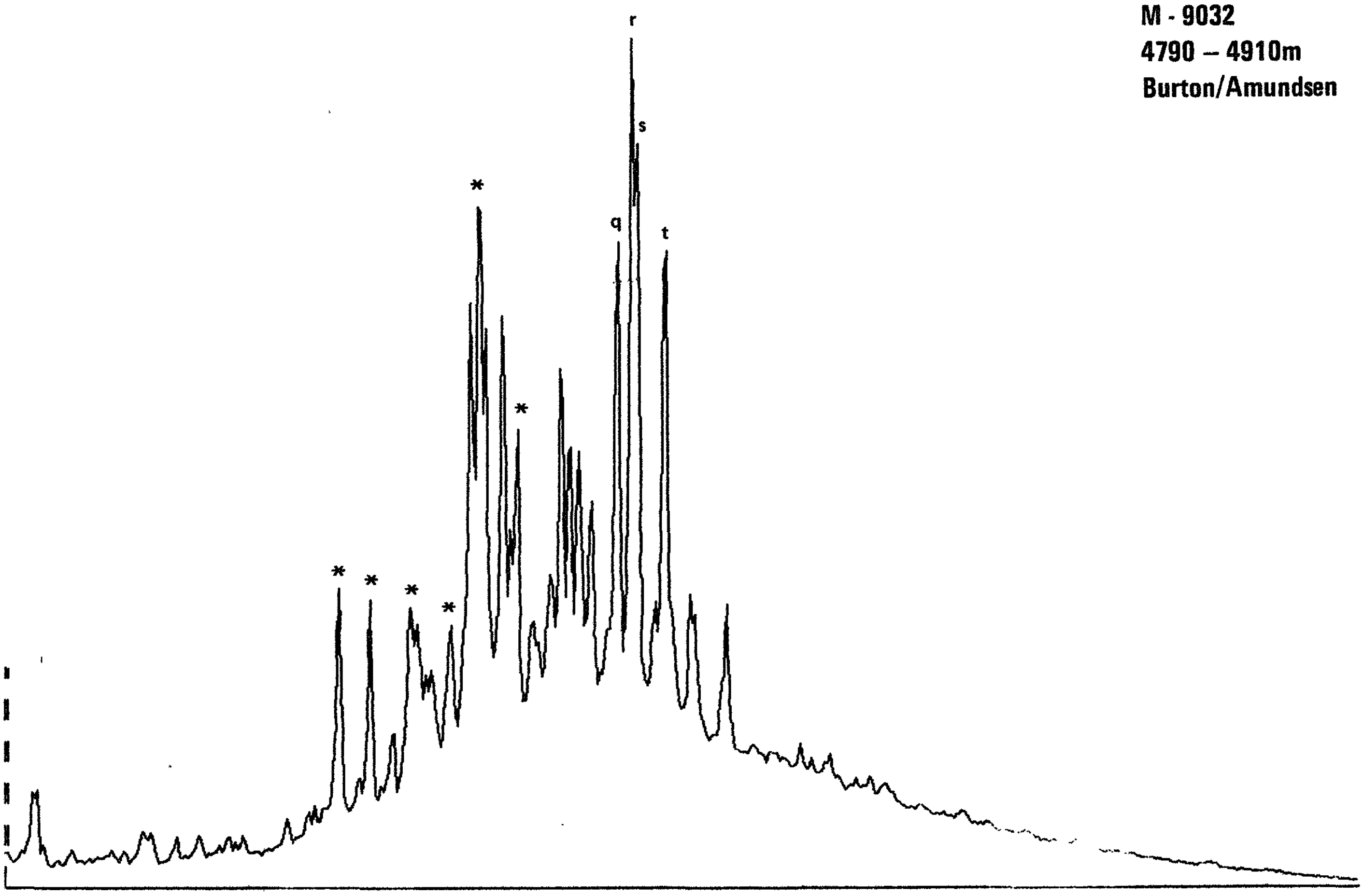
* = diasteranes
q = 14α(H),17α(H)-C_{29}-sterane(20S)
r = 14β(H),17β(H)-C_{29}-sterane(20R) + unknown sterane
s = 14β(H),17β(H)-C_{29}-sterane(20S)
t = 14α(H),17α(H)-C_{29}-sterane(20R)

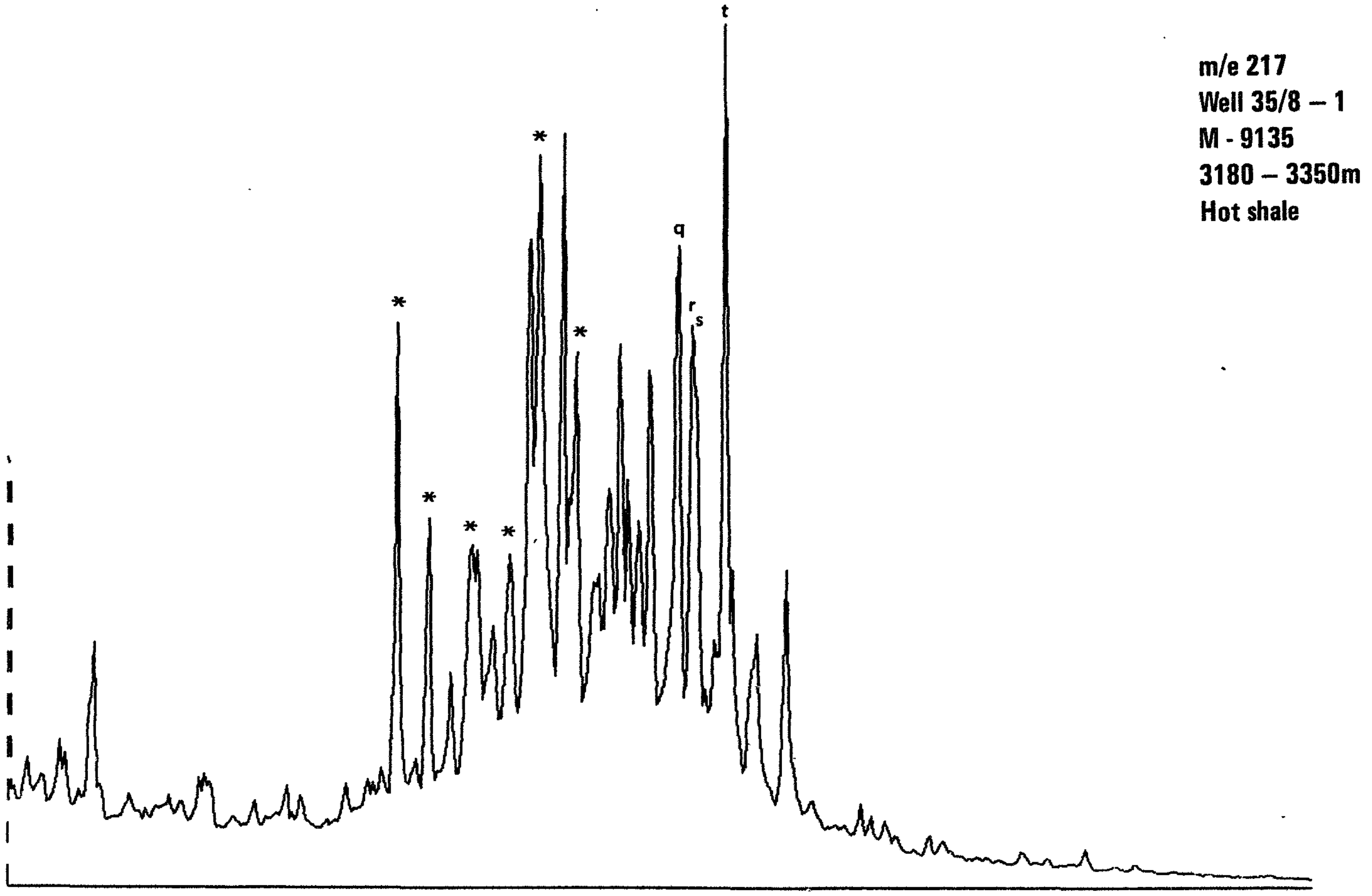

m/e 217
Well 30/7 – 7
M - 9028
3900 – 3925m
Hot shale
*
*
*
*
*
*
q
r
s
t


m/e 217
Well 30/7 – 7
M - 9029
3925 – 4200m
Heather
*
*
*
*
*
*
q
r
s
t


m/e 217
Well 30/7 – 7
M - 9030
4200 – 4500m
Heather
*
*
*
*
*
*
*
q
r
s
t


m/e 217
Well 30/7 – 7
M - 9031
4500 – 4730m
Drake
*
*
*
*
*
*
*
q
r
s
t


m/e 217
Well 30/7 – 7
M - 9032
4790 – 4910m
Burton/Amundsen
*
*
*
*
*
*
q
r
s
t


m/e 217
Well 35/8 – 1
M - 9135
3180 – 3350m
Hot shale
*
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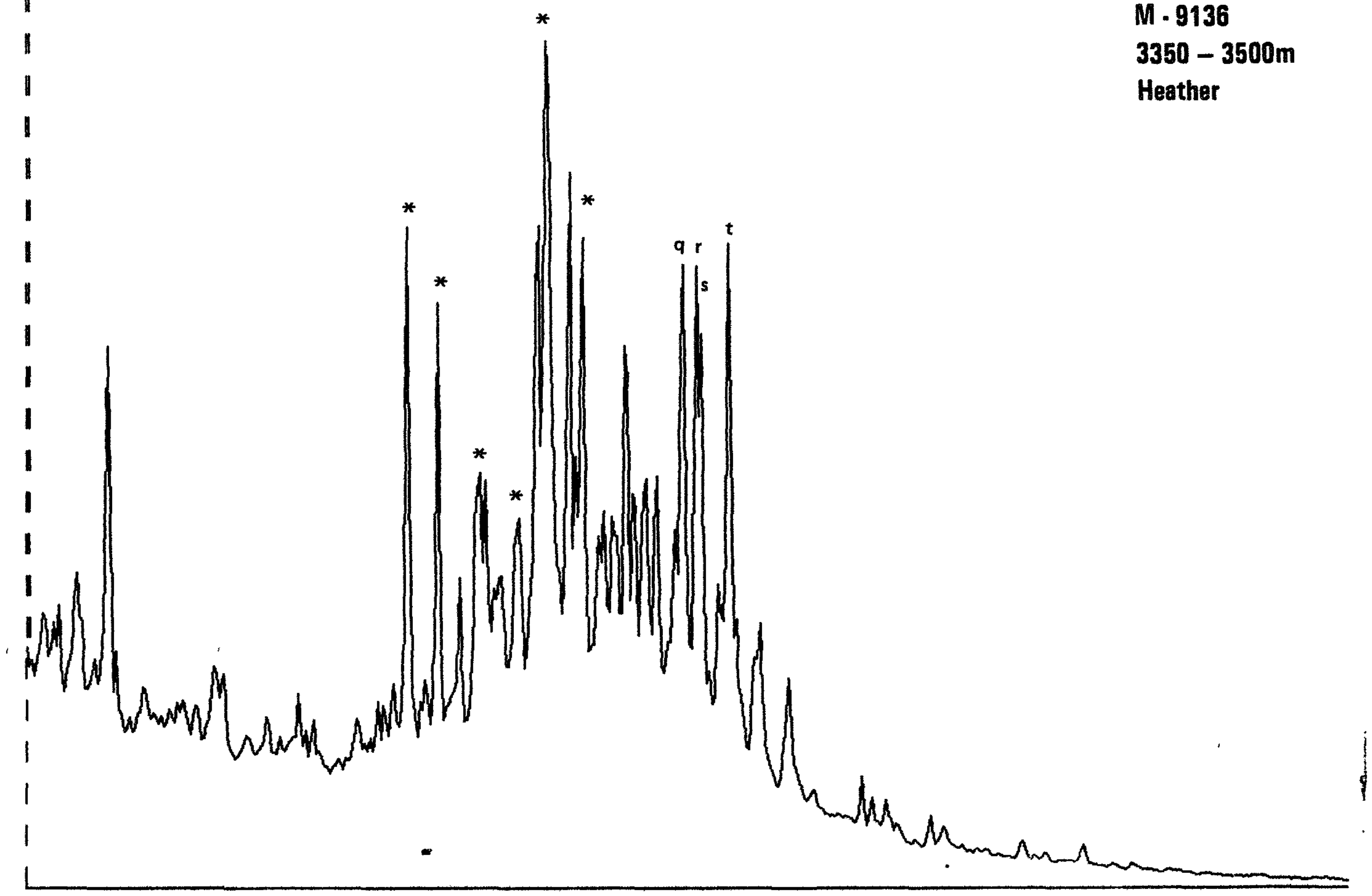
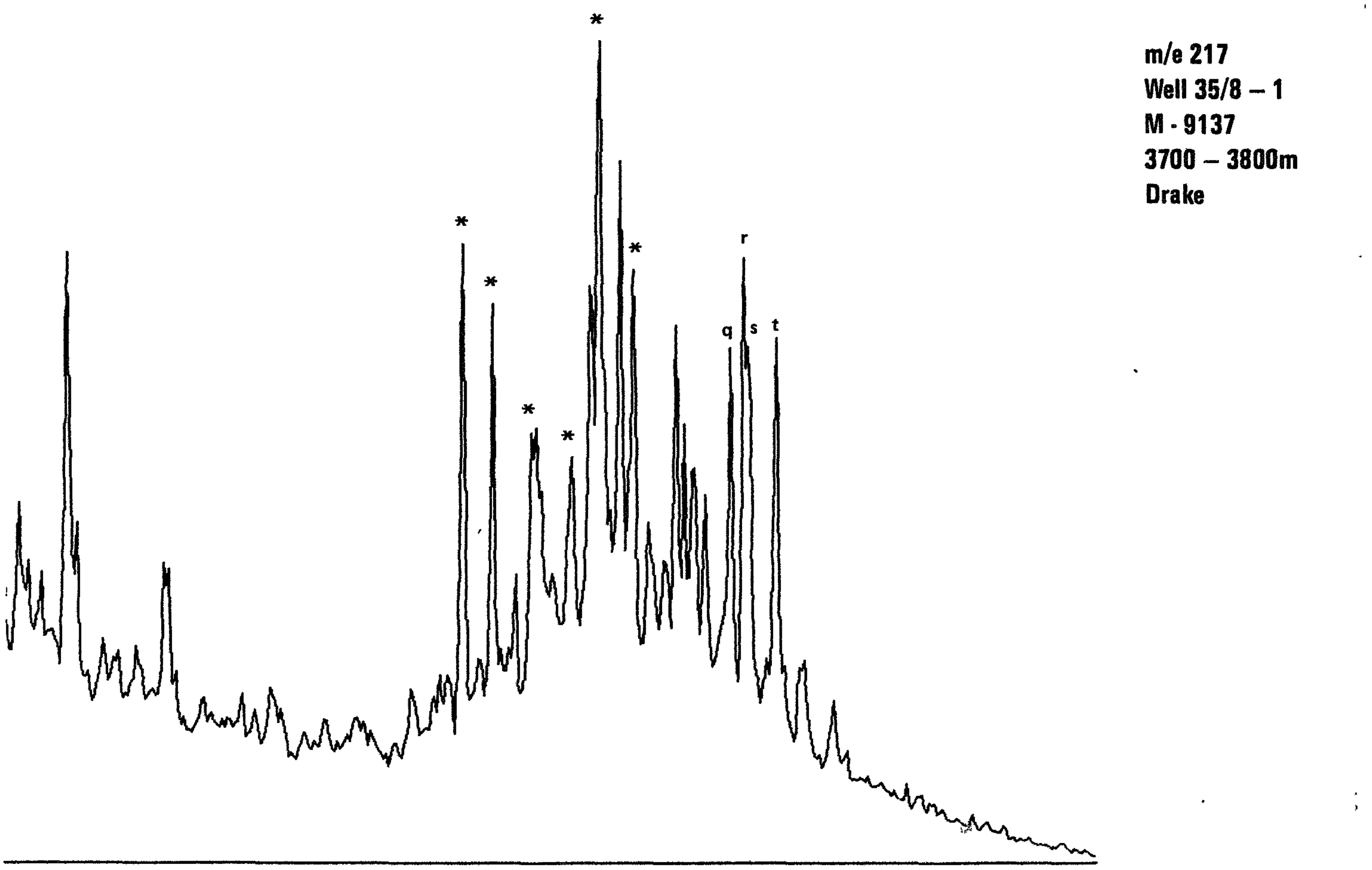
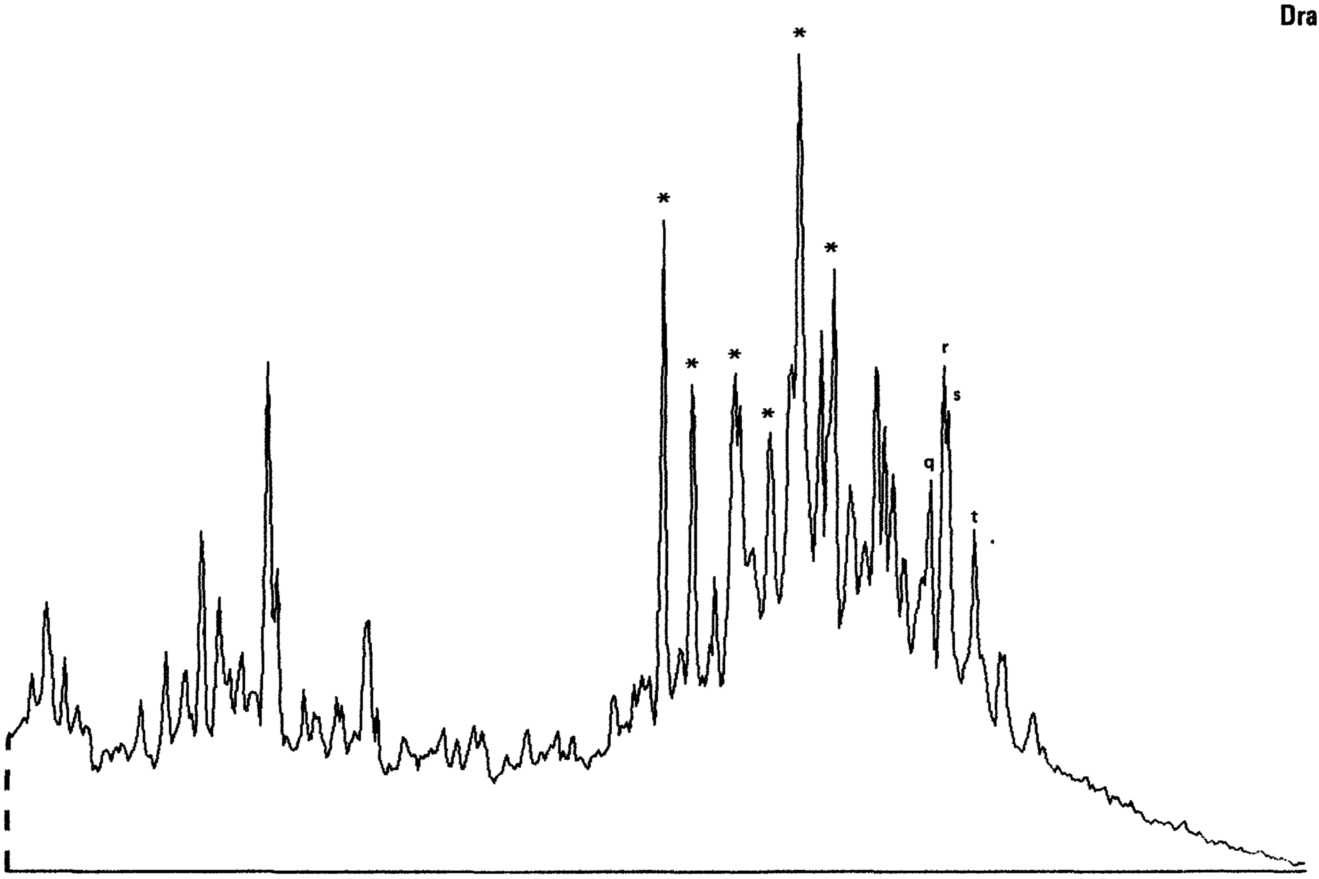
*
q
r
s
t

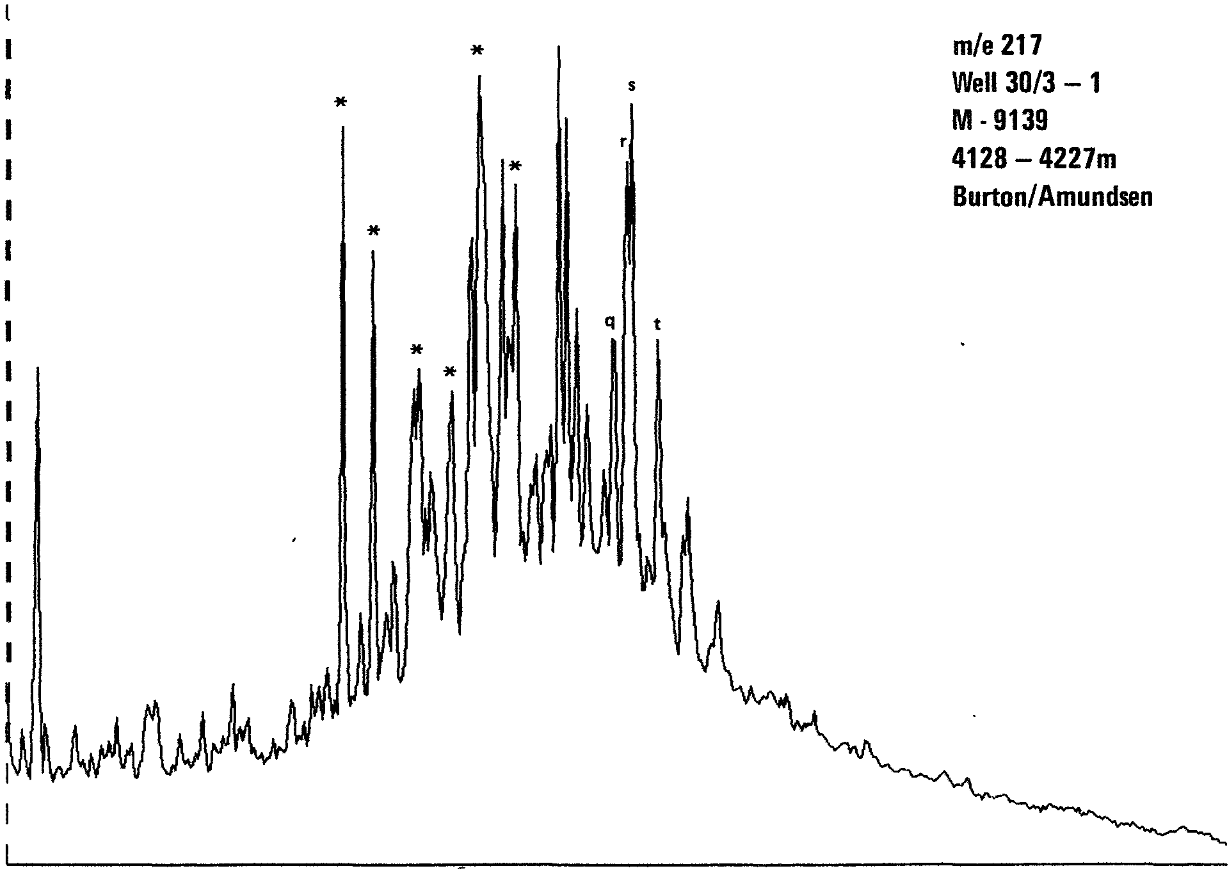


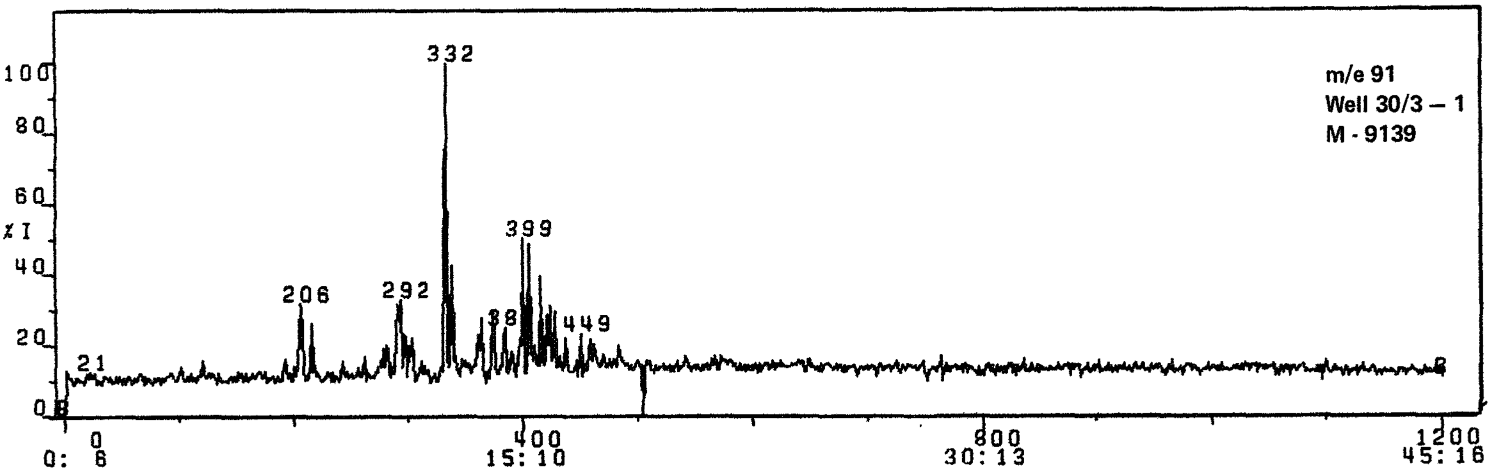
m/e 217
Well 35/8 – 1
M - 9136
3350 – 3500m
Heather

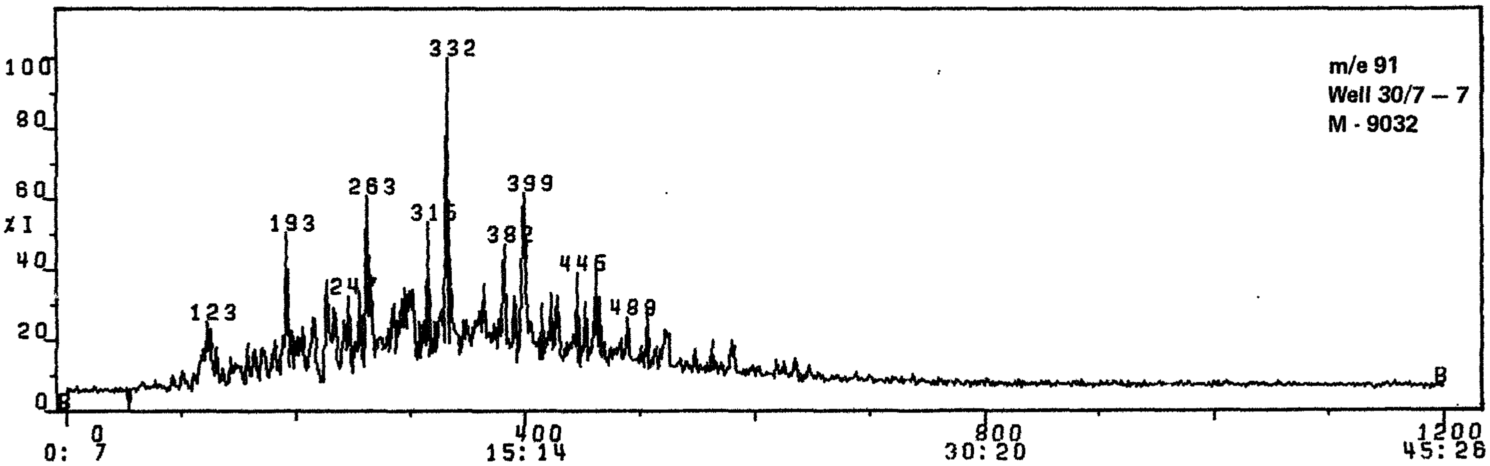


m/e 217
Well 35/8 – 1
M - 9137
3700 – 3800m
Drake


m/e 217
Well 30/3 – 1
M - 9138
3873 – 3950m
Drake
*
*
*
*
*
*
q
r
s
t


m/e 217
Well 30/3 – 1
M - 9139
4128 – 4227m
Burton/Amundsen
*
*
*
*
*
*
q
r
s
t


m/e 91
Well 30/3 – 1
M - 9139
100
80
60
%I
40
20
0
332
399
206
292
388
449
21
B
0
0: 6
400
15: 10
800
30: 13
1200
45: 16


m/e 91
Well 30/7 – 7
M - 9032
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80
60
%I
40
20
0
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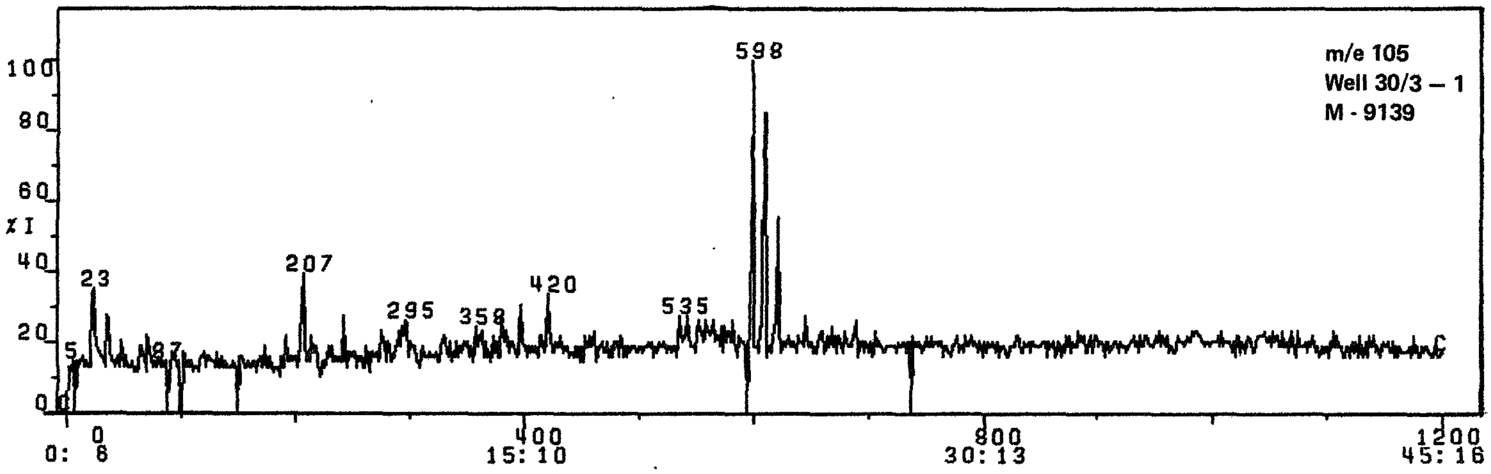
399
193
316
382
446
247
123
489
B
0
0: 7
400
15: 14
800
30: 20
1200
45: 26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Well 30/3 – 1
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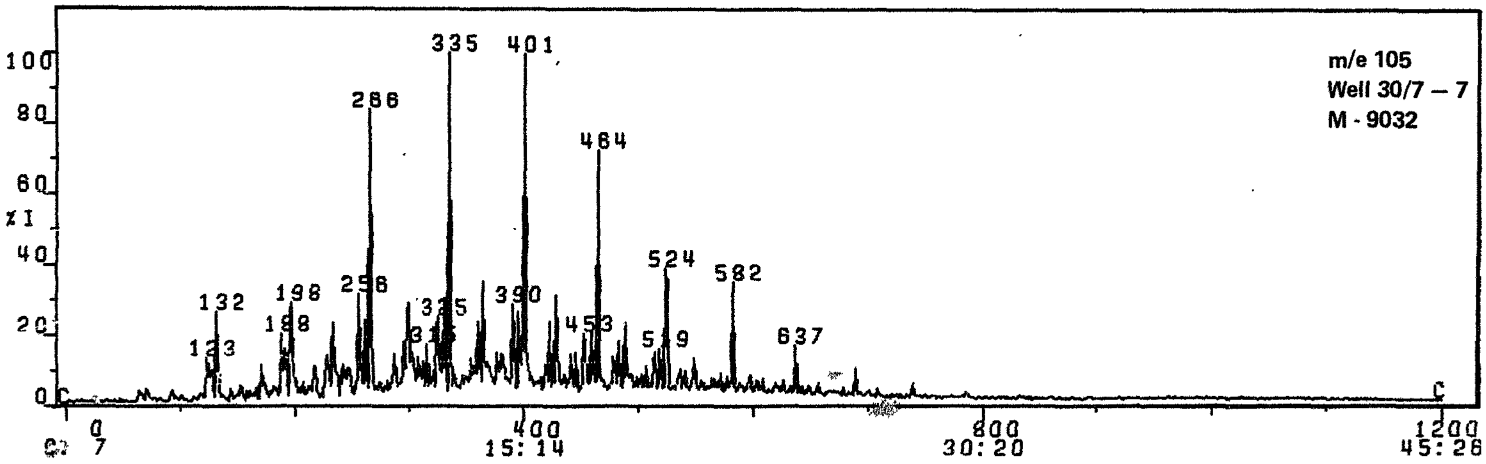
100
80
60
%I
40
20
0
598
23
207
420
295
358
535
5
87
C
0
0: 8
400
15: 10
800
30: 13
1200
45: 16


m/e 105
Well 30/7 – 7
M - 9032
100
80
60
%I
40
20
0
335
401
286
464
524
582
132
198
256
325
390
123
188
316
453
519
637
C
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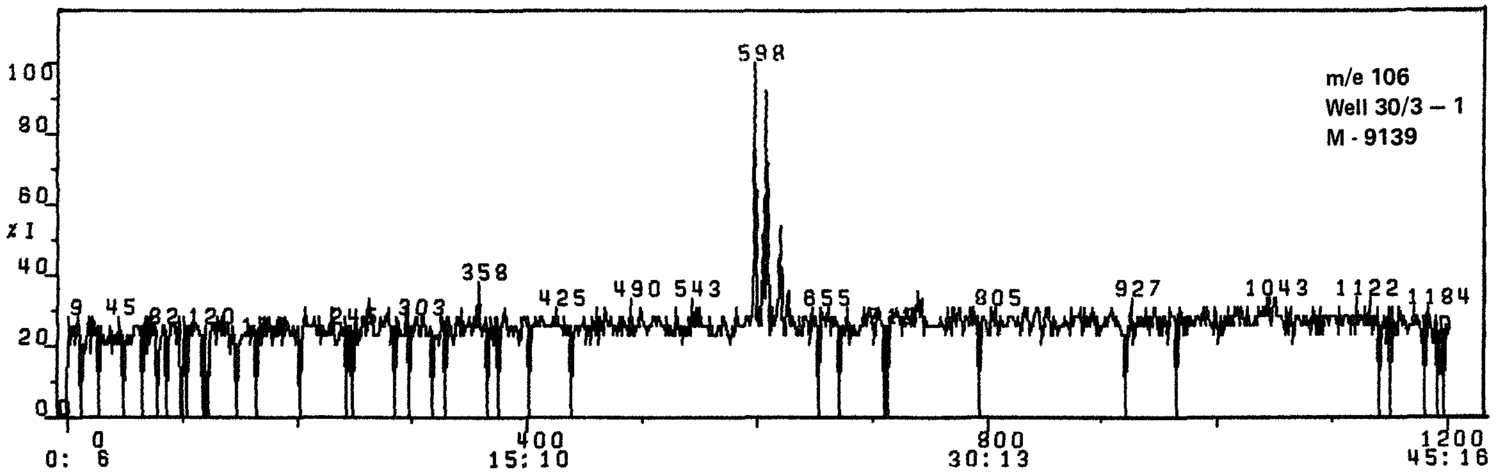
0: 7
400
15: 14
800
30: 20
1200
45: 26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358
9
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425
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543
655
805
927
1043
1122
1184
D
100
80
60
%I
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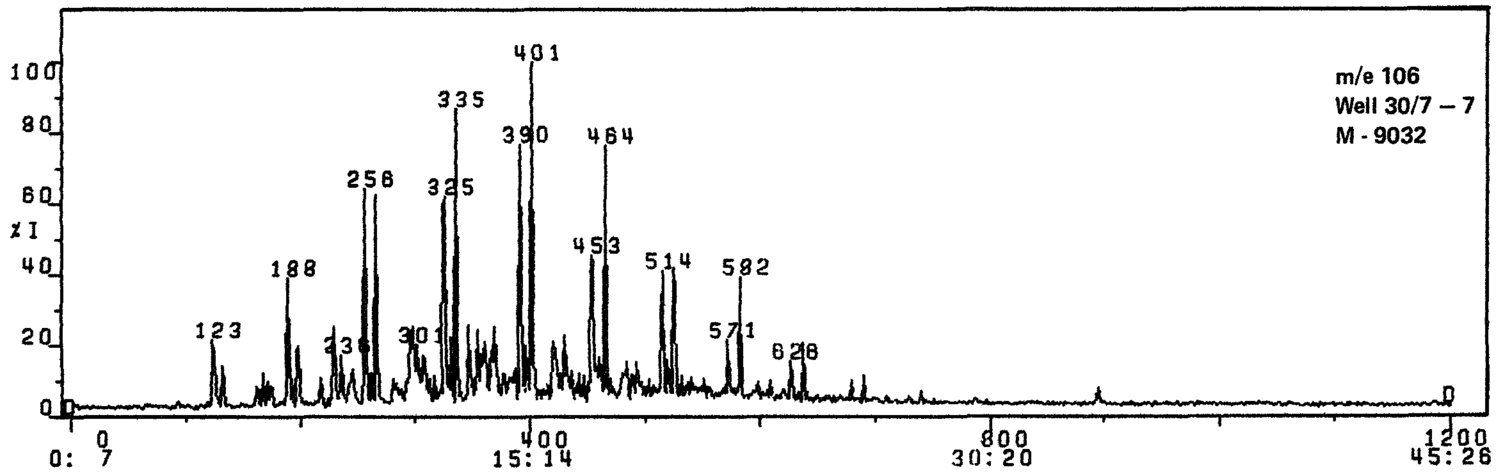
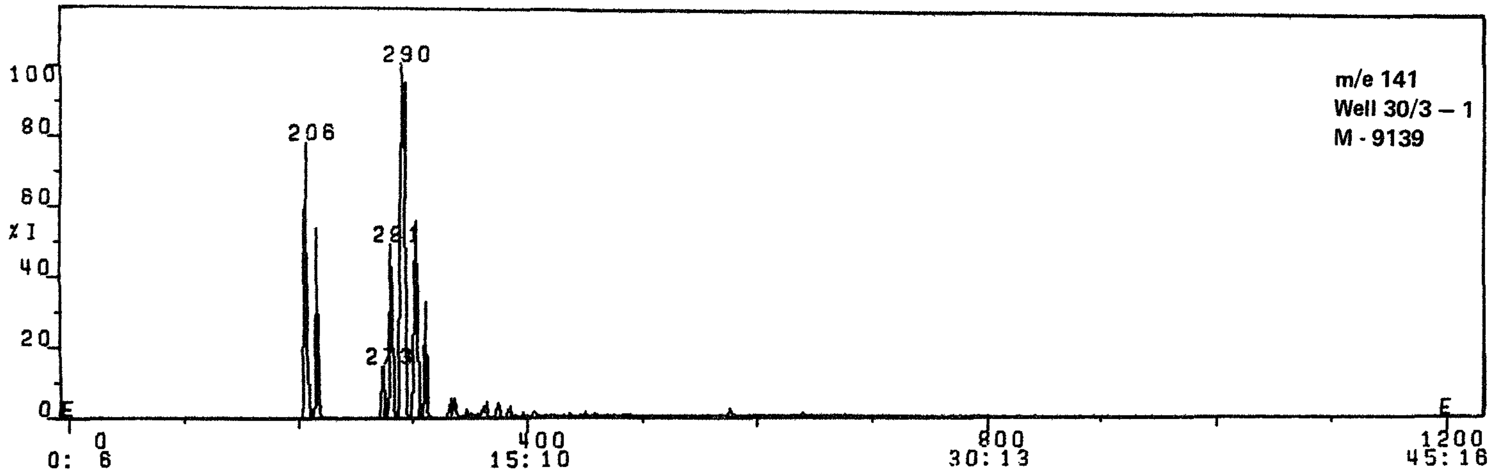
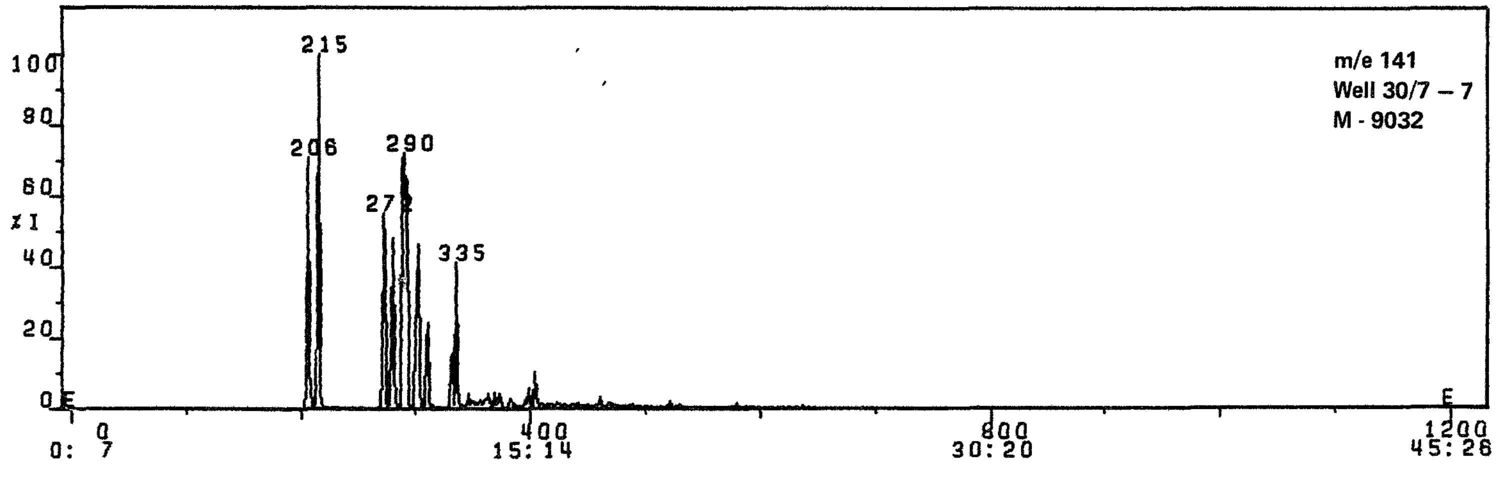
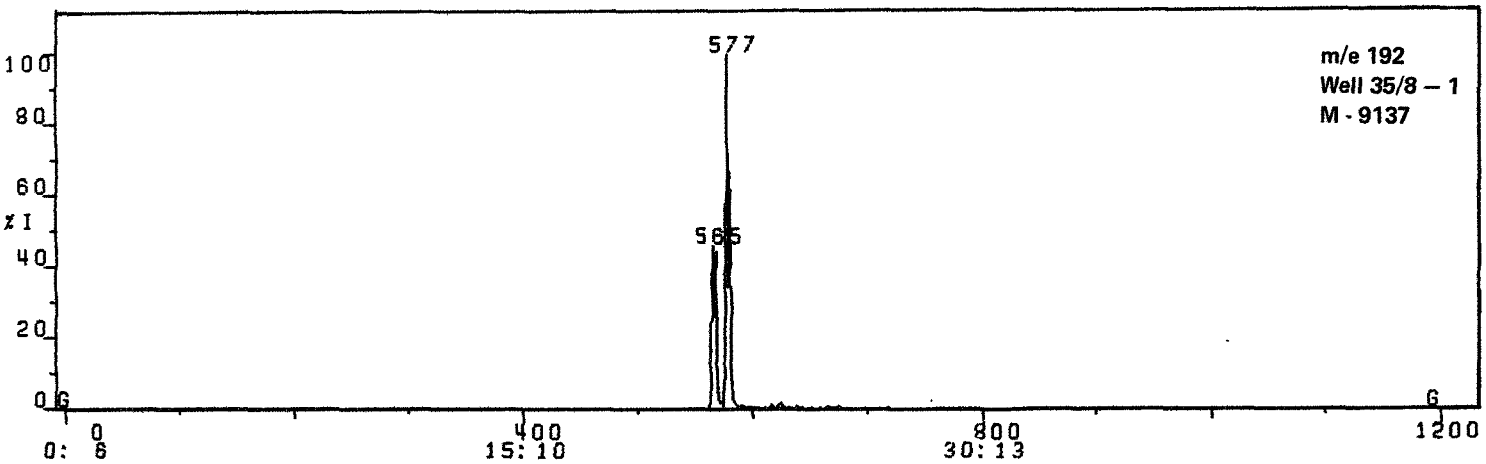
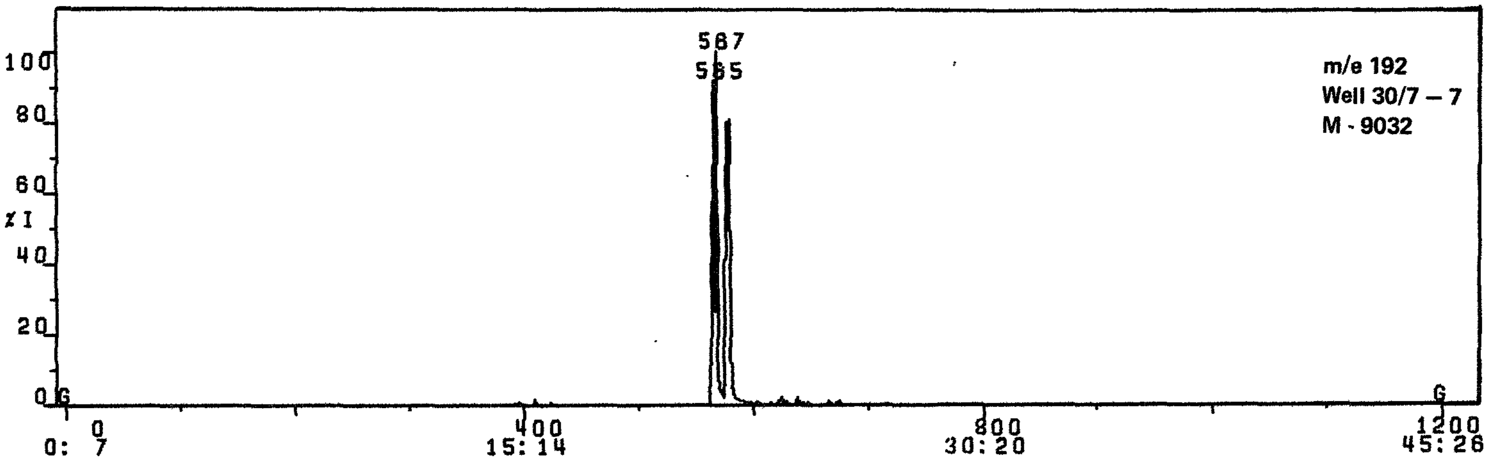
20
0
0
400
800
1200
0: 6
15: 10
30: 13
45: 16
m/e 106
Well 30/3 – 1
M - 9139

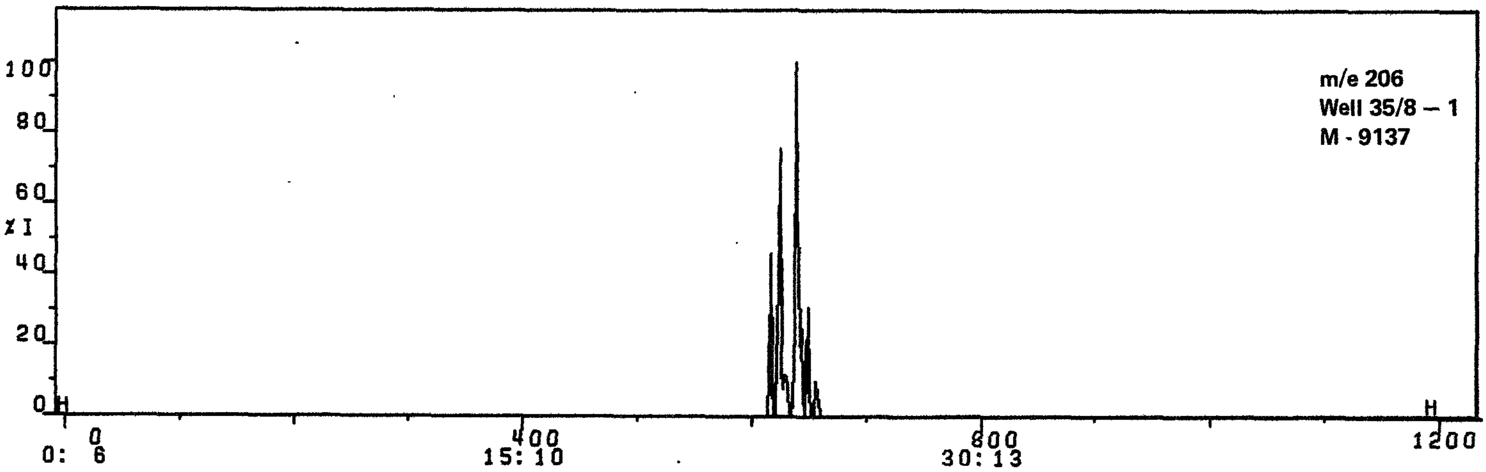

401
335
390
464
256
325
453
188
514
582
123
236
301
571
628
D
100
80
60
%I
40
20
0
0
400
800
1200
0: 7
15: 14
30: 20
45: 26
m/e 106
Well 30/7 – 7
M - 9032

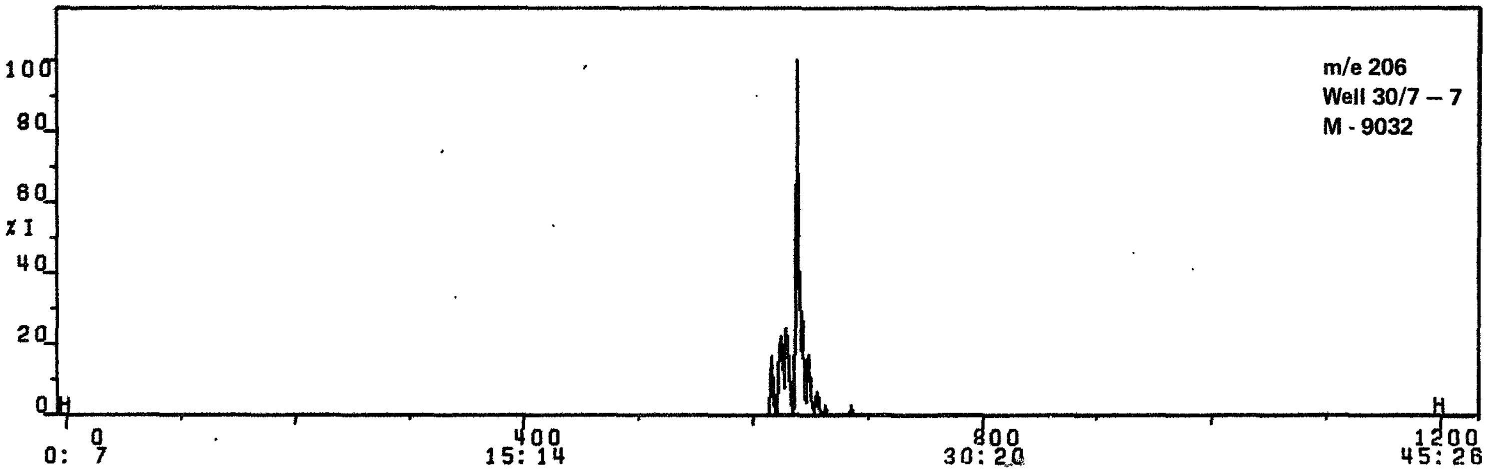

290
206
281
273
E
100
80
60
%I
40
20
0
0
400
800
1200
0: 6
15: 10
30: 13
45: 16
m/e 141
Well 30/3 – 1
M - 9139

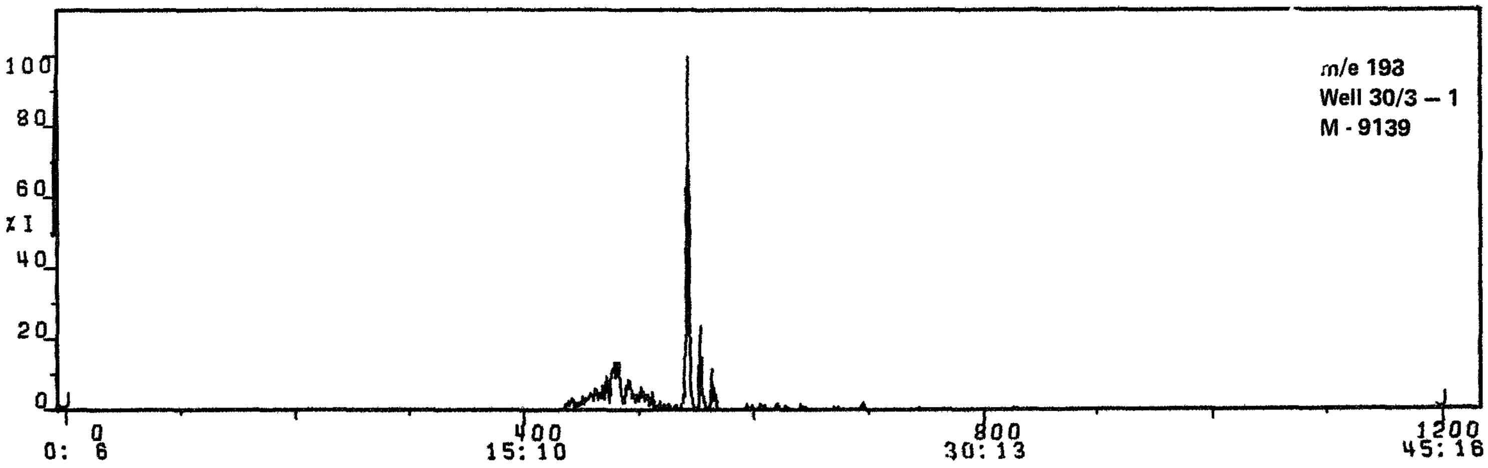

215
206
290
272
335
E
100
80
60
%I
40
20
0
0
400
800
1200
0: 7
15: 14
30: 20
45: 26
m/e 141
Well 30/7 – 7
M - 9032

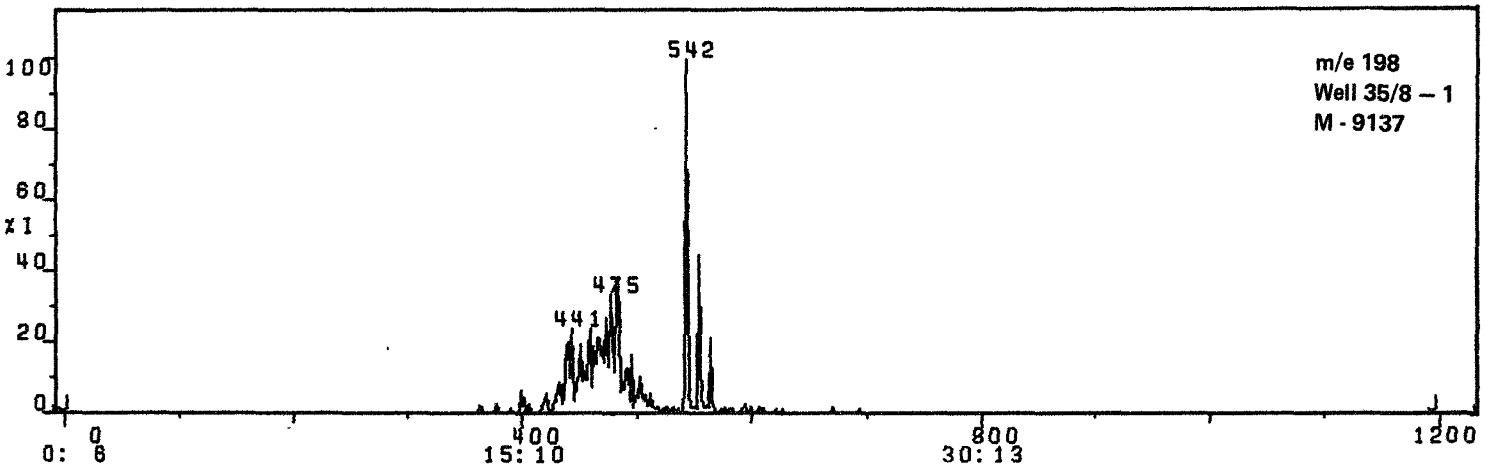

577
565
m/e 192
Well 35/8 – 1
M - 9137
100
80
60
%I
40
20
0
G
G
0
0: 6
400
15: 10
800
30: 13
1200

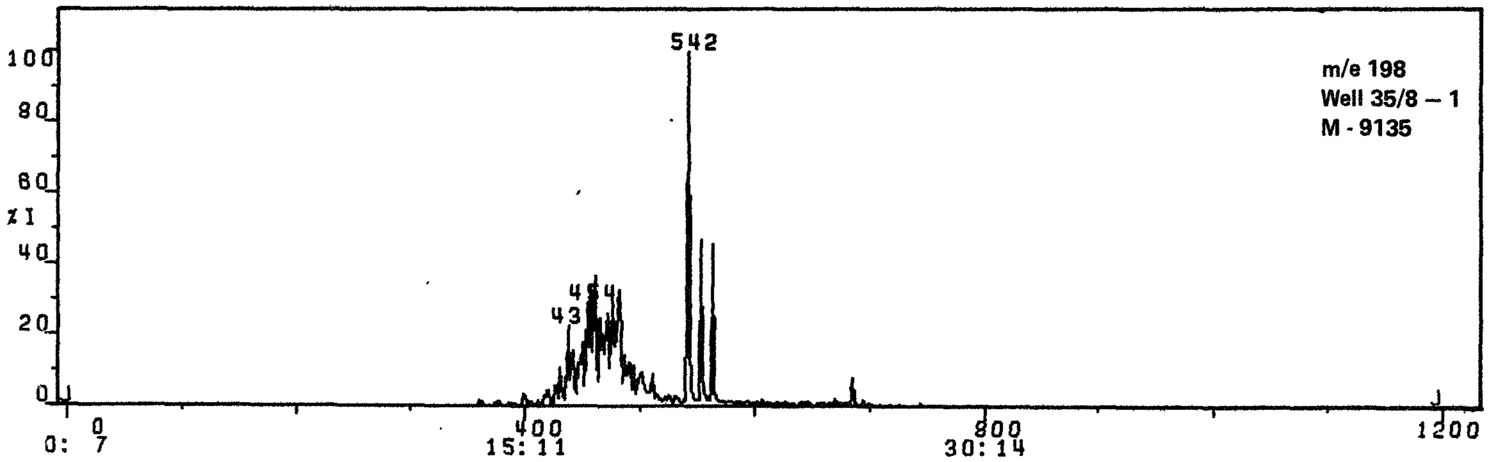

587
585
m/e 192
Well 30/7 – 7
M - 9032
100
80
60
%I
40
20
0
G
G
0
0: 7
400
15: 14
800
30: 20
1200
45: 26


m/e 206
Well 35/8 – 1
M - 9137
100
80
60
%I
40
20
0
H
H
0
0: 6
400
15: 10
800
30: 13
1200


m/e 206
Well 30/7 – 7
M - 9032
100
80
60
%I
40
20
0
H
H
0
0: 7
400
15: 14
800
30: 20
1200
45: 26


m/e 198
Well 30/3 – 1
M - 9139
100
80
60
%I
40
20
0
0
0: 6
400
15: 10
800
30: 13
1200
45: 16


542
475
441
m/e 198
Well 35/8 – 1
M - 9137
100
80
60
%I
40
20
0
0
0: 6
400
15: 10
800
30: 13
1200


542
464
43
m/e 198
Well 35/8 – 1
M - 9135
100
80
60
%I
40
20
0
0
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15: 11
800
30: 14
1200

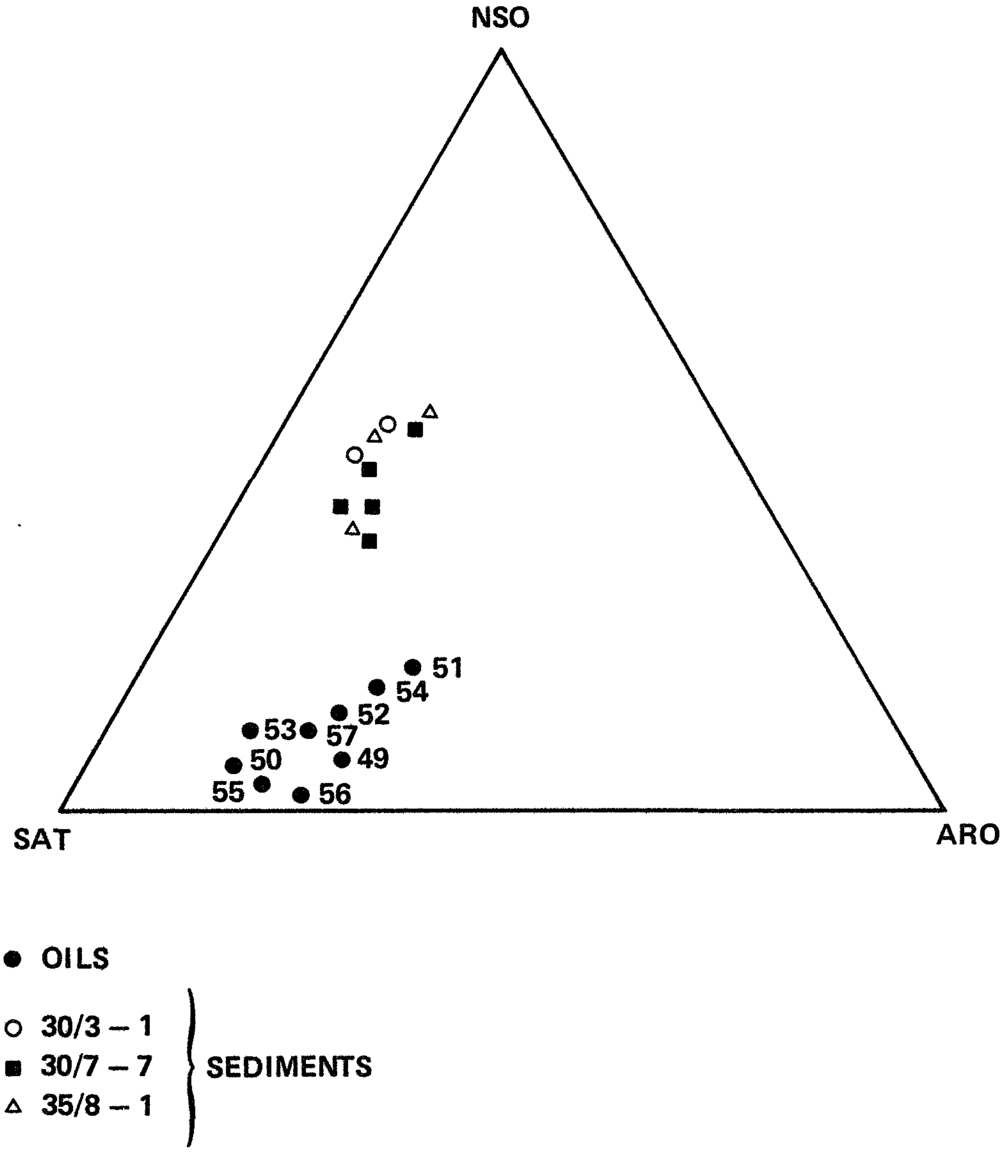

Fig. 11 Triangular plot of gross composition of oils and sediments.

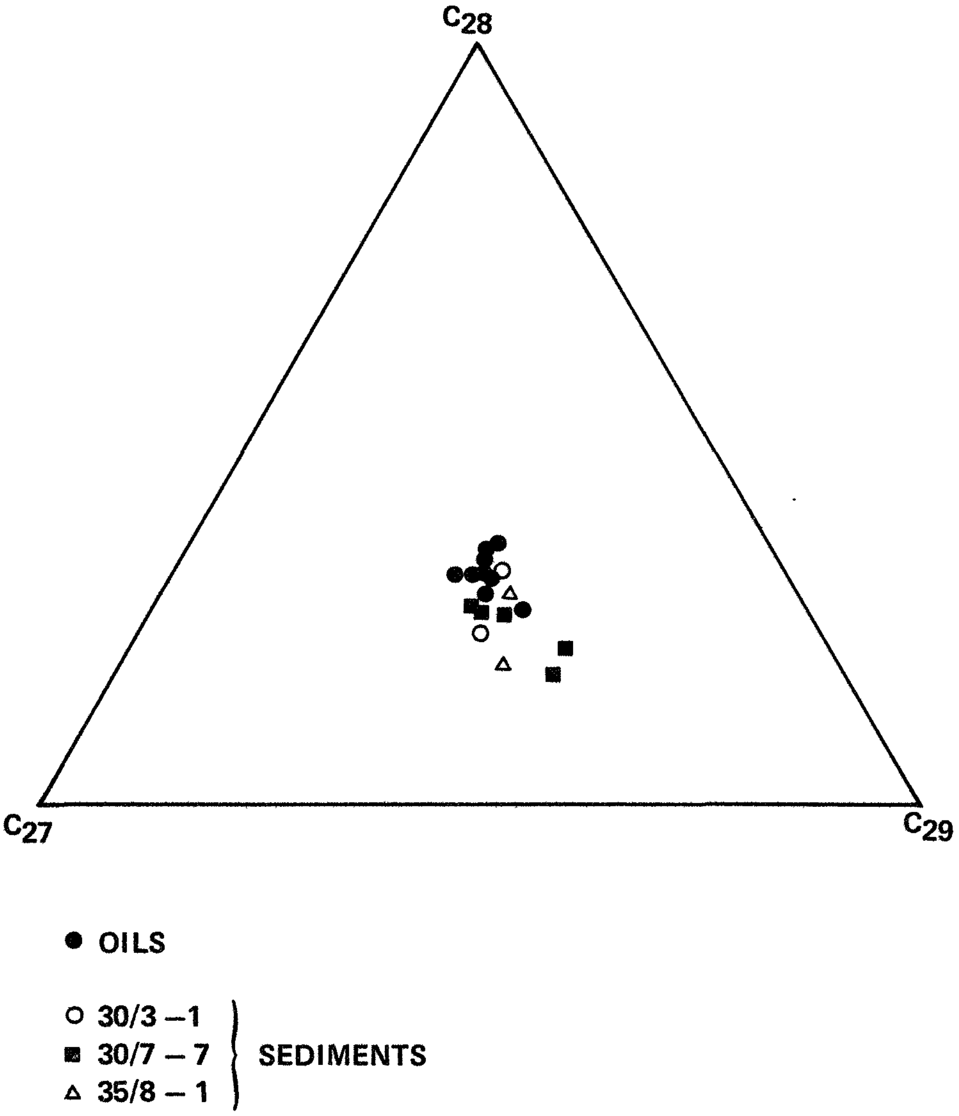

Fig. 12 Triangular plot of molecular weight distribution of steranes.

Figure 10

GC-MS ANALYSIS OF AROMATIC HYDROCARBONS

m/e 91, 105, 106	Alkylbenzenes
m/e 141	Alkylnapthalenes
m/e 192	Methylphenanthrenes
m/e 206	Dimethylphenanthrenes
m/e 198	Methyldibenzothiophenes