**ANALABS**
A Division of Macdonald Hamilton & Co. Pty. Ltd.
ANALYTICAL CHEMISTS

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PT/fmh

25th January, 1985.

Dr. R. Heath
Petroleum Geologist
Delhi Petroleum Pty. Ltd.
33 King William Street
ADELAIDE SA 5000

Dear Dr Heath,

Please find enclosed the results of the organic geochemical analyses carried out on two oil samples from the Kerinna and Limestone Creek No. 1 wells, drilled in permit PEL 5 and 6 (Nappacoongee - Murteree) of South Australia. Analysis of these two oils were carried out to characterise these crude and to determine if any genetic relationship exists between the two.

These samples were submitted to the following analytical program under Analabs Job Number 34023:

| Type of Analysis | Figure | Table |
|---|---|---|
| C1-C31 whole oil gas-liquid chromatography | 1 | 1 |
| C4-C7 detailed gasoline range compositional data | 2 | 1,2 |
| Liquid chromatography | | 3 |
| C12+ saturate gas-liquid chromatography | 3 | 4 |
| Gas chromatography-mass spectrometry (GC-MS) | 4,5 | 5,6 |
| C13/C12 Carbon isotopic determination of saturate and aromatic hydrocarbon fractions | | 7 |

A description of these analyses is presented in the Theory and Methods section located at the back of this study.

Should you have any questions regarding this study, please feel free to contact either myself or Garry Woodhouse of Analabs, Perth.

Yours faithfully,

Paul Tybor

PAUL TYBOR
Manager - Operations

## DISCUSSION OF THE RESULTS

| Well | Interval | Stratigraphic Unit |
|---|---|---|
| Kerinna No. 1 | 5140 - 5160ft | Hutton Sandstone |
| Limestone Creek No. 1 | 3936 - 3976ft | Murta |

The two oils are very similar having been sourced from terrestrial organic matter, with the only differences being slightly different thermal maturities and extent of water washing.

Based on the absence of C27 steranes and diasteranes (217 and 259 ions; Figures 5A, 6A), these crudes have originated from terrestrial organic matter (See Theory and Methods section under GC-MS for interpretation parameters). The triterpane data indicate the Kerinna Hutton oil has experienced a slightly higher geothermal history than the Limestone Creek Murta oil. This is evidenced by the fewer amounts of moretanes in the Hutton oil than in the Murta crude. Hopanes increase with maturity at the expense of the moretanes.

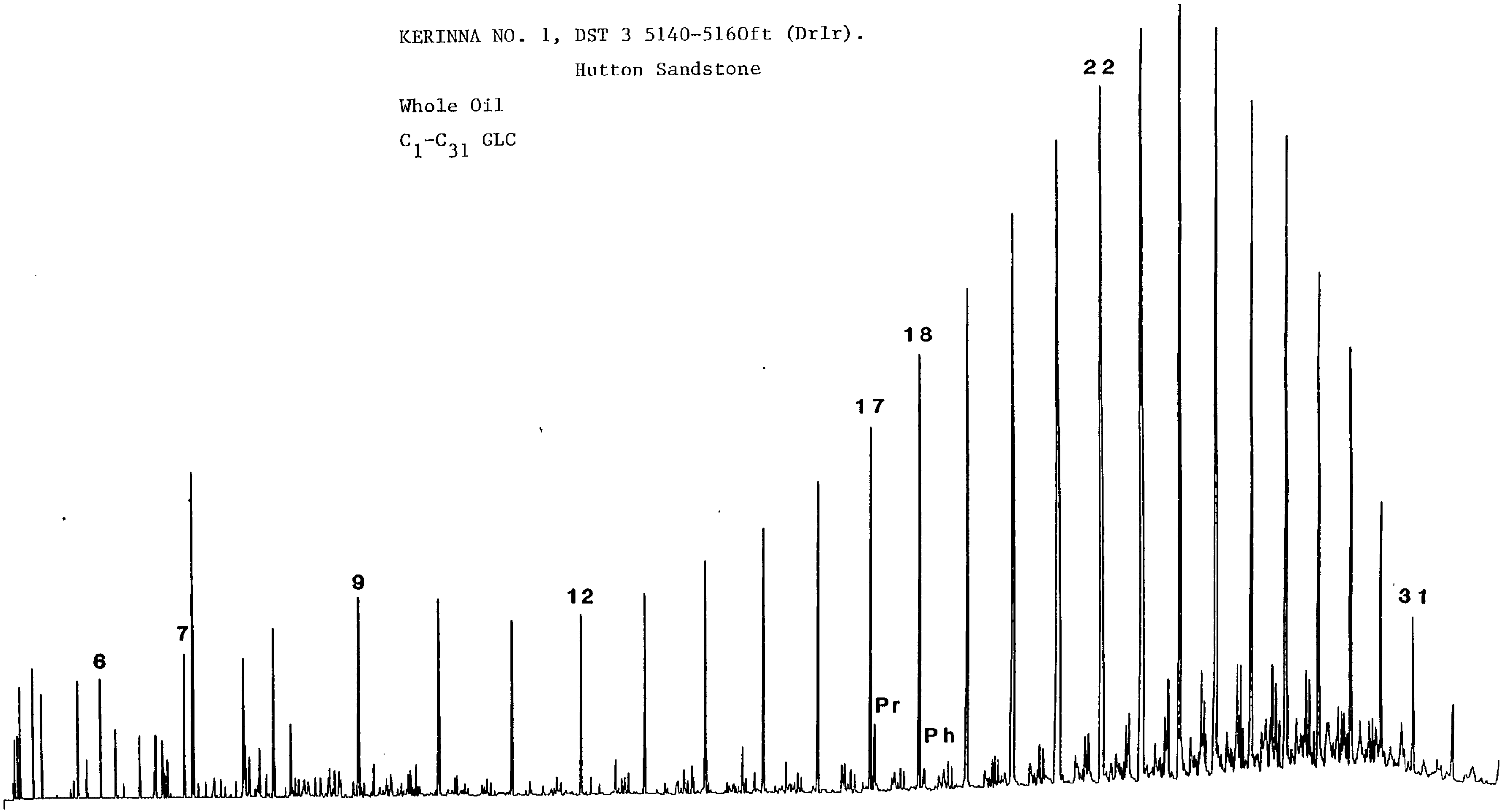
The Hutton oil has lesser amounts of nC4 to nC18 normal alkanes in relation to the high molecular weight normal alkanes (>nC20), than the corresponding normal alkanes in the Murta crude. This is the result of water washing which has removed some of the lighter molecular weight normal alkanes. However apparently the Murta sample has been exposed to a lesser degree of this alteration than has the Hutton crude. The C4-C7 detailed gasoline range hydrocarbon data (Figure 2; Tables 1,2) illustrates the extent of this alteration, as shown by the ratios containing aromatic compounds (3-MP/Bz; MCH/Tol; Ch/Bz; Table 2). The values were either uncomputable or else very high, reflecting the water solubility of the aromatics.

The GC-MS fragmentograms (Figures 4, 5) indicate the samples originated from similar source material, but at different maturities. The C1-C31 and C12+ saturate gc traces (Figures 1, 3) exhibit similar configurations. The pristane/phytane, pristane/nC17 and phytane/nC18 ratios, as well as carbon isotopes are fairly close for both samples (Table 4). As a result, the bulk of the data generated suggest these two oils are genetically related, or else originated from separate source rocks, which contain very similar organic matter.

The Murta is generally held to be an oil source rock, provided it is buried deep enough in the basin. At this well location, the Murta oil is produced from sediments that are buried less than four thousand feet deep and are probably still immature. As a result, if this oil has been sourced from the Murta, then it probably originated from the unit at a deeper, more mature position within of the basin. If this Murta oil and the Hutton oil are related then it is questionable as to whether these crudes could have originated from the Murta. However, if the Murta is positioned within the basin below the depth of the Hutton reservoir in the Kerrina well, then this possibility may exist.

Alternatively, the source for both crudes may be a unit older than Murta, or as mentioned previously, the organic nature of the various source units in the basin maybe very similar, and have yielded similar oils.

FIGURE 1A


KERINNA NO. 1, DST 3 5140-5160ft (Drlr).
Hutton Sandstone

Whole Oil

$C_1$-$C_{31}$ GLC

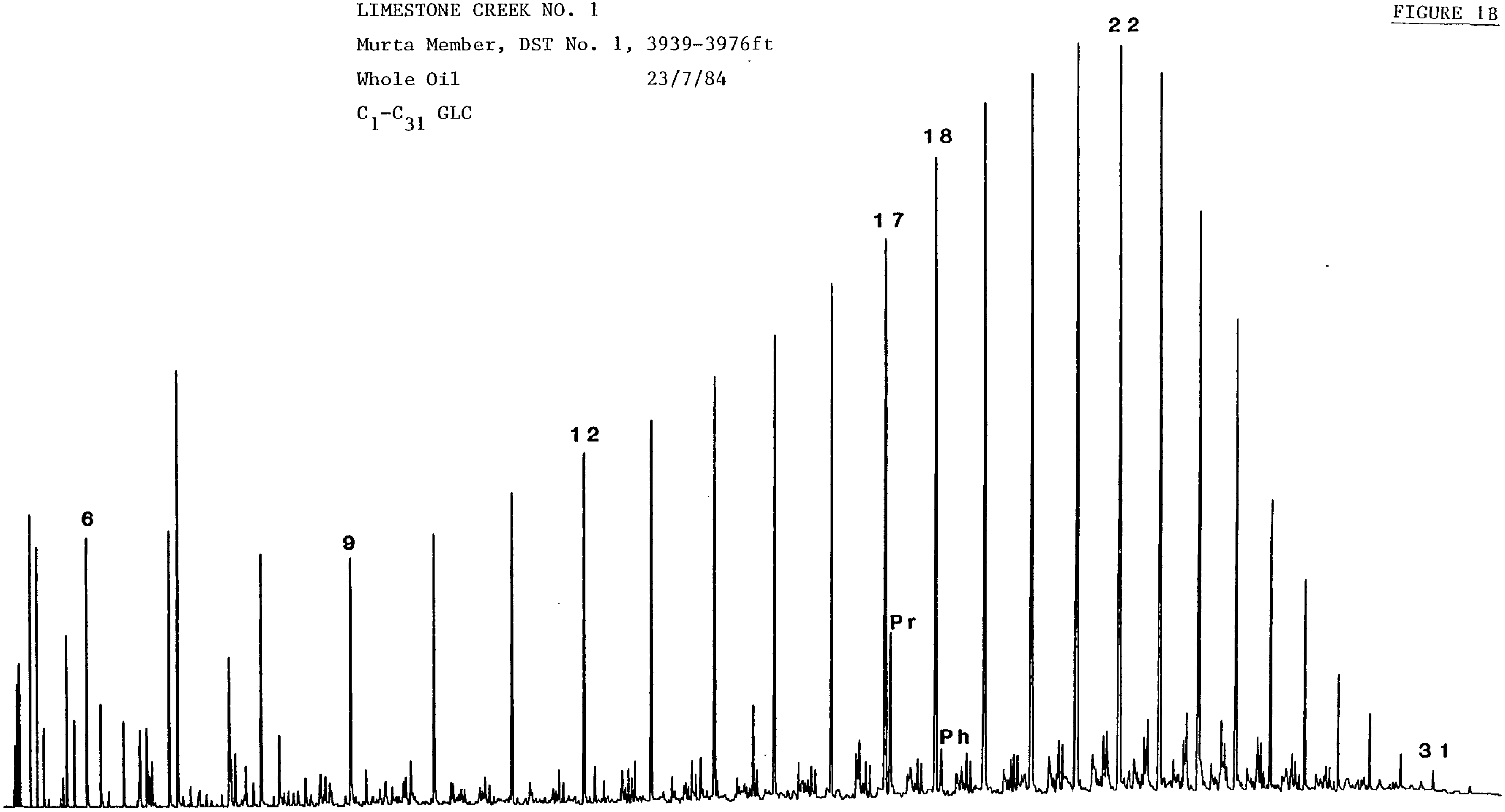
FIGURE 1B

LIMESTONE CREEK NO. 1

Murta Member, DST No. 1, 3939-3976ft

Whole Oil 23/7/84

$C_1$-$C_{31}$ GLC



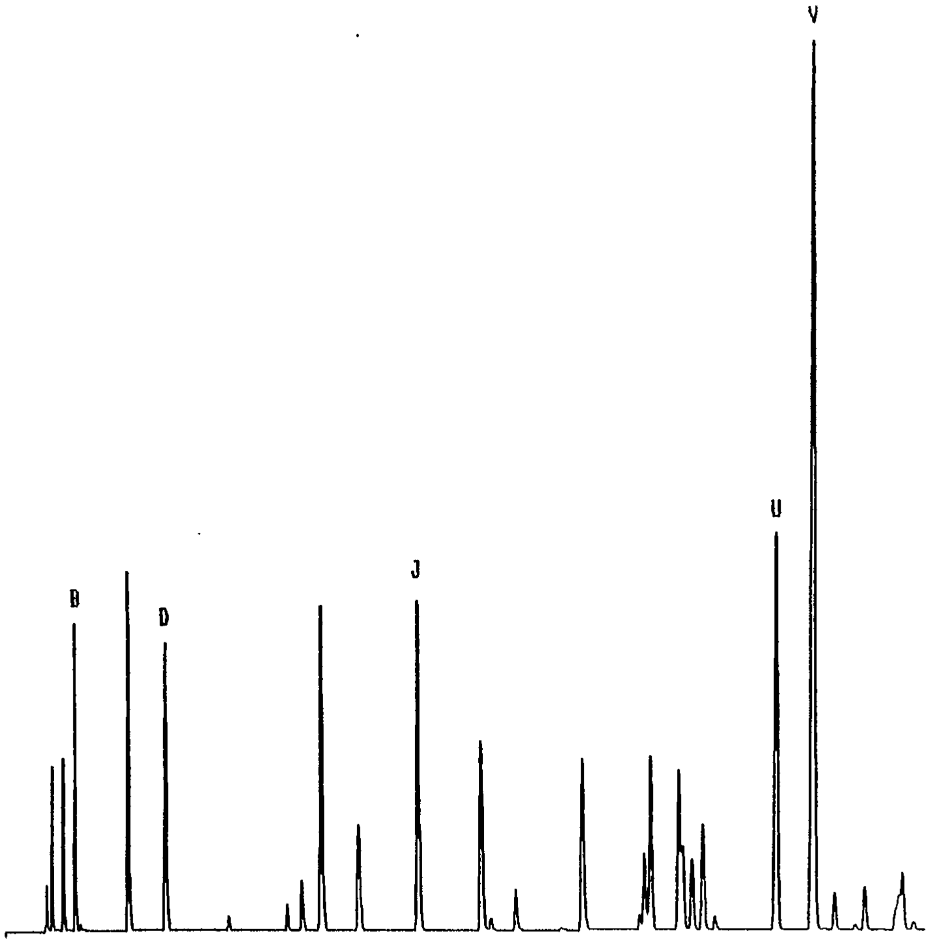
KERINNA NO. 1, DST 3 5140-5160ft (Drlr).

FIGURE 2A

Hutton Sandstone

Whole Oil

$C_1$-$C_7$ GLC

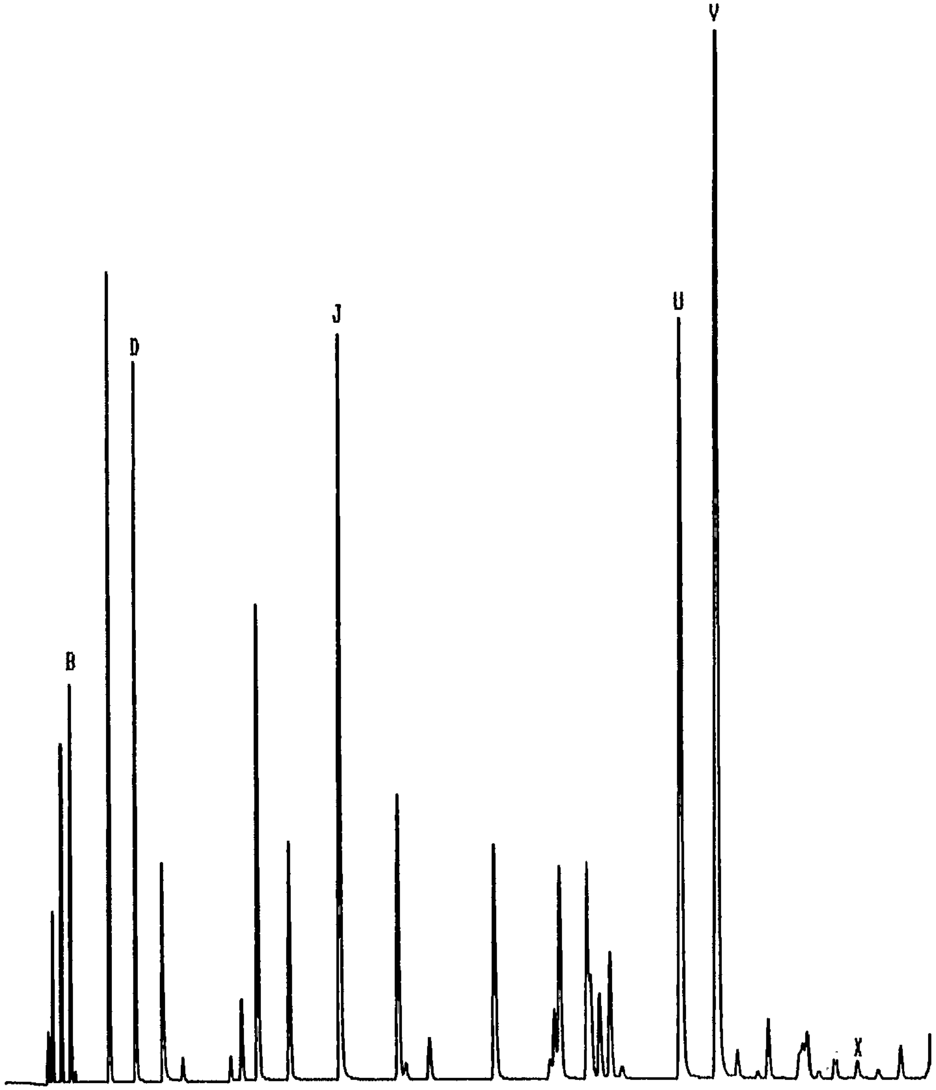


C4-7 COMPOUNDS

| | |
|---|---|
| A | isobutane |
| B | n-butane |
| C | isopentane |
| D | n-pentane |
| E | 2,2-dimethylbutane |
| F | cyclopentane |
| G | 2,3-dimethylbutane |
| H | 2-methylpentane |
| I | 3-methylpentane |
| J | n-hexane |
| K | methylcyclopentane |
| L | 2,4-dimethylpentane |
| M | benzene |
| N | cyclohexane |
| O | 1,1-dimethylcyclopentane |
| P | 2-methylhexane |
| Q | 3-methylhexane |
| R | 1 cis-3-dimethylcyclopentane |
| S | 1 trans-3-dimethylcyclopentane |
| T | 1 trans-2-dimethylcyclopentane |
| U | n-heptane |
| V | methylcyclohexane |
| W | 1 cis-2-dimethylcyclopentane |
| X | toluene |

FIGURE 2B

LIMESTONE CREEK NO. 1
Murta Member, DST No. 1, 3939-3976ft
Whole Oil 23/7/84
$C_1$-$C_7$ GLC



C4-7 COMPOUNDS

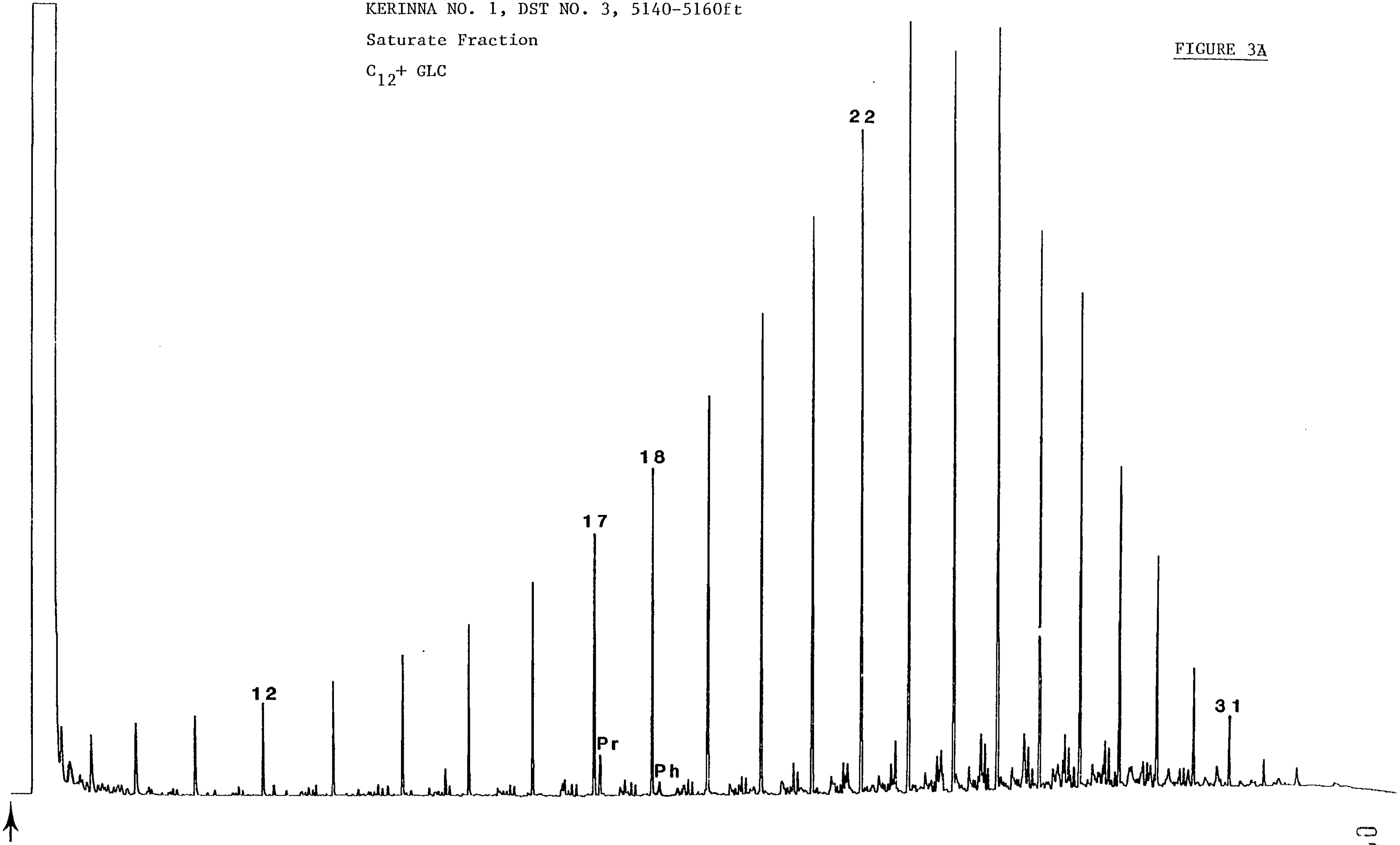
| | |
|---|---|
| A | isobutane |
| B | n-butane |
| C | isopentane |
| D | n-pentane |
| E | 2,2-dimethylbutane |
| F | cyclopentane |
| G | 2,3-dimethylbutane |
| H | 2-methylpentane |
| I | 3-methylpentane |
| J | n-hexane |
| K | methylcyclopentane |
| L | 2,4-dimethylpentane |
| M | benzene |
| N | cyclohexane |
| O | 1,1-dimethylcyclopentane |
| P | 2-methylhexane |
| Q | 3-methylhexane |
| R | 1 cis-3-dimethylcyclopentane |
| S | 1 trans-3-dimethylcyclopentane |
| T | 1 trans-2-dimethylcyclopentane |
| U | n-heptane |
| V | methylcyclohexane |
| W | 1 cis-2-dimethylcyclopentane |
| X | toluene |

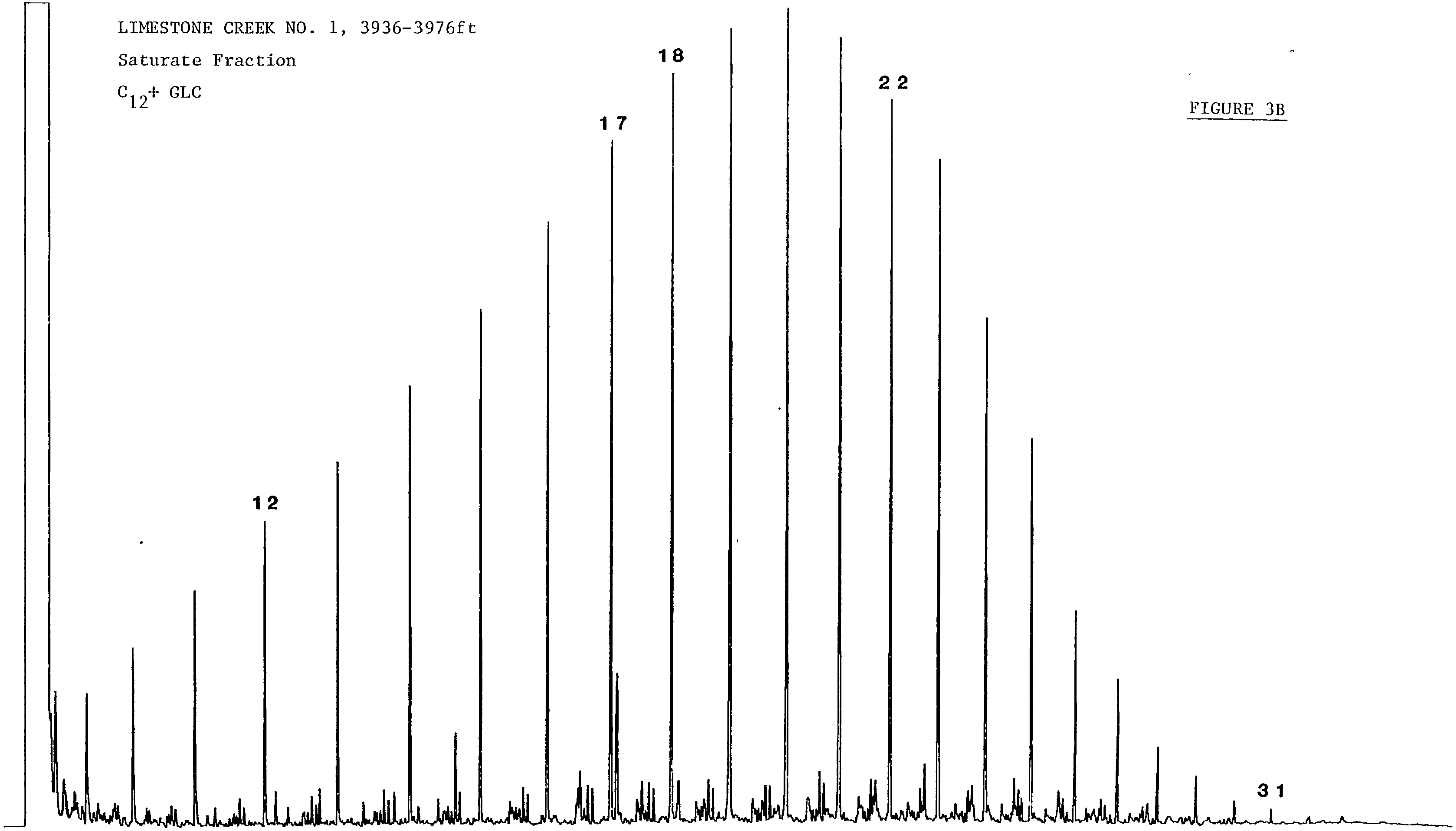
KERINNA NO. 1, DST NO. 3, 5140-5160ft

Saturate Fraction

$C_{12}$+ GLC

FIGURE 3A





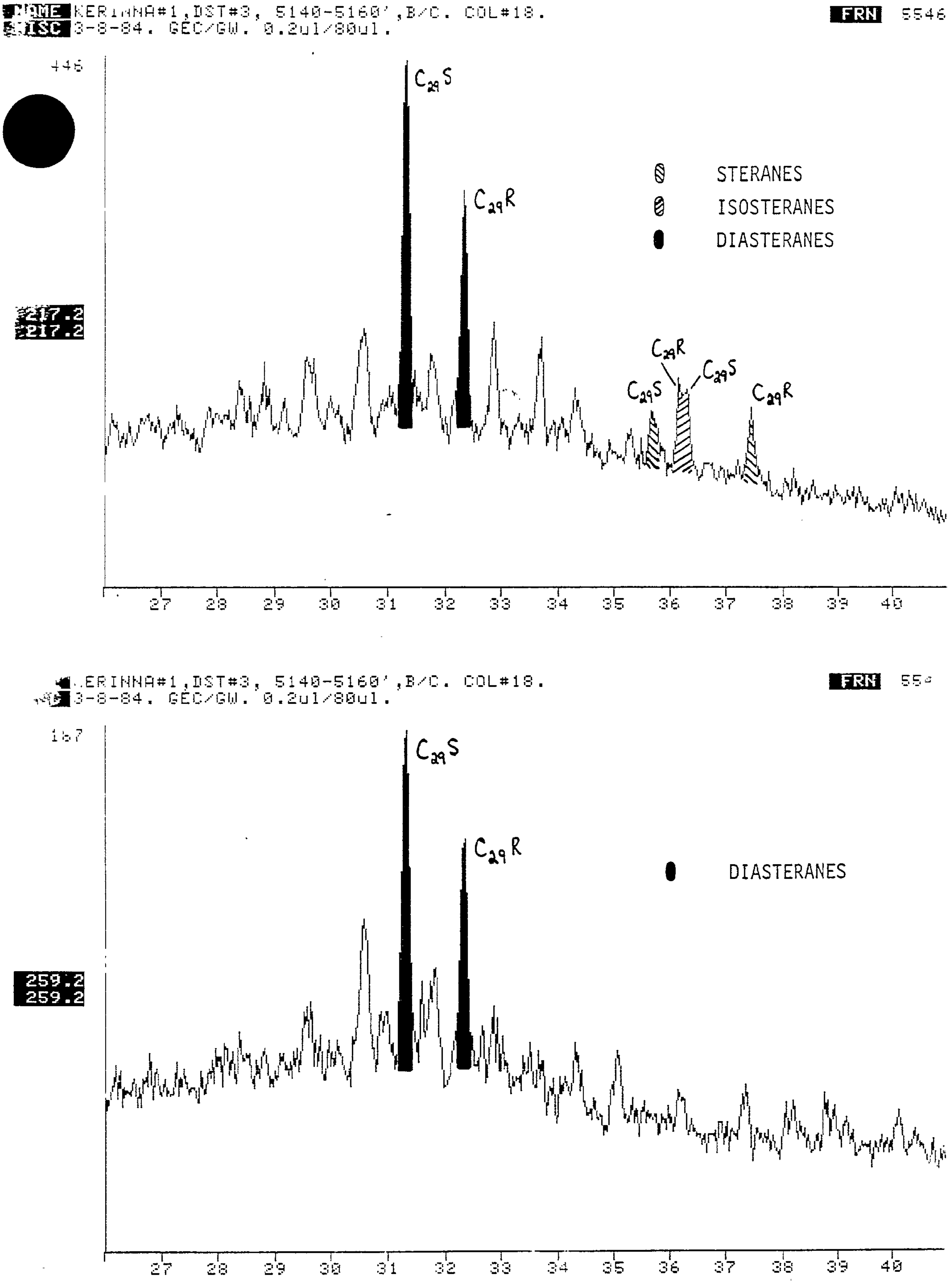
LIMESTONE CREEK NO. 1, 3936-3976ft

Saturate Fraction

$C_{12}$+ GLC

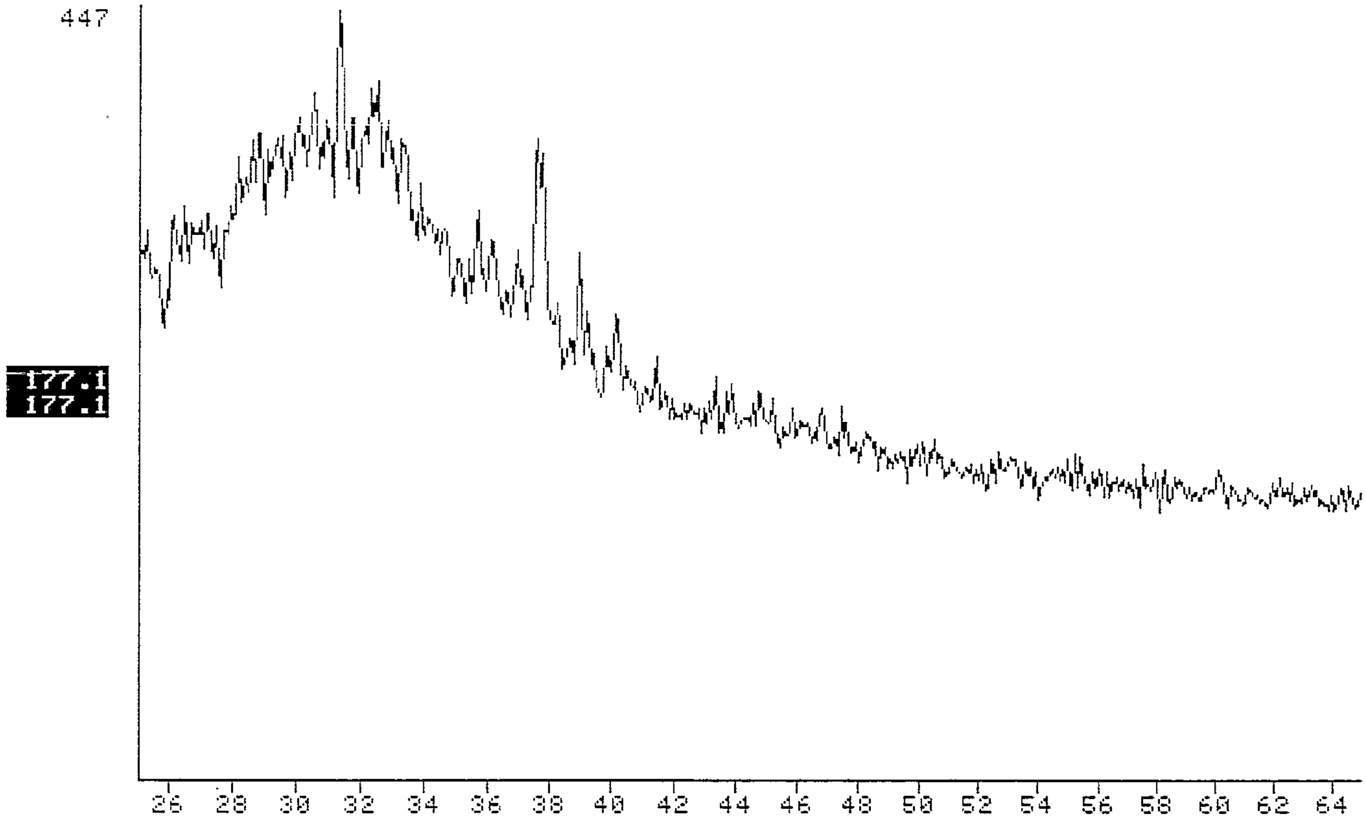
FIGURE 3B

FIGURE 4A


NAME KERINNA#1,DST#3, 5140-5160',B/C. COL#18.
MISC 3-8-84. GEC/GW. 0.2ul/80ul.
FRN 5546
446
217.2
217.2
$C_{29}S$
$C_{29}R$
▨ STERANES
▨ ISOSTERANES
● DIASTERANES
$C_{29}S$
$C_{29}R$
$C_{29}S$
$C_{29}R$
27 28 29 30 31 32 33 34 35 36 37 38 39 40
ERINNA#1,DST#3, 5140-5160',B/C. COL#18.
3-8-84. GEC/GW. 0.2ul/80ul.
FRN 55
167
259.2
259.2
$C_{29}S$
$C_{29}R$
● DIASTERANES
27 28 29 30 31 32 33 34 35 36 37 38 39 40

# FIGURE 4B

**NAME** KERINNA#1,DST#3, 5140-5160',B/C. COL#18. **FRN** 5546
**MISC** 3-8-84. GEC/GW. 0.2ul/80ul.



**ME** KERINNA#1,DST#3, 5140-5160',B/C. COL#18. **FRN** 5546
**C** 3-8-84. GEC/GW. 0.2ul/80ul.

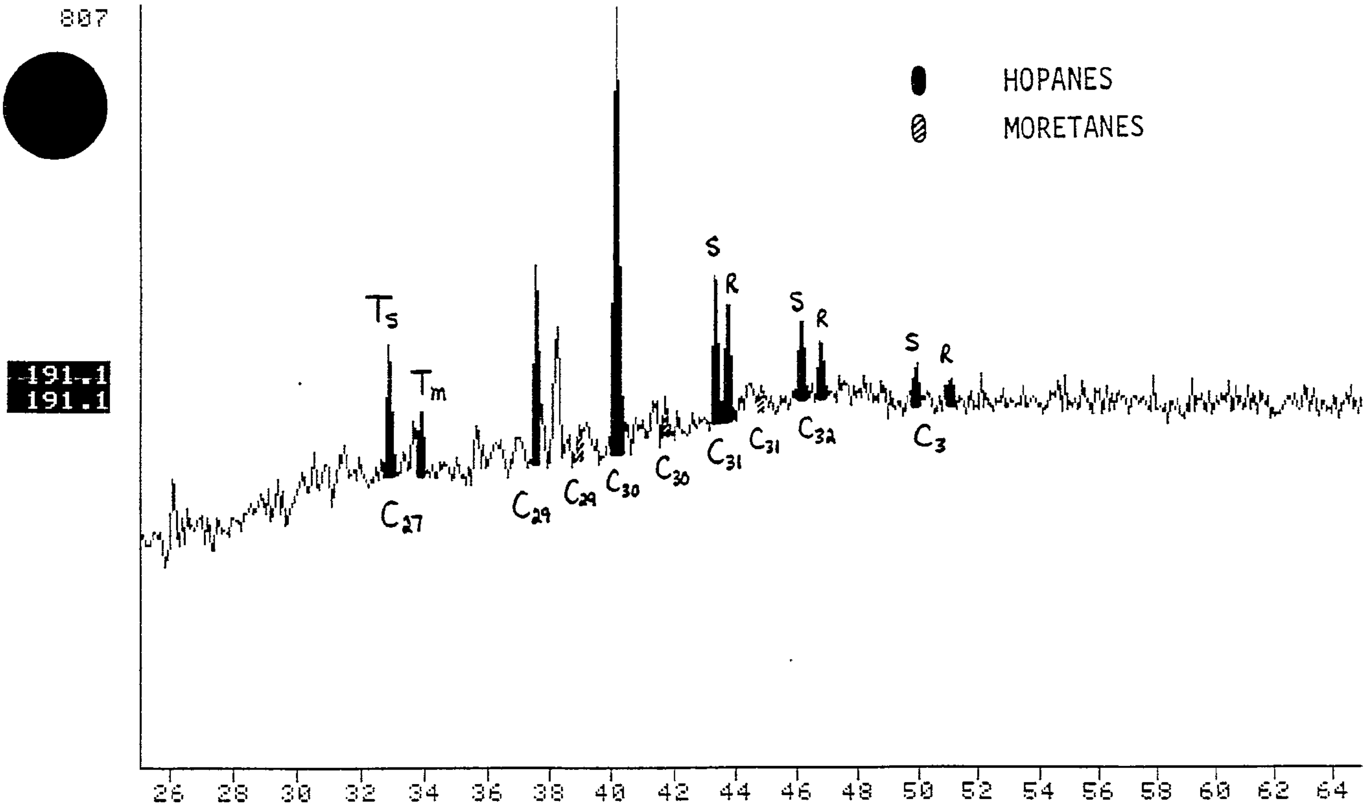
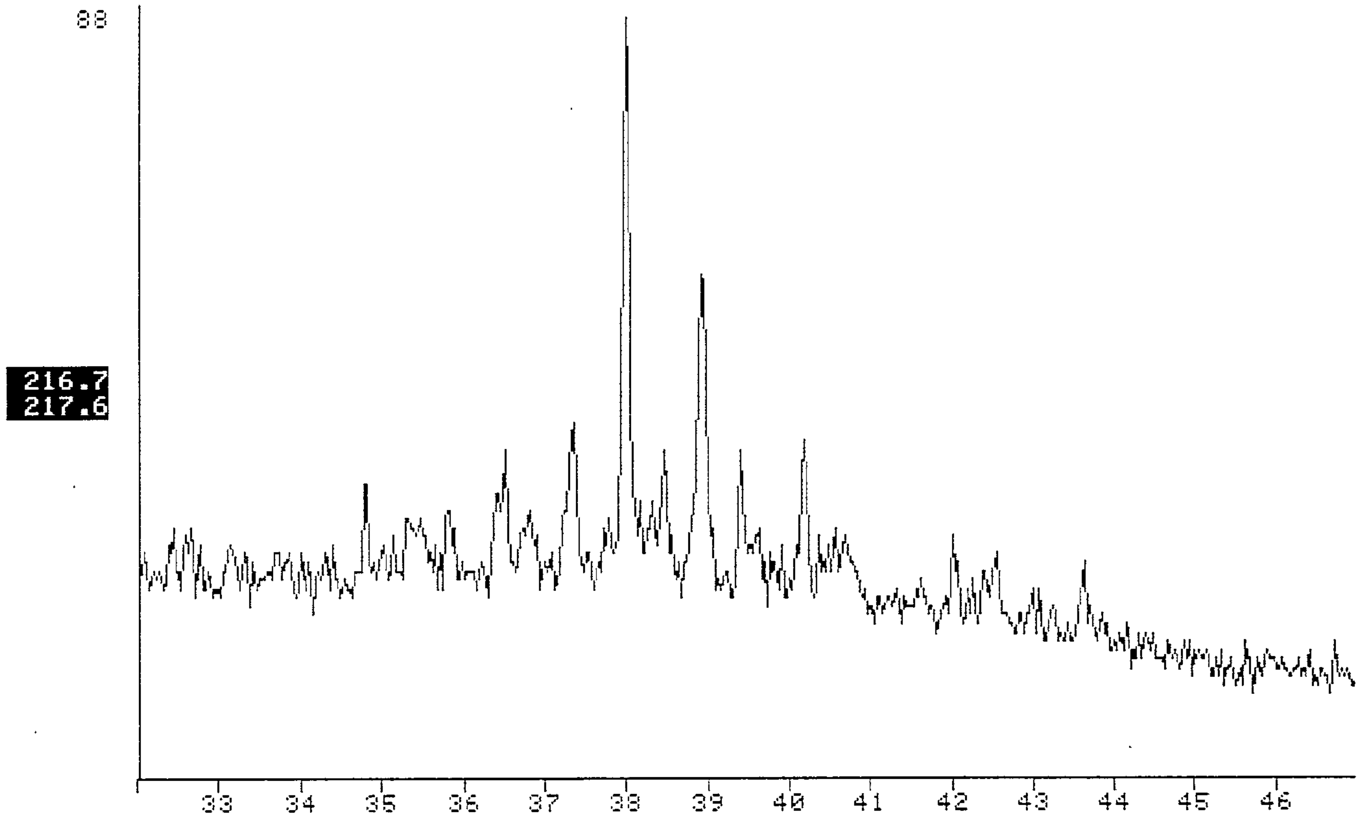


FIGURE 4C

**NAME** KERINNA#1,DST#3, 5140-5160'. B/C. COL#41. **FRN** 5589
**MISC** 12-9-84. GEC/GW. 0.2ul/200ul.



**NAME** KERINNA#1,DST#3, 5140-5160'. B/C. COL#41. **FRN** 5589
**MISC** 12-9-84. GEC/GW. 0.2ul/200ul.

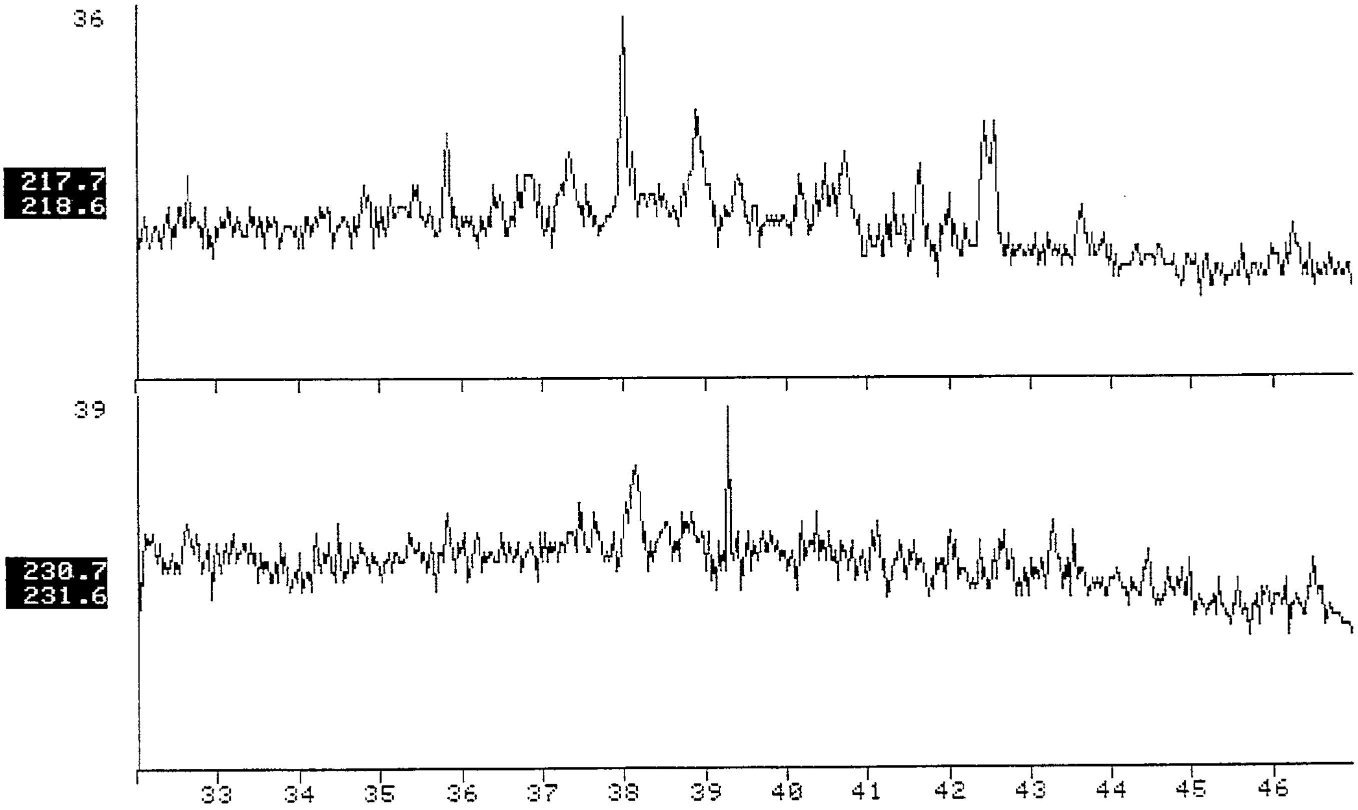


FIGURE 4D

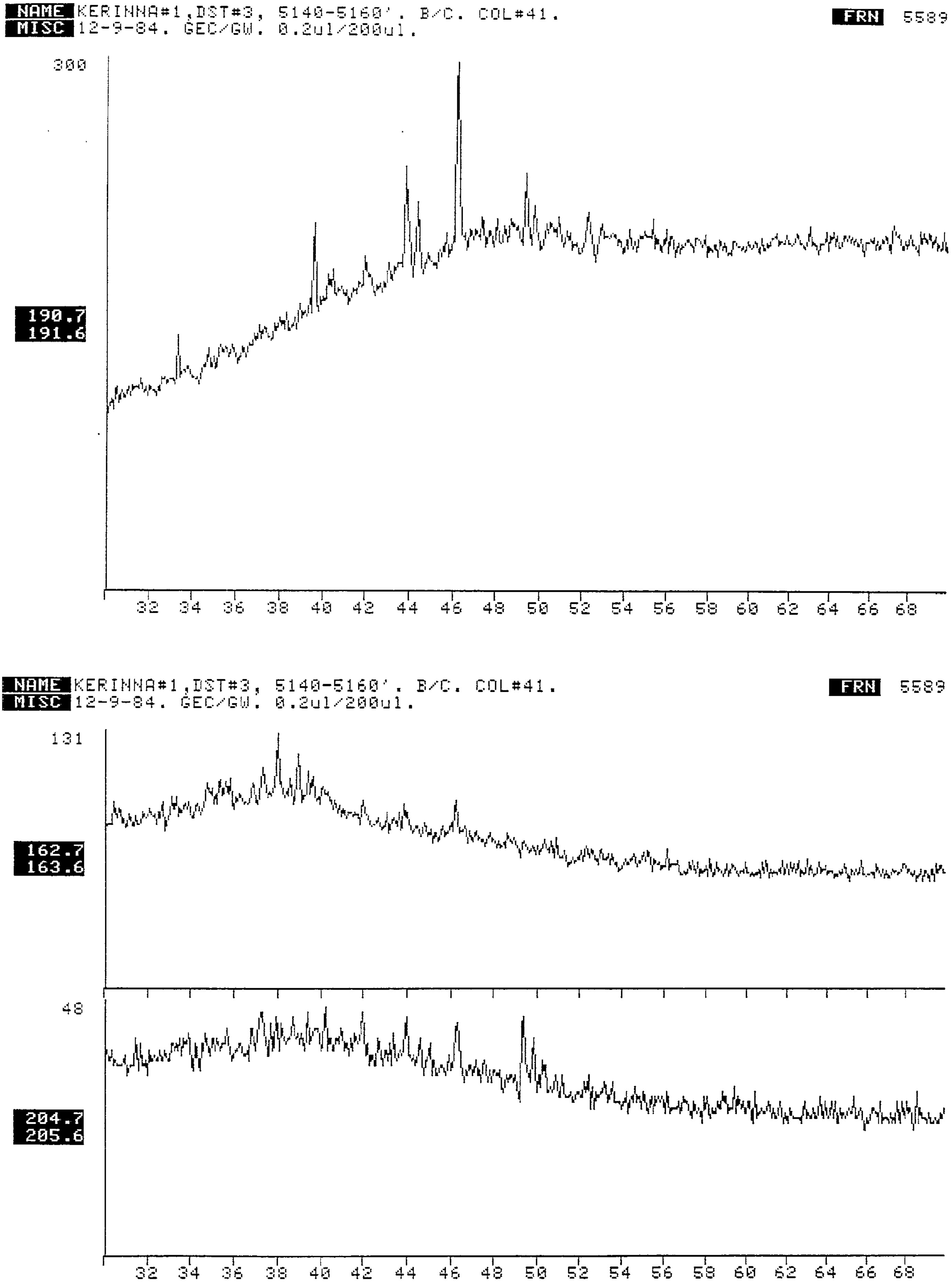
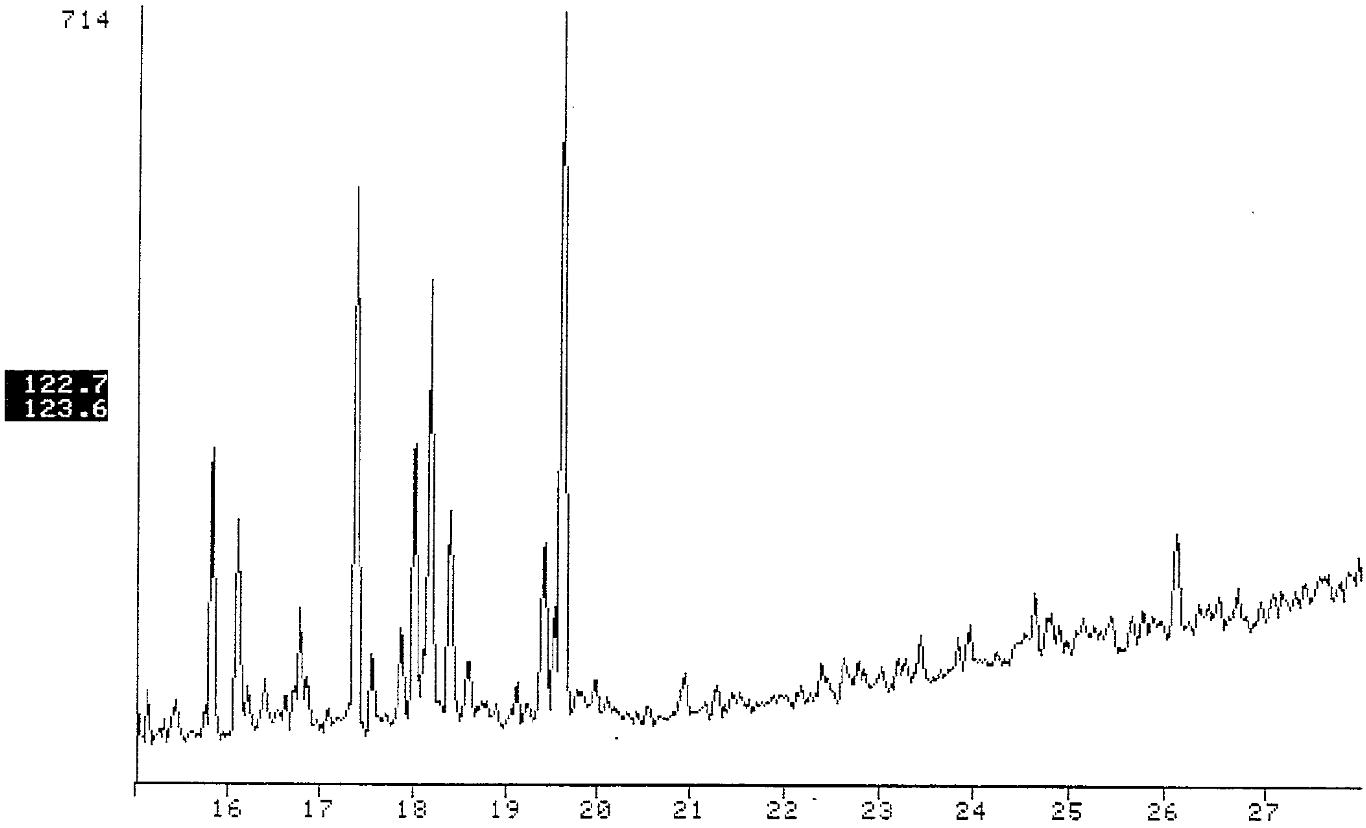

NAME KERINNA#1,DST#3, 5140-5160'. B/C. COL#41.
MISC 12-9-84. GEC/GW. 0.2ul/200ul.
FRN 5589
300
190.7
191.6
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
NAME KERINNA#1,DST#3, 5140-5160'. B/C. COL#41.
MISC 12-9-84. GEC/GW. 0.2ul/200ul.
FRN 5589
131
162.7
163.6
48
204.7
205.6
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68

FIGURE 4E

**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41.
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.

**FRN** 5613



**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41.
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.

**FRN** 5613

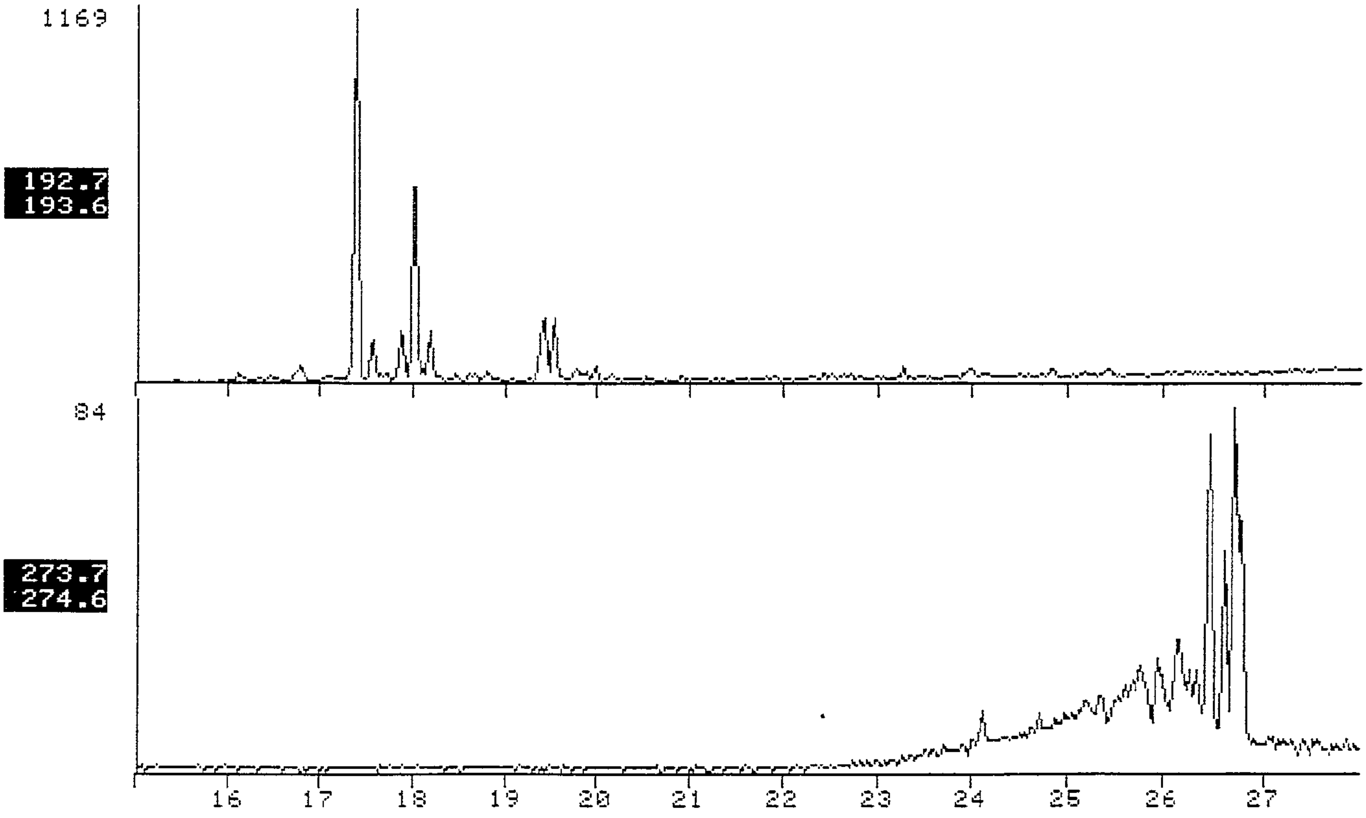


FIGURE 4F

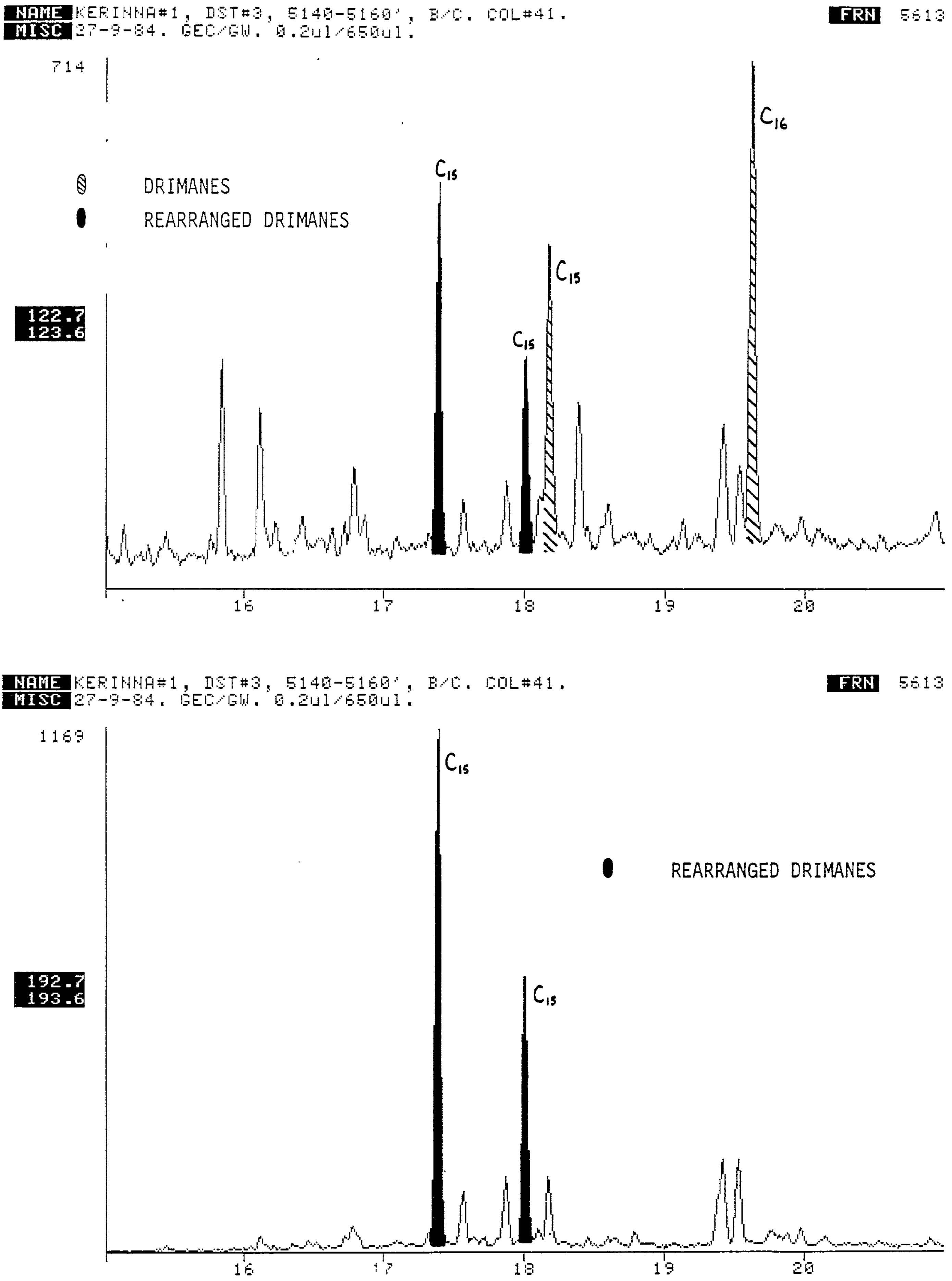
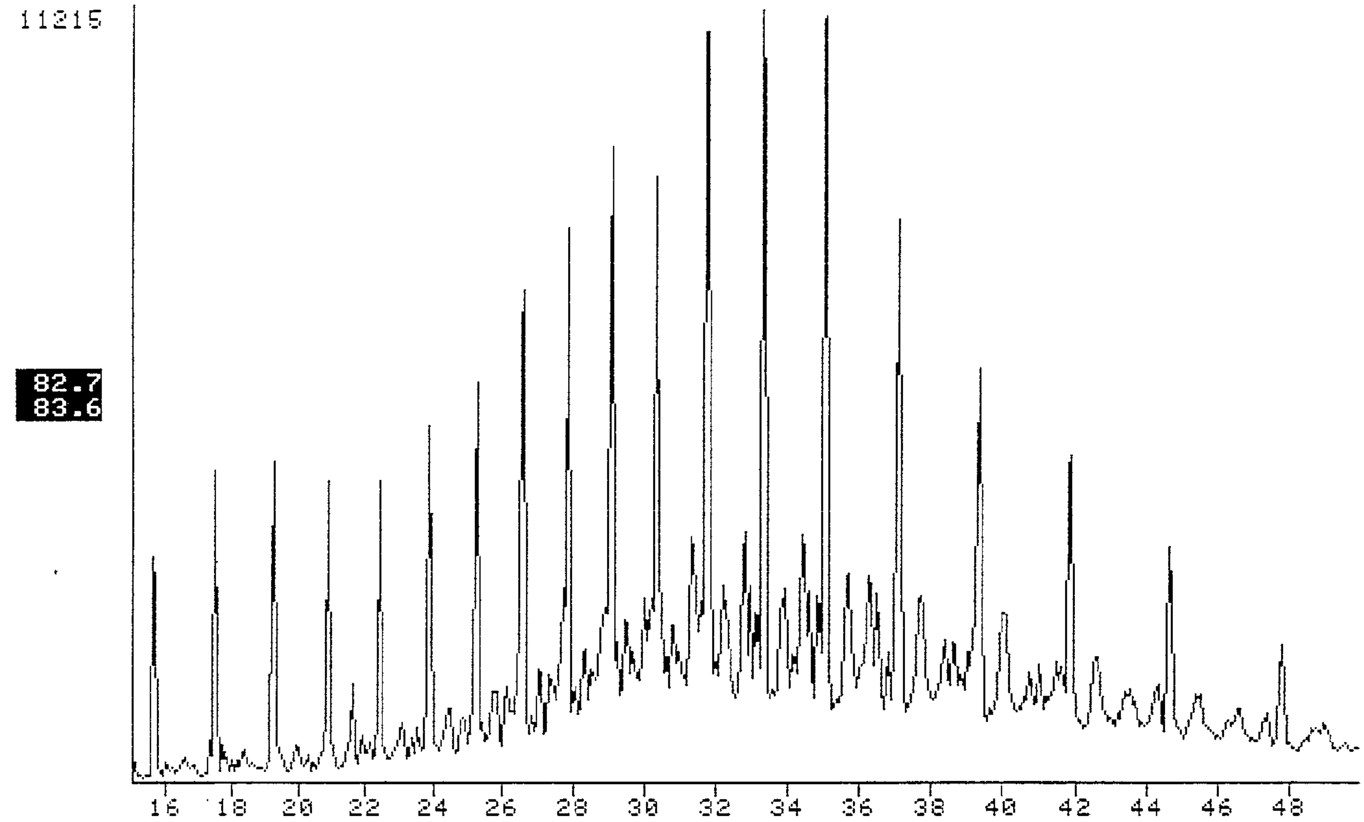

NAME KERINNA#1, DST#3, 5140-5160', B/C. COL#41.
MISC 27-9-84. GEC/GW. 0.2ul/650ul.
FRN 5613
714
▨ DRIMANES
● REARRANGED DRIMANES
122.7
123.6
$C_{15}$
$C_{15}$
$C_{15}$
$C_{16}$
16
17
18
19
20
NAME KERINNA#1, DST#3, 5140-5160', B/C. COL#41.
MISC 27-9-84. GEC/GW. 0.2ul/650ul.
FRN 5613
1169
● REARRANGED DRIMANES
192.7
193.6
$C_{15}$
$C_{15}$
16
17
18
19
20

FIGURE 4G

**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.



**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.

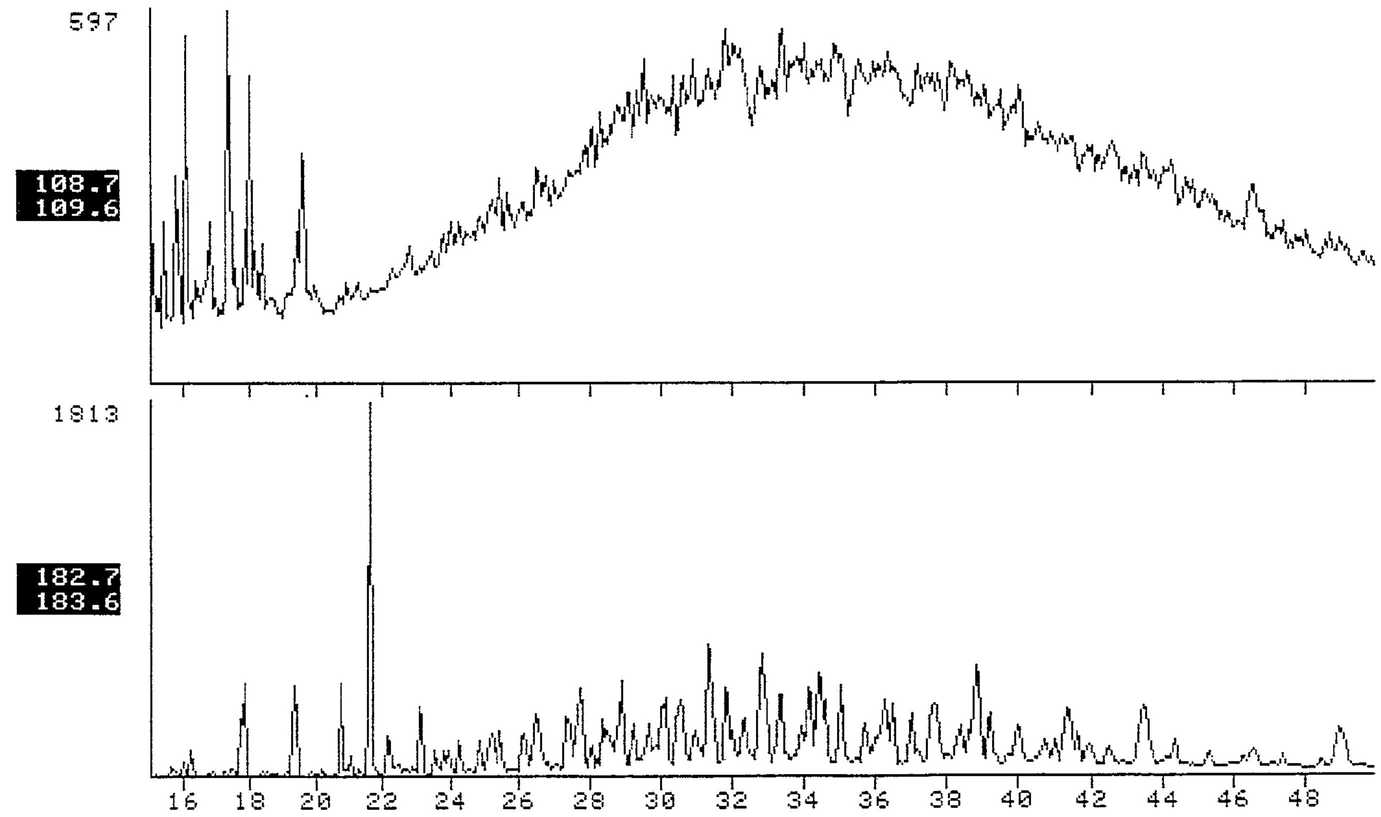
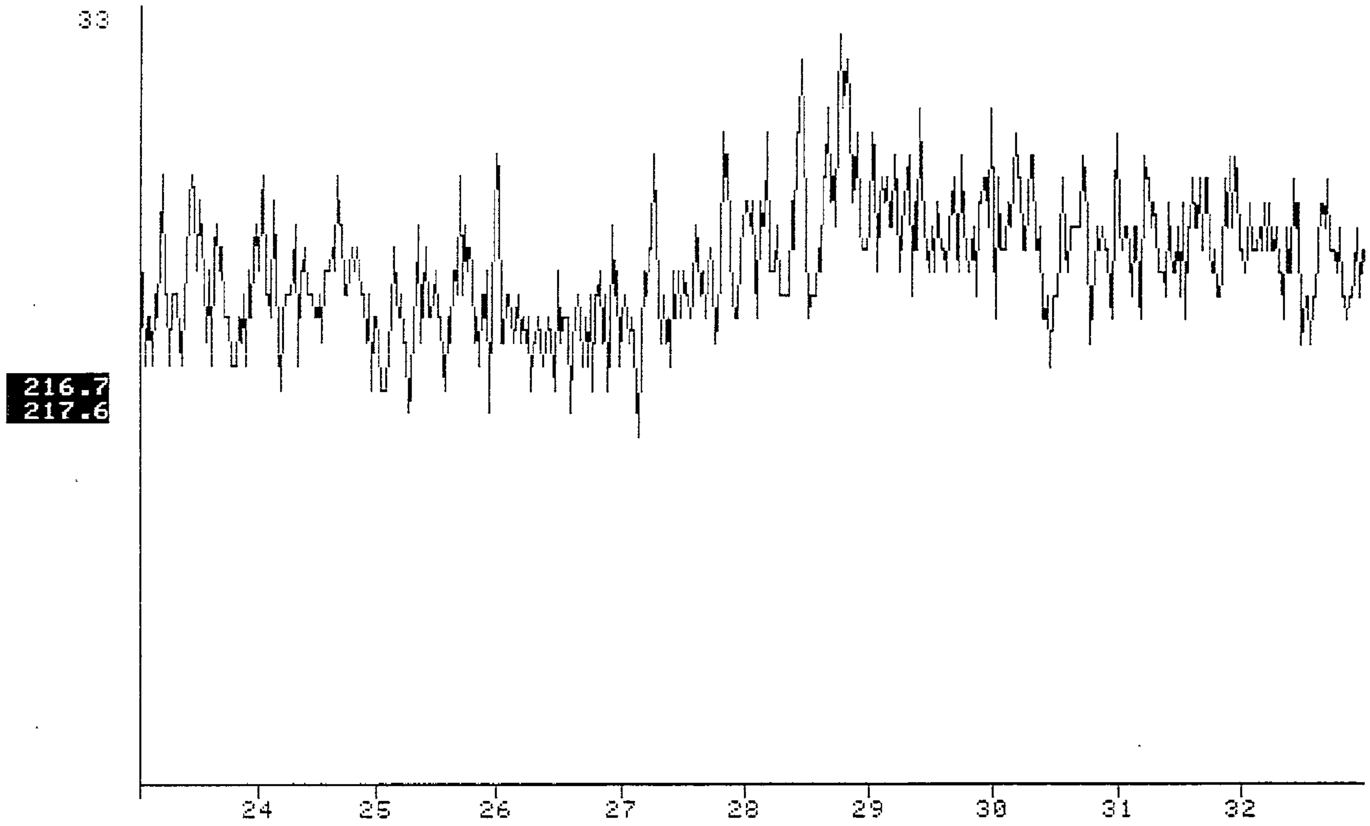


FIGURE 4H

**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.



**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.

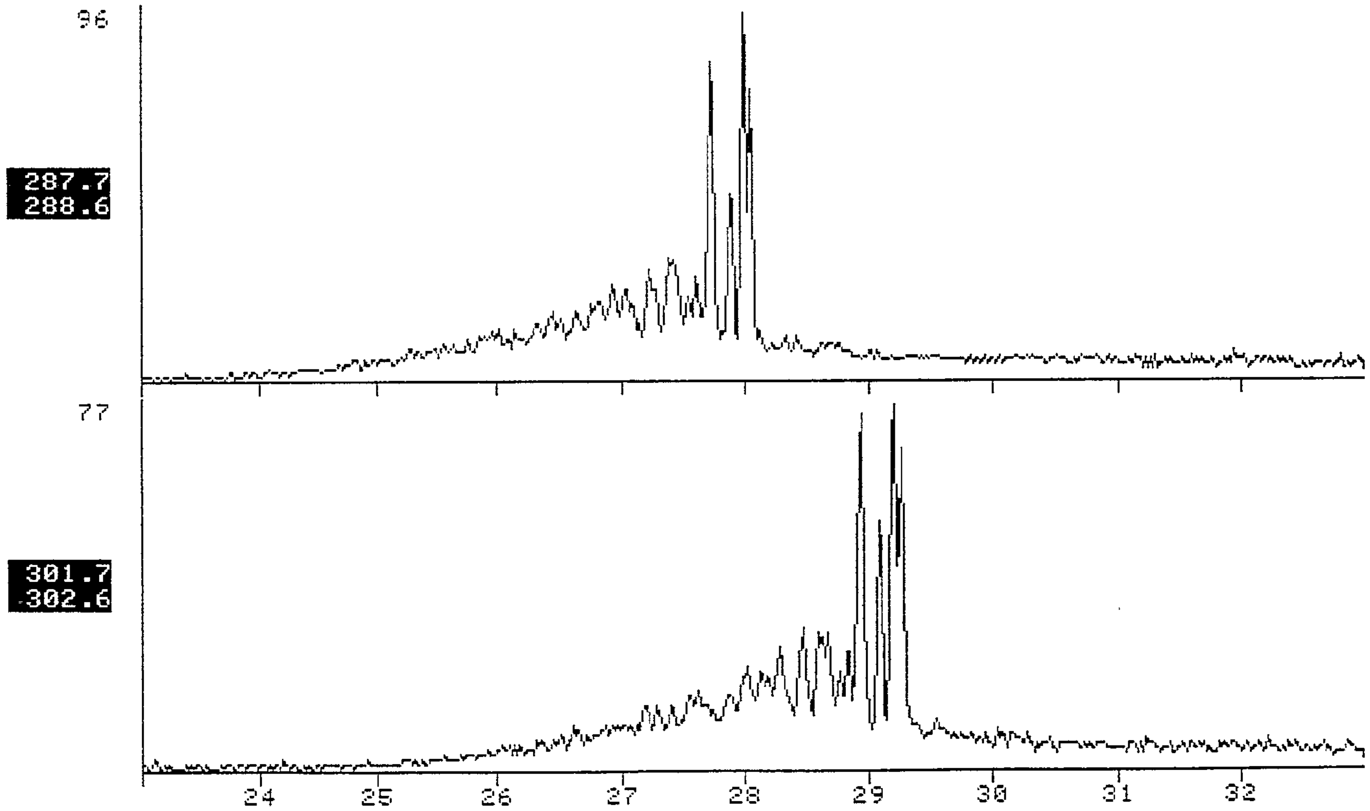
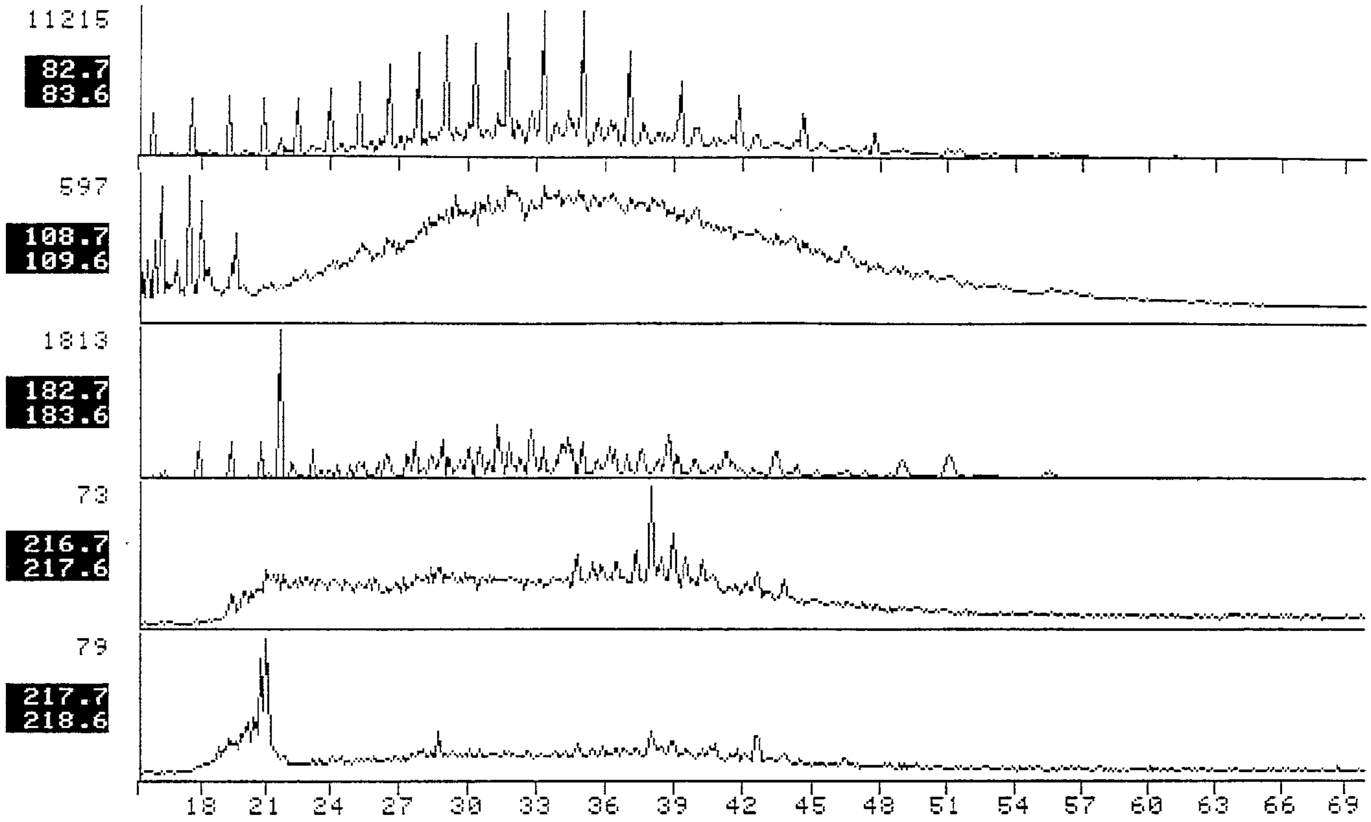


FIGURE 4I

**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.



**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.

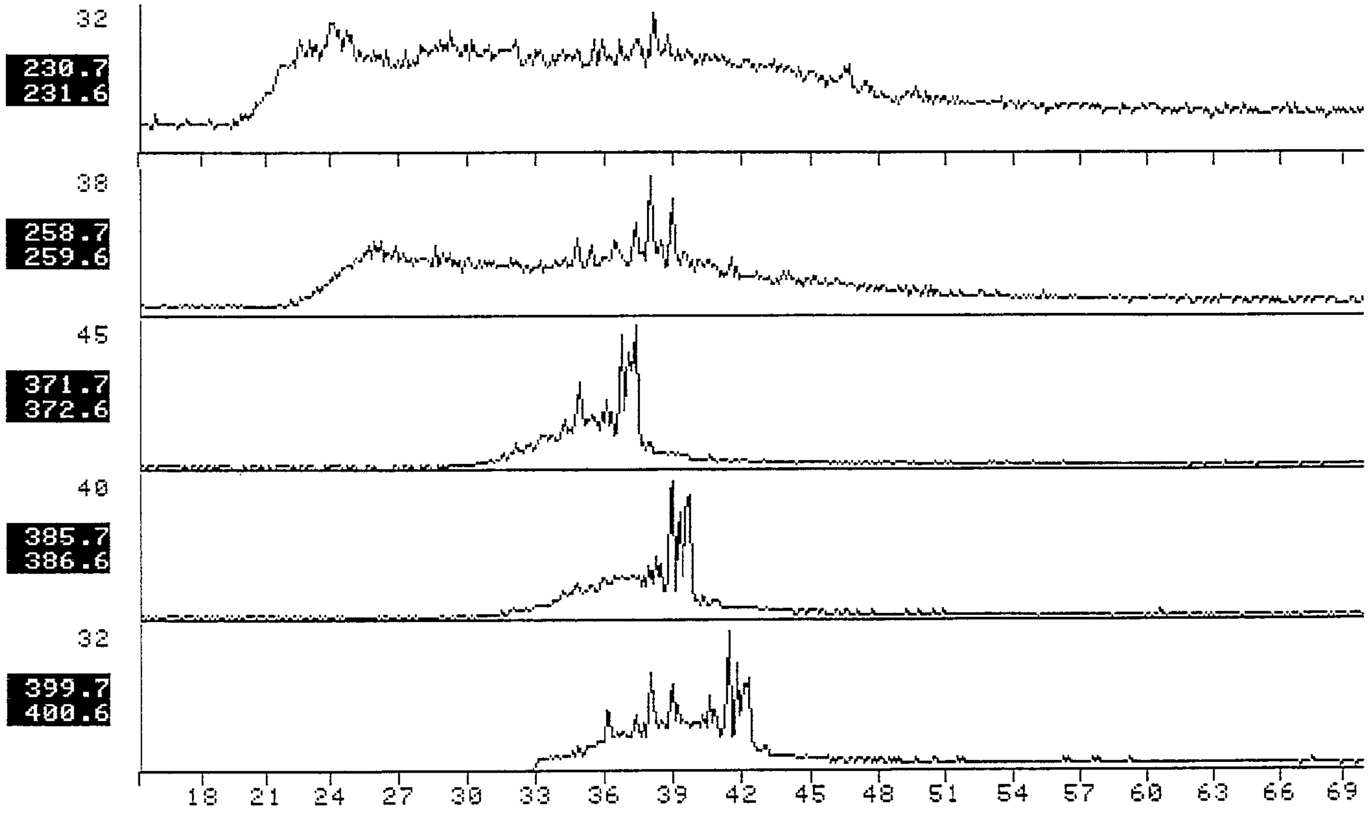
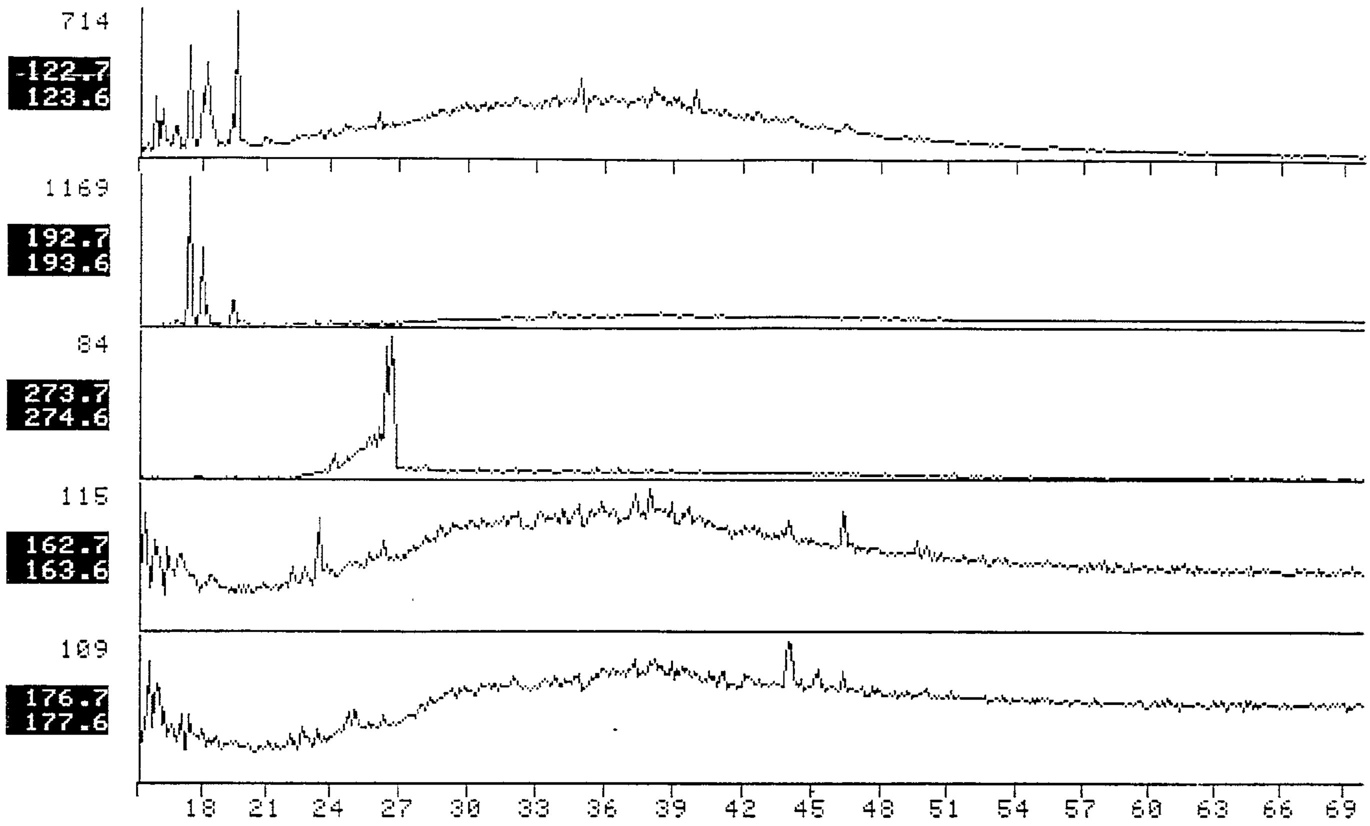


FIGURE 4J

**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.



**NAME** KERINNA#1, DST#3, 5140-5160', B/C. COL#41. **FRN** 5613
**MISC** 27-9-84. GEC/GW. 0.2ul/650ul.

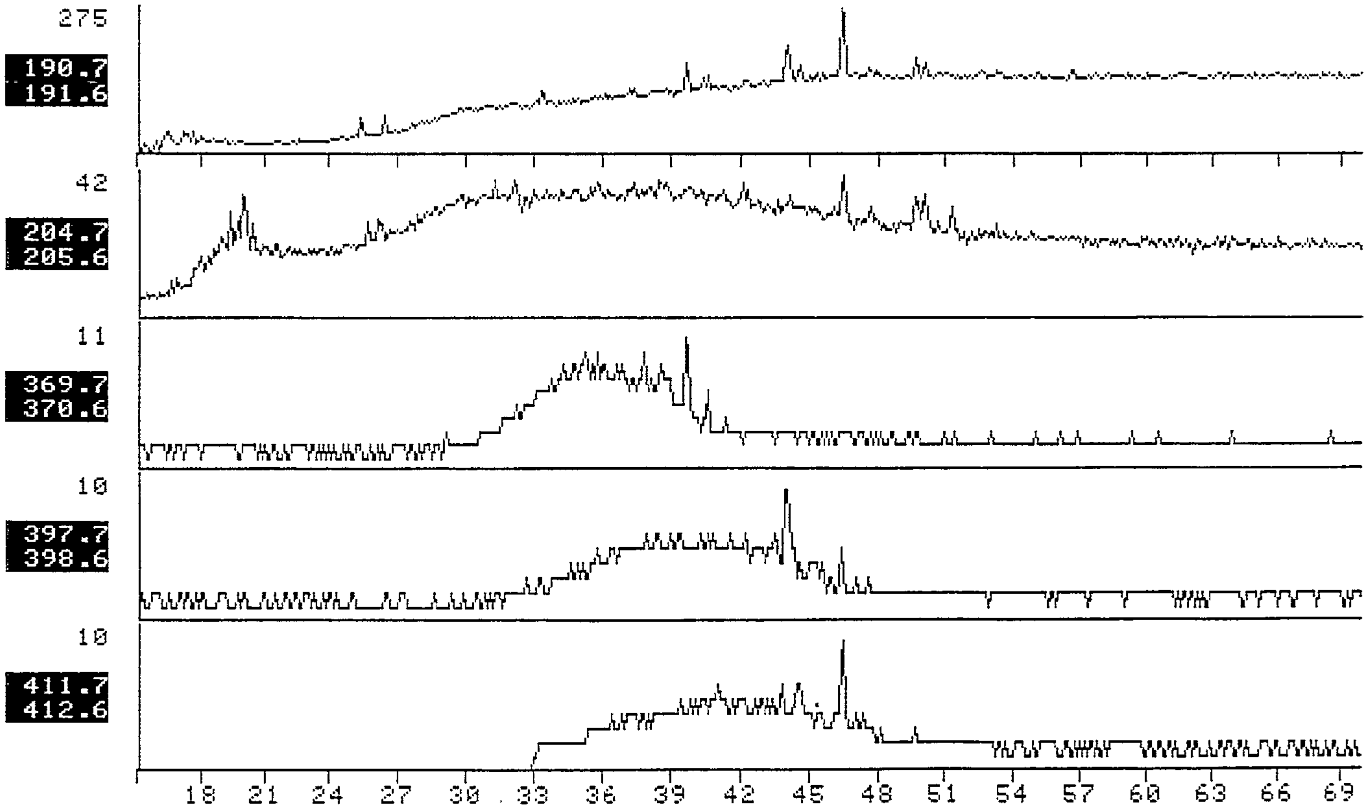
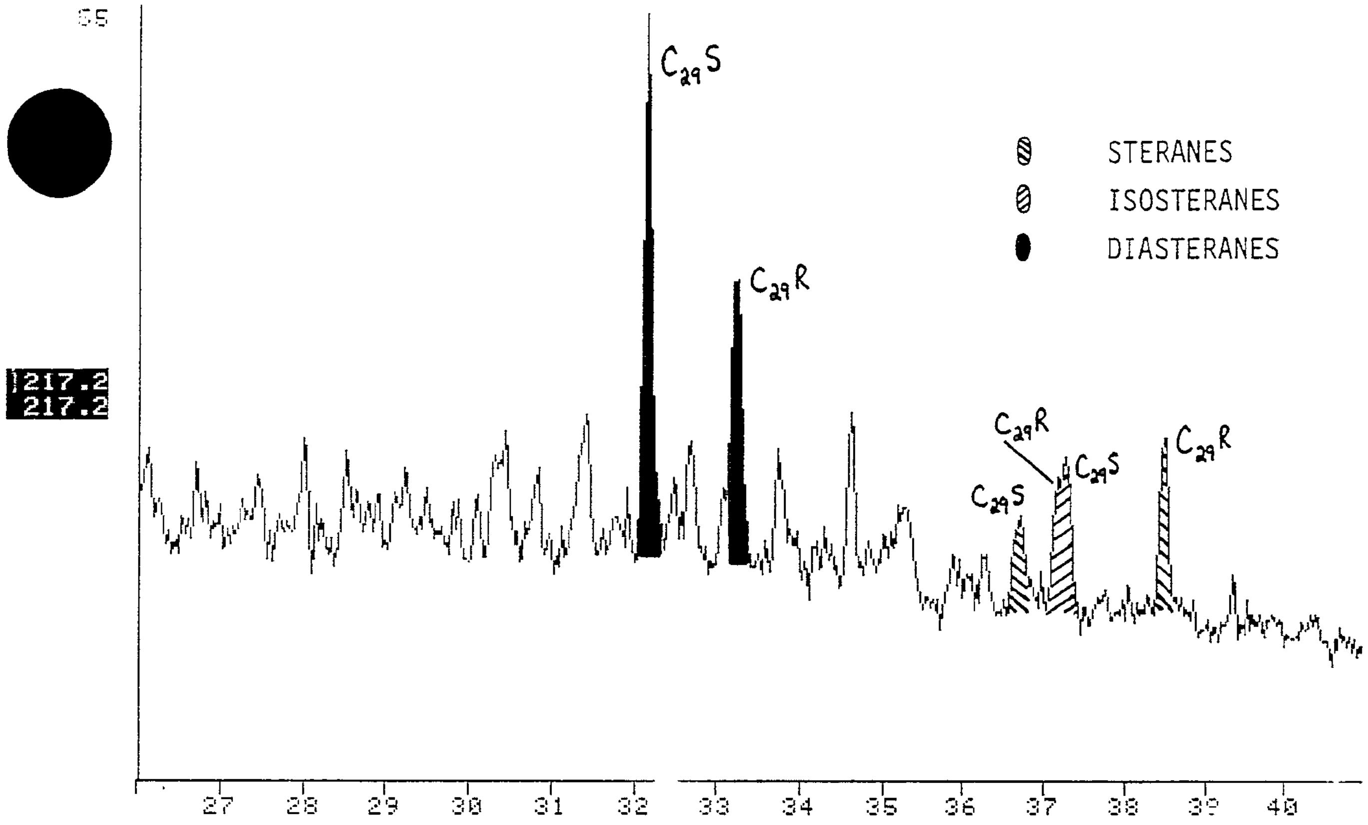


FIGURE 5A

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#18. **FRN** 5568
**MISC** 27-8-84. GEC/GW. 0.2ul/120ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#18. [illegible]
**MISC** 27-8-84. GEC/GW. 0.2ul/120ul.

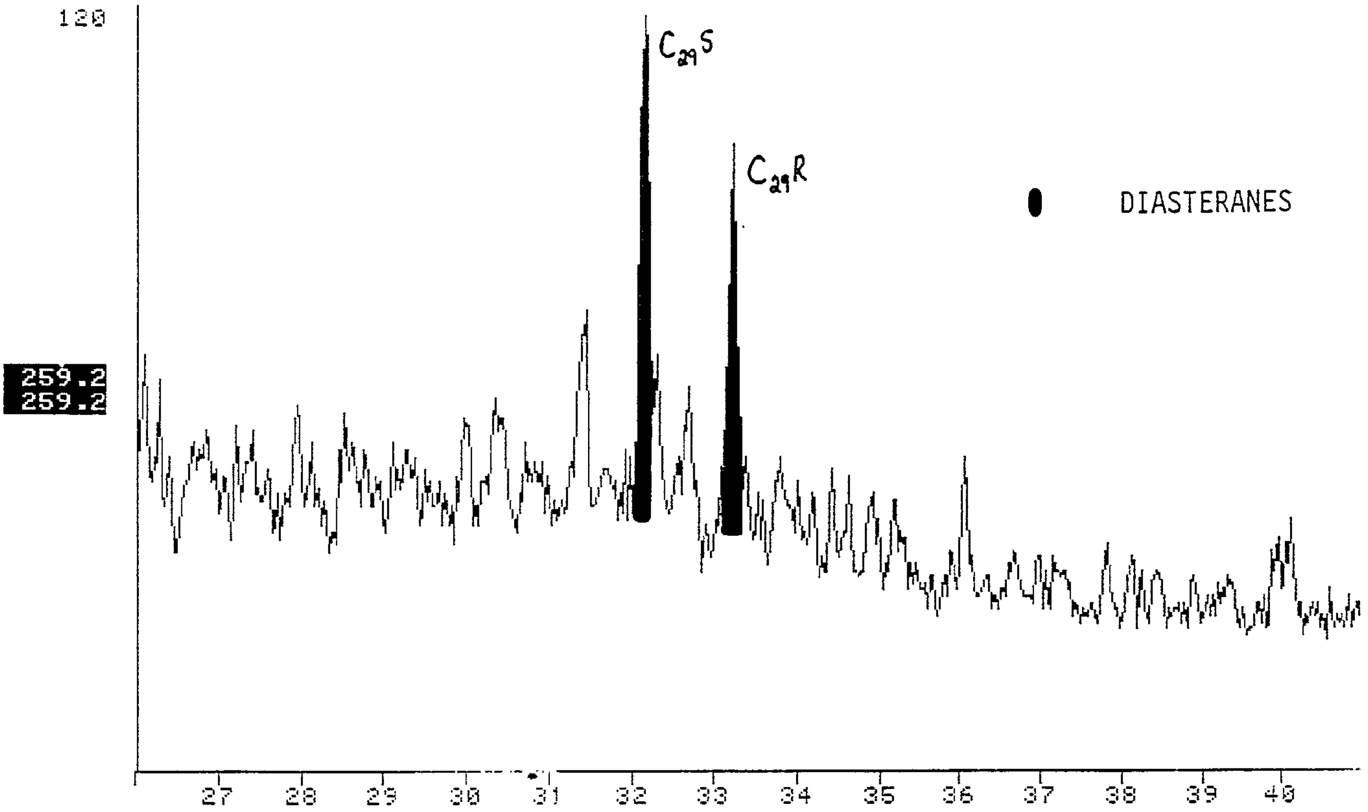


FIGURE 5B

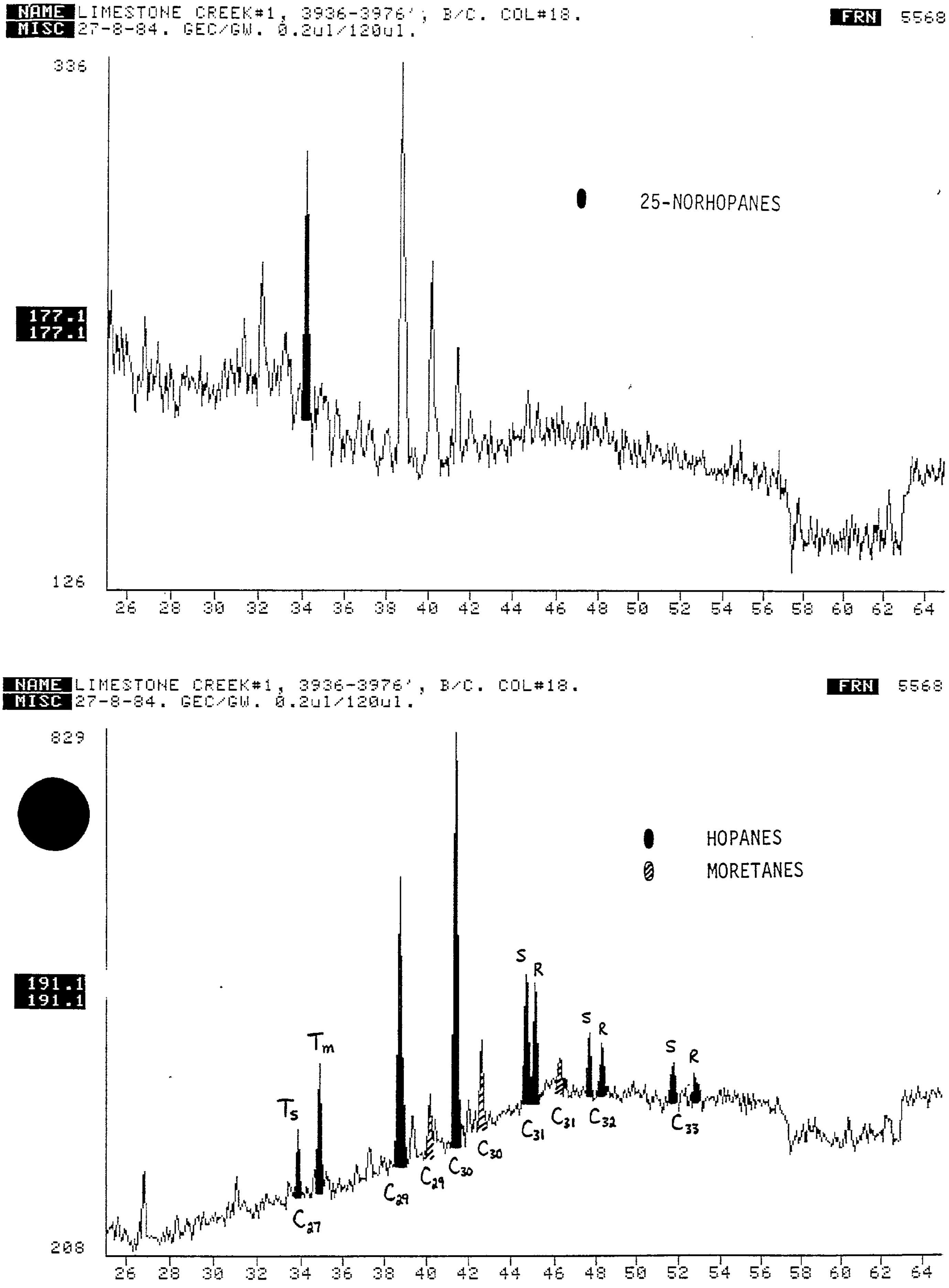
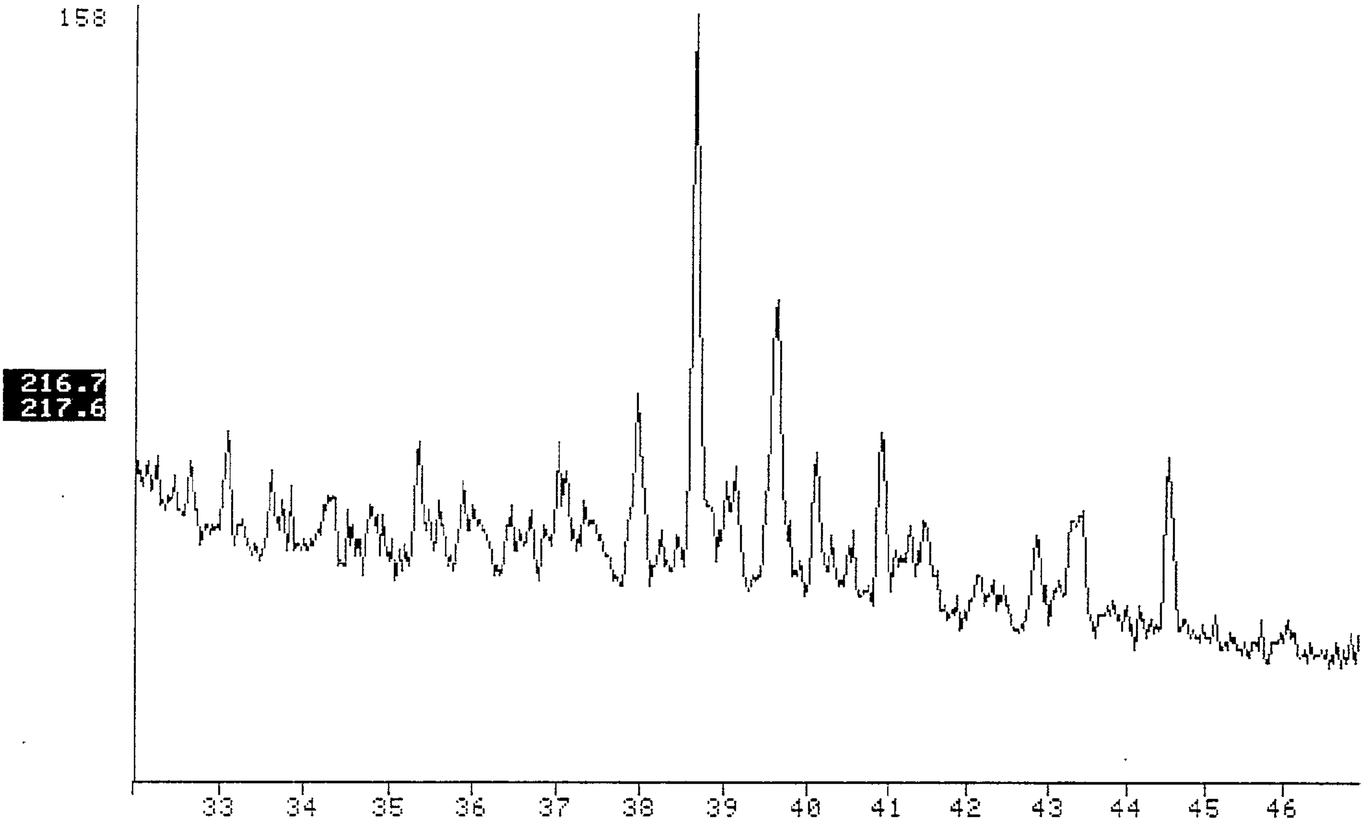

NAME LIMESTONE CREEK#1, 3936-3976', B/C. COL#18.
MISC 27-8-84. GEC/GW. 0.2ul/120ul.
FRN 5568
336
177.1
177.1
126
25-NORHOPANES
26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64
NAME LIMESTONE CREEK#1, 3936-3976', B/C. COL#18.
MISC 27-8-84. GEC/GW. 0.2ul/120ul.
FRN 5568
829
191.1
191.1
208
HOPANES
MORETANES
Ts
Tm
C27
C29
C29
C30
C30
S
R
C31
C31
S
R
C32
S
R
C33
26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64

FIGURE 5C

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

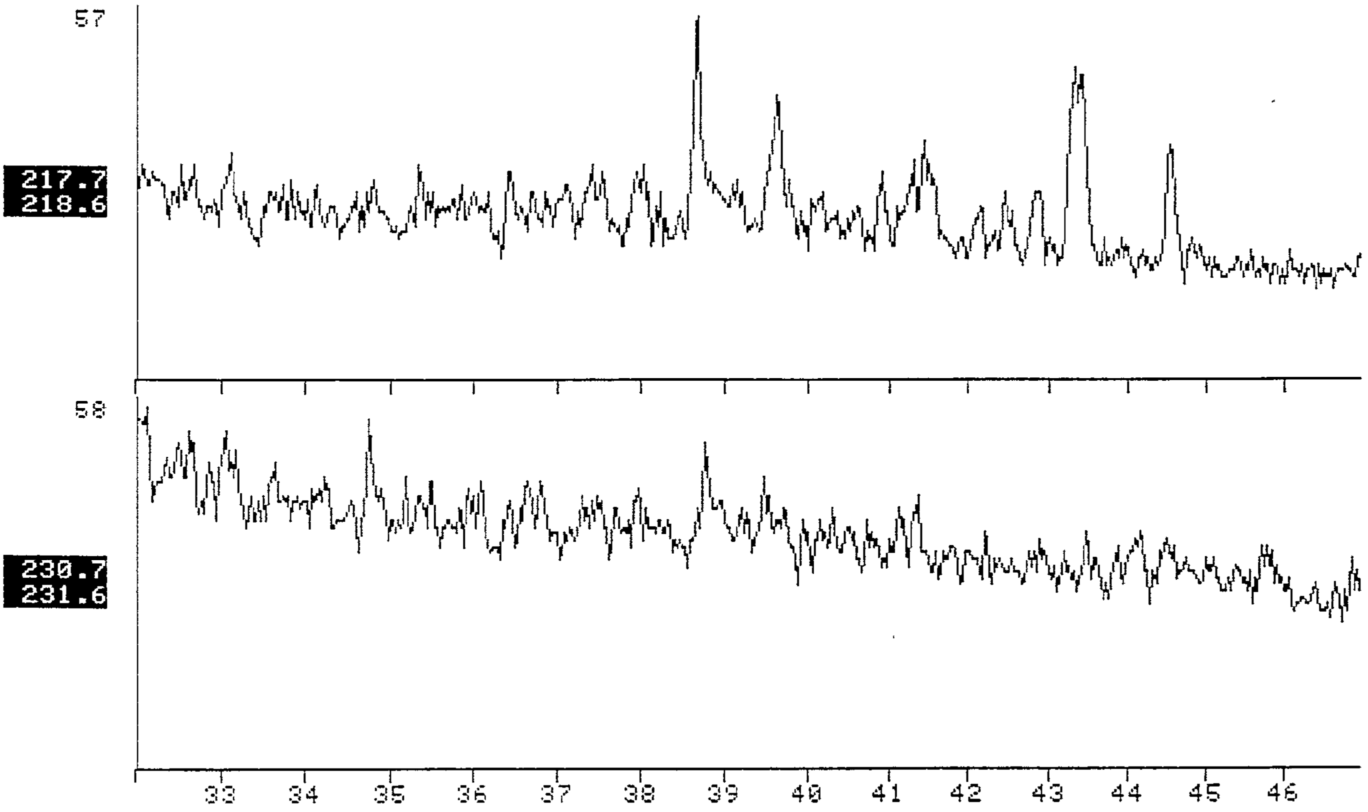
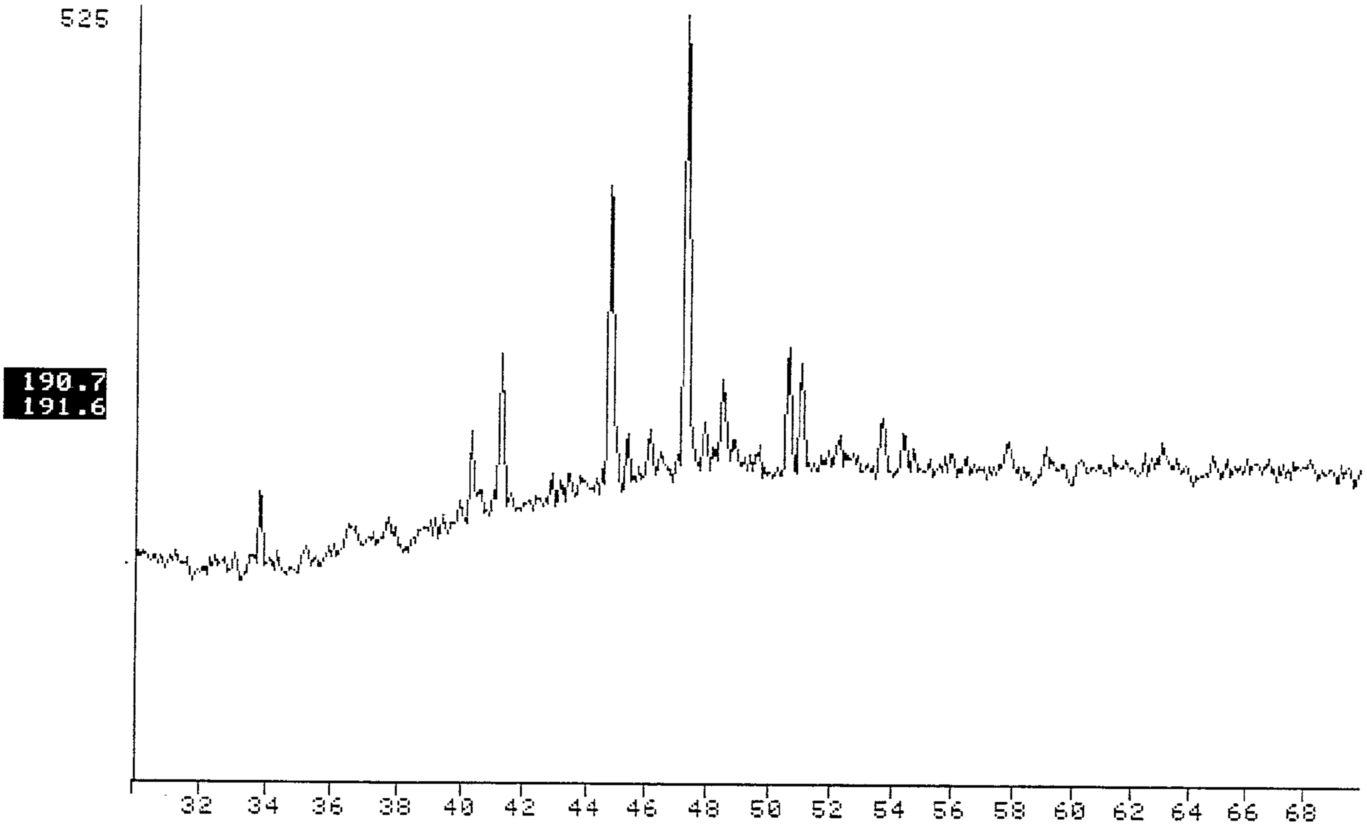


FIGURE 5D

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

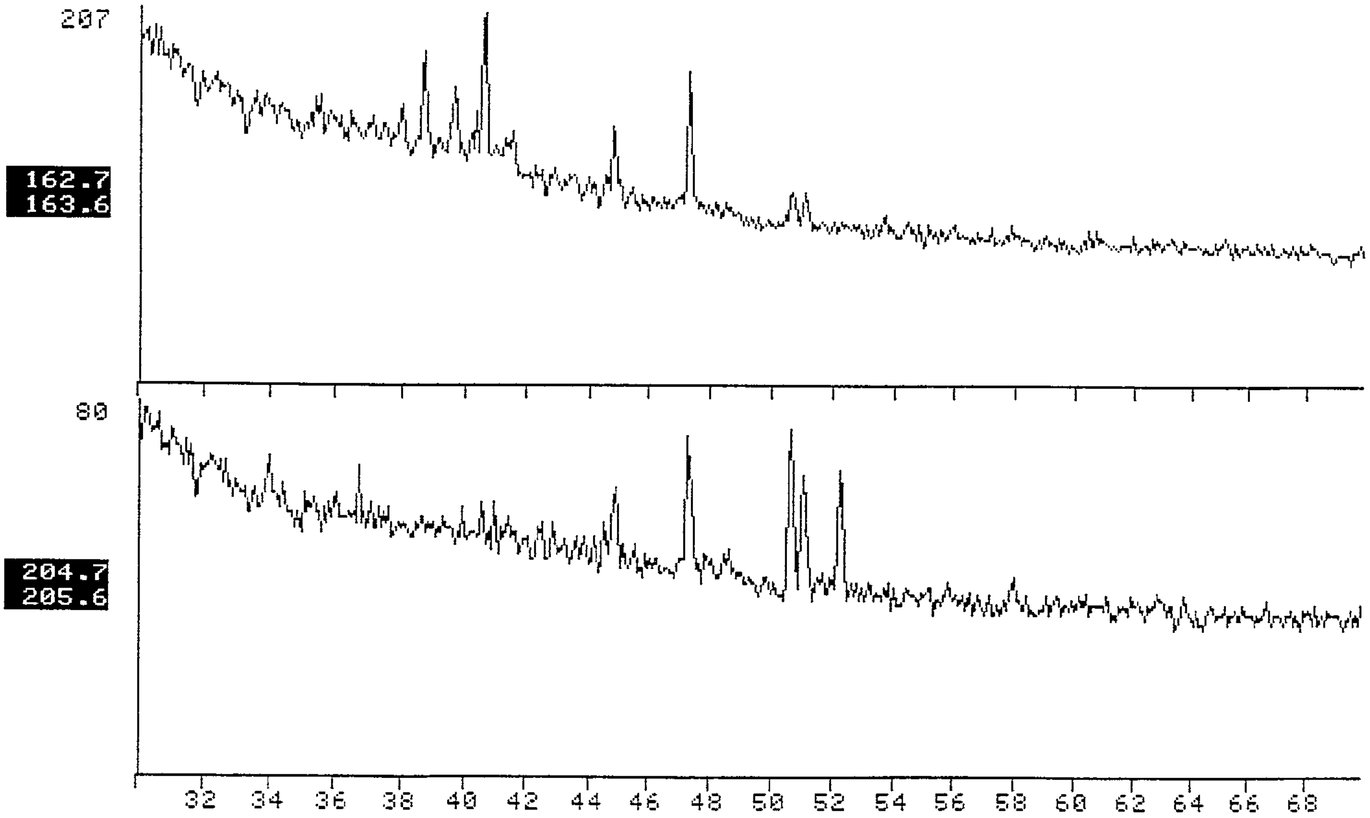
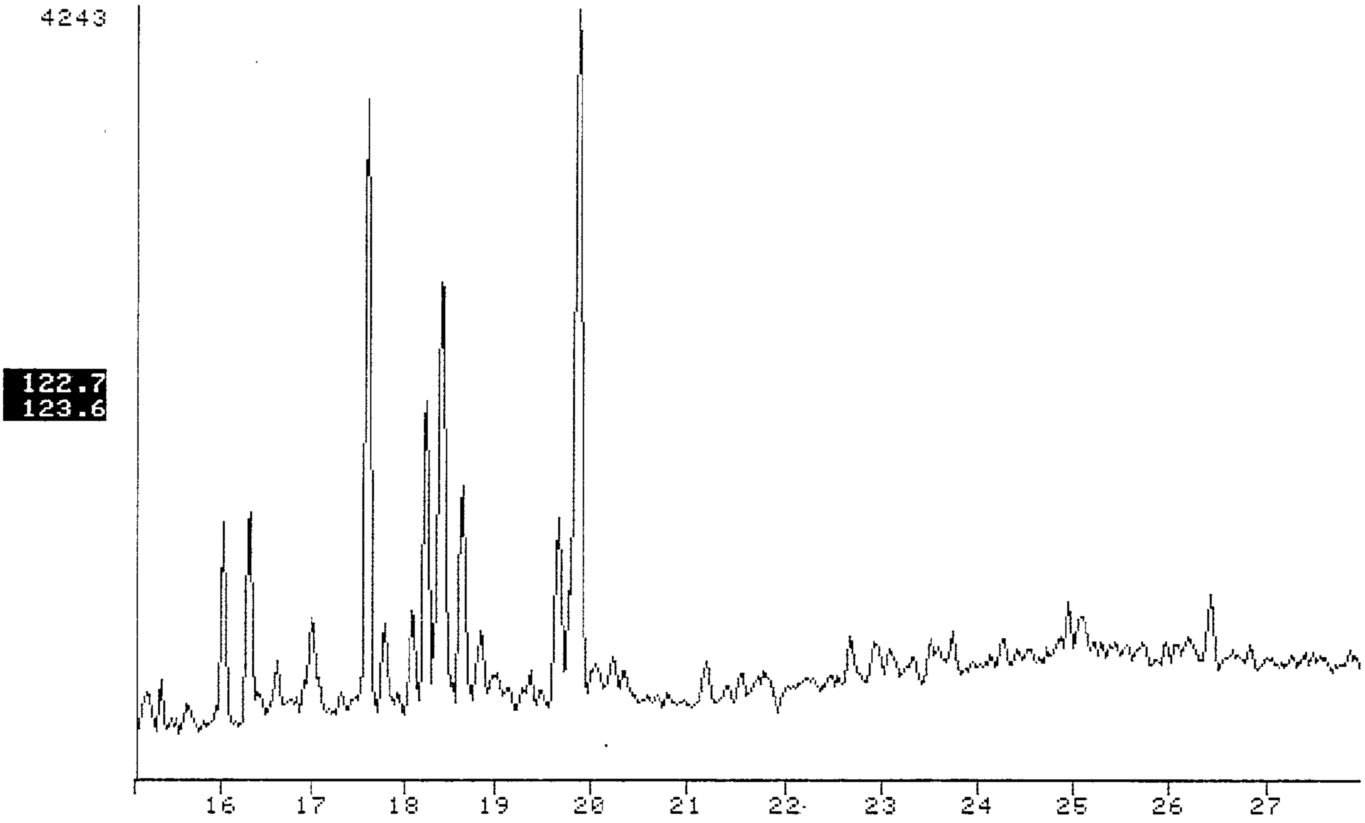


FIGURE 5E

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

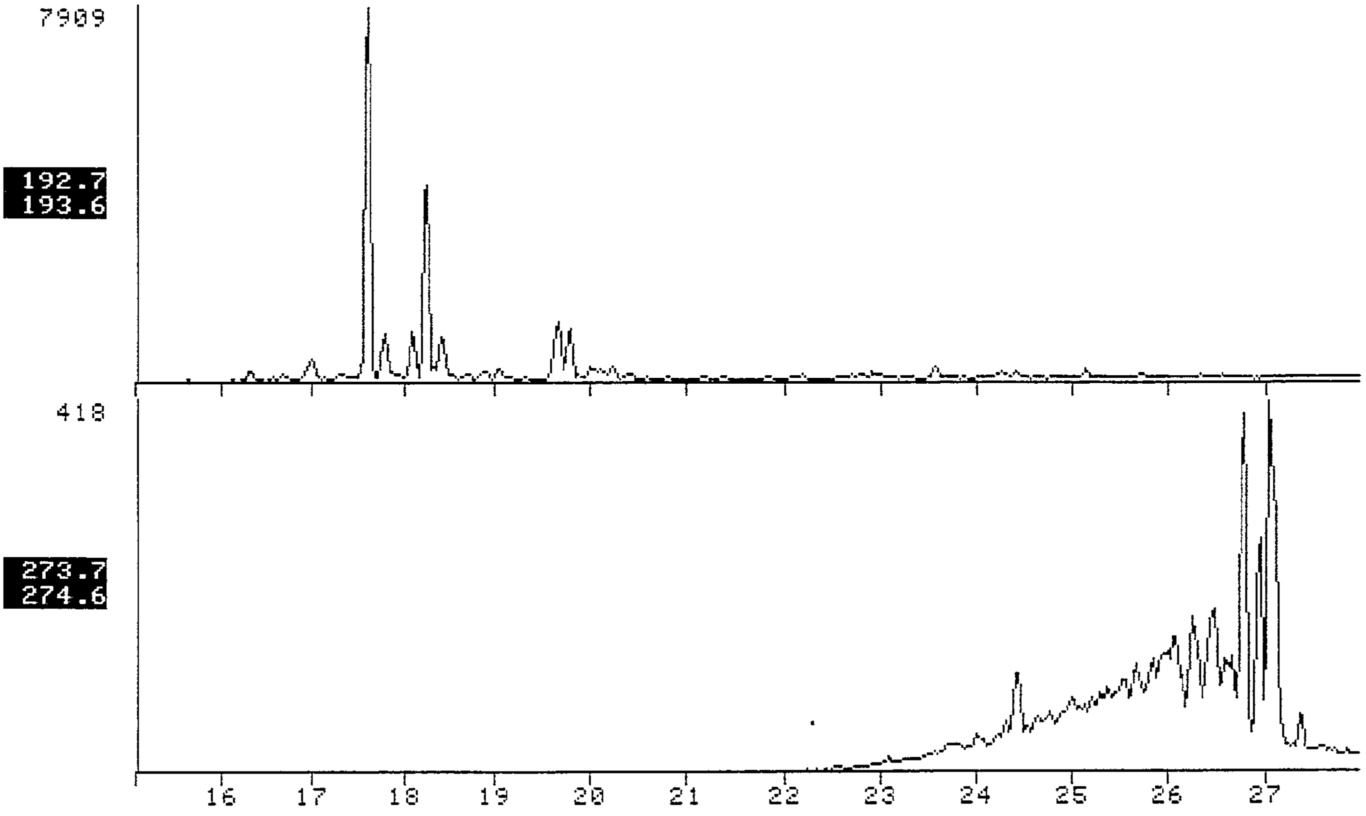
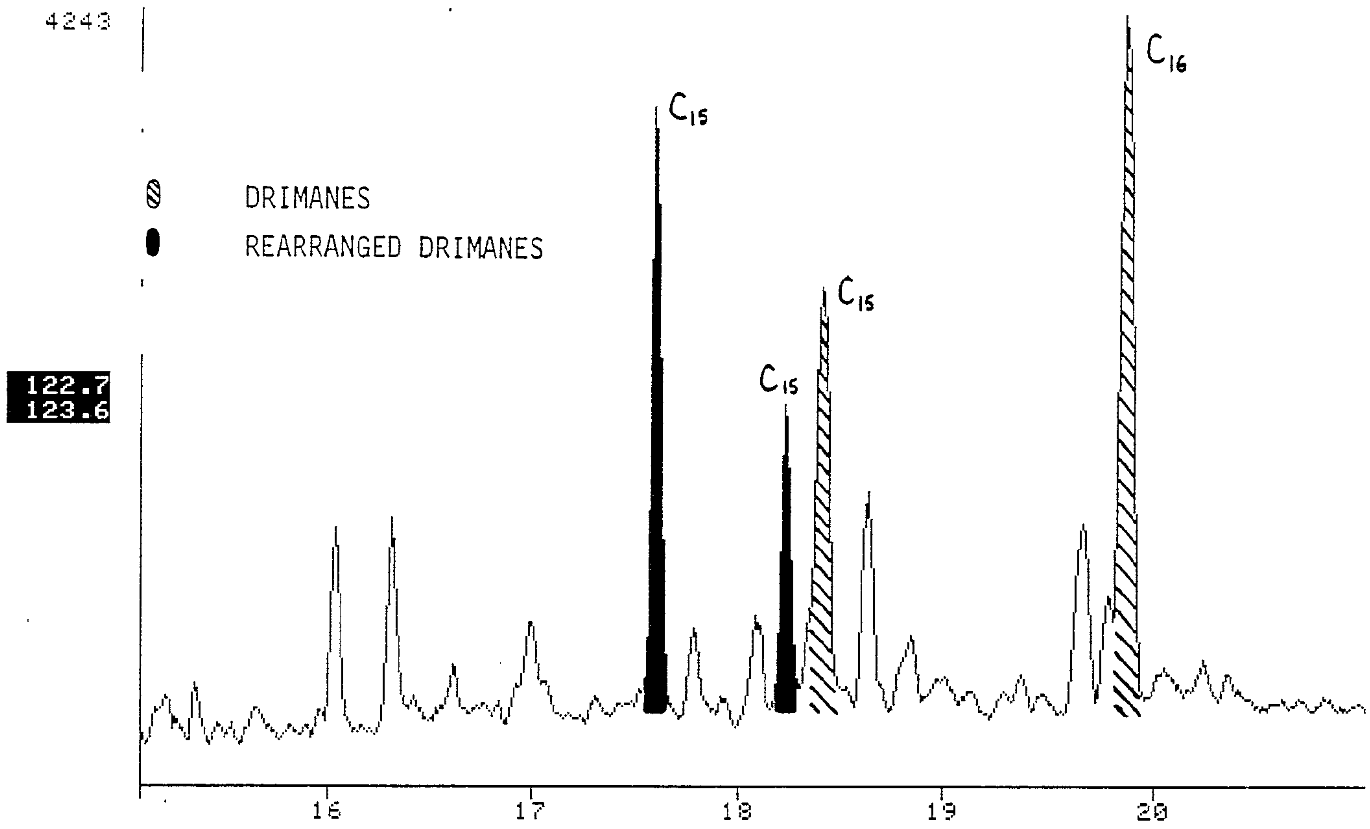


FIGURE 5F

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

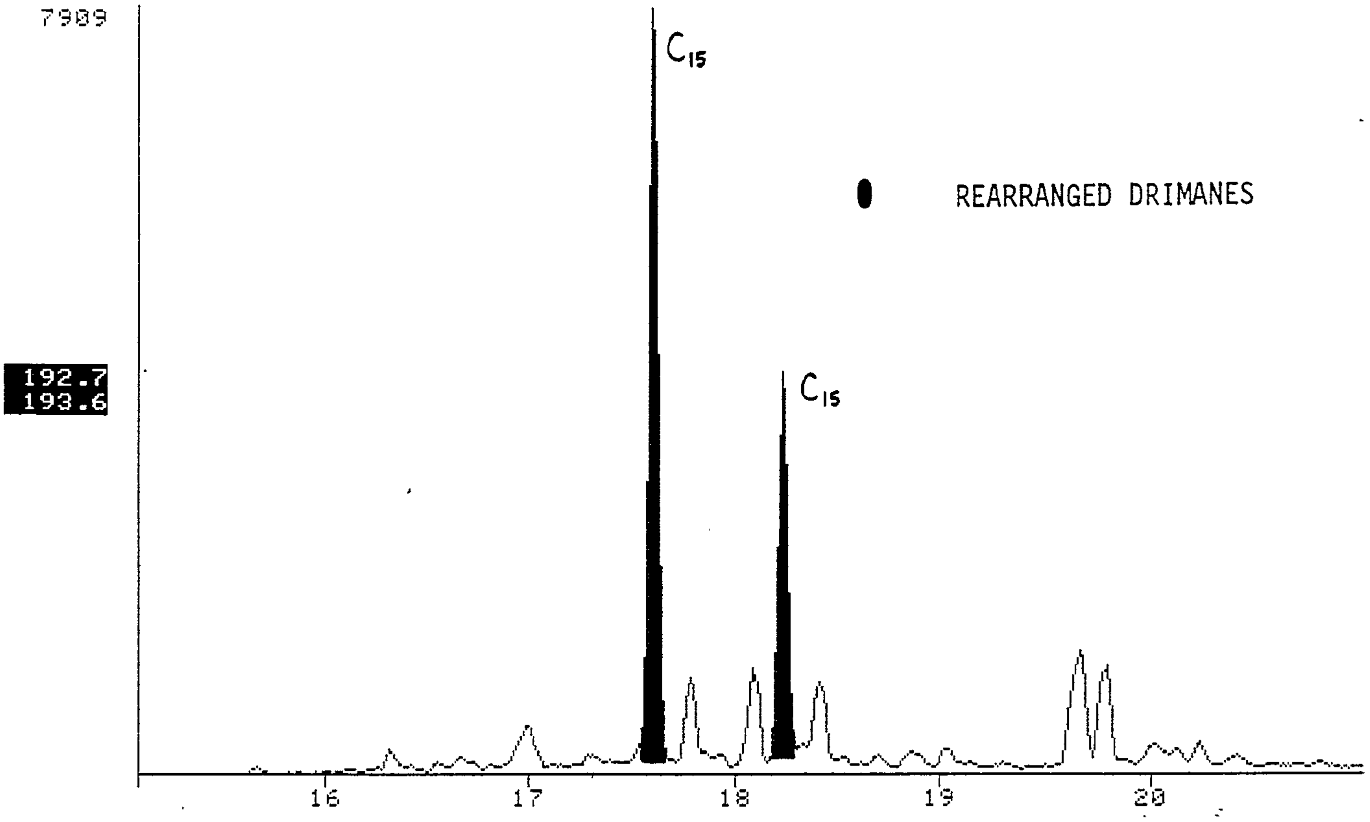
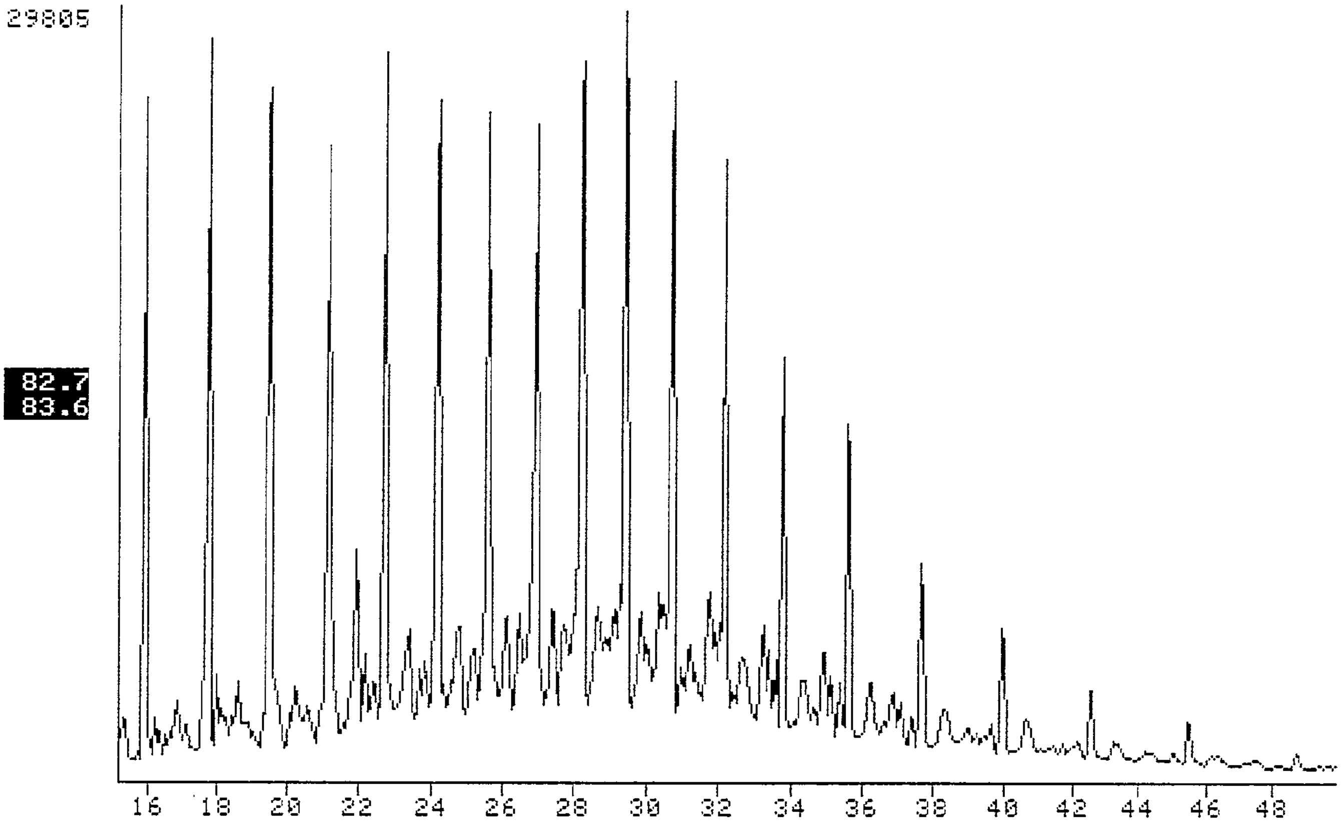


FIGURE 5G

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

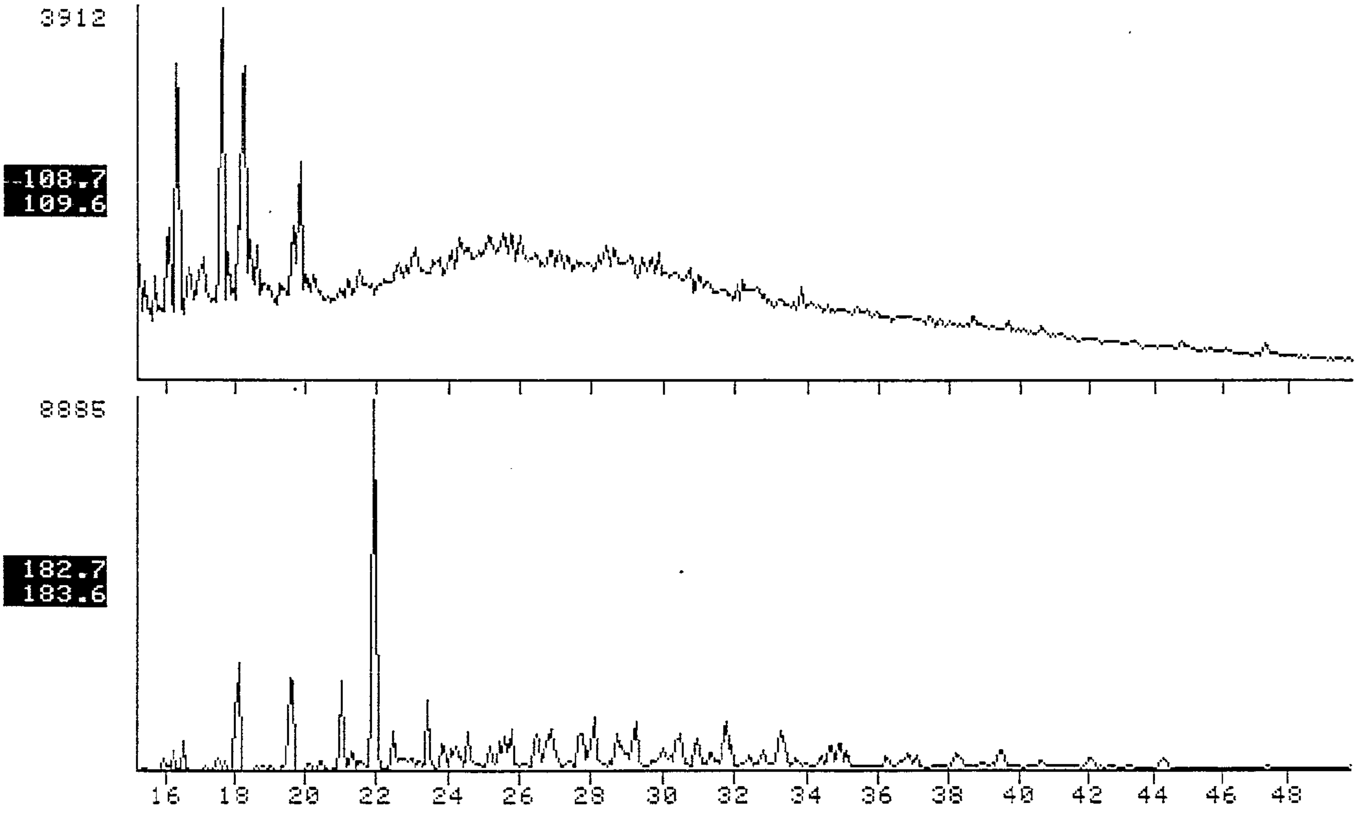
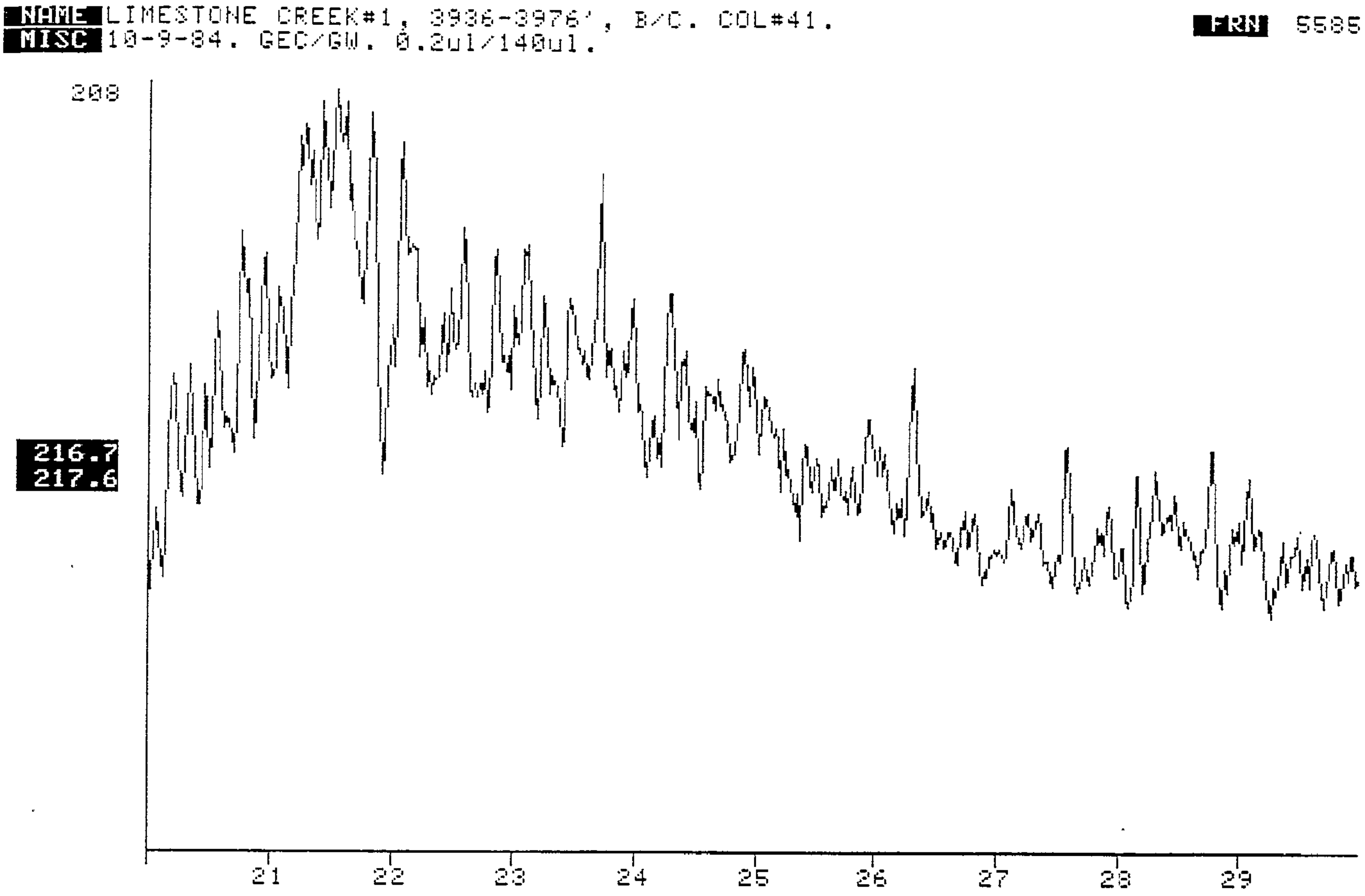
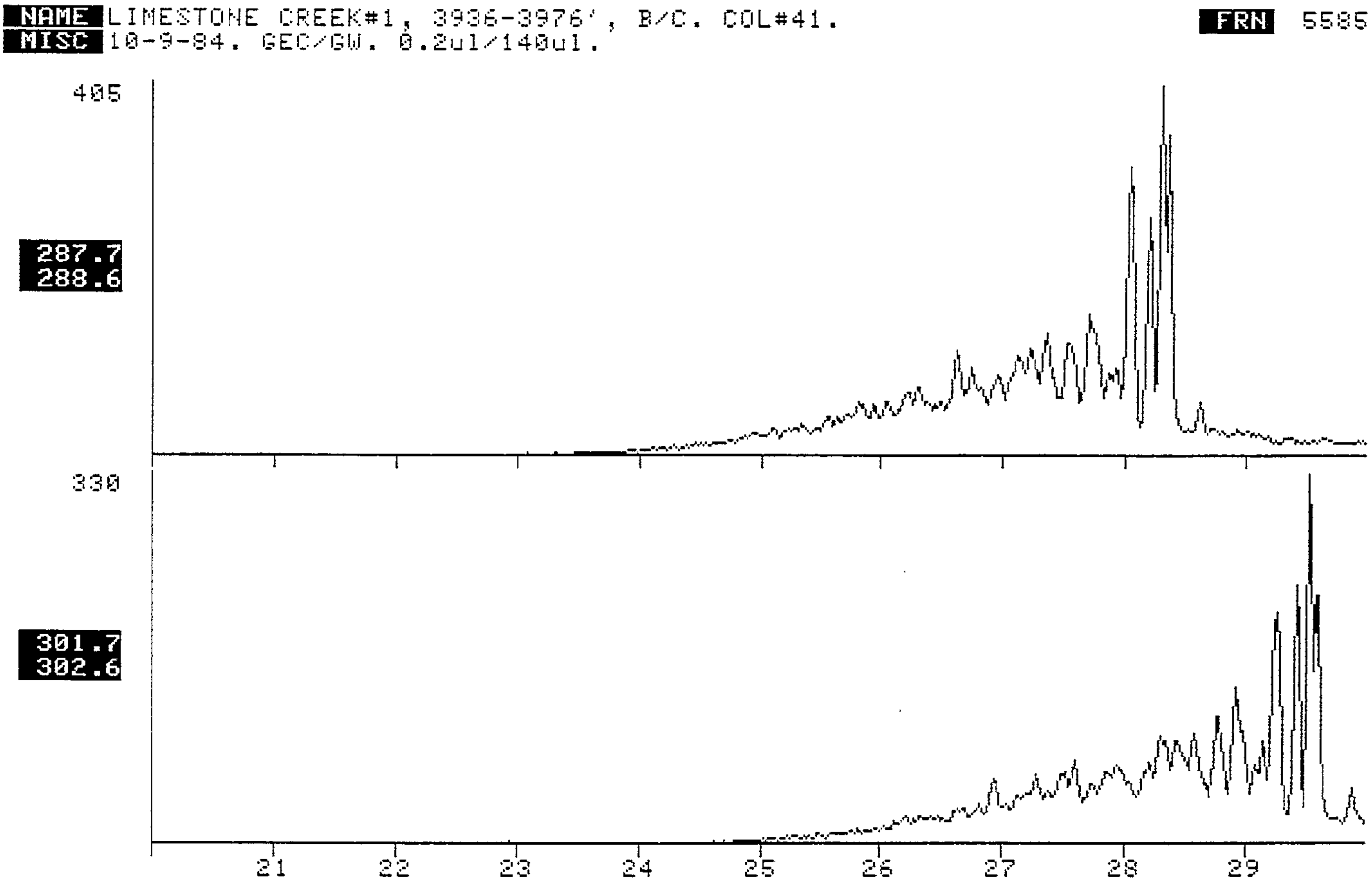


FIGURE 5H



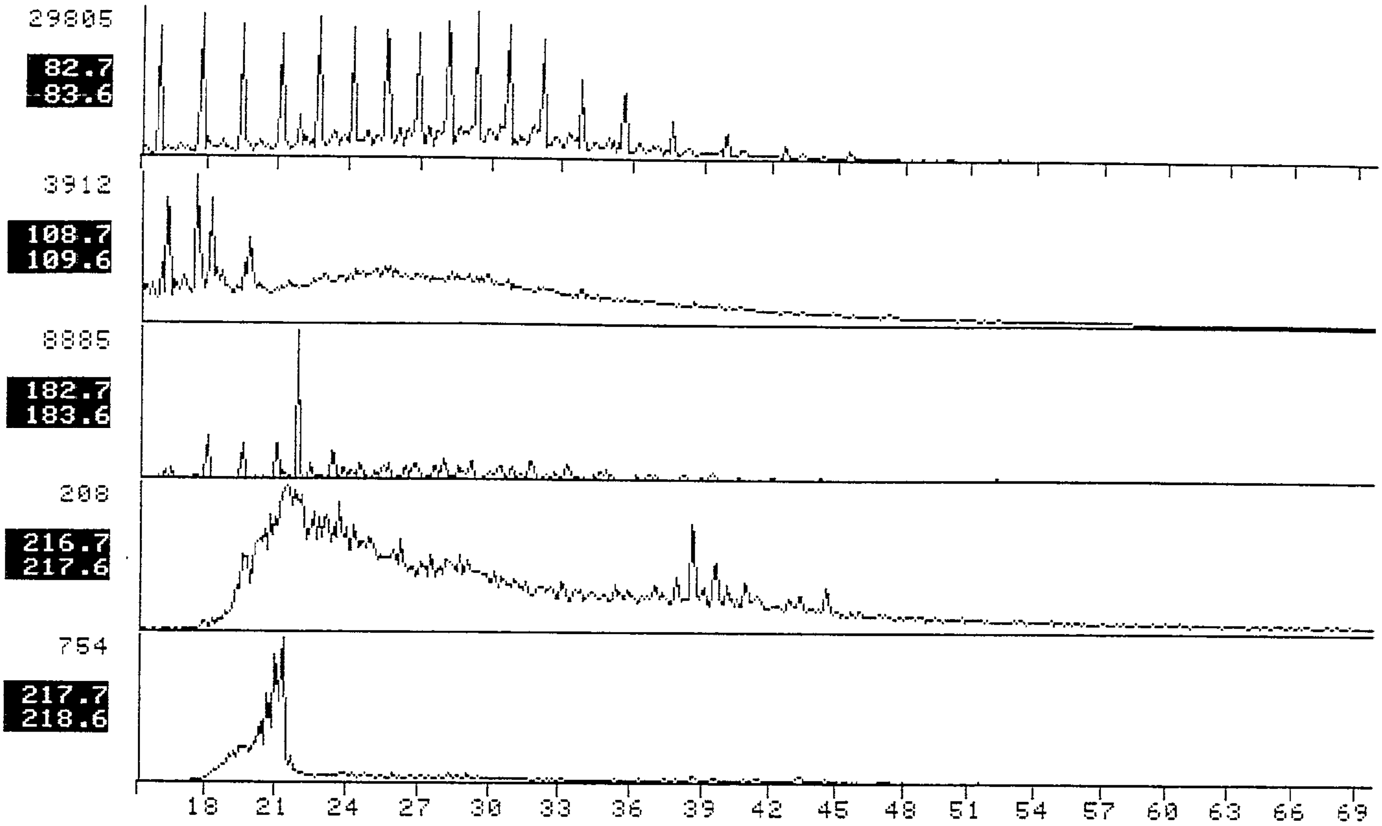
**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

FIGURE 5I

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.

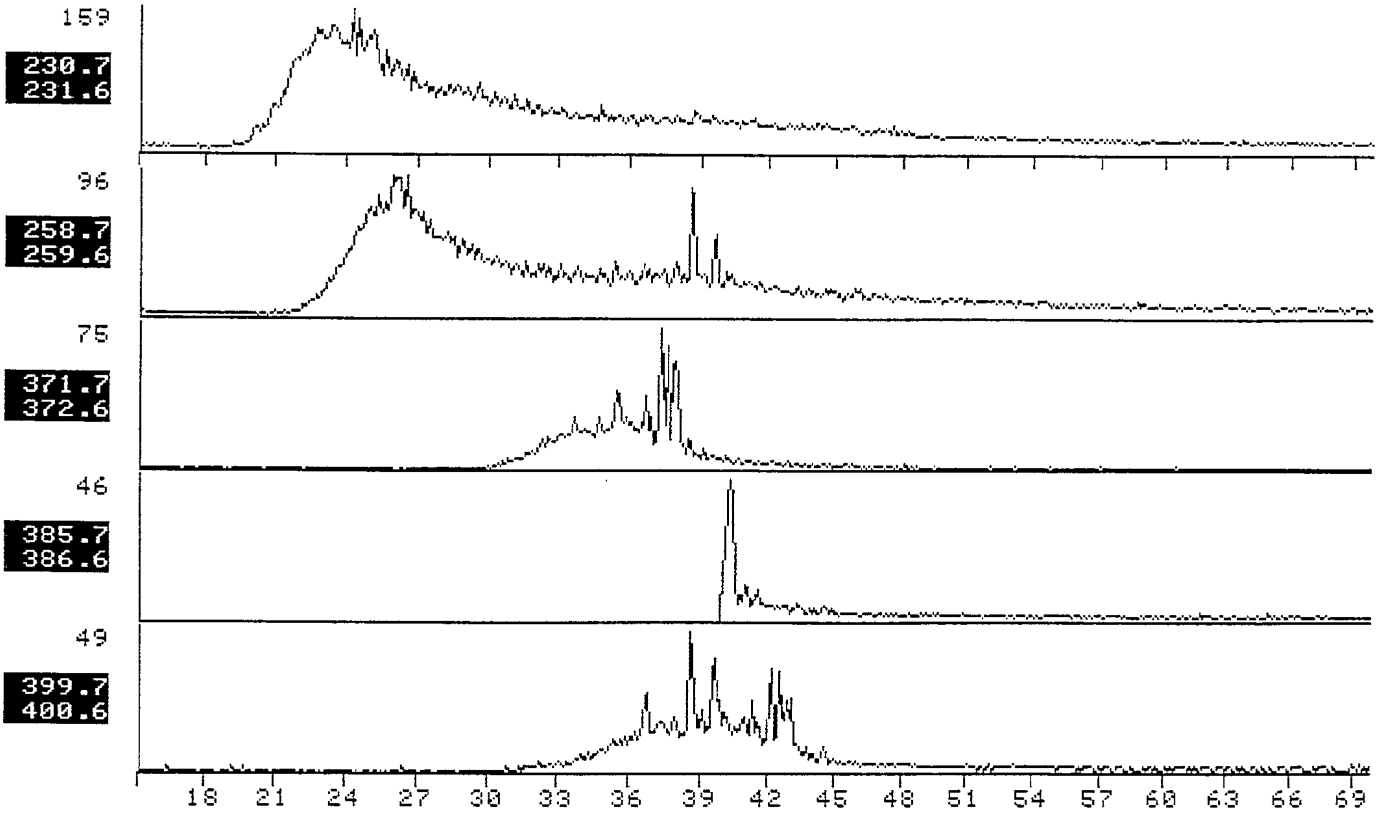
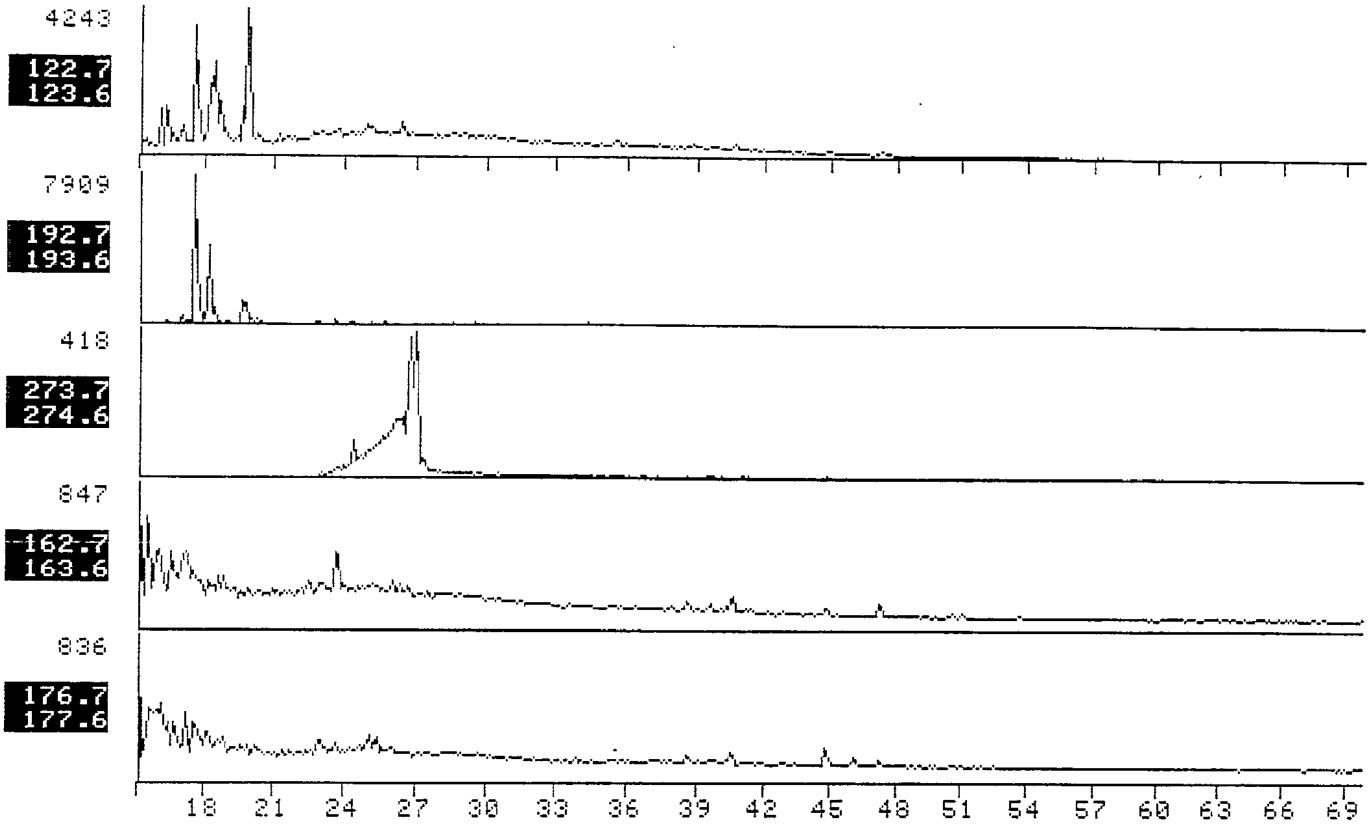
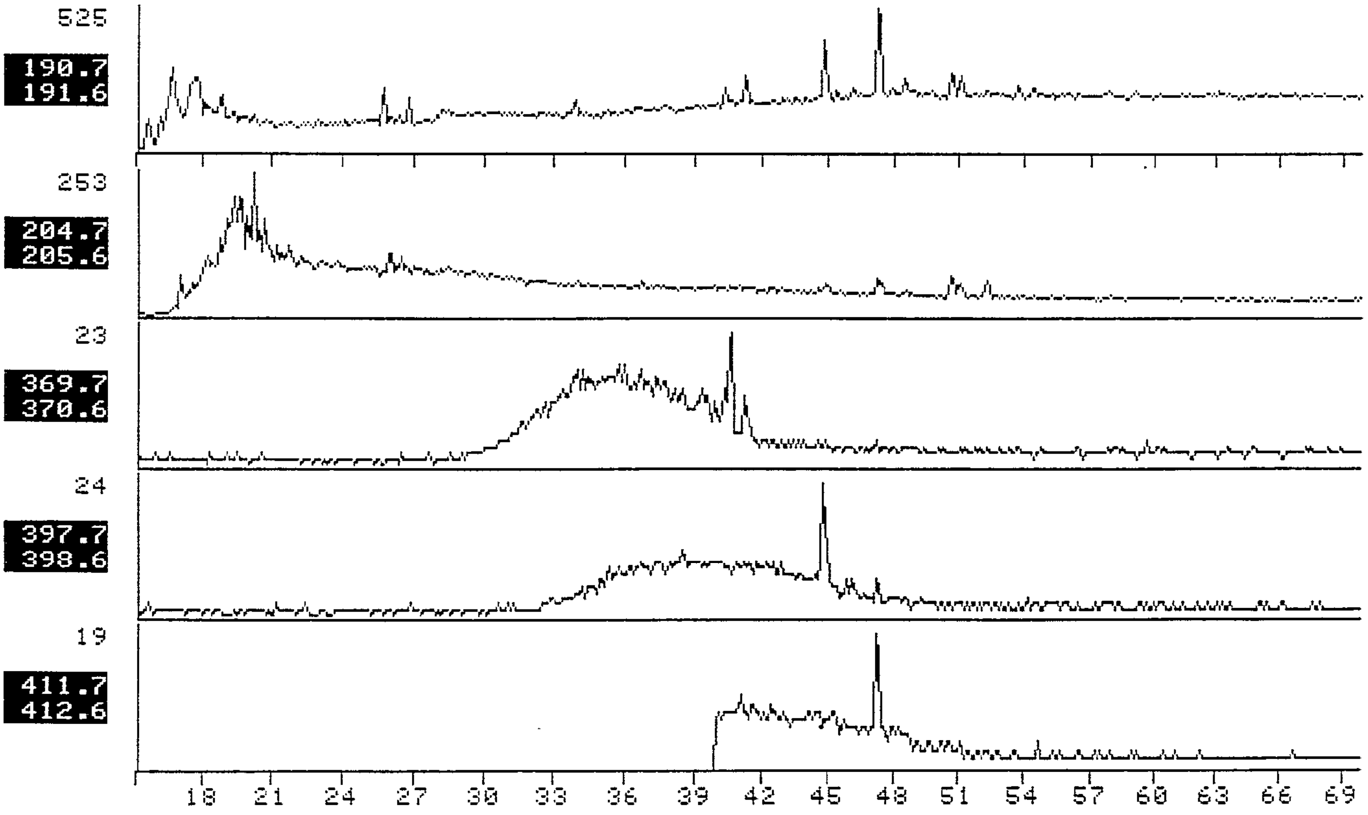


FIGURE 5J

**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



**NAME** LIMESTONE CREEK#1, 3936-3976', B/C. COL#41. **FRN** 5585
**MISC** 10-9-84. GEC/GW. 0.2ul/140ul.



## TABLE 1A

## SUMMARY OF WHOLE OIL GAS CHROMATOGRAPHY

## KERINNA NO. 1, DST NO. 3, 5140-5160ft., Hutton Sandstone

$C_{1-31}$

| Carbon No. | Weight% |
|---|---|
| 1 - 3 | 0.05 |
| 4 | 0.15 |
| 5 | 0.34 |
| 6 | 0.86 |
| 7 | 2.23 |
| 8 | 2.46 |
| 9 | 1.89 |
| 10 | 1.20 |
| 11 | 1.02 |
| 12 | 1.10 |
| 13 | 1.19 |
| 14 | 1.34 |
| 15 | 1.70 |
| 16 | 1.87 |
| 17 | 2.43 |
| 18 | 2.61 |
| 19 | 3.43 |
| 20 | 4.20 |
| 21 | 5.18 |
| 22 | 5.99 |
| 23 | 6.87 |
| 24 | 7.62 |
| 25 | 8.51 |
| 26 | 7.37 |
| 27 | 7.71 |
| 28 | 6.60 |
| 29 | 5.76 |
| 30 | 4.76 |
| 31 | 3.55 |

$C_{4-7}$

| | Compound | Weight% |
|---|---|---|
| A | isobutane | 1.88 |
| B | n-butane | 2.90 |
| C | isopentane | 5.54 |
| D | n-pentane | 4.77 |
| E | 2,2-dimethylbutane | 0.29 |
| F | Cyclopentane | 0.52 |
| G | 2,3-dimethylbutane | 1.09 |
| H | 2-methylpentane | 5.56 |
| I | 3-methylpentane | 2.97 |
| J | n-hexane | 7.12 |
| K | methylcyclopentane | 5.10 |
| L | 2,4-dimethylpentane | 1.02 |
| M | benzene | nd |
| N | cyclohexane | 5.00 |
| O | 1,1-dimethylcyclopentane | 1.90 |
| P | 2-methylhexane | 4.10 |
| Q | 3-methylhexane | 6.43 |
| R | 1 cis-3-dimethylcyclopentane | 1.96 |
| S | 1 trans-3-dimethylcyclopentane | 3.02 |
| T | 1 trans-2-dimethylcyclopentane | 0.34 |
| U | n-heptane | 11.18 |
| V | methylcyclohexane | 26.22 |
| W | 1 cis-2-dimethylcyclopentane | 1.11 |
| X | toluene | nd |

## TABLE 1B

## SUMMARY OF WHOLE OIL GAS CHROMATOGRAPHY

## LIMESTONE CREEK NO. 1, 3936-3976ft

$C_{1-31}$

| Carbon No. | Weight% |
|---|---|
| 1 - 3 | 0.75 |
| 4 | 0.29 |
| 5 | 0.76 |
| 6 | 1.65 |
| 7 | 2.97 |
| 8 | 3.64 |
| 9 | 2.26 |
| 10 | 2.17 |
| 11 | 2.06 |
| 12 | 2.68 |
| 13 | 2.84 |
| 14 | 3.53 |
| 15 | 3.68 |
| 16 | 4.58 |
| 17 | 5.66 |
| 18 | 5.60 |
| 19 | 6.11 |
| 20 | 7.10 |
| 21 | 7.68 |
| 22 | 7.69 |
| 23 | 7.34 |
| 24 | 5.95 |
| 25 | 4.62 |
| 26 | 3.34 |
| 27 | 1.93 |
| 28 | 1.33 |
| 29 | 0.81 |
| 30 | 0.82 |
| 31 | 0.15 |

$C_{4-7}$

| | Compound | Weight% |
|---|---|---|
| A | isobutane | 2.31 |
| B | n-butane | 2.81 |
| C | isopentane | 6.63 |
| D | n-pentane | 6.46 |
| E | 2,2-dimethylbutane | 0.25 |
| F | Cyclopentane | 0.25 |
| G | 2,3-dimethylbutane | 0.76 |
| H | 2-methylpentane | 6.00 |
| I | 3-methylpentane | 3.19 |
| J | n-hexane | 10.44 |
| K | methylcyclopentane | 4.32 |
| L | 2,4-dimethylpentane | 0.67 |
| M | benzene | nd |
| N | cyclohexane | 4.07 |
| O | 1,1-dimethylcyclopentane | 0.38 |
| P | 2-methylhexane | 3.82 |
| Q | 3-methylhexane | 5.45 |
| R | 1 cis-3-dimethylcyclopentane | 1.59 |
| S | 1 trans-3-dimethylcyclopentane | 2.35 |
| T | 1 trans-2-dimethylcyclopentane | 0.25 |
| U | n-heptane | 14.09 |
| V | methylcyclohexane | 22.69 |
| W | 1 cis-2-dimethylcyclopentane | 0.55 |
| X | toluene | 0.67 |

# TABLE 2

## SELECTED LIGHT HYDROCARBON RATIOS

| Parameter | Kerinna No. | Limestone Creek No. 1 |
|---|---|---|
| Paraffin Index 1 * | 2.0 | 2.2 |
| Paraffin Index II * | 18.6 | 25.8 |
| n-$C_6$/methylcyclopentane | 1.4 | 2.4 |
| n-$C_7$/methylcyclohexane | 0.43 | 0.62 |
| 3-methylpentane/benzene | nd | nd |
| methylcyclohexane/toluene | nd | 33.9 |
| cyclohexane/benzene | nd | nd |
| 2-methylbutane/n-pentane | 1.2 | 1.0 |
| 3-methylpentane/n-hexane | 0.42 | 0.31 |

NOTE: * from K.F.M. Thompson, 1979, Geochimica Cosmochimica Acta, 43, 657-672. Data obtained from whole oil analysis.

## TABLE 3

### Summary of Physical Property and Sulphur Data

Date of Job: AUGUST 1984

| Sample | API Gravity | %Sulphur(w/w) | Viscosity( 25°C) | Viscosity( 60°C) |
|---|---|---|---|---|
| KERINNA #1 5140-5160' | nd | nd | nd | nd |
| IESTONE CREEK #1 3936-3976' | nd | nd | nd | nd |

## TABLE 3

### Summary of Liquid Chromatography(Compositional Data)

Date of Job: AUGUST 1984

|  | -----Hydrocarbons------ |  |  | -----Nonhydrocarbons------ |  |  | SAT | ASPH | HC |
|---|---|---|---|---|---|---|---|---|---|
| Sample | %SAT. | %AROM. | %HC's | %NSO's | %ASPH. | %Non HC's | AROM | NSO | Non HC |
| KERINNA #1 5140-5160' | 92.1 | 5.4 | 97.5 | 2.5 | nd | 2.5 | 17.07 | nd | 39.0 |
| IESTONE CREEK #1 3936-3976' | 91.0 | 5.8 | 96.8 | 3.2 | nd | 3.2 | 15.78 | nd | 30.4 |

na = not applicable     nd = no data

## TABLE 3A

## SATURATE COMPOSITION DATA

| Sample | % n-alkanes | % branched+cyclics |
|---|---|---|
| Kerinna No. 1 5140-5160ft | 82.5 | 17.5 |
| Limestone Creek No. 1 3936-3976ft | 72.5 | 27.5 |

NOTE:

%'s are a % of the saturate fraction

## TABLE 4

### Summary of Gas Chromatography Data

A. Alkane Compositional Data

Date of Job: AUGUST 1984

| Sample | Prist./Phyt. | Prist./n-C17 | Phyt./n-C18 | CPI(1) | CPI(2) | (C21+C22)/(C28+C29) |
|---|---|---|---|---|---|---|
| KERINNA #1 5140-5160' | 2.70 | .22 | .06 | 1.09 | 1.08 | 2.21 |
| LIMESTONE CREEK #1 3936-3976' | 3.24 | .28 | .07 | 1.14 | 1.14 | 14.16 |

## TABLE 4

### Summary of Gas Chromotography Data

B. n-Alkane Distributions

Date of Job: AUGUST 1984

| Sample | nC12 | nC13 | nC14 | nC15 | nC16 | nC17 | iC19 | nC18 | iC20 | nC19 | nC20 | nC21 | nC22 | nC23 | nC24 | nC25 | nC26 | nC27 | nC28 | nC29 | nC30 | nC31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KERINNA #1 5140-5160' | 1.1 | 1.3 | 1.6 | 2.0 | 2.5 | 3.2 | .7 | 3.9 | .3 | 4.9 | 6.2 | 7.6 | 8.8 | 10.5 | 10.3 | 10.6 | 7.6 | 6.8 | 4.3 | 3.1 | 1.7 | .9 |
| LIMESTONE CREEK #1 3936-3976' | 3.0 | 3.5 | 4.2 | 5.1 | 6.2 | 7.3 | 2.0 | 8.6 | .6 | 9.5 | 9.7 | 9.3 | 8.4 | 7.7 | 5.6 | 4.1 | 2.2 | 1.5 | .8 | .5 | .2 | .1 |

na = not applicable    nd = no data

## TABLE 5A

## SATURATE FRACTION GC/MS DATA - RELATIVE COMPOUND ABUNDANCE

Sample: KERINNA NO. 1, DST NO. 3, 5140-5160ft

| Compound | Ion Used | Relative Abundance (area counts) | Relative Abundance (%) | Confirmed |
|---|---|---|---|---|
| 18α(H)-Trisnorhopane ($T_s$) | 191 | 1409 | 1.86 | * |
| 17α(H)-Trisnorhopane ($T_m$) | 191 | 926 | 1.22 | * |
| $C_{28}$ Hopane | 191 | nd | nd | |
| $C_{29}$ Hopane | 191 | 2550 | 3.36 | * |
| Compound Z | 191 | 686 | 0.90 | * |
| Compound X | 191 | 1845 | 2.43 | * |
| $C_{29}$ Moretane | 191 | 341 | 0.45 | * |
| 18α(H)-Oleanane | 191 | ~~nd~~ | nd | |
| $C_{30}$ Hopane | 191 | 5644 | 7.43 | * |
| $C_{30}$ Moretane | 191 | 368 | 0.48 | * |
| $C_{31}$ S Hopane | 191 | 1650 | 2.17 | * |
| $C_{31}$ R Hopane | 191 | 1323 | 1.74 | * |
| $C_{31}$ S+R Moretane | 191 | 220 | 0.29 | * |
| $C_{32}$ S Hopane | 191 | 1205 | 1.59 | * |
| $C_{32}$ R Hopane | 191 | 820 | 1.08 | * |
| $C_{32}$ S Moretane | 191 | nd | nd | |
| $C_{32}$ R Moretane | 191 | nd | nd | |
| $C_{33}$ S Hopane | 191 | 303 | 0.40 | * |
| $C_{33}$ R Hopane | 191 | 230 | 0.30 | * |
| Rearranged Drimane ($R_1$) | 123 | 13055 | 17.19 | * |
| Rearranged Drimane ($R_2$) | 123 | 7087 | 9.33 | * |
| 8β(H)-Drimane ($C_{15}$) | 123 | 11190 | 14.73 | * |
| 8β(H)-Homodrimane ($C_{16}$) | 123 | 16972 | 22.35 | * |
| Phyllocladane | 123 | nd | nd | |
| $C_{27}$ S Diasterane | 217 (259) | nd (nd) | nd | |
| $C_{27}$ R Diasterane | 217 (259) | nd (nd) | nd | |
| $C_{29}$ S Diasterane | 217 (259) | 5569 3169 (1395) | 4.17 | * * |
| $C_{29}$ R Diasterane | 217 (259) | 2400 (972) | 3.16 | * * |
| $C_{21}$ Sterane (pregnane) | 217 | nd | nd | |
| $C_{22}$ Sterane | 217 | nd | nd | |
| $C_{27}$ S Sterane | 217 | nd | nd | |
| $C_{27}$ R Sterane | 217 | nd | nd | |
| $C_{27}$ S Isosterane | 217 | nd | nd | |
| $C_{27}$ R Isosterane | 217 | nd | nd | |
| $C_{28}$ S Sterane | 217 | nd | nd | |
| $C_{28}$ R Sterane | 217 | nd | nd | |
| $C_{28}$ S Isosterane | 217 | nd | nd | |
| $C_{28}$ R Isosterane | 217 | nd | nd | |
| $C_{29}$ S Sterane | 217 | 488 | 0.64 | * |
| $C_{29}$ R Sterane | 217 | 577 | 0.76 | * |
| $C_{29}$ S Isosterane | 217 | 749 | 0.99 | * |
| $C_{29}$ R Isosterane | 217 | 745 | 0.98 | * |

NOTES: Confirmed samples (*) are those which have been reliably identified and integrated.
nd = no data.
% = % of all compounds integrated.

## TABLE 5B

## SATURATE FRACTION GC/MS DATA - CALCULATED VALUES

Sample: KERINNA NO. 1, DST NO. 3, 5140-5160ft

| Parameter | Value | | |
|---|---|---|---|
| | (Area Counts) | (%) | (No Units) |
| $C_{27}$ Terpanes | 2335 | 3.08 | |
| $C_{28}$ Terpanes | nd | nd | |
| $C_{29}$ Terpanes | 5422 | 7.14 | |
| $C_{30}$ Terpanes | 6012 | 7.91 | |
| Total Terpanes | 19520 | 25.70 | |
| $(C_{27}+C_{28})/(C_{29}+C_{30})$ Terpanes | | | 0.20 |
| $T_s/T_m$ | | | 1.52 |
| $C_{30}$ Hopane/$C_{30}$ Moretane | | | 15.48 |
| $C_{27}/C_{29}$ Steranes | | | nd |
| $C_{27}/C_{29}$ Diasteranes | | | nd |
| $C_{29}$ S/R Steranes | | | 0.85 |
| $C_{29}$ [Diasteranes/ (Steranes+Isosteranes)] | | | 2.18 |
| $C_{30}$ Terpanes/$C_{29}$ Steroidal Compounds[a] | | | 0.74 |
| Drimane/Homodrimane[b] | | | 0.66 |
| Rearranged/Normal Drimanes[c] | | | 0.72 |

3 1.25
4 1.32
6 0.84
9 nd

NOTES:
a = steranes, diasteranes and isosteranes
b = both are $8\beta(H)$ epimer
c = rearranged = $R_1+R_2$; normal = $8\beta(H)$-Drimane + $8\beta(H)$-Homodrimane
nd = no data

## TABLE 6A

## SATURATE FRACTION GC/MS DATA - RELATIVE COMPOUND ABUNDANCE

Sample: LIMESTONE CREEK NO. 1

| Compound | Ion Used | Relative Abundance (area counts) | (%) | Confirmed |
|---|---|---|---|---|
| 18α(H)-Trisnorhopane ($T_s$) | 191 | 707 | 0.37 | * |
| 17α(H)-Trisnorhopane ($T_m$) | 191 | 1551 | 0.81 | * |
| $C_{28}$ Hopane | 191 | nd | nd | |
| $C_{29}$ Hopane | 191 | 3317 | 1.73 | * |
| Compound Z | 191 | 753 | 0.39 | * |
| Compound X | 191 | 586 | 0.31 | * |
| $C_{29}$ Moretane | 191 | 704 | 0.37 | * |
| 18α(H)-Oleanane | 191 | ~~nd~~ | nd | |
| $C_{30}$ Hopane | 191 | 5948 | 3.11 | * |
| $C_{30}$ Moretane | 191 | 1119 | 0.58 | * |
| $C_{31}$ S Hopane | 191 | 1841 | 0.96 | * |
| $C_{31}$ R Hopane | 191 | 1704 | 0.89 | * |
| $C_{31}$ S+R Moretane | 191 | 506 | 0.26 | * |
| $C_{32}$ S Hopane | 191 | 952 | 0.50 | * |
| $C_{32}$ R Hopane | 191 | 812 | 0.42 | * |
| $C_{32}$ S Moretane | 191 | nd | nd | |
| $C_{32}$ R Moretane | 191 | nd | nd | |
| $C_{33}$ S Hopane | 191 | 562 | 0.29 | * |
| $C_{33}$ R Hopane | 191 | 405 | 0.21 | * |
| Rearranged Drimane ($R_1$) | 123 | 47398 | 24.75 | * |
| Rearranged Drimane ($R_2$) | 123 | 24339 | 12.71 | * |
| 8β(H)-Drimane ($C_{15}$) | 123 | 35228 | 18.39 | * |
| 8β(H)-Homodrimane ($C_{16}$) | 123 | 58288 | 30.44 | * |
| Phyllocladane | 123 | nd | nd | |
| $C_{27}$ S Diasterane | 217 (259) | nd (nd) | nd | |
| $C_{27}$ R Diasterane | 217 (259) | nd (nd) | nd | |
| $C_{29}$ S Diasterane | 217 (259) | 2808 1612 (842) | 0.84 | * * |
| $C_{29}$ R Diasterane | 217 (259) | 1196 (585) | 0.62 | * * |
| $C_{21}$ Sterane (pregnane) | 217 | nd | nd | |
| $C_{22}$ Sterane | 217 | nd | nd | |
| $C_{27}$ S Sterane | 217 | nd | nd | |
| $C_{27}$ R Sterane | 217 | nd | nd | |
| $C_{27}$ S Isosterane | 217 | nd | nd | |
| $C_{27}$ R Isosterane | 217 | nd | nd | |
| $C_{28}$ S Sterane | 217 | nd | nd | |
| $C_{28}$ R Sterane | 217 | nd | nd | |
| $C_{28}$ S Isosterane | 217 | nd | nd | |
| $C_{28}$ R Isosterane | 217 | nd | nd | |
| $C_{29}$ S Sterane | 217 | 367 | 0.19 | * |
| $C_{29}$ R Sterane | 217 | 640 | 0.33 | * |
| $C_{29}$ S Isosterane | 217 | 532 | 0.28 | * |
| $C_{29}$ R Isosterane | 217 | 444 | 0.23 | * |

NOTES: Confirmed samples (*) are those which have been reliably identified and integrated.
nd = no data.
% = % of all compounds integrated.

## TABLE 6B

## SATURATE FRACTION GC/MS DATA - CALCULATED VALUES

Sample: LIMESTONE CREEK NO. 1

| Parameter | Value (Area Counts) | (%) | (No Units) |
|---|---|---|---|
| $C_{27}$ Terpanes | 2258 | 1.18 | |
| $C_{28}$ Terpanes | nd | nd | |
| $C_{29}$ Terpanes | 5360 | 2.80 | |
| $C_{30}$ Terpanes | 7067 | 3.69 | |
| Total Terpanes | 21467 | 11.21 | |
| $(C_{27}+C_{28})/(C_{29}+C_{30})$ Terpanes | | | 0.18 |
| $T_s/T_m$ | | | 0.46 |
| $C_{30}$ Hopane/$C_{30}$ Moretane | | | 5.34 |
| $C_{27}/C_{29}$ Steranes | | | nd |
| $C_{27}/C_{29}$ Diasteranes | | | nd |
| $C_{29}$ S/R Steranes | | | 0.57 |
| $C_{29}$ [Diasteranes/ (Steranes+Isosteranes)] | | | 1.42 |
| $C_{30}$ Terpanes/$C_{29}$ Steroidal Compounds[a] | | | 1.48 |
| Drimane/Homodrimane[b] | | | 0.60 |
| Rearranged/Normal Drimanes[c] | | | 0.77 |
| | | 3 | 1.08 |
| | | 4 | 1.39 |
| | | 6 | 0.74 |
| | | 9 | n.d. |

NOTES:

a = steranes, diasteranes and isosteranes

b = both are 8β(H) epimer

c = rearranged = $R_1+R_2$; normal = 8β(H)-Drimane + 8β(H)-Homodrimane

nd = no data

## TABLE 7

## CARBON ISOTOPE DATA

| Sample | $\delta^{13}C$ SATS | $\delta^{13}C$ AROM |
|---|---|---|
| Kerinna No. 1, 5140-5160ft | -26.21 | -24.68 |
| Limestone Creek No. 1, 3936-3976ft | -25.19 | -24.92 |

NOTE: All values relative to PDB

## THEORY AND METHODS

This section details a series of geochemical methods which are commonly used in our laboratory, including those used to obtain the data presented in this report. Where applicable, the discussion is accompanied by a summary of the general theory used tc interpret the data generated by each method.

### 1. SEDIMENTARY GAS ANALYSIS

### a) Headspace Analysis

Headspace analysis is carried out using sealed containers (usually tinned cans) of wet cuttings. The containers are approximately three quarters filled with the cuttings and water to leave an appreciable headspace into which volatile hydrocarbons contained in the cuttings diffuse.

After covering about 1cm2 of the container lid with silicone and allowing the silicone to dry, the procedure involves placing a small hole in the lid through the silicone, then sampling an aliquot of the headspace gas with a gas injection syringe, and finally gas chromatographing this sample of gas under the following conditions: instrument = Shimadzu GC-8APF; column = 6' x 1/8" Chromosorb 102; column temperature = 110 Deg. C; carrier gas = nitrogen at 23mls/min; injector temperature = 120 Deg. C.; analysis cycle = C1-C4 components are flushed from the column in the forward direction and then the C5-C7 compounds are removed from the column by backflushing.

The integrated areas of peaks representing each of the C1-C7 components of the headspace gas are compared to the areas of corresponding components of a standard gas of known composition. The calculated amount of each component in the sample gas is adjusted for the total headspace volume and reported as ppm (parts of gas per million parts of sediment by volume).

Data from headspace analysis is commonly used to identify the zone of oil generation by plotting gas wetness (C2-C4/C1-C4) expressed as a % against sediment burial depth. Gas containing appreciable quantities of C2-C4 components, termed wet gas (Fuex, 1977), is generally considered to be gas associated with oil generation. In addition, the ratio of isomeric butanes can sometimes be used for assessment of sediment maturity (Alexander et. al., 1981). The amount of gas in sediments can be used to identify zones of significant gas generation and out-of-place gas (LeTran et. al., 1975).

### b) Cuttings Gas Analysis

This analysis is the same as Headspace Analysis with the exception that instead of analysing the gas in the container headspace, a known volume of the wet cuttings are transferred to the blender bowl of a Kenwood electronic blender with the lid modified to incorporate a septum, water at 75 Deg. C is added to leave a headspace of 160ml, and the mixture is blended at maximum speed for 2 minutes. Following a 2 minute settling period 1ml of the blending bowl headspace gas is analysed as described in section 1a.

It is recommended that for the most meaningful gas data both headspace and cuttings gas analysis are carried out. In such cases we provide tabulations of the headspace, gas, and combined headspace/cuttings gas data. Normally, the combined data is used for plotting purposes.

## 2. SAMPLE PREPARATION

a) Cuttings

Cuttings samples are inspected by our qualified geological staff and then water washed according to the drilling mud content and lithology. In special cases (e.g. diesel contamination) it is necessary to lightly solvent wash samples. After washing, the samples are air dried, either sieved or picked free of cavings, and crushed to 0.1mm using a ring pulveriser.

b) Sidewall Cores

Sidewall samples are freed of mud cake and any other visible contaminants, and are also inspected for lithologic homogeneity. For homogeneous samples, the minimum amount of material required for the requested analyses is air dried and handcrushed to 0.1mm. For non-homogeneous samples, the whole sample is air dried and handcrushed to 0.1mm.

c) Conventional Core and Outcrop Samples

These sample types are firstly inspected for visible contaminants, and where applicable, are freed of these contaminants to the best of our ability. Commonly, the surface of conventional core and outcrop samples are lightly solvent washed. The samples are then crushed to approximately 1/8" chips using a jaw crusher, air dried, and finally further crushed to 0.1mm using a ring pulveriser.

d) Petroleum/Aqueous Mixtures

The most common sample type in this category are RFT tests containing oil, water and mud. The mixture is placed in a separation funnel and allowed to stand for several hours which enables the petroleum and water/mud fractions to separate. The neat petroleum is isolated by removal of the lower layer (water/mud) from the funnel. To remove the last traces of water and mud, the neat petroleum is centrifuged at moderate speed.

When the volume of petroleum accounts for only a very small part of the sample the method above is unsatisfactory and the petroleum is solvent extracted from the mixture with dichloromethane. The petroleum is recovered by careful evaporation of the solvent from the organic layer.

## 3. TOTAL ORGANIC CARBON DETERMINATION

The total organic carbon value (TOC) is determined on the unextracted sediment sample. The value is determined by treating a known weight of sediment with hot dilute HCl for 1 hour to remove carbonate minerals, and then heating the residue to 1700 Deg. C (Leco Induction Furnace CS-044) in an atmosphere of pure oxygen. The carbon dioxide produced is transferred to an infra-red detector which has been calibrated with a series of standards, and the microprocessor of the Leco unit then automatically calculates the % TOC in the sample. To ensure reliable data a standard is run after every 10 samples, regular sample repeats are carried out, and at least one blank determination is carried out for each batch of samples.

The following scales are normally used for source rock classification based on % TOC data:

| Classification | Clastics | Carbonates |
|---|---|---|
| Poor | 0.00 - 0.50 | 0.00 - 0.25 |
| Fair | 0.50 - 1.00 | 0.25 - 0.50 |
| Good | 1.00 - 2.00 | 0.50 - 1.00 |
| Very Good | 2.00 - 4.00 | 1.00 - 2.00 |
| Excellent | > 4.00 | > 2.00 |

## 4. ROCK-EVAL PYROLYSIS

Although a preliminary source rock classification is made using TOC data a more accurate assessment accounting for organic source type and maturity is made by pyrolysis analysis. Two types of Rock-Eval pyrolysis services are offered: "one run" which involves pyrolysis of the crushed but otherwise untreated sediment and "two run" which involves pyrolysis of both the crushed, untreated sediment and sediment which has been rendered free of carbonate minerals by treatment with hot dilute HCl. The two run service offers considerably more reliable S3 data.

The method involves accurately weighing approximately 100mg of the sample into a sintered steel crucible and subjecting it to the following pyrolysis cycle:

Stage (i) - Sample purged with helium for 3.5 minutes in unheated part of pyrolysis furnace;

Stage (ii) - Sample heated at 300 Deg. C for 3 minutes to liberate free petroleum (S1 peak);

Stage (iii) - Sample heated from 300 Deg. C to 550 Deg. C at 25 Deg. C/minute to produce petroleum from kerogen (S2 peak). The furnace is maintained at 550 Deg. C for one minute. Carbon dioxide produced during this pyrolysis up to 390 Deg. C in the case of "one run" and 550 Deg. C for "two run" is absorbed on a molecular sieve trap;

Stage (iv) - During the cool down period the carbon dioxide produced during pyrolysis is measured (S3 peak).

The units used for Rock-Eval data are as follows:

S1, S2, S3 = kg/tonne or mg/g of rock

Tmax = Deg. C

Hydrogen Index = $\frac{S2}{TOC} \times \frac{100}{1}$

Oxygen Index = $\frac{S3}{TOC} \times \frac{100}{1}$

Rock-Eval data is most commonly used in the following manner:

(i) S1 - indicates the level of oil and or/gas already generated by the sample according to the following scale:

| S1 (mg/g or kg/tonne) | Classification |
|---|---|
| 0.00 - 0.20 | Poor |
| 0.20 - 0.40 | Fair |
| 0.40 - 0.80 | Good |
| 0.80 - 1.60 | Very Good |
| > 1.60 | Excellent |

(ii) S1+S2 - referred to as the genetic potential this parameter is used for source rock classification according to the following criteria:

| S1+S2 (mg/g or kg/tonne) | Classification |
|---|---|
| 0.00 - 1.00 | Poor |
| 1.00 - 2.00 | Marginal |
| 2.00 - 6.00 | Moderate |
| 6.00 - 10.00 | Good |
| 10.00 - 20.00 | Very Good |
| > 20.00 | Excellent |

(iii) S1/(S1+S2)- this parameter is the production index (PI) which is a measure of the level of maturity of the sample. For oil prone sediments, values less than 0.1 are indicative of immaturity, the values increase from 0.1 to 0.4 over the oil window and values greater than 0.4 represent over maturity. For gas prone sediments, the PI data shows a relatively smaller change with increasing maturity.

(iv) Tmax - the temperature corresponding to the S2 maxima. This temperature increases with increasingly mature sediments. Values less than 430 Deg. C are indicative of immaturity while values from 430/435 to 460 Deg. C represent the maturity range of the oil window. Tmax values greater than 460 Deg. C are indicative of over maturity.

(v) HI, OI - the hydrogen ((S2 x 100)/TOC) and oxygen ((S3 x 100)/TOC) indices when plotted against one another provide information about the type of kerogen contained in the sample and the maturity of the sample. Both parameters decrease in value with increasing maturity. Samples with large HI and low OI are dominantly oil prone and conversely samples with low HI and large OI are at best gas prone.

## 5. EXTRACTION OF SEDIMENT SAMPLES

Crushed sediment (maximum of 250g) and 300mls of purified dichloromethane are placed in a 500ml conical flask and are then blended for ten minutes with a Janke and Kunkel Ultra-Turrax T45/2G high efficiency disperser. After a ten minute settling period the solvent is separated from the sediment using a large Buchner filtration system. The extract is recovered by careful evaporation of the solvent on a steam bath and weighed. The weight of extract is used to calculate % EOM and ppm EOM using the following formulae:

$$\%\ \text{EOM} = \frac{\text{Wt EOM}}{\text{Wt Sediment Extracted (g)}} \times \frac{100}{1}$$

$$\text{ppm EOM} = \frac{\text{Wt EOM (mg)}}{\text{Wt Sediment Extracted (kg)}}$$

The following scale is used to classify the source rock richness of samples based or C12+ extractables:

| Classification | ppm Total Extract |
|---|---|
| Poor | 0 - 500 |
| Fair | 500 - 1000 |
| Good | 1000 - 2000 |
| Very Good | 2000 - 4000 |
| Excellent | > 4000 |

## 6. SEPARATION OF PETROLEUM INTO CONSTITUENT FRACTIONS

Sediment extracts and crude oil or condensate samples are separated into saturate, aromatic and NSO (asphaltenes plus resins) fractions by medium pressure liquid chromatography (MPLC). That part of the petroleum which is soluble in pentane is applied to the MPLC system via a sample loop and is then pumped using pentane to a partially activated silicic acid pre-column which prevents further movement of the non-hydrocarbon compounds. The hydrocarbon components are pumped further to a Merck Si60 column where the saturate fraction is obtained by forward flushing and the aromatic fraction is recovered by reverse flushing. This separation procedure is monitored using a refractive index detector. To complete the separation the pre-column is removed from the MPLC system and flushed with dichloromethane: methanol (1:10). This non-hydrocarbon fraction is combined with the pentane insoluble material which is not applied to the MPLC system, and is labelled as the NSO fraction. The neat fractions are recovered by careful removal of the solvent by distillation and are weighed.

The weight of each fraction is used to calculate the % of each fraction in the sediment according to the following formulas:

$$\%\ \text{Fraction} = \frac{\text{Wt Fraction}}{\text{Wt all Fractions}} \times \frac{100}{1}$$

$$\text{ppm Fraction} = \frac{\text{Wt Fraction (mg)}}{\text{Wt Sediment Extracted (kg)}}$$

The ppm hydrocarbon (saturates and aromatics) and ppm saturate values can be used to classify source rock richness and oil source potential respectively according to the following criteria:

| Classification | ppm Hydrocarbon | ppm Saturates |
|---|---|---|
| Poor | 0 - 300 | 0 - 200 |
| Fair | 300 - 600 | 200 - 400 |
| Good | 600 - 1200 | 400 - 800 |
| Very Good | 1200 - 2400 | 800 - 1600 |
| Excellent | > 2400 | > 1600 |

The composition of the extracts can also provide information about their levels of maturity and/or source type (LeTran et. al., 1974; Philippi, 1974). Generally, marine extracts have relatively low concentrations of saturated and NSO compounds at low levels of maturity, but these concentrations increase with increased maturation. Terrestrially derived organic matter often has a low level of saturates and large amount of aromatic and NSO compounds irrespective of the level of maturity.

N.B. If requested by a client the NSO fraction is separated into asphaltenes and resins by conventional methods.

## 7. EXTRACTABLE/TOTAL ORGANIC CARBON RATIOS

The ratios of EOM(mg)/TOC(g) and SAT(mg)/TOC(g) are determined from the appropriate data. The EOM(mg)/TOC(g) ratio can be used as a maturation indicator, especially if the parameter is plotted against depth for a given sedimentary sequence. In an absolute sense it is less reliable as a maturation indicator, although previous work (Tissot et. al., 1971; LeTran et. al., 1974) suggests that the following criteria can be used to determine maturity with this parameter.

| | |
|---|---|
| < 50 | Low maturity |
| 50 - 100 | Moderate maturity |
| > 100 | High maturity |

The ratios of EOM(mg)/TOC(g) and SAT(mg)/TOC(g) can be used collectively to provide information about source type. For example, if SOM(mg)/TOC(g) is > 100, suggesting a high level of maturity, but the SAT(mg)/TOC(g) < 20 it is very likely that the organic matter is gas prone. Conversely, the same EOM(mg)/TOC(g) value with a SAT(mg)/TOC(g) value > 40 suggests oil prone source type.

## 8. PYROLYSIS GAS CHROMATOGRAPHY

Pyrolysis-gas chromatography (PGC) incorporates a Chemical Data System Pyroprope 150 flash pyrolysis unit interfaced with a capillary gas chromatograph. A sample (5-10mg) of extracted sediment is placed in a quartz tube inside the element coil of the pyrolysis probe and is then heated to 610 Deg. C in a few milliseconds, and is maintained at this temperature for 20 seconds. Products generated from the pyrolysis are swept onto the bonded phase capillary column of the gas chromatograph and are chromatographed from -20 Deg. C (isothermal for two minutes) to 280 Deg. C at 4 Deg. C/minute. The product distribution is dominated by the nature of the kerogen from which it is derived.

## 9. C12+ GAS CHROMATOGRAPHY

C12+ gas chromatography is commonly carried out on the saturate fraction but in certain instances is carried out on neat oil, condensate or extract. The analysis is carried out under the following conditions: instrument = Shimadzu GC-9A; column = 50m x 0.2mm ID OV101 vitreous silica; column temperature = programmed from 60 Deg. C to 280 Deg. C at 4 Deg. C/min; injection system = Grob splitless using a 30 second dump time and split ratio of 25:1, carrier gas = hydrogen at 2mls/min; sample = 1μl of 0.5% soln in pentane.

The following information is commonly obtained from C12+ gas chromatographic analysis:

(a) n-Alkane Distribution - The C12-C31 n-alkane distribution is determined from the area under peaks representing each of these n-alkanes. This distribution can yield information about both the level of maturity and the source type (LeTran et. al., 1974).

(b) Carbon Preference Index - Two values are determined:

$$\mathrm{CPI}\ (1) = \frac{(C23 + C25 + C27 + C29)\ \mathrm{Wt\%} + (C25 + C27 + C29 + C31)\ \mathrm{Wt\%}}{2 \times (C24 + C26 + C28 + C30)\ \mathrm{Wt\%}}$$

$$\mathrm{CPI}\ (2) = \frac{(C23 + C25 + C27)\ \mathrm{Wt\%} + (C25 + C27 + C29)\ \mathrm{Wt\%}}{2 \times (C24 + C26 + C28)\ \mathrm{Wt\%}}$$

The CPI is believed to be a function of both the level of maturity (Cooper and Bray, 1963; Scalan and Smith, 1970) and the source type (Tissot and Welte, 1978). Marine extracts tend to have values close to 1.0 irrespective of maturity whereas values for terrestrial extracts decrease with maturity from values as high as 20 but do not usually reach a value of 1.0

(c) (C21+C22)/(C28+C29) - This parameter provides information about the source of the organic matter (Philippi, 1974). Generally, terrestrial source material gives values <1.2 whereas a aquatic source material results in values >1.5.

(d) Pristane/Phytane Ratio - This value was determined from the areas of peaks representing these compounds. The ratio renders information about the depositional environment according to the following scale (Powell and McKirdy, 1975):

| | |
|---|---|
| < 3.0 | Relatively reducing depositional environment |
| 3.0-4.5 | Reducing/oxidizing depositional environment |
| >4.5 | Relatively oxidizing depositional environment |

(e) Pristane/n-C17 Ratio - This ratio was determined from the areas of peaks representing these compounds. The value can provide information about both the depositional environment and the level of maturation (Lijmbach, 1975). Very immature crude oil has a pristane/n-C17 ratio >1.0, irrespective of the depositional environment. However, the following classification can be applied to mature crude oil:

| | |
|---|---|
| <0.5 | Open water depositional environment |
| 0.5-1.0 | Mixed depositional environment |
| >1.0 | Peat-swamp depositional environment |

In the case of sediment extracts these values are significantly higher and the following classification is used:

| | |
|---|---|
| <1.0 | Open water depositional environment |
| 1.0-1.5 | Mixed depositional environment |
| >1.5 | Peat-swamp depositional environment |

(f) Phytane/n-C18 Ratio - This ratio was determined from the areas of peaks representing these compounds. The value usually only provides information about the level of maturity of petroleum. The value decreases with increased maturation.

(g) Relative Amounts of n-Alkanes and Naphthenes - Since n-alkanes and naphthenes are the two dominant classes of compounds in the saturate fraction, a semi-quantitative estimate of the relative amounts of these compounds can be made from saturate GLC's. This information can be used to assess the degree of maturation and/or the source type of the petroleum (Philippi, 1974; Tissot and Welte, 1978). Very immature petroleum has only small proportions of n-alkanes, but as maturity increases the relative amount of n-alkanes increases. In addition, terrestrial petroleum has a greater proportion of high molecular weight naphthenes than petroleum comprising aquatic source material.

## 10. API/SPECIFIC GRAVITY

A specific gravity (SG) bottle was accurately weighed, then filled with crude oil at 60 Deg. F and finally reweighed. The weight difference was divided by the weight of an equal volume of water at 60 Deg. F to obtain the specific gravity. The following formula was then used to calcuate the API gravity:

$$\text{API Gravity} = \left[ \frac{141.5}{\text{SG (60 Deg. F)}} \right] - 131.5$$

The reported gravity value is the average of duplicate determinations.

## 11. SULPHUR DETERMINATION

The % sulphur by weight is determined by dissolving 0.5g of the petroleum in 50mls kerosene and then analysing this mixture with an inductively coupled plasma (ICP) instrument which has been calibrated with a series of sulphur standards.

This parameter is influenced by the nature of the source material from which a crude is derived, the depositional environment of the source rocks, and reservoir alteration processed such as bacterial alteration.

## 12. C1-C31 WHOLE SAMPLE GAS CHROMATOGRAPHY

This method of analysis is normally only applied to oil or condensate samples. The technique provides a "picture" of the sample which shows good resolution of the low, medium and high molecular weight components. Whole sample GC data is considered to be more useful than C12+ saturate fraction GC data for oil or condensate samples.

The analysis is carried out under the same conditions as for the C12+ GC analysis with the following exceptions: column temperature = programmed from -20 Deg. C to 280 Deg. C at 4 Deg. C/min (uses cryogenic mode); injection is carried out in split mode; sample = 0.1 µl of neat petroleum.

C1-C31 analysis data can be used to obtain the same information as that obtained from C12+ GC but further provides detailed compositional data on the C1-C11 fraction and enables calculation of the distillation range of the sample.

## 13. MOLECULAR SIEVE EXTRACTION

This technique is used to isolate the branched/cyclic alkanes from the saturate fraction for gas chromatography/mass spectometry analysis. A mixture of saturates: 5A molecular sieves: purified benzene in the proportions 1:5:12 by weight is placed in a 100ml round bottom flask and refluxed for 24 hours. After cooling, the seives are filtered from the liquid phase and are washed with 4 x 10ml aliquots of benzene. The liquid phase plus washing are freed of benzene by distillation yielding the branched/cyclic compounds.

## 14. COMPUTERIZED GAS CHROMATOGRAPHY/MASS SPECTOMETRY (GC/MS)

Gas chromatography/mass spectrometry employs a capillary column gas chromatograph linked in series with a mass spectrometer and data system (GC/MS/DS). As molecules are eluted from the capillary column they are bled into the analyser tube of the mass spectrometer where they are bombarded with high energy electrons and consequently fragment to form several ions each with molecular weights less than that of the parent molecule. The fragmentation pattern is characteristic of the particular molecular type. The spectrum of these ions (referred to as a mass spectrum) is recorded approximately once every second and all of the mass spectra recorded during a GC/MS/DS analysis are memorised by the data system. Since any given class of molecules will breakdown in the analyser type to give one or more characteristic ion fragments of known molecular weight, after a GC/MS/DS analysis it is possible to examine the distribution of compounds within a given class by having the data system reproduce a mass fragmentogram (plot of ion concentration against gas chromatography retention time) representative of the particular class.

GC/MS/DS analyses can be carried out using one of the two following modes of operation:

(i) Acquire mode - in which all ions in each mass spectrum are memorised by the data system;

(ii) Selective ion monitoring (SIM) mode - in which only selected ions of interest are memorised by the data system.

At present the sterane/triterpane/bicyclane fraction of petroleum is considered most useful for GC/MS/DS analysis and therefore we commonly use the second of the above mentioned modes of operation and run the following twenty-two ions which are pertinent to the sterane/triterpane/bicuclane fraction.

| Ion | Molecular Type |
|---|---|
| 177 | Demethylated triterpanes |
| 191 | Normal triterpanes |
| 205 | Methyl triterpanes |
| 163 | Specific dethylated triterpanes |
| 356 | Parent ion - C26 triterpanes |
| 370 | Parent ion - C27 triterpanes |
| 384 | Parent ion - C28 triterpanes |
| 398 | Parent ion - C29 triterpanes |

| | |
|---|---|
| 412 | Parent ion - C30 triterpanes |
| 426 | Parent ion - C31 triterpanes |
| 183 | Isoprenoids |
| 217 | Normal steranes |
| 218 | Normal steranes |
| 231 | 4-methylsteranes |
| 259 | Diasteranes |
| 358 | Parent ion - C26 steranes |
| 372 | Parent ion - C27 steranes |
| 386 | Parent ion - C28 steranes |
| 400 | Parent ion - C29 steranes |
| 414 | Parent ion - C30 steranes |

GC/MS/DS analysis of the sterane/triterpane/bicyclane fraction can often provide information about the maturity and source type of petroleum and whether it has been affected by micro-organisms. This technique is also often useful for oil:oil and oil:source rock correlation. The following sections indicate which parameters are used to obtain this information and summarize the theory behind their use.

Maturity

(i) Based on Steranes

(a) The biologically produced $\alpha\alpha\alpha$ (20R) sterioisomer is converted in sediment to a mixture of the $\alpha\alpha\alpha$ (20R) and $\alpha\alpha\alpha$ (20S) compounds. The ratio of C29 $\dfrac{\alpha\alpha\alpha\,(20S)}{\alpha\alpha\alpha\,(20R) + \alpha\alpha\alpha\,(20S)}$ expressed as a percentage is about 25% at the onset of oil generation and increases almost linearily to a value of about 50% at the peak of oil generation.

(ii) Based on Triterpanes

(a) The C31, C32, C33, C34 and C35 hopanes have the biological R configuration at C22. On mild thermal maturation equilibration occurs to produce a 60/40 mixture of S/R. This equilibration occurs before the onset of oil generation.

(b) The conversion of the biological $17\beta,21\beta$ hopanes to the corresponding $17\alpha,21\beta$ and $17\beta,21\alpha$ compounds is also maturation dependant. For C30 triterpanes the ration of $\dfrac{17\beta\,,21\alpha}{17\alpha\,,21\beta}$ decreases steadily from a value of about 0.4 at the onset of oil generation to a value of about 0.1 at peak oil generation.

(c) Two of the C27 triterpanes can also be used as maturity indicators. The ratio of 18 $\alpha$(H) trisnorhopane to 17 $\alpha$(H) trisnorhopane increases exponentially with increasing maturity from a value of approximately 0.2 at the onset of oil generation to approximately 1.0 at peak oil generation.

(d) It is our experience that the ratio of the C27 $18\alpha$(H) + C27 $17\alpha$ (H) triterpanes to C30 $17\alpha,21\beta$ triterpane is maturity dependent. The ratio decreased from values around 1.0 at the onset of oil generation to a value of approximately 0.4 at peak oil generation. With increasing maturity at levels greater than that equivalent to peak oil generation the ratio increases steadily to values greater than 3.0.

## Source Type

(i) Based on Steranes
Algal organic matter contains steranes in which the C27 compounds are more abundant than the C29 compounds. General aquatic organic matter has approximately equivalent amounts of the C27 and C29 compounds while organic matter rich in land-plants usually has a lot more of the C29 steranes.

(ii) Based on Triterpanes
The triterpane components in petroleum can be derived from both bacteria and higher plants. The common bacterial products are the C27-C35 hopanes and moretanes whereas the higher plant triterpanes are compounds other than hopanes or moretanes and are commonly C30 compounds.

(iii) Based on Diasteranes
The diasteranes are not produced biologically but are formed during early diagenesis from sterane precursors. The diasterane ratios $\frac{\mathrm{C27(20R)}}{\mathrm{C29(20R)}}$ and $\frac{\mathrm{C27(20R+20S)}}{\mathrm{C29(20R+20S)}}$ should reflect the nature of the organic matter in the same manner as that outlined above for the steranes.

## Biodegradation

It has been observed that in severely biodegraded petroleum the series of normal hopanes are converted to a series of A ring demethylated hopanes and the C29 (20R) sterane is selectively removed. For altered crudes which have not been degraded to this extent the severity of biodegradation can often be gauged by studying the isoprenoid and aromatic fractions. However, this type of investigation extends beyond a standard GC/MS/DS analysis.

## Correlation

Our present approach to oil:oil or oil:source rock correlation problems is as follows:

(i) Compare the distribution of compounds in the 123, 177, 191, 205, 217, 218, 231 and 259 mass fragmentograms for an oil or sediment extract to the distribution of compounds in the respective fragmentograms for the other oil(s) or sediment extract(s). It is necessary in this type of comparison to make allowance for small variations due to possible maturity differences.

(ii) Examine the fragmentograms for peaks or sets of peaks which may represent compounds that are specific to the geological system under investigation. Normal steranes, diasteranes and bacterial hopanes cannot be used for this purpose because they are present in virtually all crude oils and sediment extracts. However, compounds like higher plant triterpanes, bisnorhopane and botryococcane can often prove very useful for this purpose.

## 15. CARBON ISOTOPE ANALYSIS

The measurement is carried out on one or more of the following mixtures; topped oil; saturate fraction; aromatic fraction; NSO fraction. The organic matter is combusted at 860 Deg. C in oxygen and the carbon dioxide formed is purified and transferred to an isotope mass spectrometer. The carbon isotope ratio is measured relative to a standard gas of known isotopic composition. In our case the standard gas is prepared from the NBS No. 22 oil. However, since the isotopic relationship between NBS No. 22 oil and the international reference PDB limestone are known, the values are adjusted to be relative to PDB limestone.

Although carbon isotope data has been commonly used for oil:oil and oil:source rock correlation its most significant application is the identification of the source of gas according to the following criteria (Fuex, 1977):

| $\delta$13C (PDB) | Gas Type |
|---|---|
| -85 to -58 | Biogenic methane |
| -58 to -40 | Wet gas/associated with oil |
| -40 to -25 | Thermal methane |

## 16. VITRINITE REFLECTANCE MEASUREMENT

Vitrinite is a coal maceral which responds to increasing levels of thermal maturity. This response can be measured by the percent of light reflected off a polished surface of a vitrinite particle immersed in oil. Reflectance measurements are made on a number (40 if possible) of vitrinite particles in each sample, in order to establish a range and mean for reflectance values. Immature rocks have low reflectance values (0.2% Ro to 0.6% Ro), with mature values ranging from 0.6% Ro to 1.2% Ro. Very mature values are between 1.2 % Ro and 1.8% Ro, while severely altered rocks have reflectances above 1.8% Ro.

Vitrinite reflectance results are best obtained from coals or rocks deposited in environments receiving large influxes of terrestrially-derived organic matter. Unfortunately, these environments are not conducive to the accumulation of large quantities of oil-prone organic mater. Also vitrinite reflectance cannot be performed on rocks older than Devonian Age, due to the absence of land plants in the older geological time periods.

## 17. VISUAL KEROGEN

Visual kerogen assessment is carried out by the coal petrologist and/or the palynologist. In the case of the petrologist the assessment is made in reflected light using the plug prepared for vitrinite reflectance measurement, and reports the relative amounts of alginite, exinite, vitrinite and inertinite particles.

Visual study of kerogen by the palynologist is carried out in transmitted light and can indicate the relative abundance, size and state of preservation of the various recognizable kerogen types and hence indicates the source character of a sedimentary rock. In addition, the colour of the kerogen is related to the thermal maturity of the sediments and is often used as a maturation indicator.

The preparation of slides for visual kerogen assessment by the palynologist firstly involves concentration of the organic matter by removal of the rock matrix using hydrochloric and hydrofluoric acid treatment and heavy liquid separation. The organic concentrate is then mounted on a glass slide using Petropoxy.

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