Amoco Australia Petroleum Company

GEOCHEMICAL SOURCE ROCK STUDY

ANGLESEA-1

by

ANALABS

16 MAR 1992

GEOCHEMICAL SOURCE ROCK STUDY

ANGLESEA 1

Introduction

Core samples from the Anglesea 1 well, drilled in the Torquay Embayment, Bass Basin, have been submitted to organic geochemical analyses. The shale and coal samples range in depth from 497ft to 10060ft, comprising Middle Eocene to Jurassic-Cretaceous sediments.

The study is aimed at evaluating the source potential of the sequence penetrated chemically and palynologically. A palynology report has been sent to Amoco Australia under separate cover in January 1987.

Analytical Techniques

Four core samples (497ft Core 1, 2565ft Core 10, 6239ft Core 23, 10060ft Core 33) were forwarded to Analabs for screening analysis. All samples were crushed, air dried and submitted to total organic carbon determination. Rock-Eval pyrolysis was performed on those three samples with TOC values higher than 0.5%.

These three samples (497ft, 2565ft, 6239ft) were then extracted, subjected to gas chromatography of the whole extract and liquid chromatography to obtain the saturate, aromatic and NSO fractions. On all three samples GC-MS of the branched and cyclic saturate fraction as well as of the aromatic fraction was performed.

The results of these analyses are presented in the following figures and tables:

Type of Analysis	Figure	Table
TOC		1
Rock-Eval		1
Extraction and liquid chromatography		2
Whole extract GC	1	3
GC-MS saturate fraction	2	4
GC-MS aromatic fraction	3	5

The analytical procedures applied in this study are described in the chapter "Theory and Methods" at the back of the report.

General Information

Copies of this report have been sent to Mr C W Waring of Amoco Australia Petroleum Company in Sydney, NSW.

Any questions related to this study may be directed to Dr Birgitta Hartung-Kagi of Analabs in Perth, WA.

All data and interpretations given herein are proprietary to Amoco Australia Petroleum Company, and are treated as highly confidential material by all Analabs personnel.

Results and Interpretations

Based on Rock-Eval pyrolysis results, only the coal sample at 497ft (Core 1) can be regarded as a potential source rock. A genetic potential ($S_1 + S_2$, mg/g rock) of 122.05, along with 47.71% TOC and a hydrogen index of 241 indicate excellent source rock qualities for this sample on maturation. S_1, S_2 and $S_1 + S_2$ values obtained for the two deeper samples (2565ft and 6236ft), however, do not indicate any significant source potential.

Whole extract GC trace and data for the Core 1 sample are typical for an immature coal, with odd-even-predominances in the $nC_{25}+$ range of the trace, a carbon preference index above 3 as well as low $(C_{21} + C_{22}) / (C_{28} + C_{29})$ and EOM/TOC ratios of 0.29 and 24, respectively.

With increasing depth in the well, the GC traces evidence higher maturity levels. The peaks are shifted towards the light ends, indicating a further breakdown of the high molecular weight compounds with maturation. Sample 2565ft yielded a saturate rich extract with carbon preference indices of around 1.5 and a $(C_{21} + C_{22}) / (C_{28} + C_{29})$ ratio of nearly 5, which is probably due both to a higher level of maturity and to a marine source of the organic matter. Sample 6239ft contains about equal amounts of saturates and aromatics and very low levels of $C_{23}+$ compounds, so that no CPI and $(C_{21} + C_{22}) / (C_{28} + C_{29})$ values were calculated.

Pristane/phytane ratios are low with values just below 1.00, indicating a relatively reducing depositional environment of the organic matter. Pristane/nC_{17} values, however, range at around 0.5 to 0.6 which is believed to characterise a mixed depositional environment.

GC-MS results obtained for the three Anglesea 1 samples evidence terrestrially dominated organic matter for sample 497ft, Core 1 and mainly marine material for sample 6239ft, Core 23. The source interpretation for the coal sample at 497ft is based on the presence of isopimarane (m/z 123), a diterpane of higher plant origin, and eudesmane (m/z 123), widespread bicyclic sesquiterpenoid hydrocarbon which is a marker for higher plants as well. Neither $C_{29}R$ diasteranes nor $C_{27}R$ steranes could be identified in this sample (m/z 259 and m/z 217, respectively) and hence no judgement about the source type could be based on sterane and diasterane distributions.

The dark shale at 6239ft, Core 23, yielded useful C_{27} and C_{29} sterane and diasterane ratios which indicate the predominantly marine origin of the organic matter (Table 4-3).

In sample 2565ft, Core 10, no C_{29} diasteranes and C_{27} steranes could be identified, nor are any biomarkers present which could give a clear characterisation of the source.

3

Maturity parameters for the coal sample (497ft), i.e. Ts/Tm, C_{30} hopane / C_{30} moretane, C_{29} 20S/20R steranes, vary between a very low level of maturity and about onset of oil generation, whereas sterane and triterpane data for the two deeper samples are somehow contradicting.

Based on pyrolysis data (Tmax, PI), the 2565ft shale is presently within the oil window. Sterane data obtained are characteristic for the upper range of the oil generative zone and are regarded as more reliable than Ts/Tm and C_{30} hopane / moretane ratios which indicate immaturity.

The deepest sample analysed by GC-MS, 6239ft, Core 23, is classified as over-mature for oil generation by Tmax values, but sterane biomarkers only indicate a maturity level equivalent to about 0.55% Ro. Delays of sterane epimerisation are sometimes observed in areas where oil is generated by rapid cracking of kerogen in coals, i.e. the steranes have not enough time to change. Coals in general tend to retard the expimerisation of steranes. If this particular sample contains coaly pieces which carry the majority of organic compounds, this might be the reason for the low sterane (C_{29} 20S / 20R) ratio which does not represent the true level of maturity.

The biomarker distribution of the three samples analysed does not seem to be very similar but based on three samples only which are spread over a depth of more than 6000ft it is not possible to determine any major geochemical trends and a correlation does not seem to be useful. The Anglesea 1 results will therefore be re-evaluated together with the results of the Bass Basin Study which is presently underway.
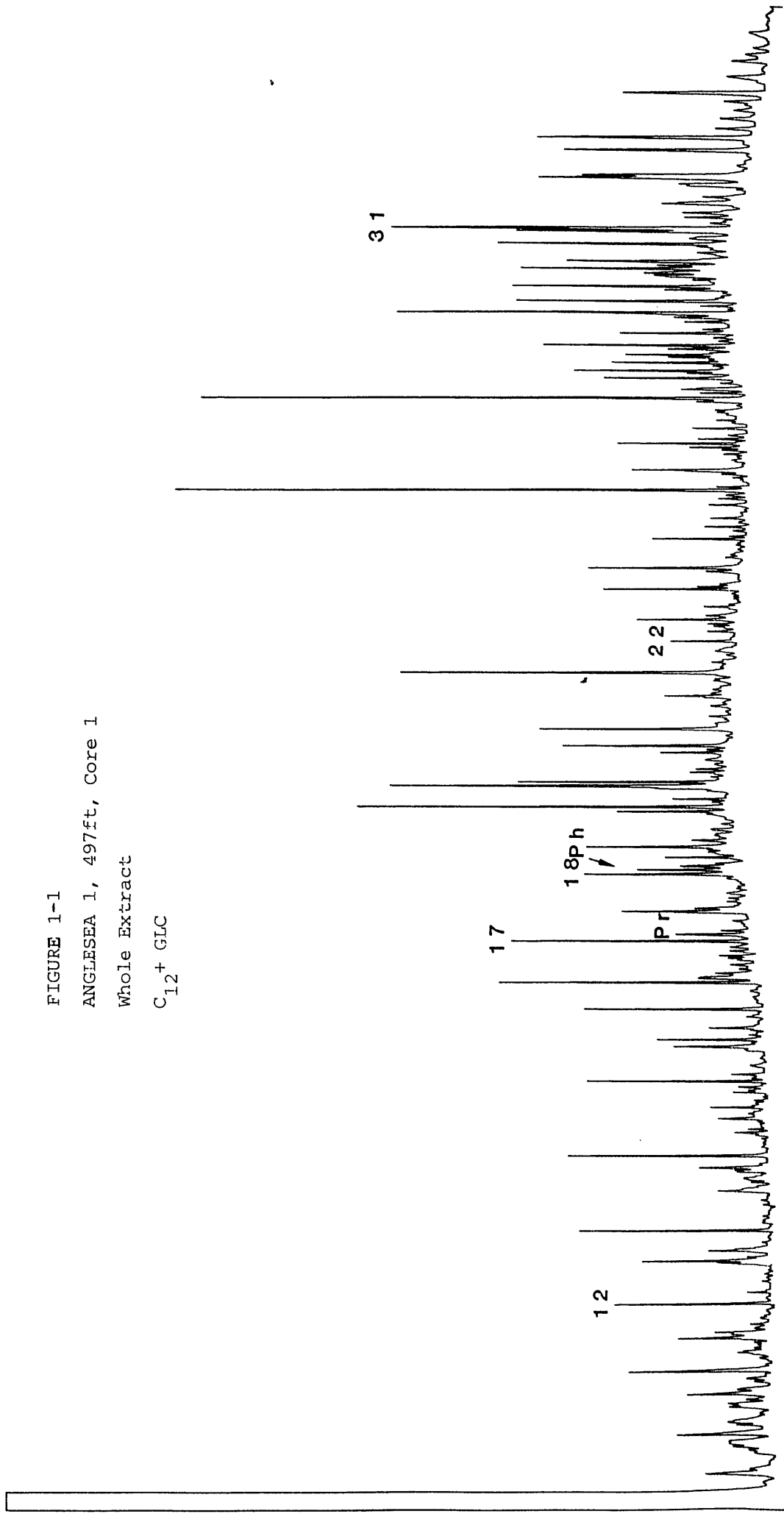
FIGURE 1-1

ANGLESEA 1, 497ft, Core 1

Whole Extract

C_{12}^+ GLC
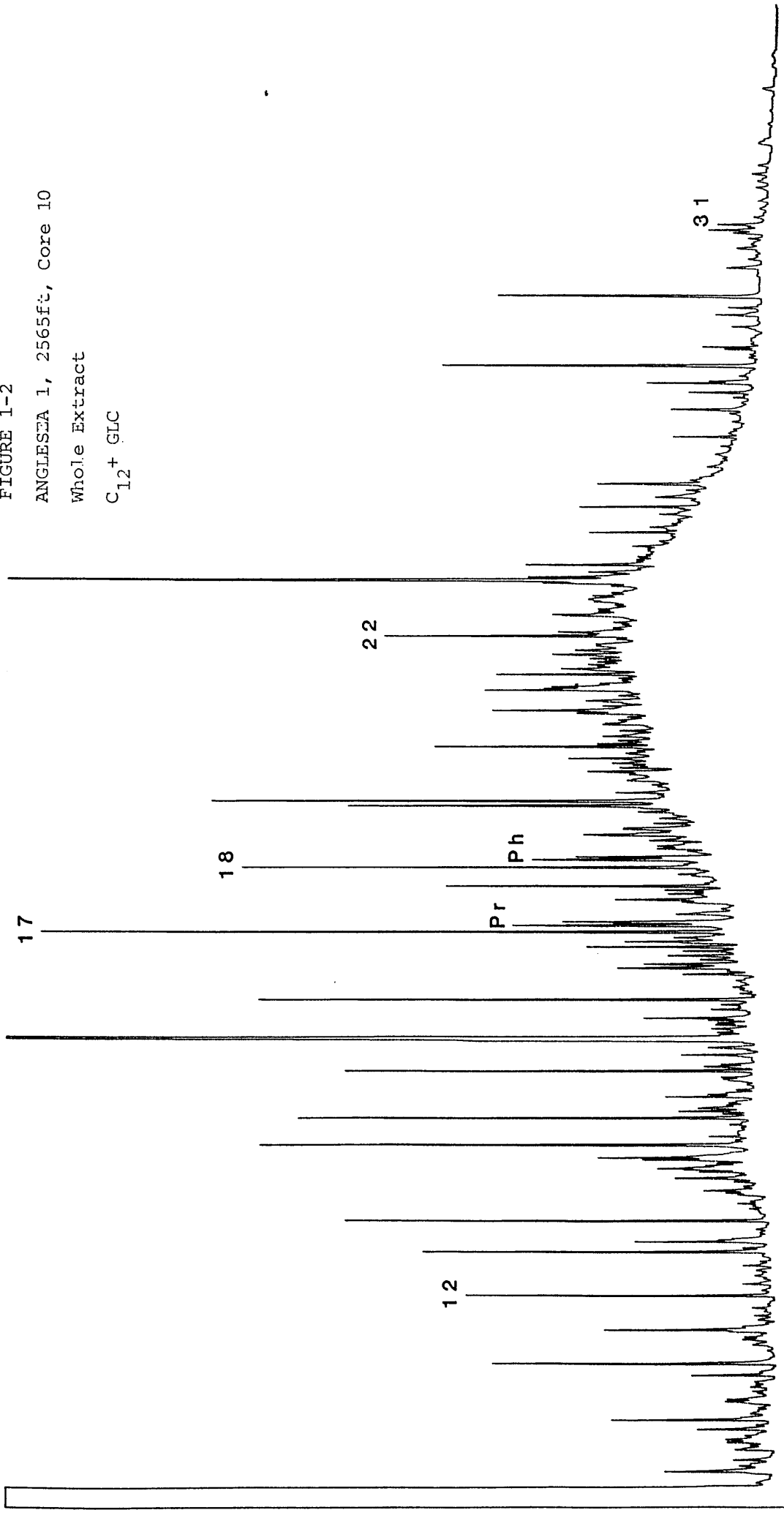
FIGURE 1-2

ANGLESEA 1, 2565ft, Core 10

Whole Extract

C_{12}^{+} GLC

FIGURE 1-3

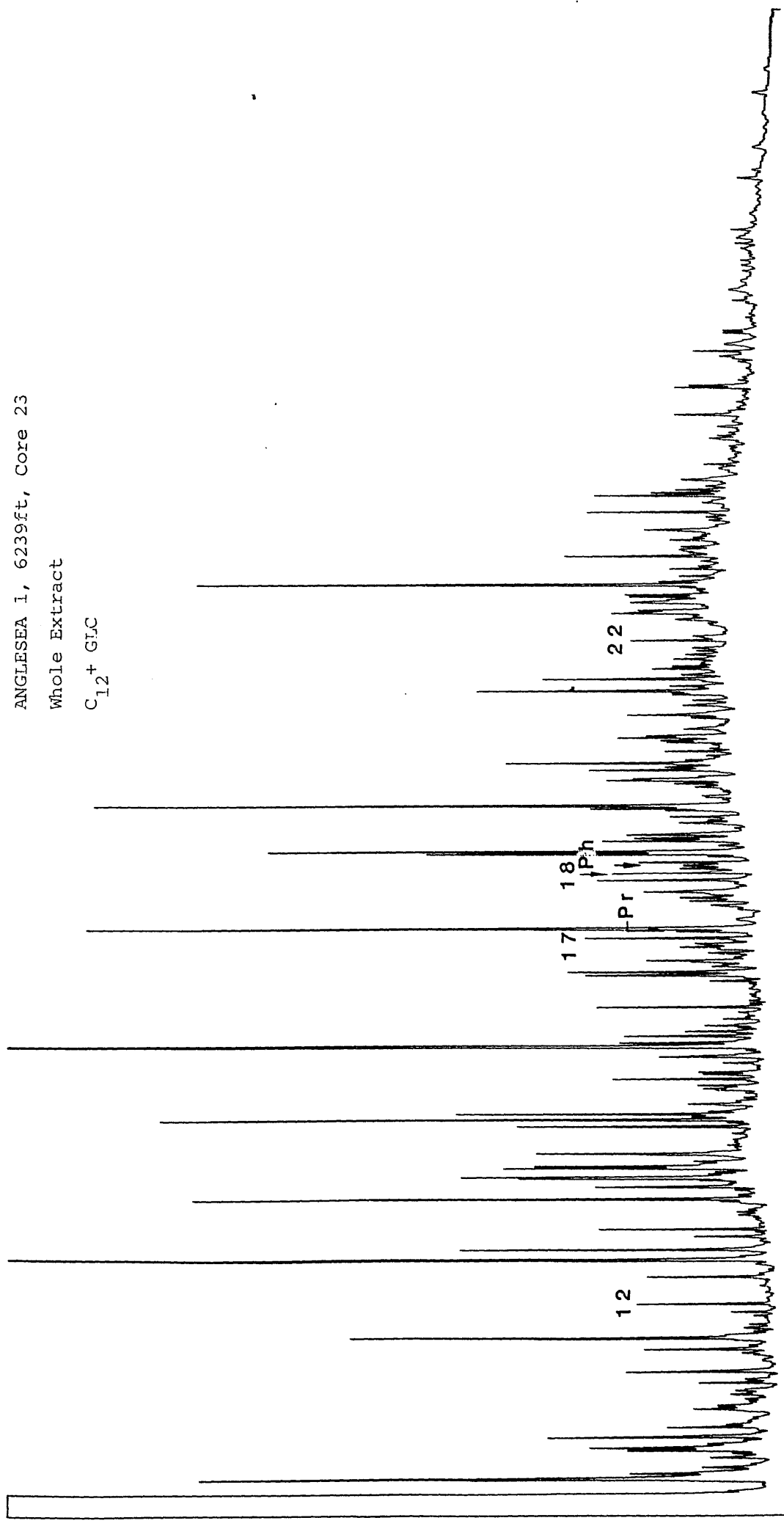ANGLESEA 1, 6239ft, Core 23

Whole Extract

$C_{12}+$ GLC

FIGURE 2-1a

DIASTERANES

$C_{27}S$

$C_{27}R$

$C_{29}S$

37

258.7
259.6

34 35 36 37 38 39 40 41 42 43 44 45 46 47

STERANES
ISOSTERANES
DIASTERANES

$C_{29}R$

$C_{27}S$ $C_{27}R$

$C_{29}R$
$C_{29}S$
$C_{29}S$

113

216.7
217.6

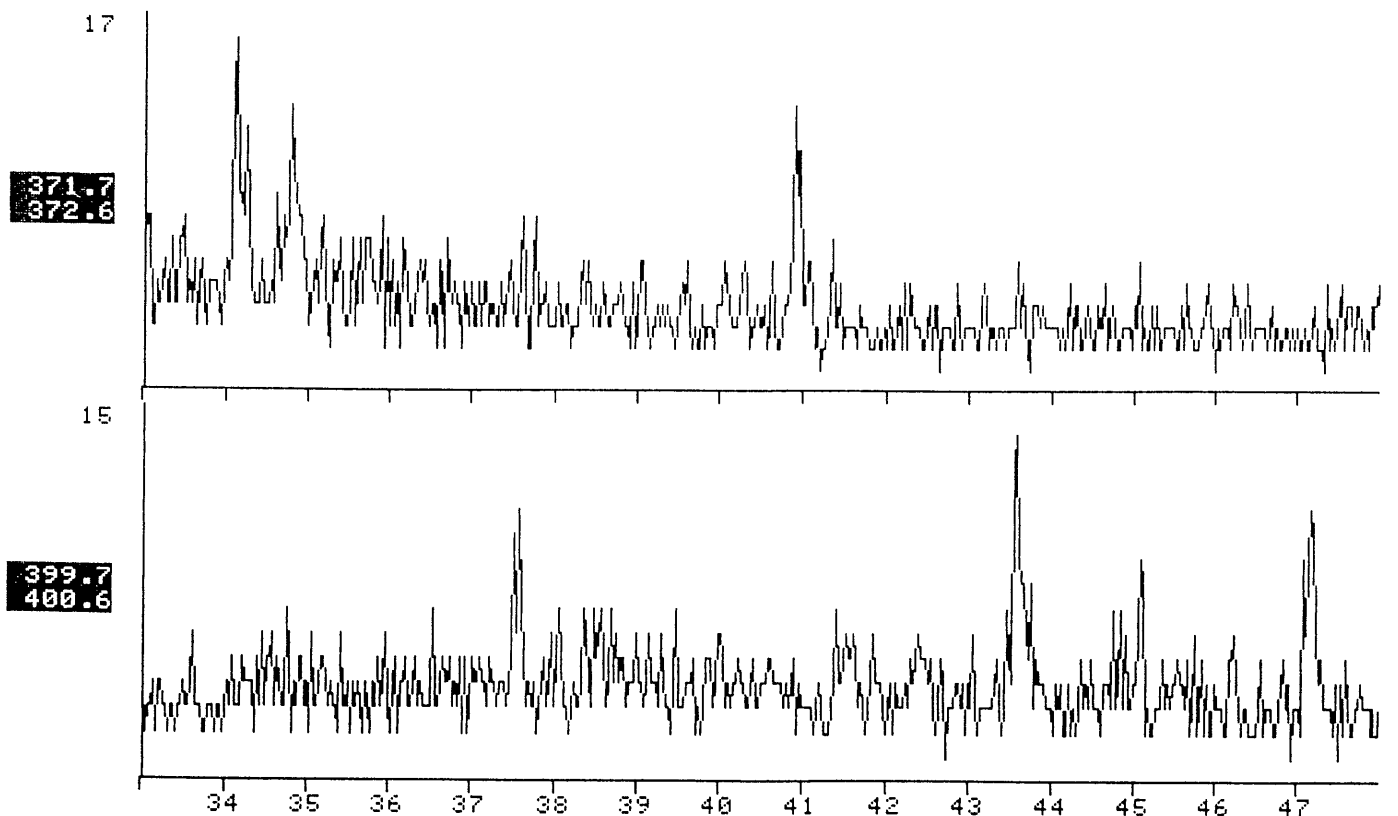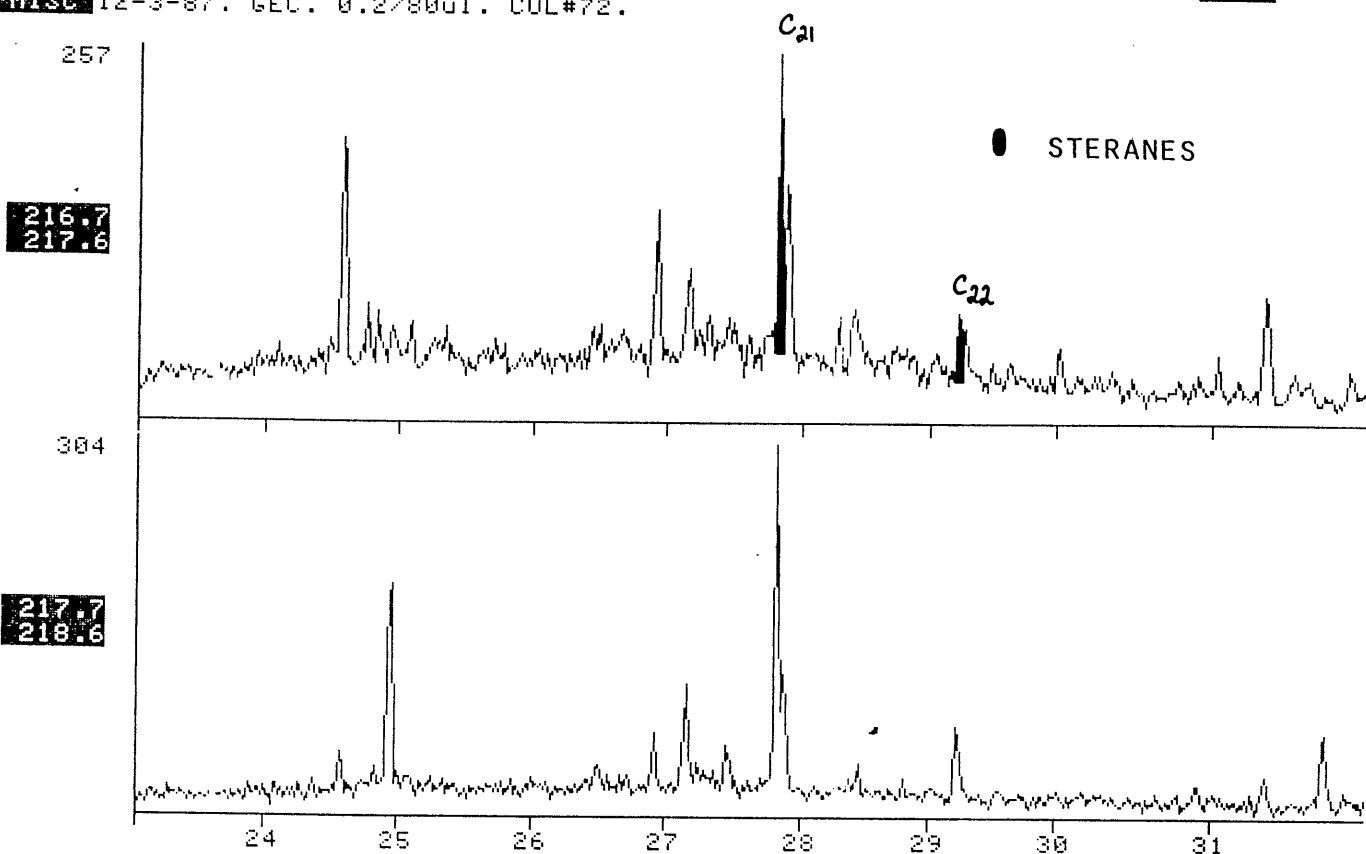34 35 36 37 38 39 40 41 42 43 44 45 46 47
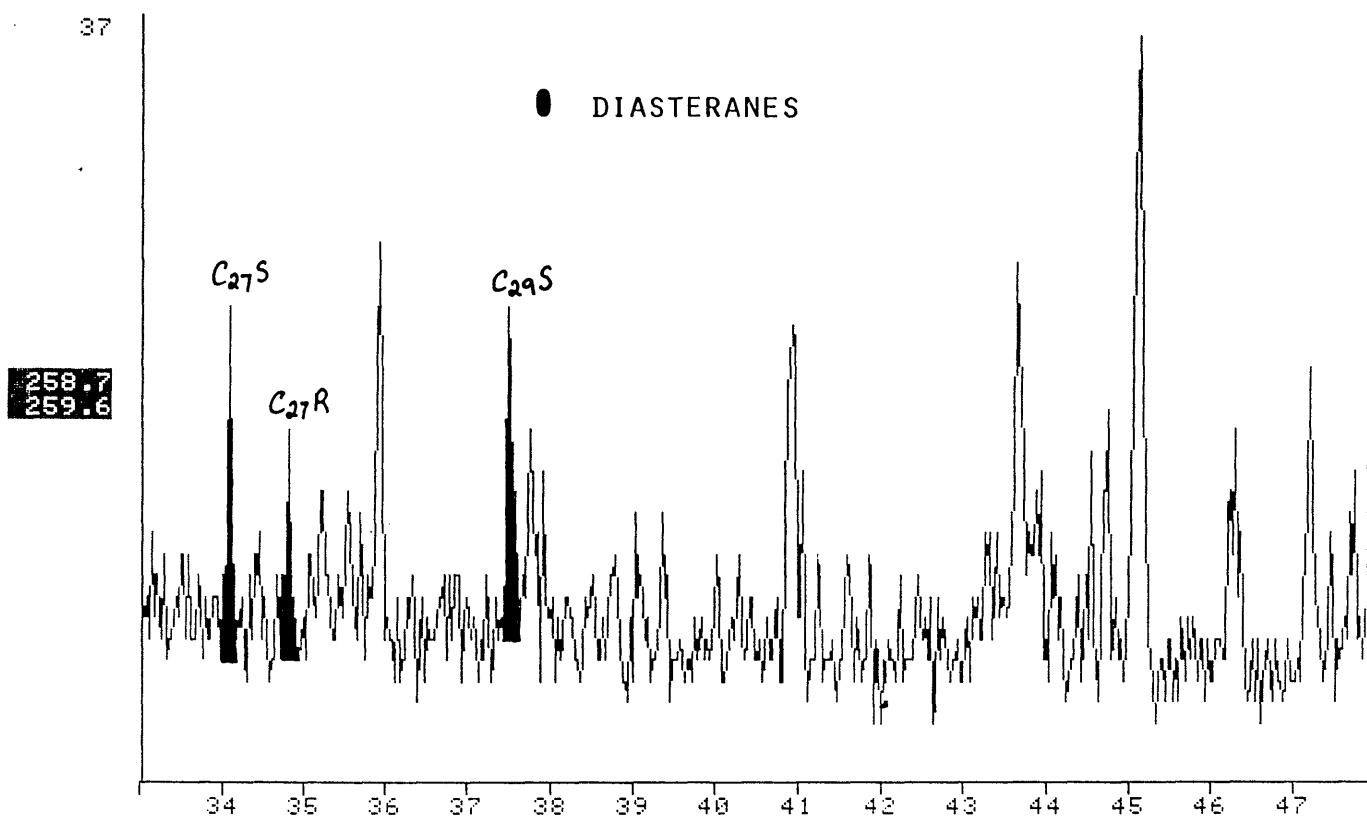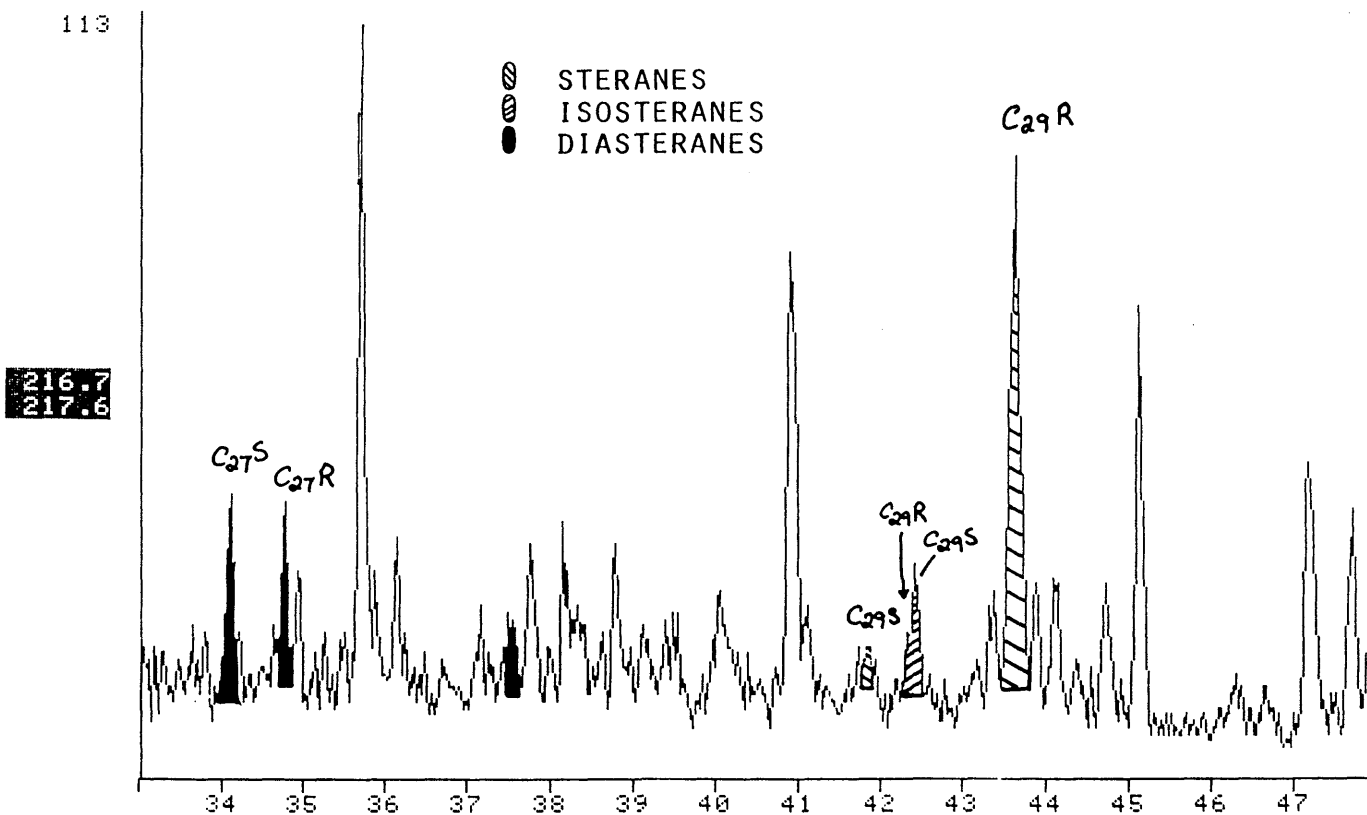
FIGURE 2-1b

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6218
MISC 12-3-87. GEC. 0.2/80ul. COL#72.
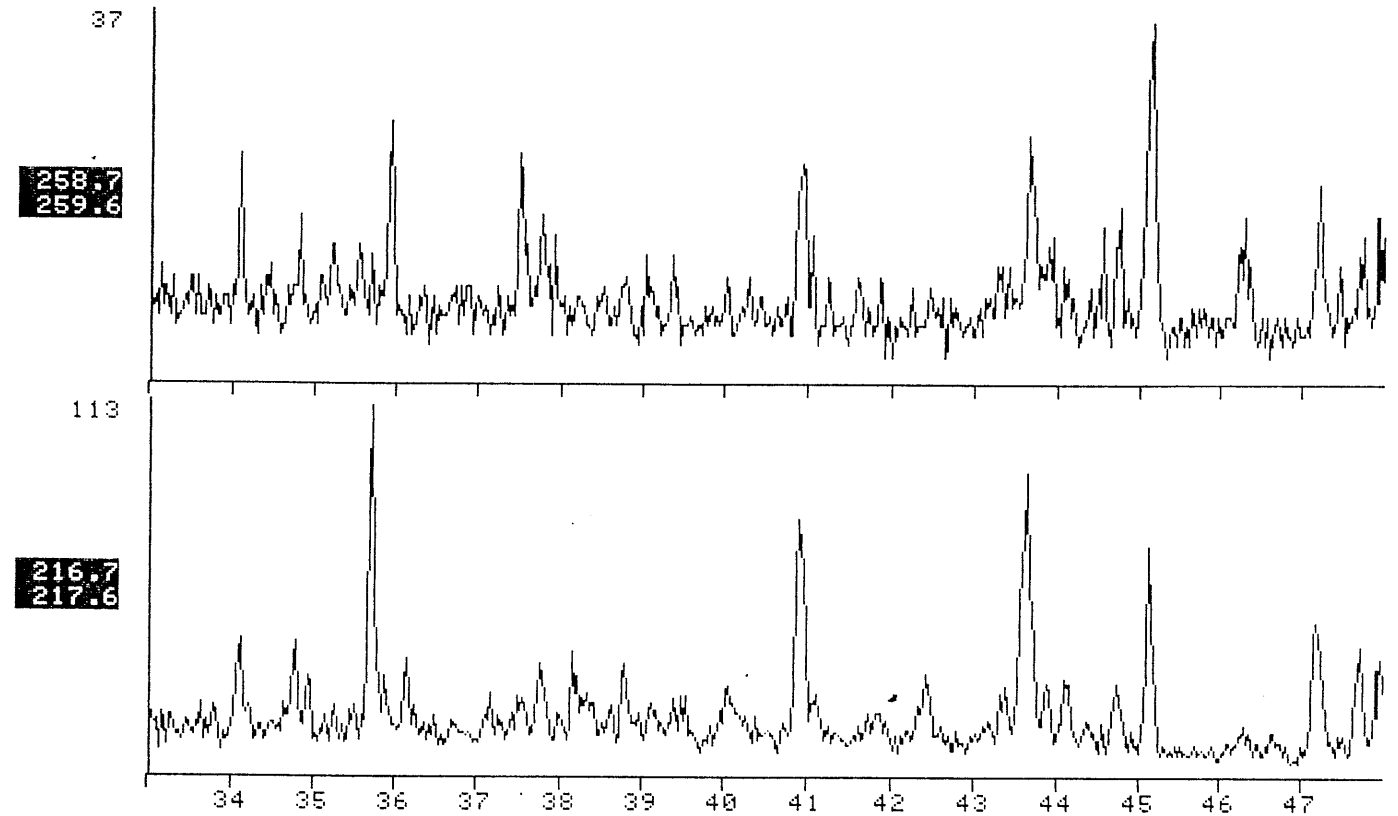
NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6218
MISC 12-3-87. GEC. 0.2/80ul. COL#72.

FIGURE 2-1c

257

216.7
217.6

C_{21}

● STERANES

C_{22}

304

217.7
218.6

24   25   26   27   28   29   30   31

7995

82.7
83.6

● ALKYL CYCLOHEXANES

C_{15}

809

P_r

182.7
183.6

Ph

● PRISTANE/PHYTANE

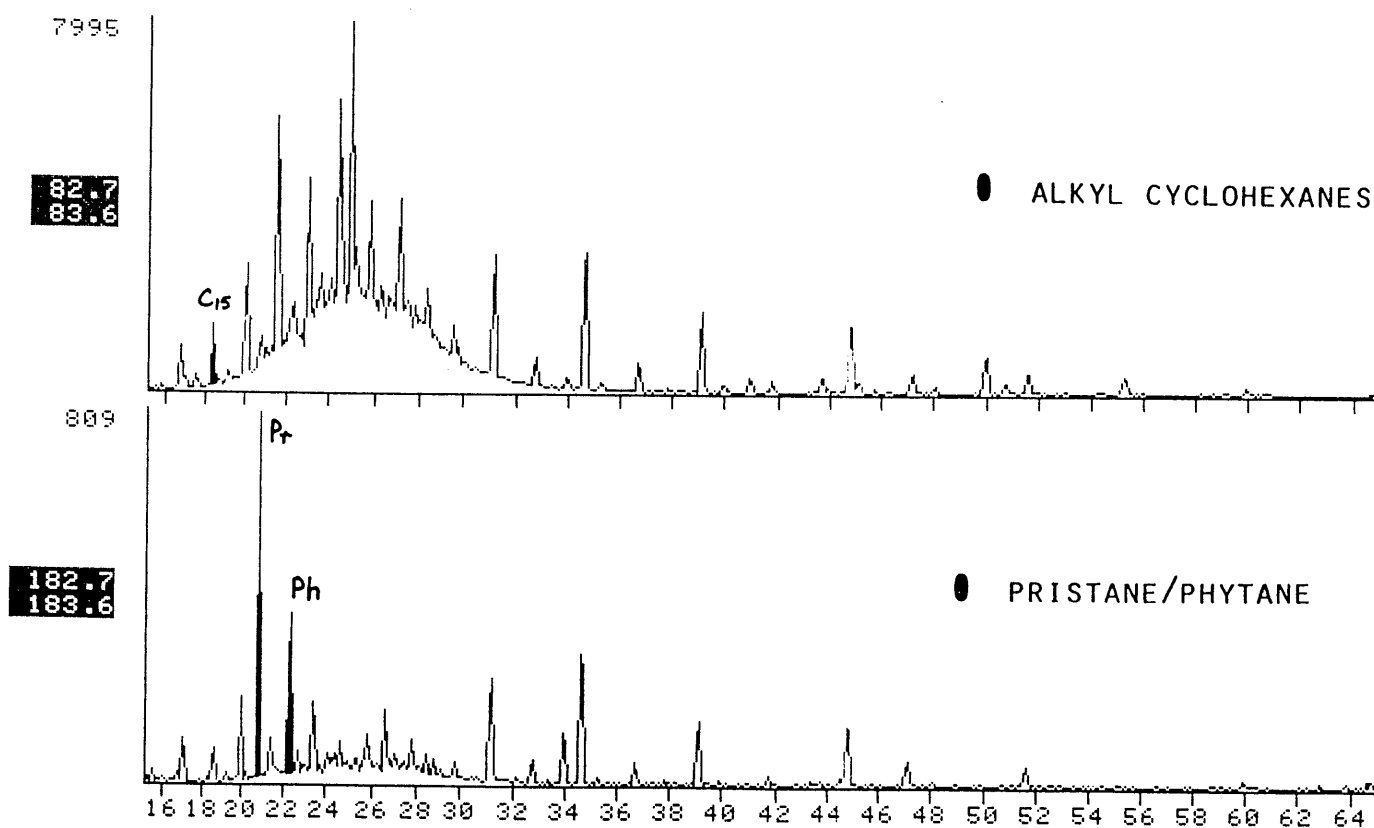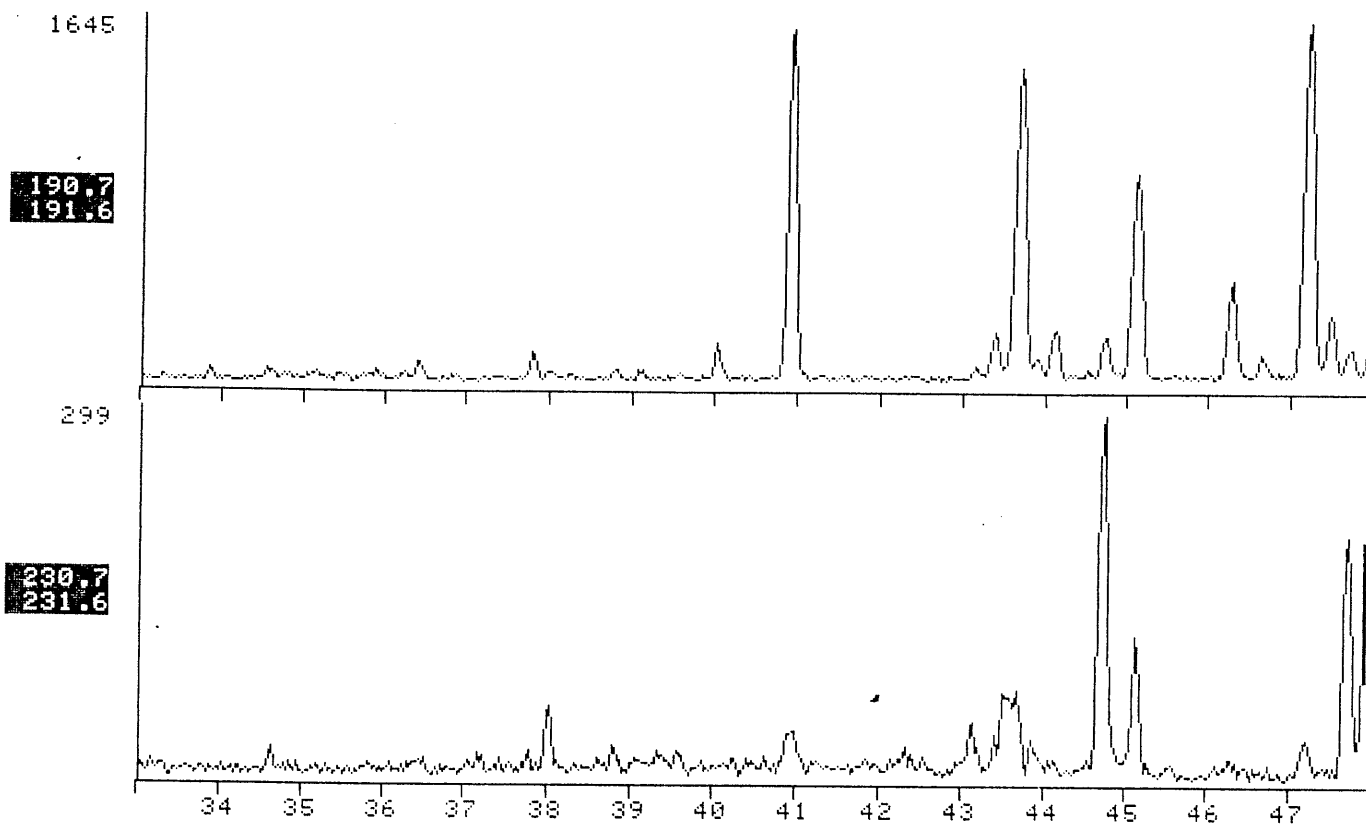16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64

FIGURE 2-1d

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 12-3-87. GEC. 0.2/80ul. COL#72.
FRN 6218

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.
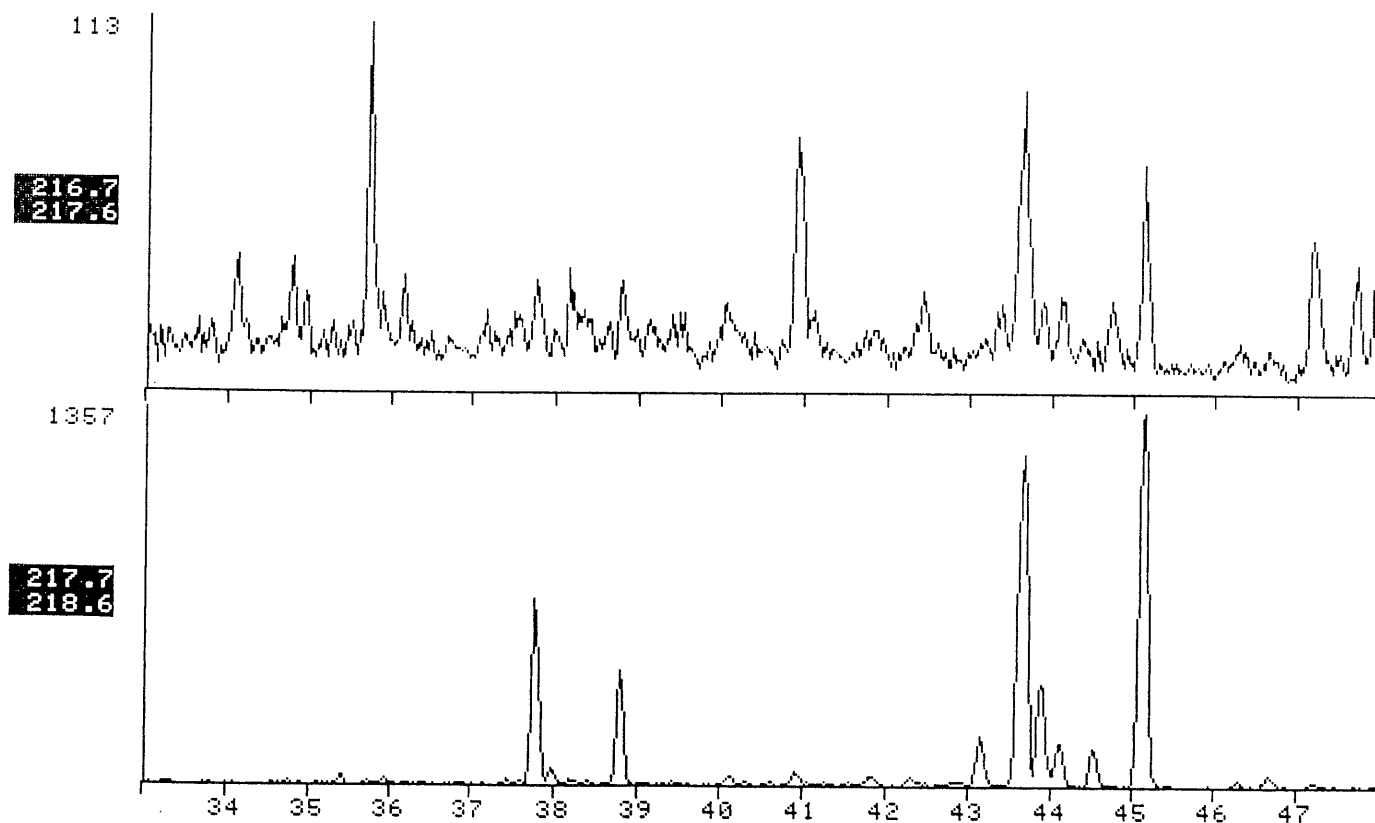MISC 12-3-87. GEC. 0.2/80ul. COL#72.
FRN 6218

FIGURE 2-1e

FIGURE 2-1f

FIGURE 2-1g

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 12-3-87. GEC. 0.2/80ul. COL#72.
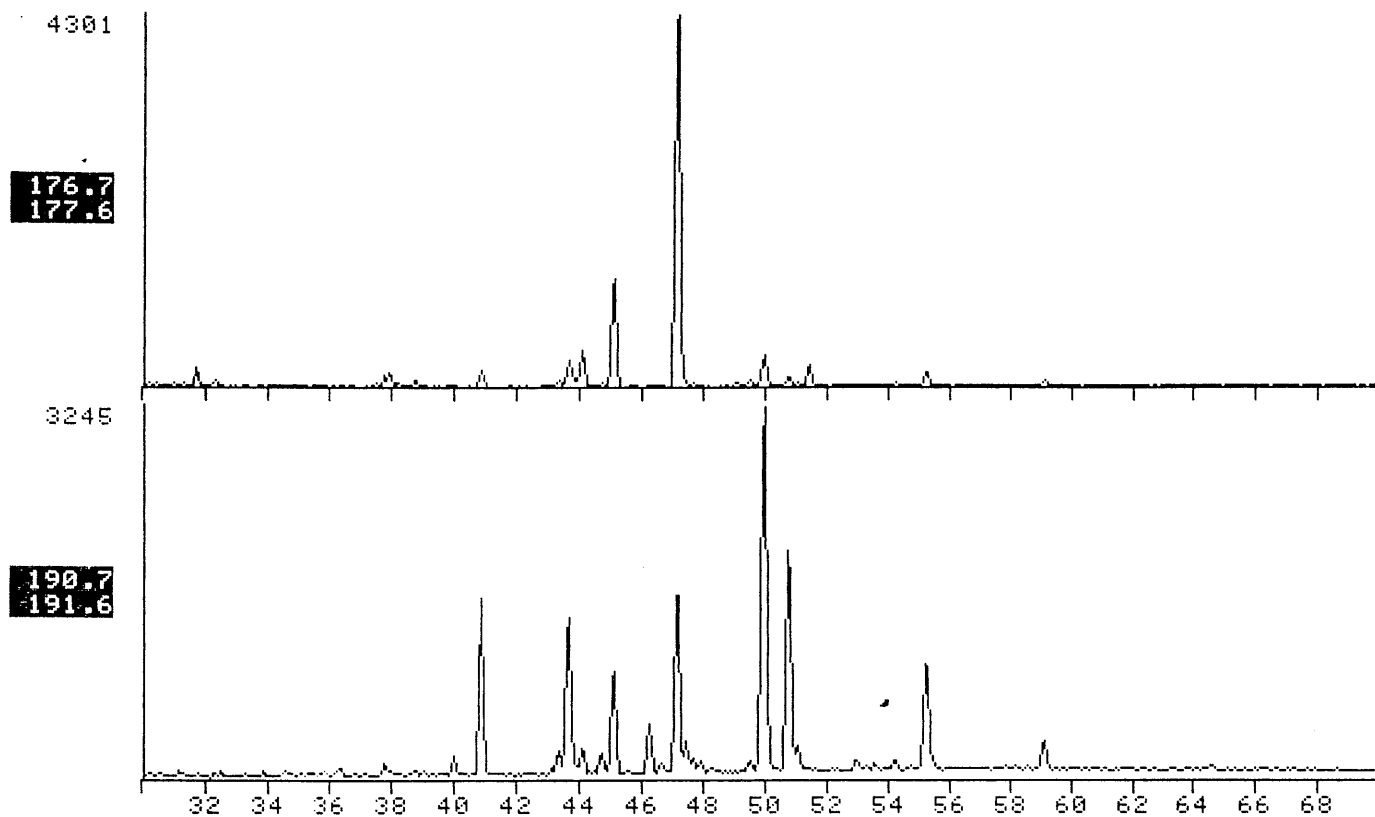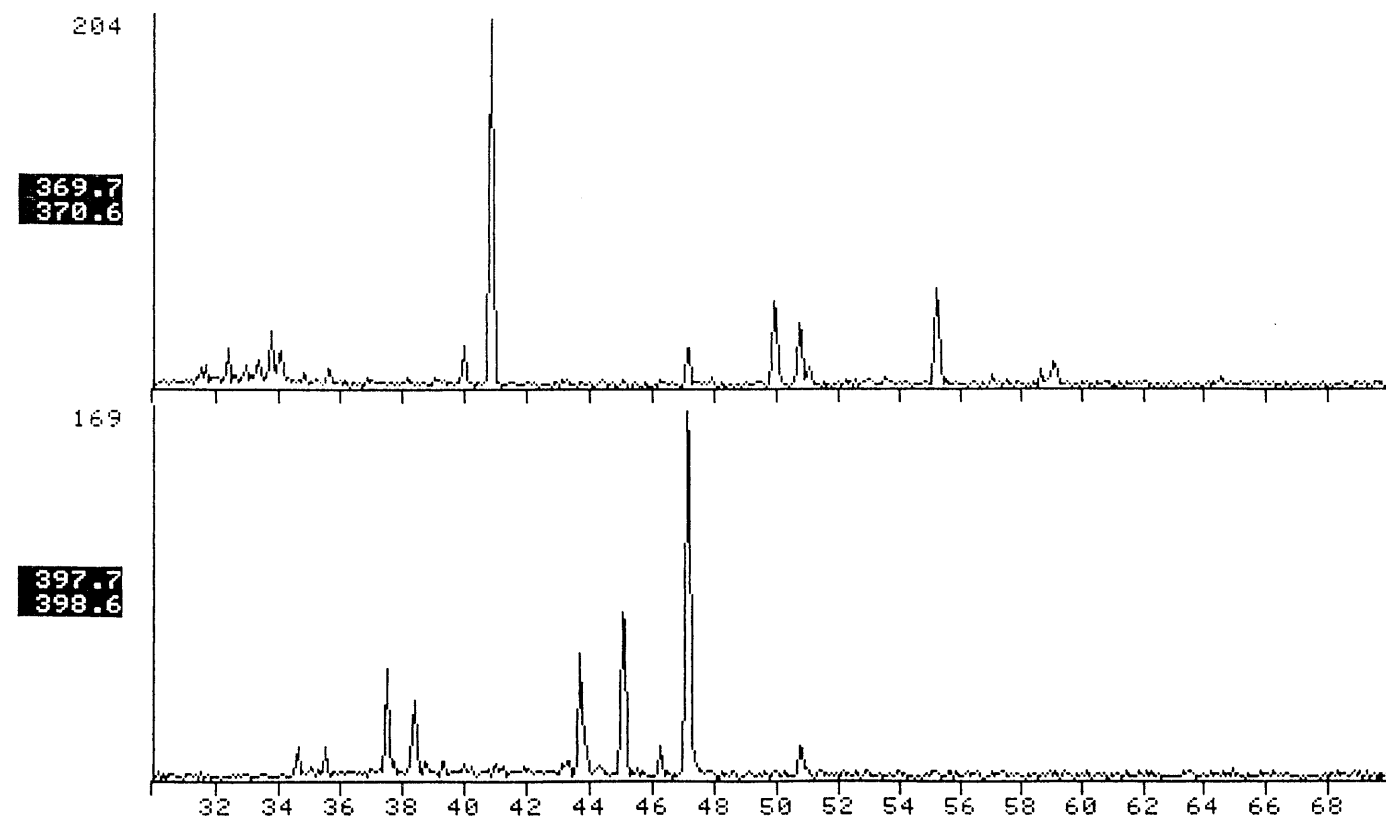
FRN 6218

FIGURE 2-1h

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6218
MISC 12-3-87. GEC. 0.2/80ul. COL#72.
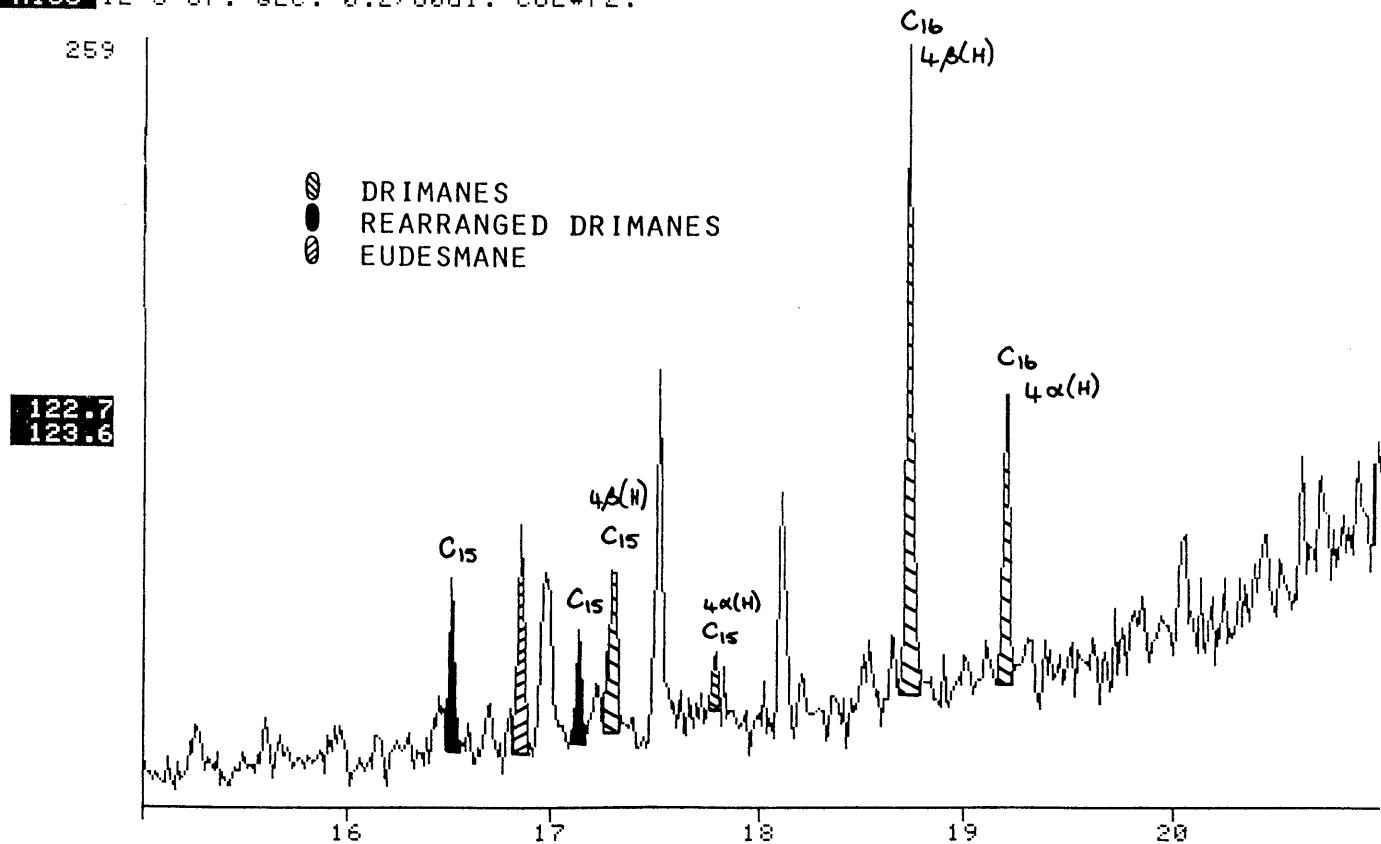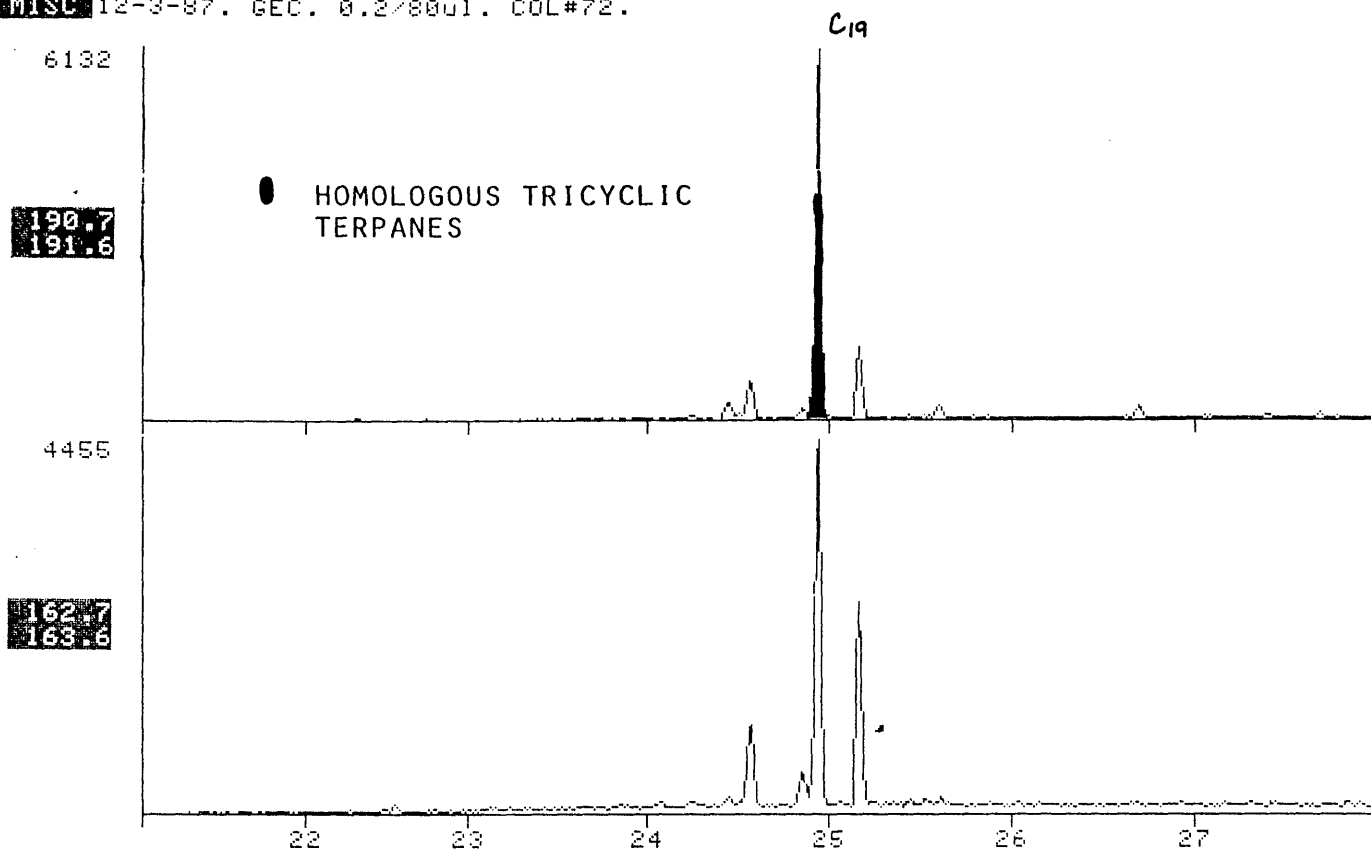
NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6218
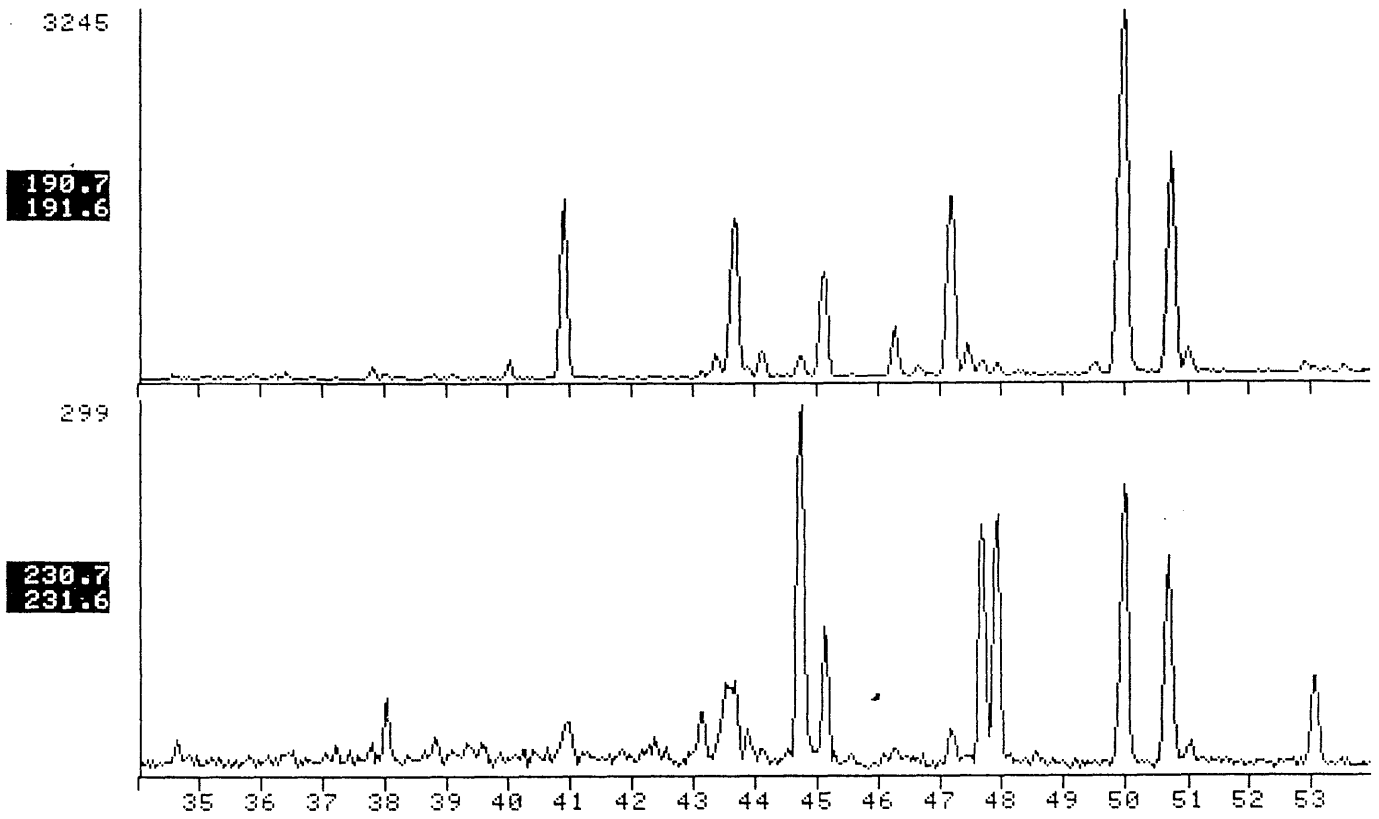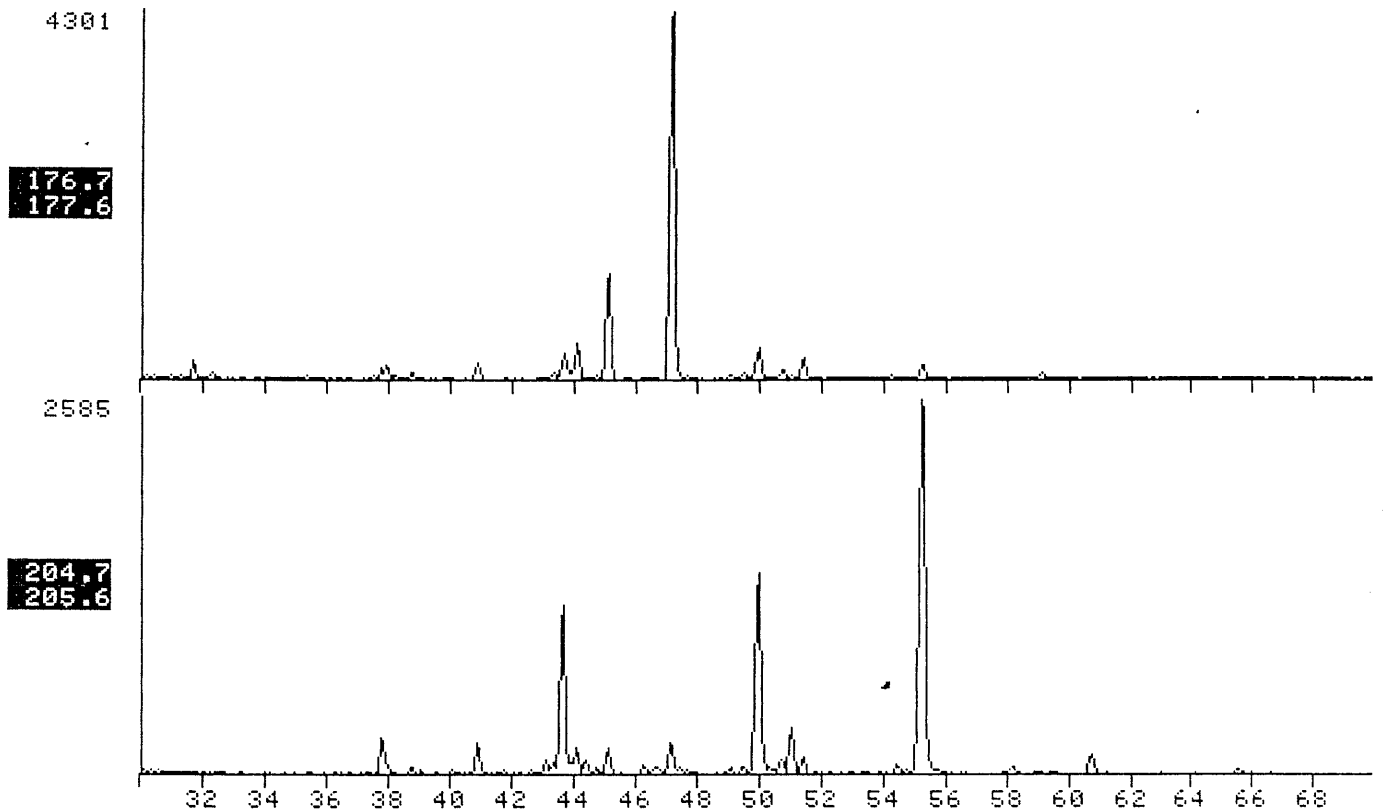MISC 12-3-87. GEC. 0.2/80ul. COL#72.

FIGURE 2-1i

FIGURE 2-1j

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 12-3-87. GEC. 0.2/80ul. COL#72.
FRN 6218

NAME ANGLESEA#1, 497'. BRANCHED CYCLIC FRAGMENTOGRAM.
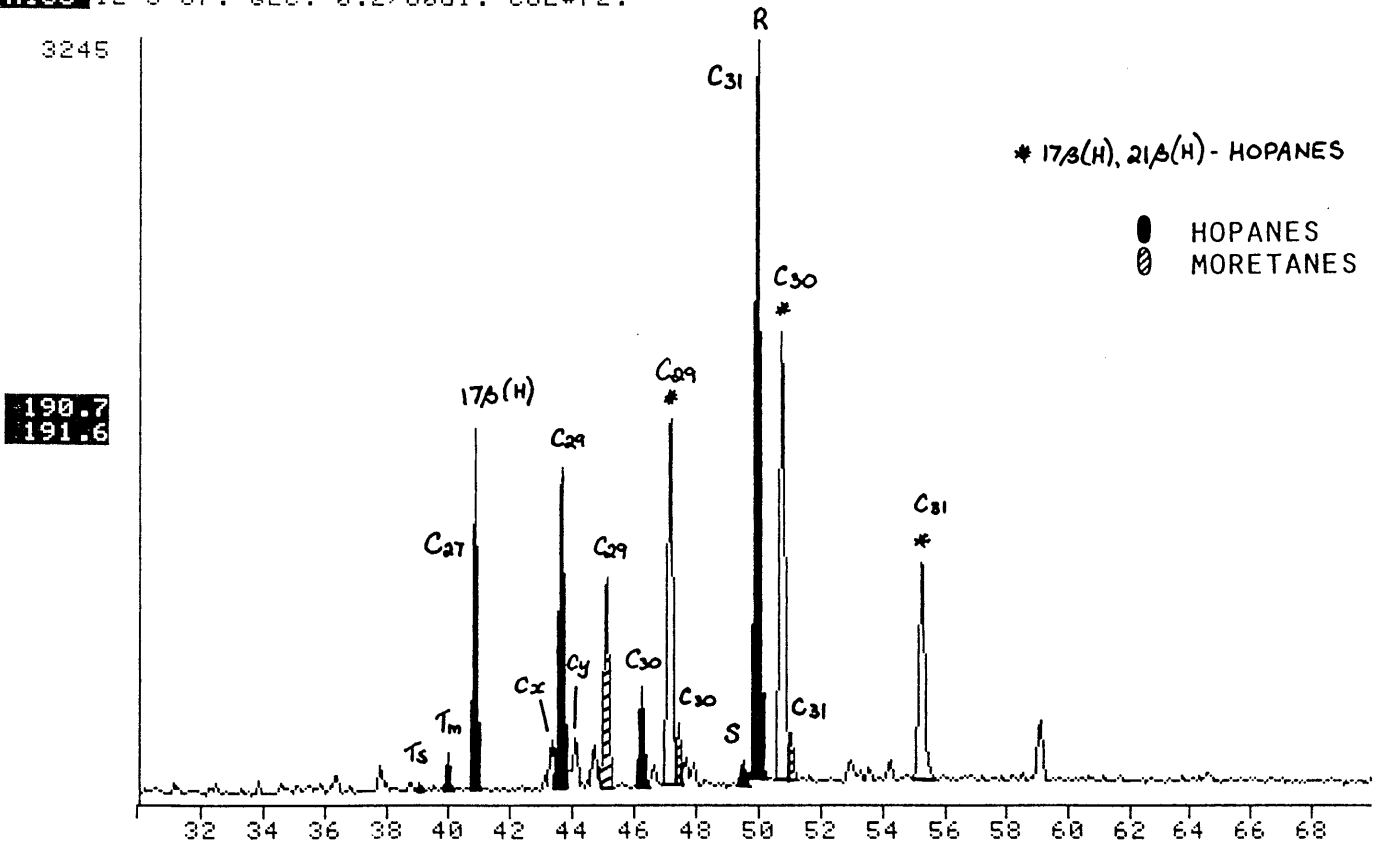MISC 12-3-87. GEC. 0.2/80ul. COL#72.
FRN 6218

FIGURE 2-2a

FIGURE 2-2b

FIGURE 2-2c

378

216.7
217.6

C_{21} ● STERANES

C_{22}

394

217.7
218.6

24   25   26   27   28   29   30   31

15478

82.7
83.6

● ALKYL CYCLOHEXANES

C_{15}

899

182.7
183.6

Pr

Ph

● PRISTANE/PHYTANE

16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64

FIGURE 2-2d

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.

FIGURE 2-2e

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.

● HOPANES
∅ MORETANES

FIGURE 2-2f

ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.
16-1-87. GEC. 0.2/70ul. COL#72.
FRN 6163
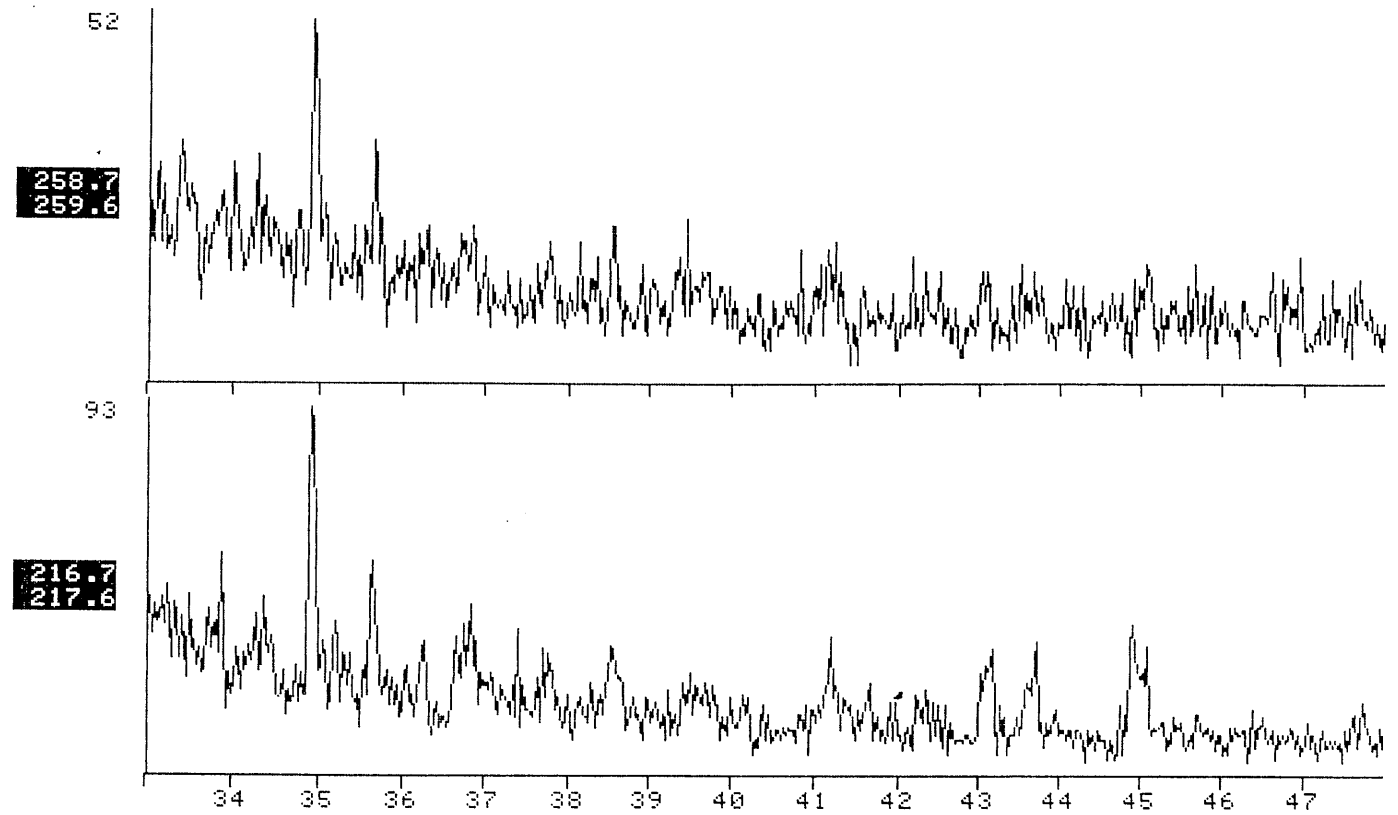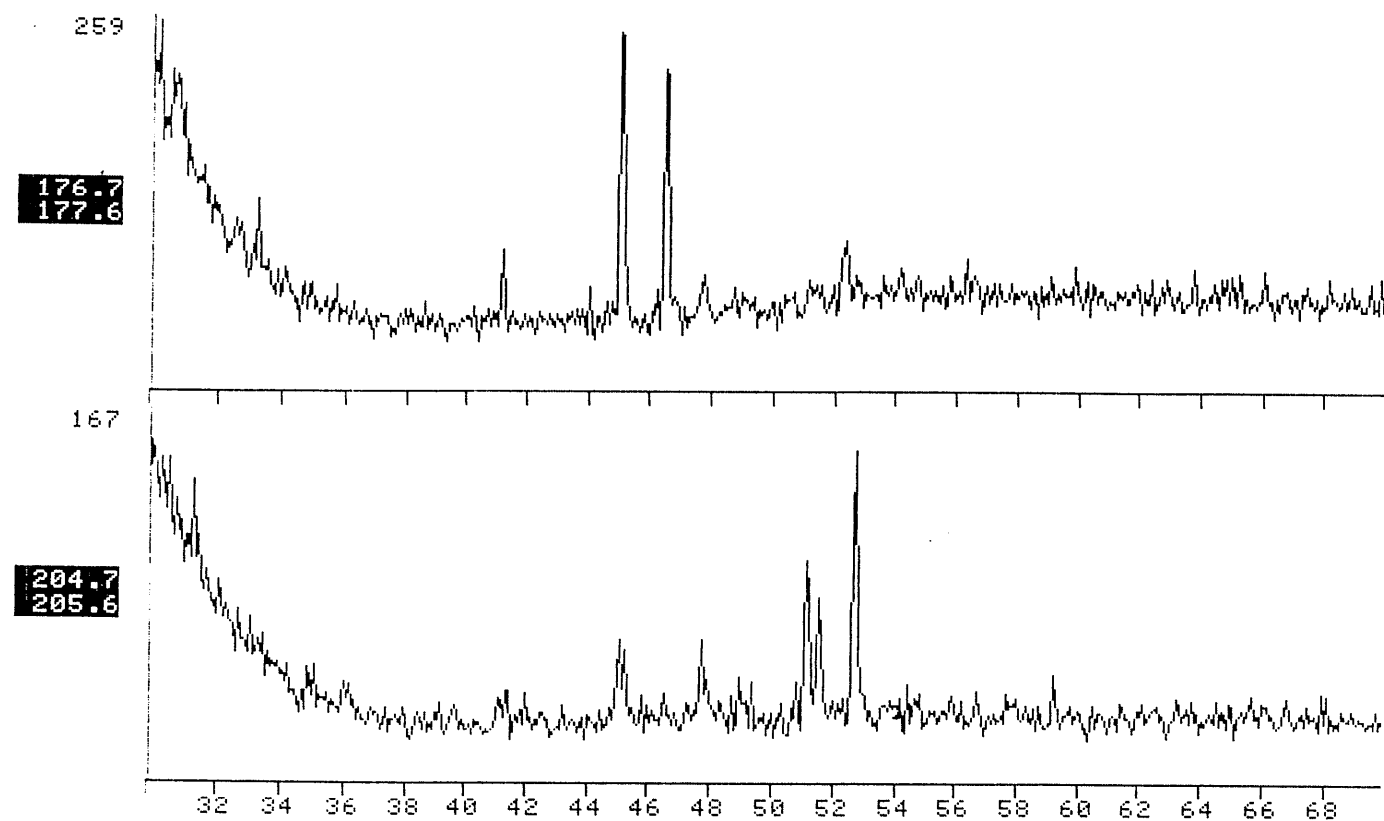
ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.
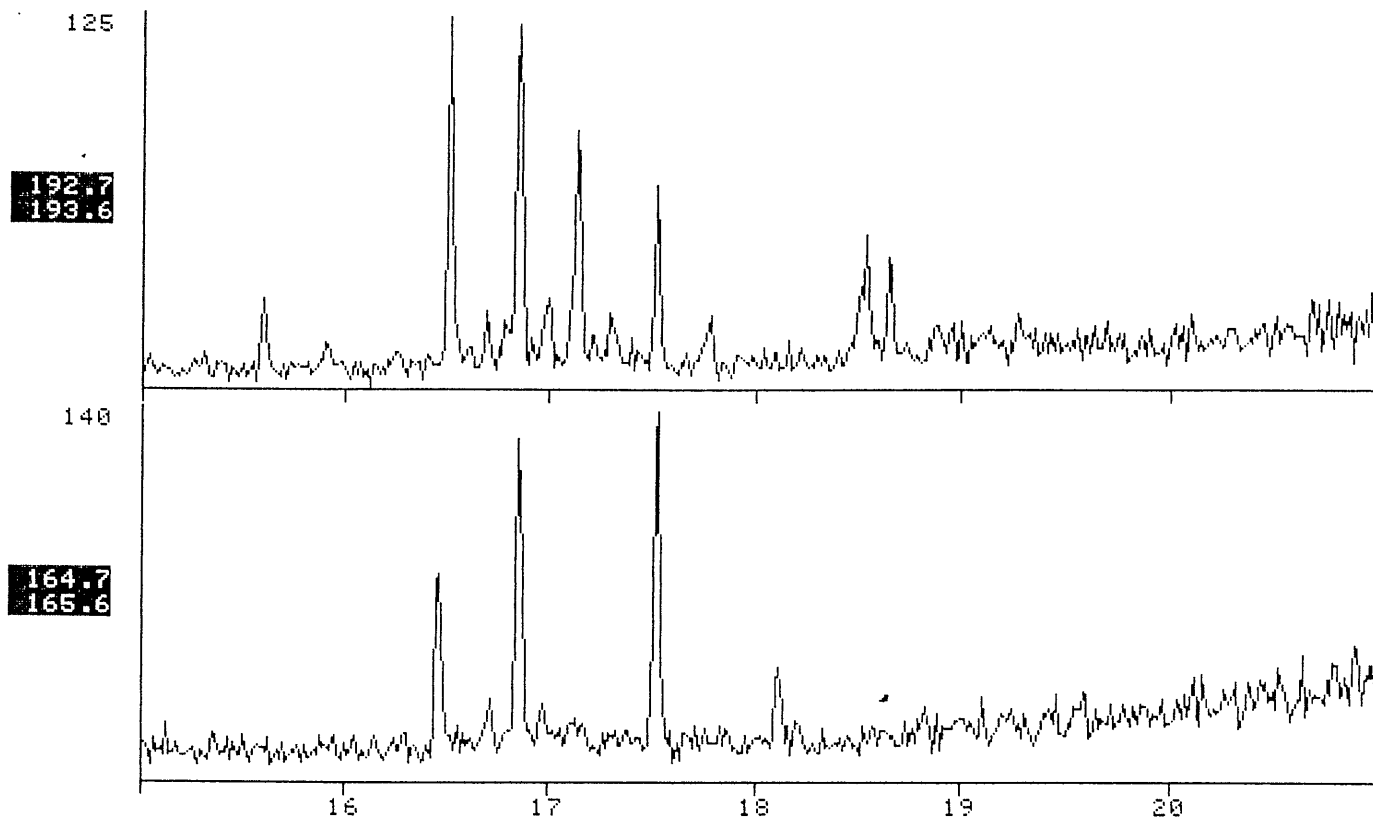16-1-87. GEC. 0.2/70ul. COL#72.
FRN 6163
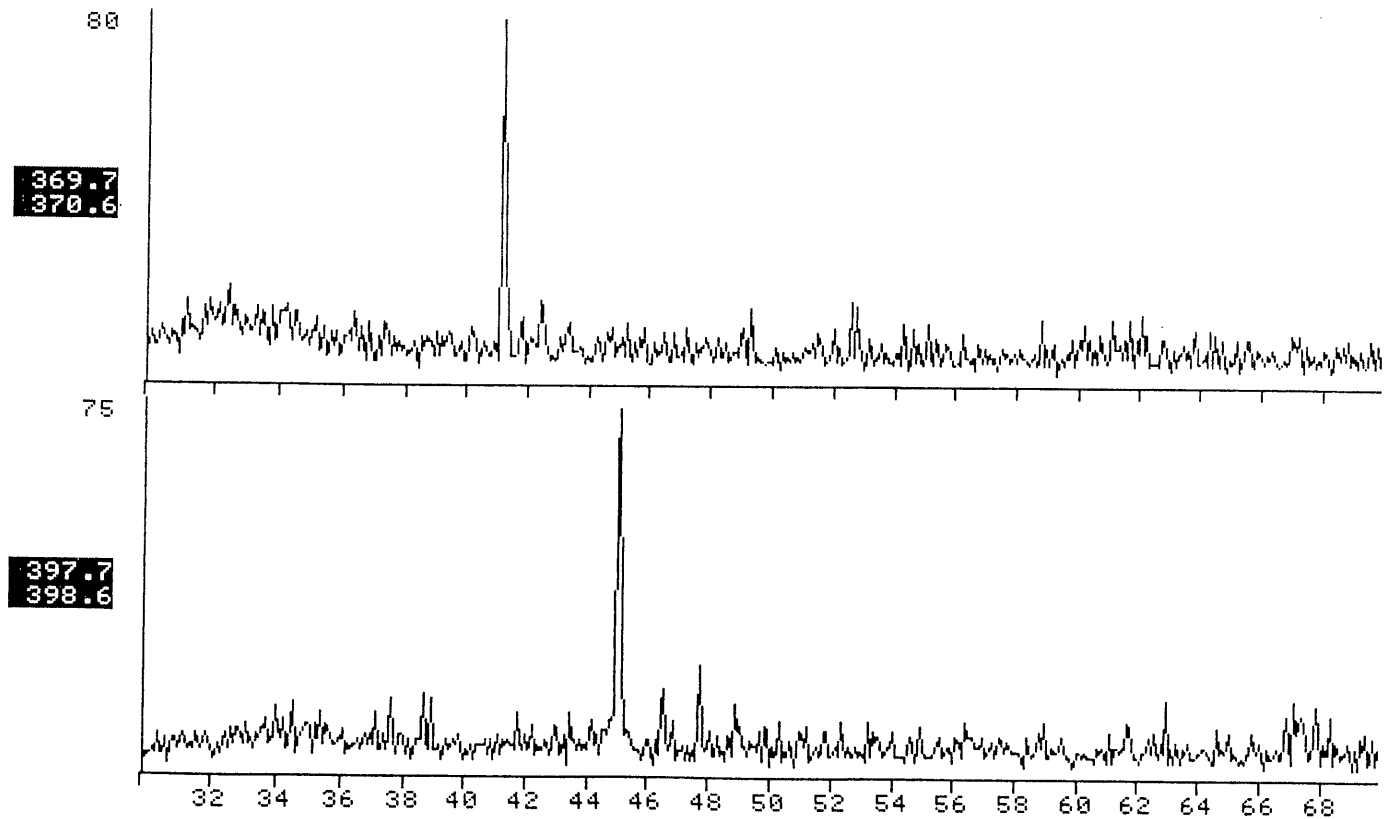
FIGURE 2-2g

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.

DRIMANES
REARRANGED DRIMANES
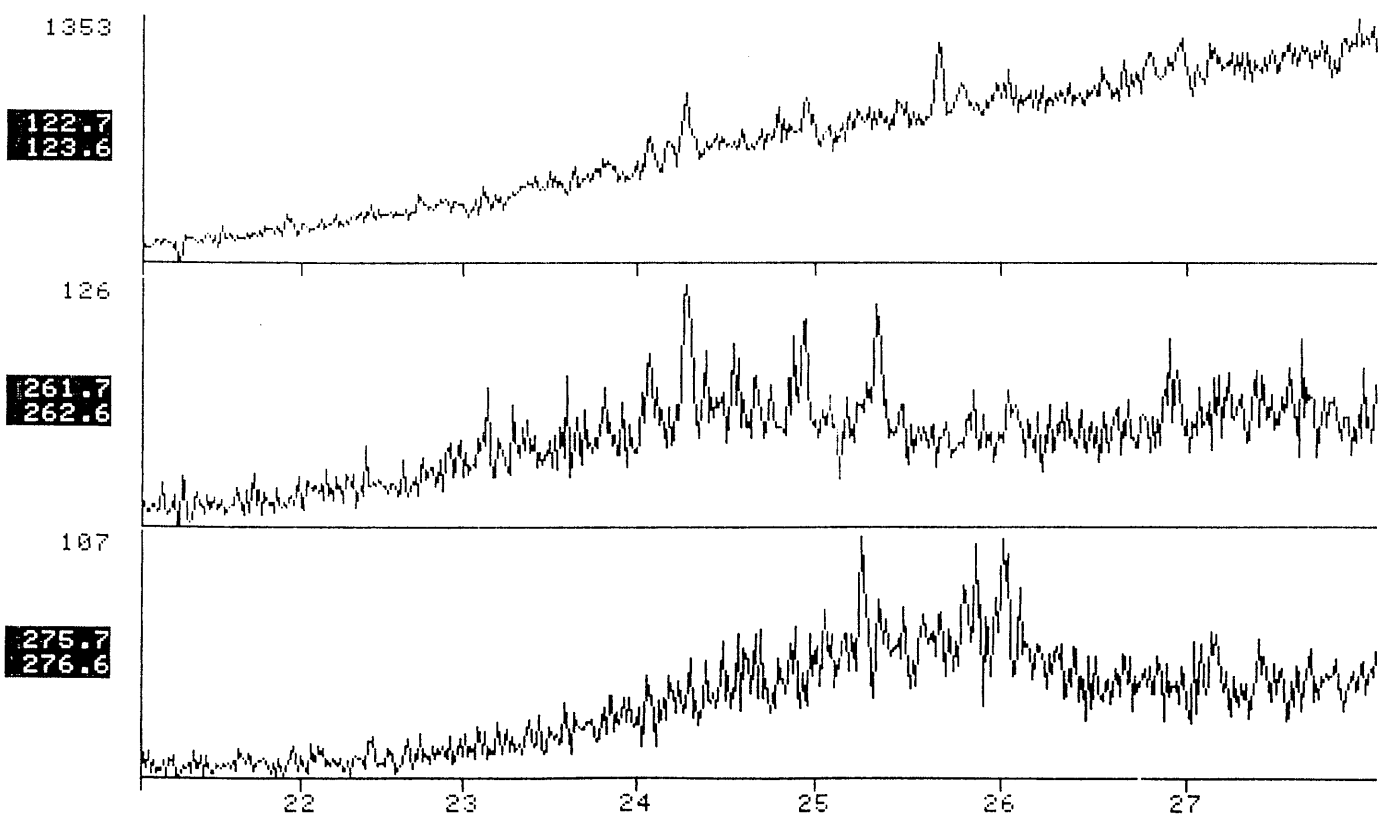
FIGURE 2-2h

FIGURE 2-2i

NAME ANGLESEA#1, 2565'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6163
MISC 16-1-87. GEC. 0.2/70ul. COL#72.
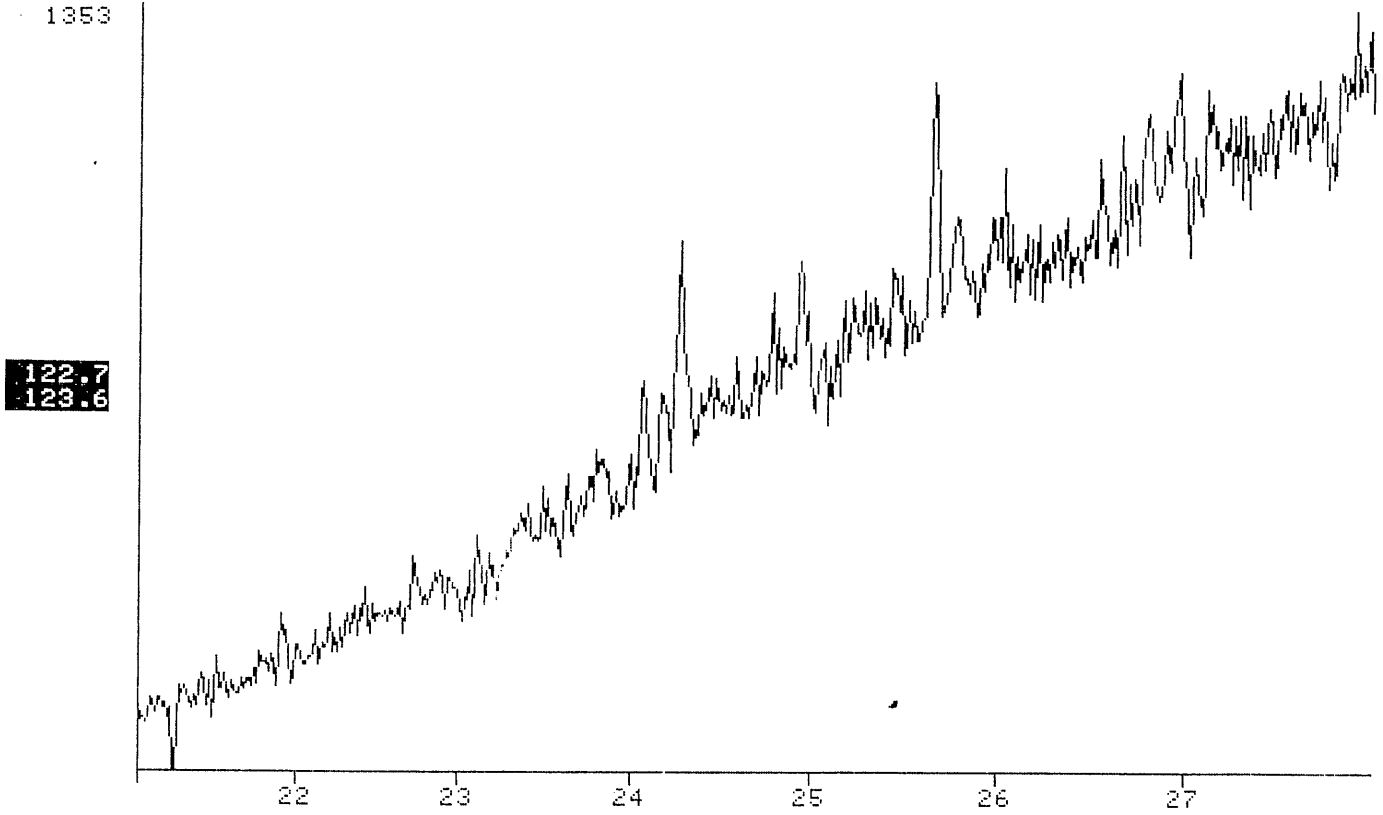
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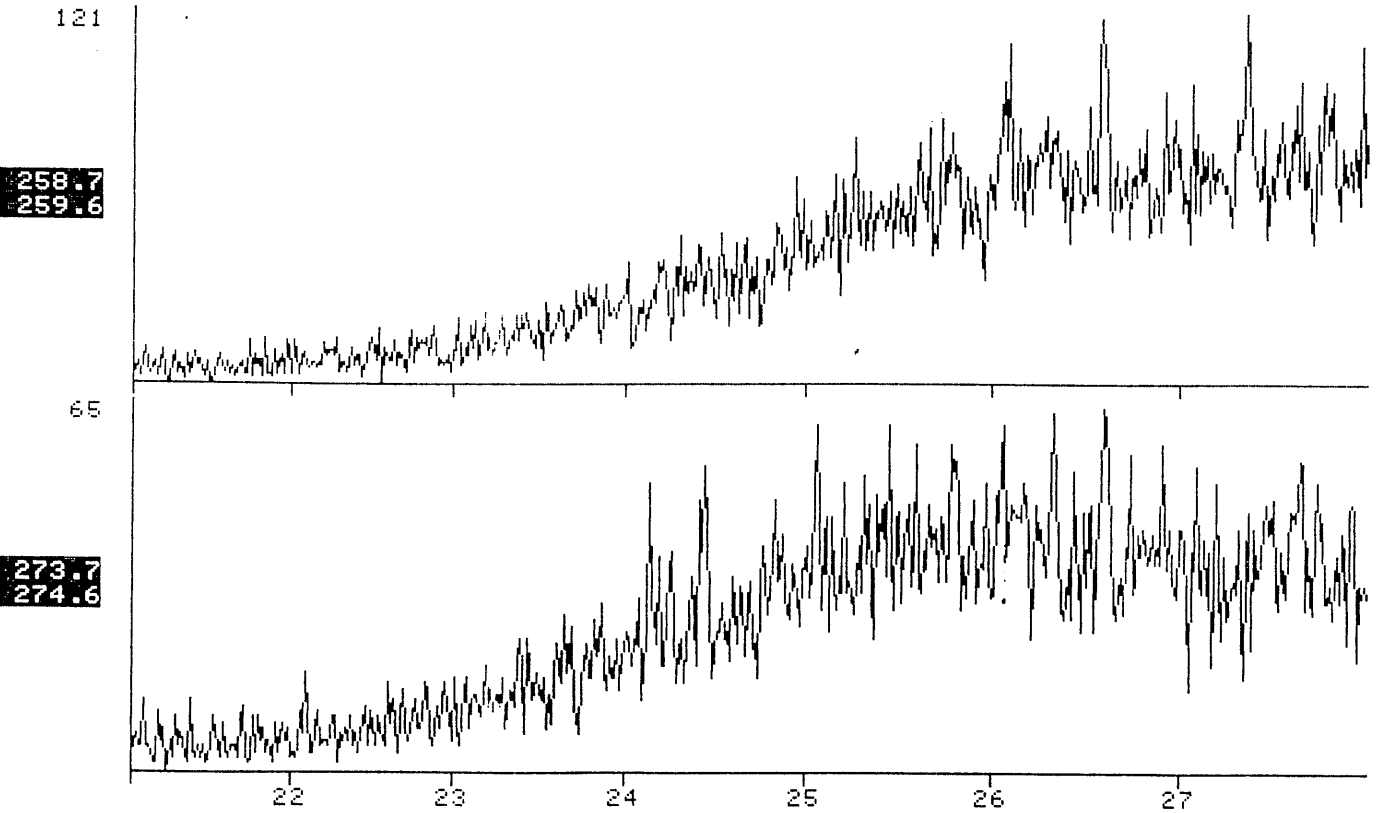
FIGURE 2-3a

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 30-3-87. GEC. 0.2/70ul. COL#72.

FRN 6252

● DIASTERANES

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 30-3-87. GEC. 0.2/70ul. COL#72.

FRN 6252

⊘ STERANES
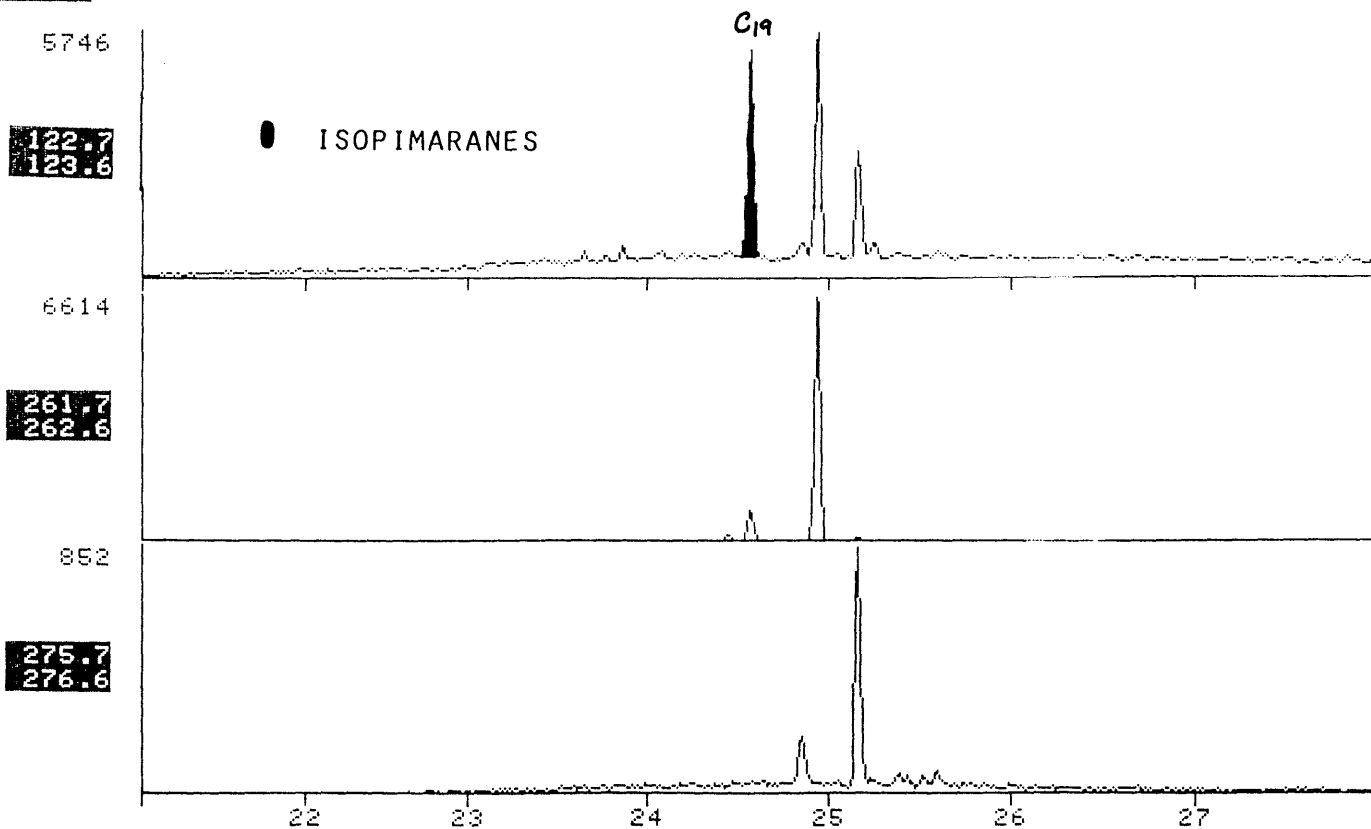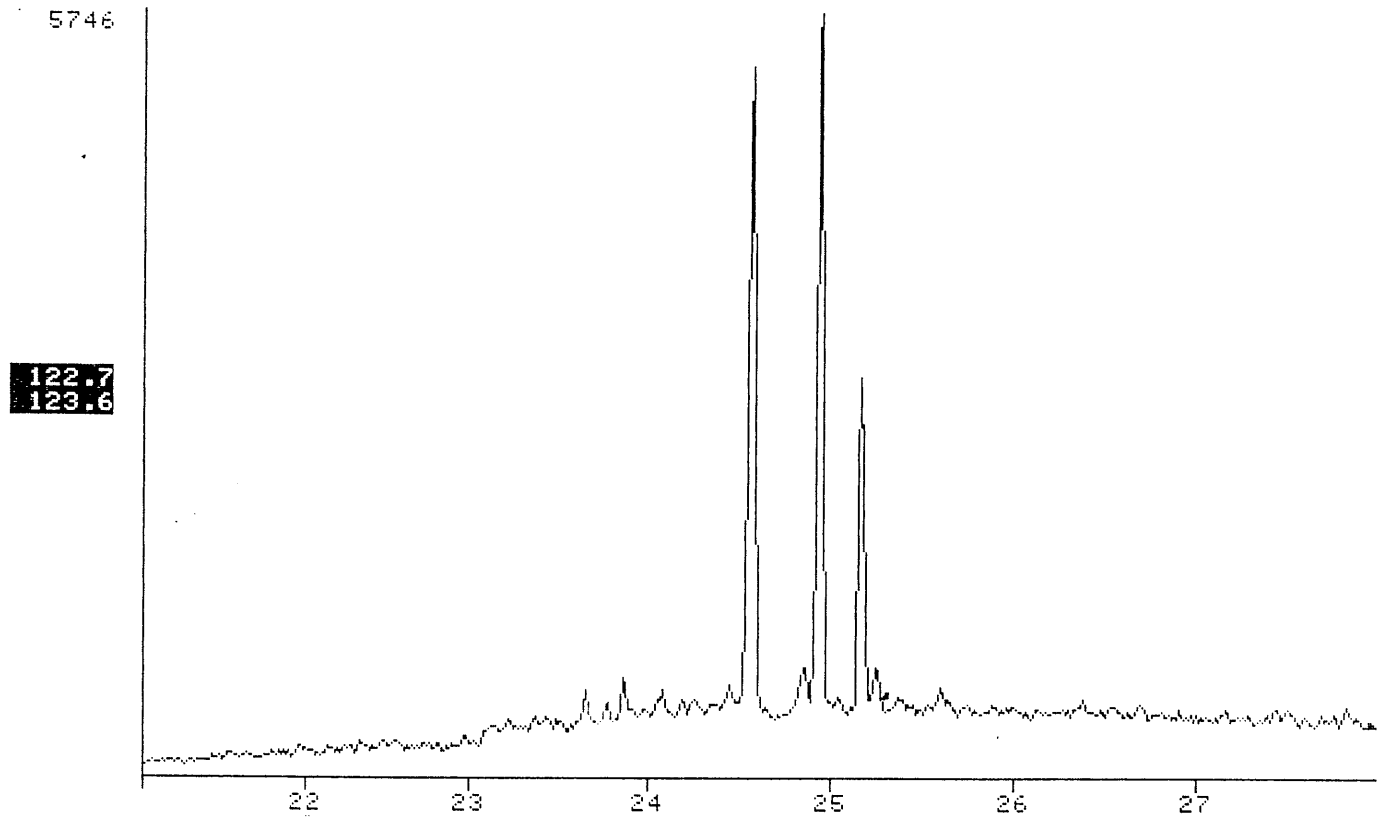⊘ ISOSTERANES
● DIASTERANES
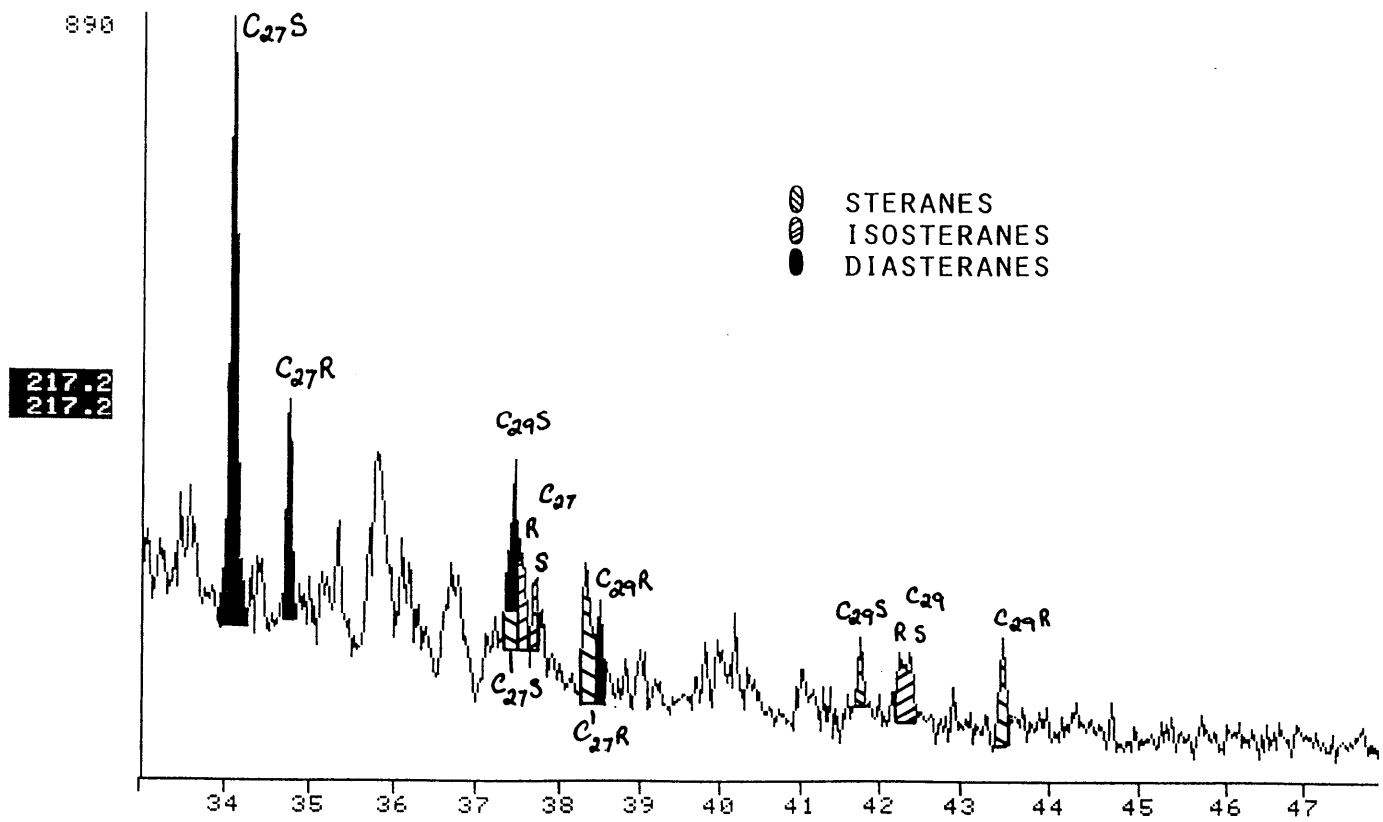
FIGURE 2-3b

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 30-3-87. GEC. 0.2/70ul. COL#72.   FRN 6252
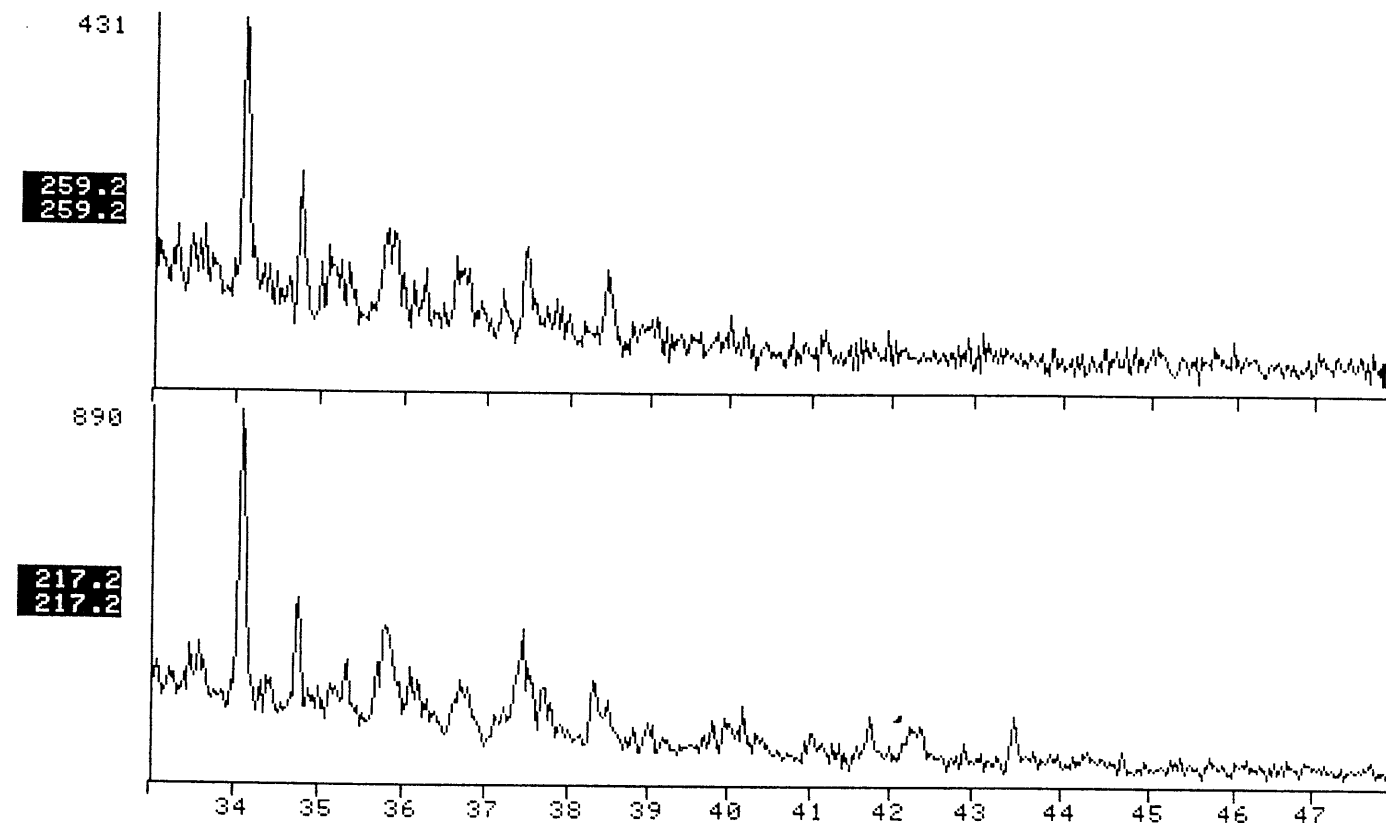
NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 30-3-87. GEC. 0.2/70ul. COL#72.   FRN 6252
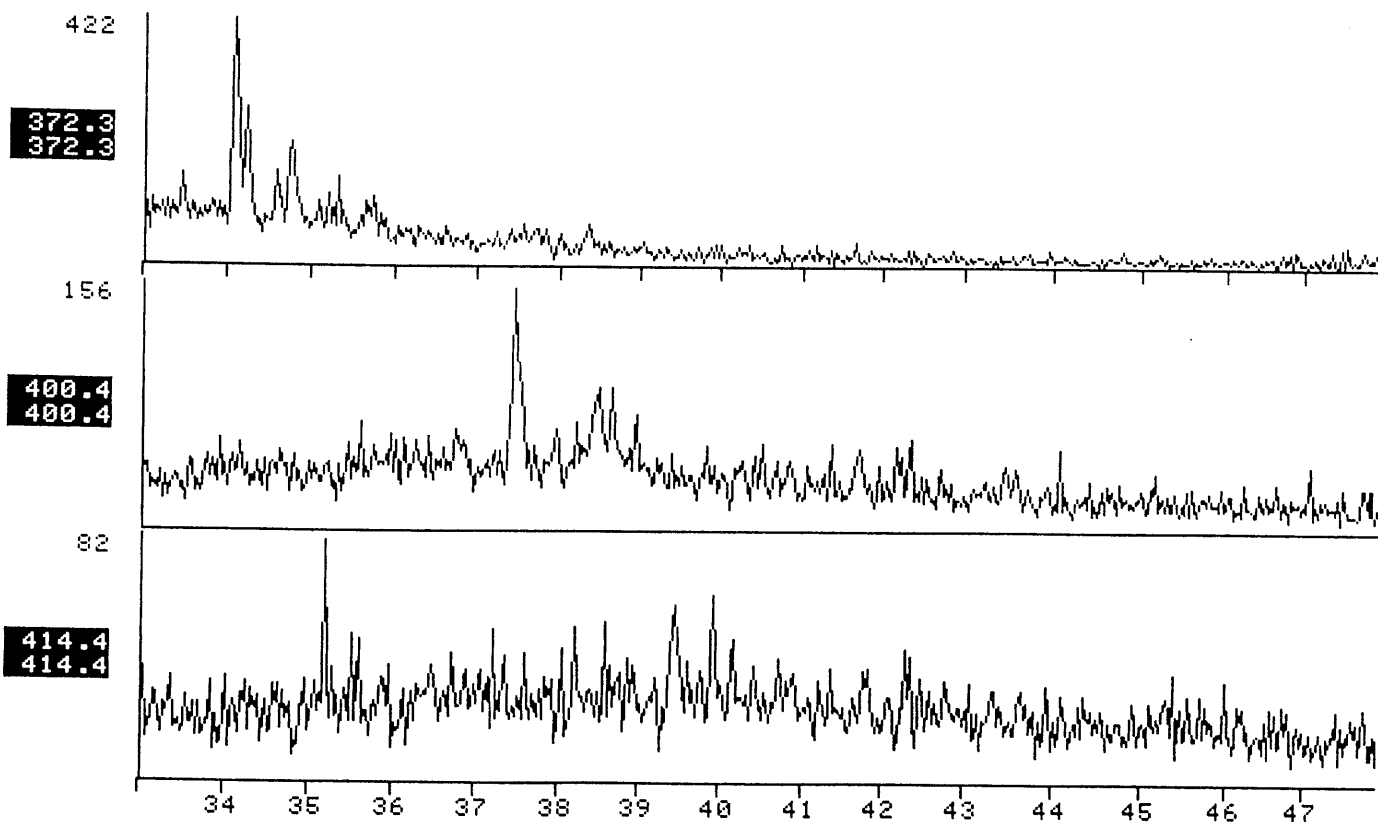
FIGURE 2-3c

FRN 6252

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 30-3-87. GEC. 0.2/70ul. COL#72.

FRN 6252

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 30-3-87. GEC. 0.2/70ul. COL#72.
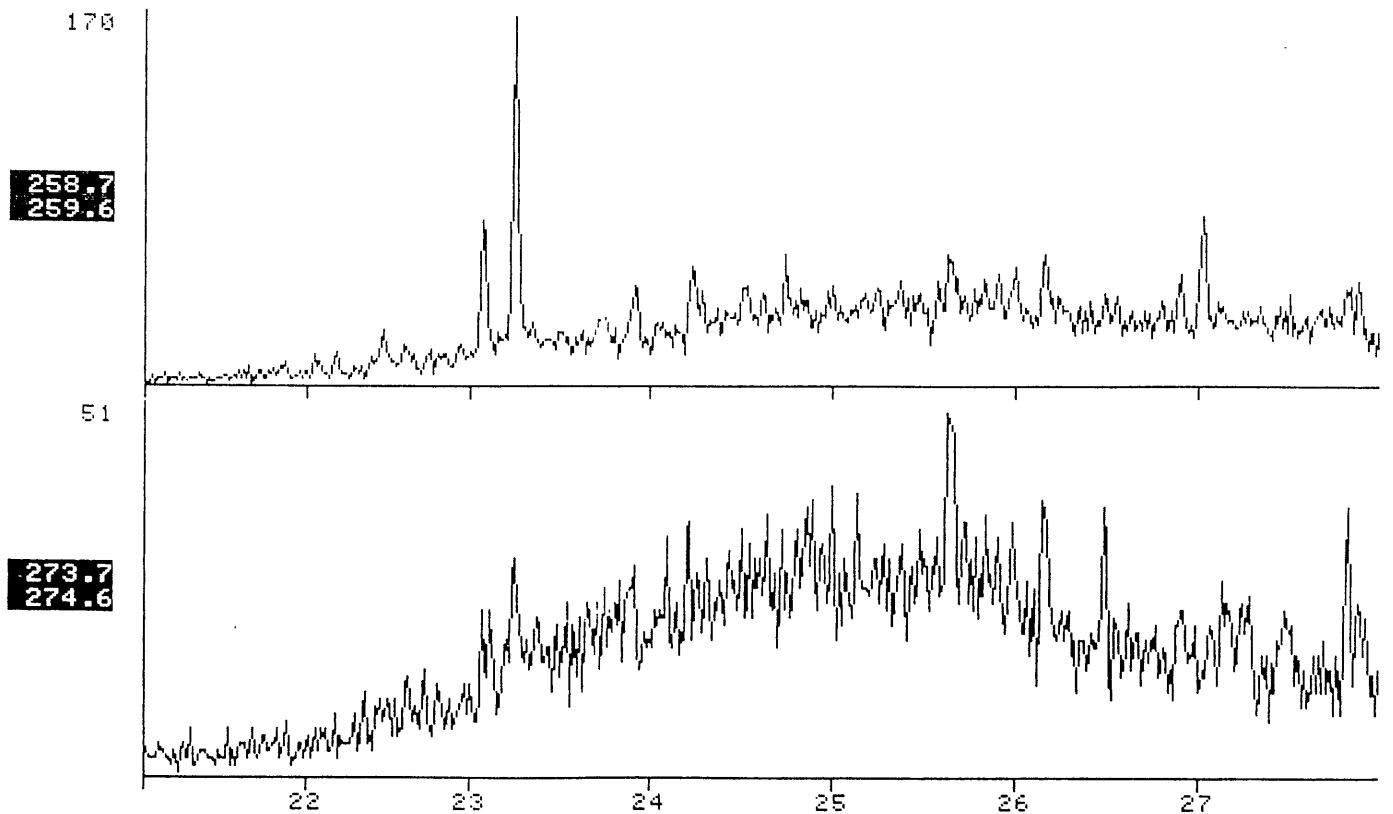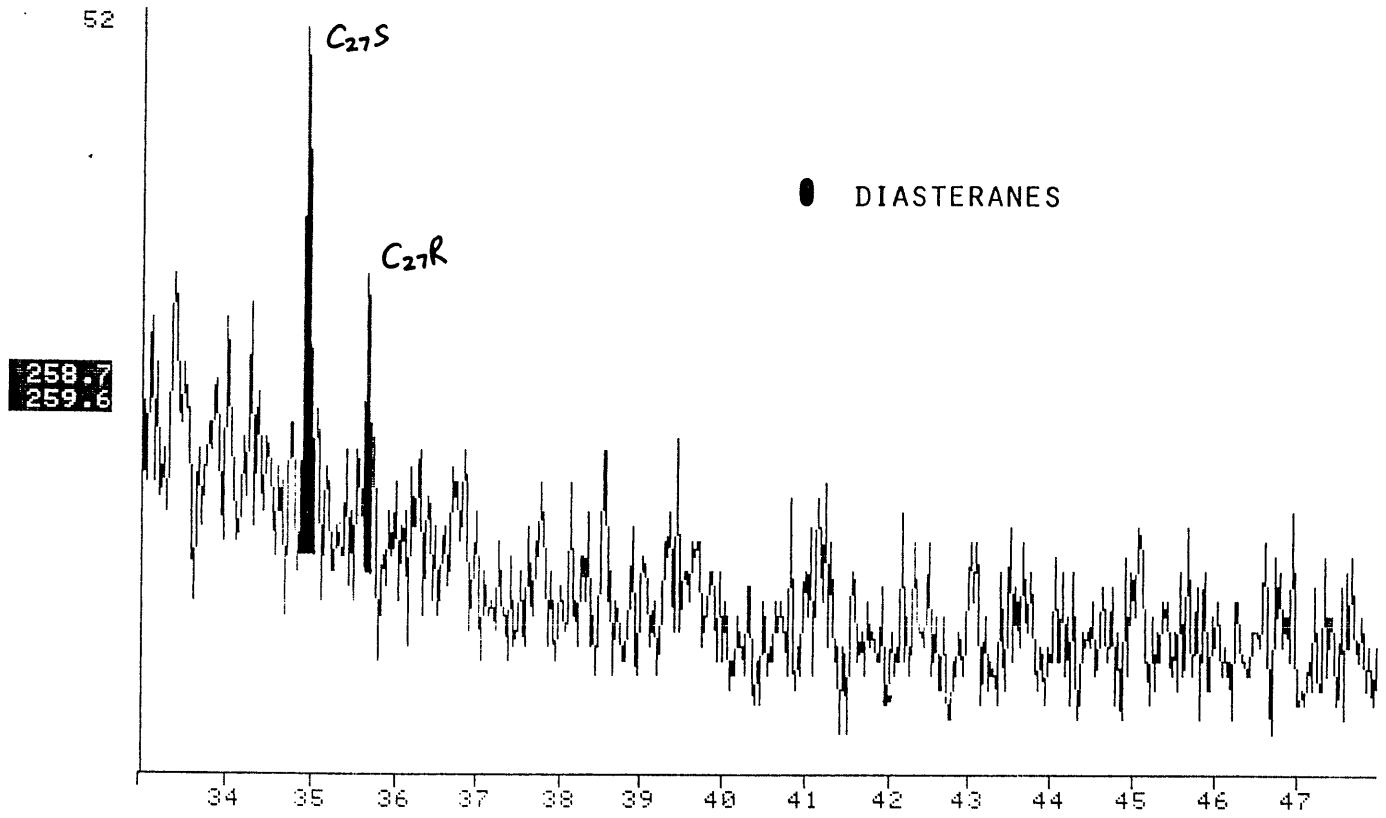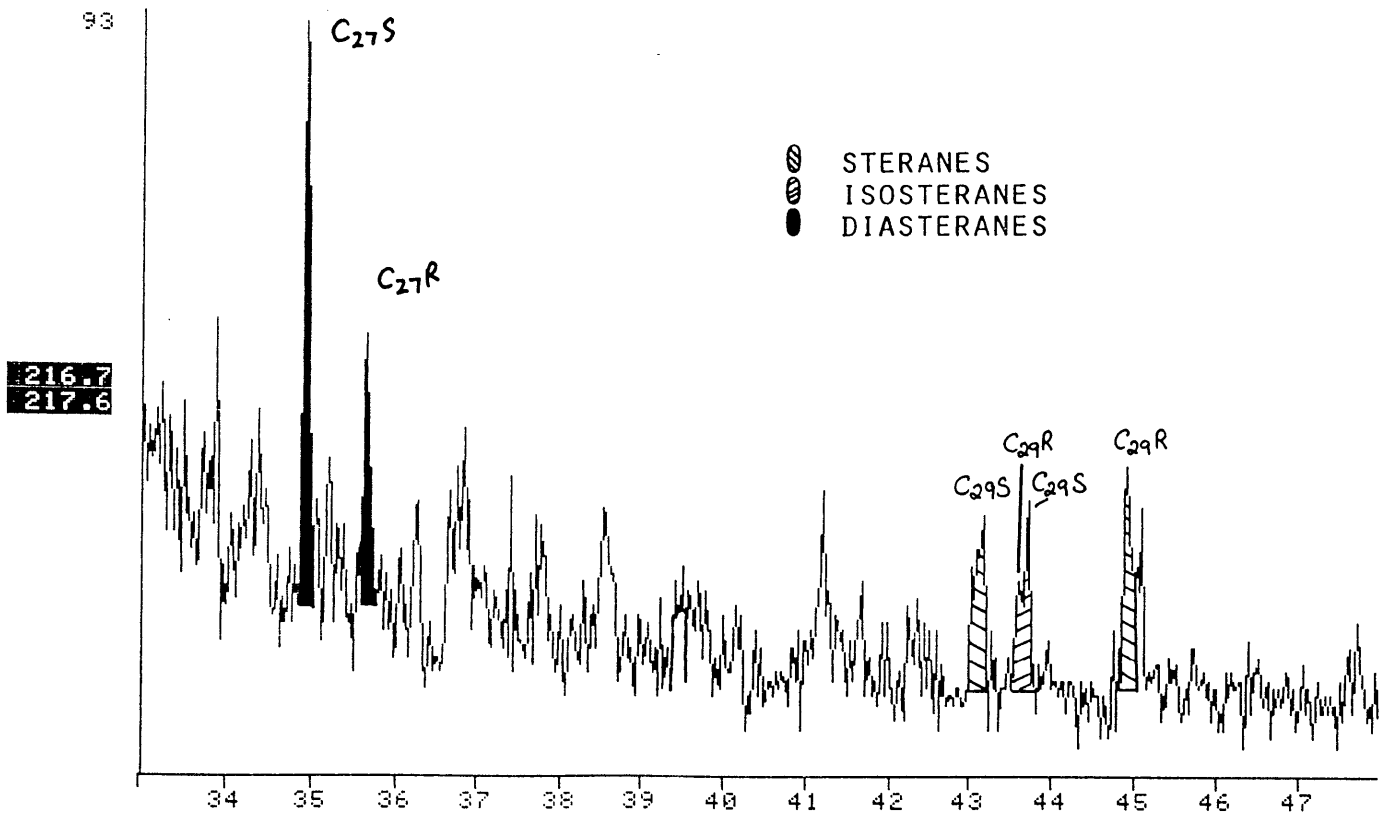
FIGURE 2-3d

FIGURE 2-3e

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 16-1-87. GEC. 0.2/70ul. COL#720$
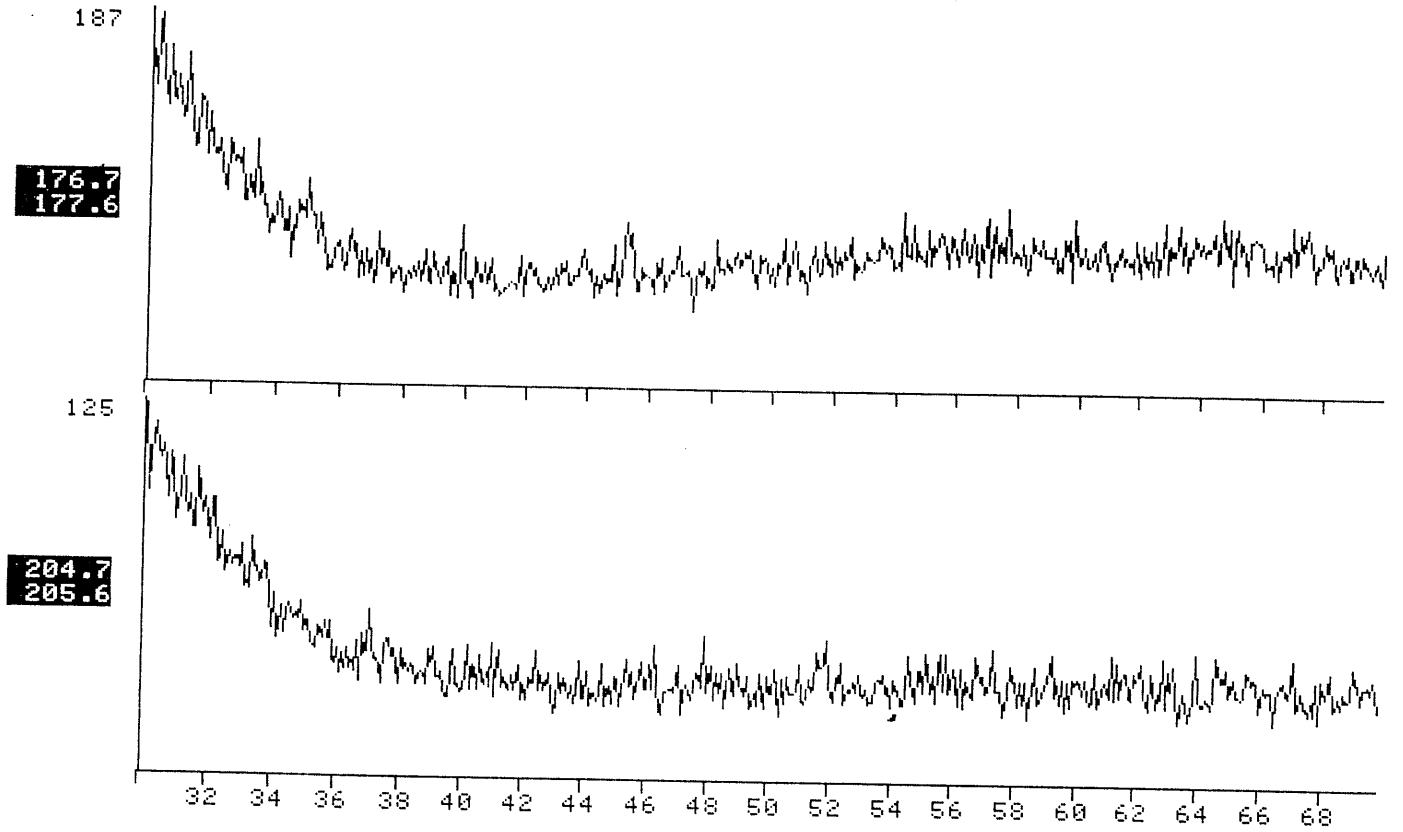
FRN 6164

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.
MISC 16-1-87. GEC. 0.2/70ul. COL#720$

FRN 6164

HOPANES
MORETANES
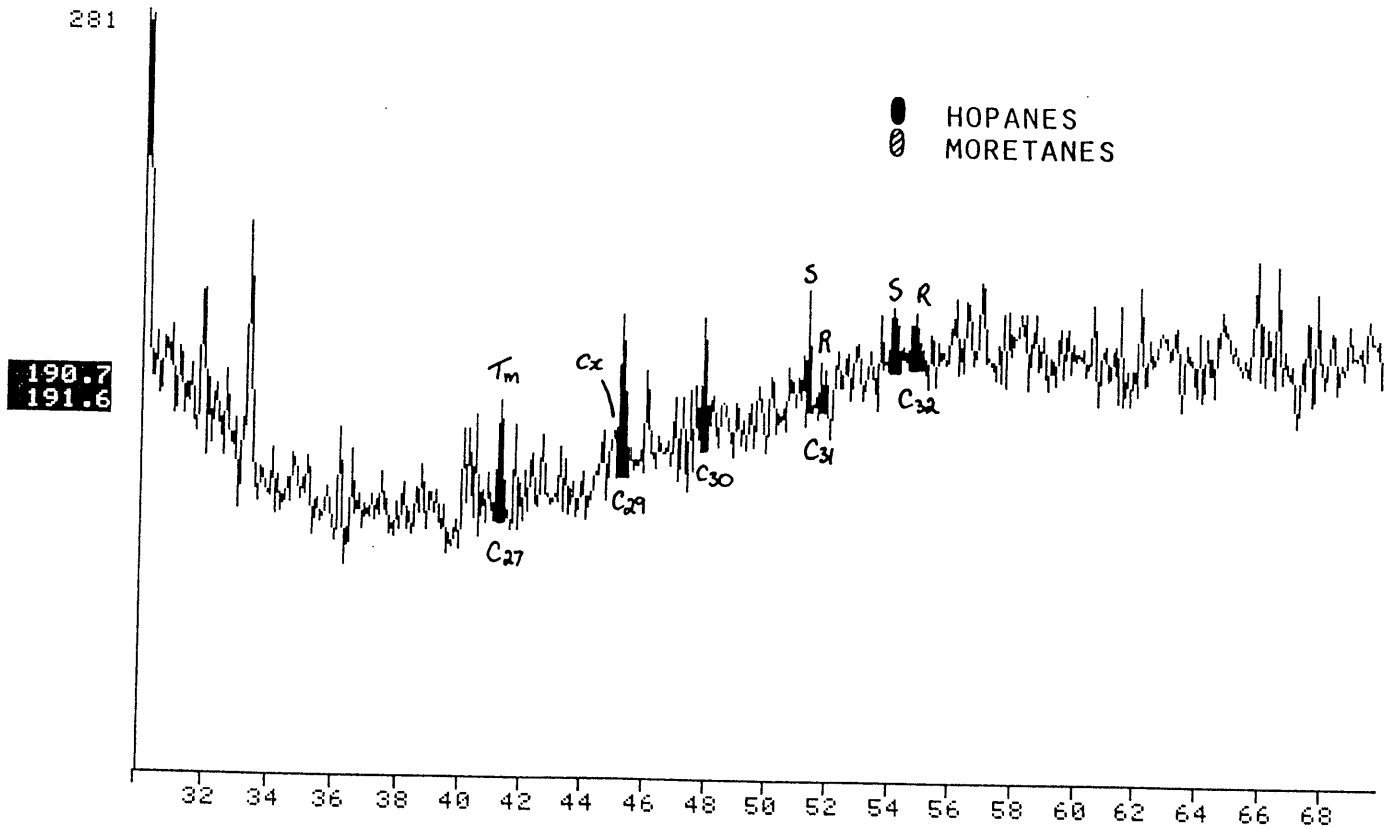
FIGURE 2-3f

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6164
MISC 16-1-87. GEC. 0.2/70ul. COL#72@$

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.   FRN 6164
MISC 16-1-87. GEC. 0.2/70ul. COL#72@$

FIGURE 2-3g

C_{15} C_{16} C_{15} C_{15}

⌀ DRIMANES
● REARRANGED DRIMANES
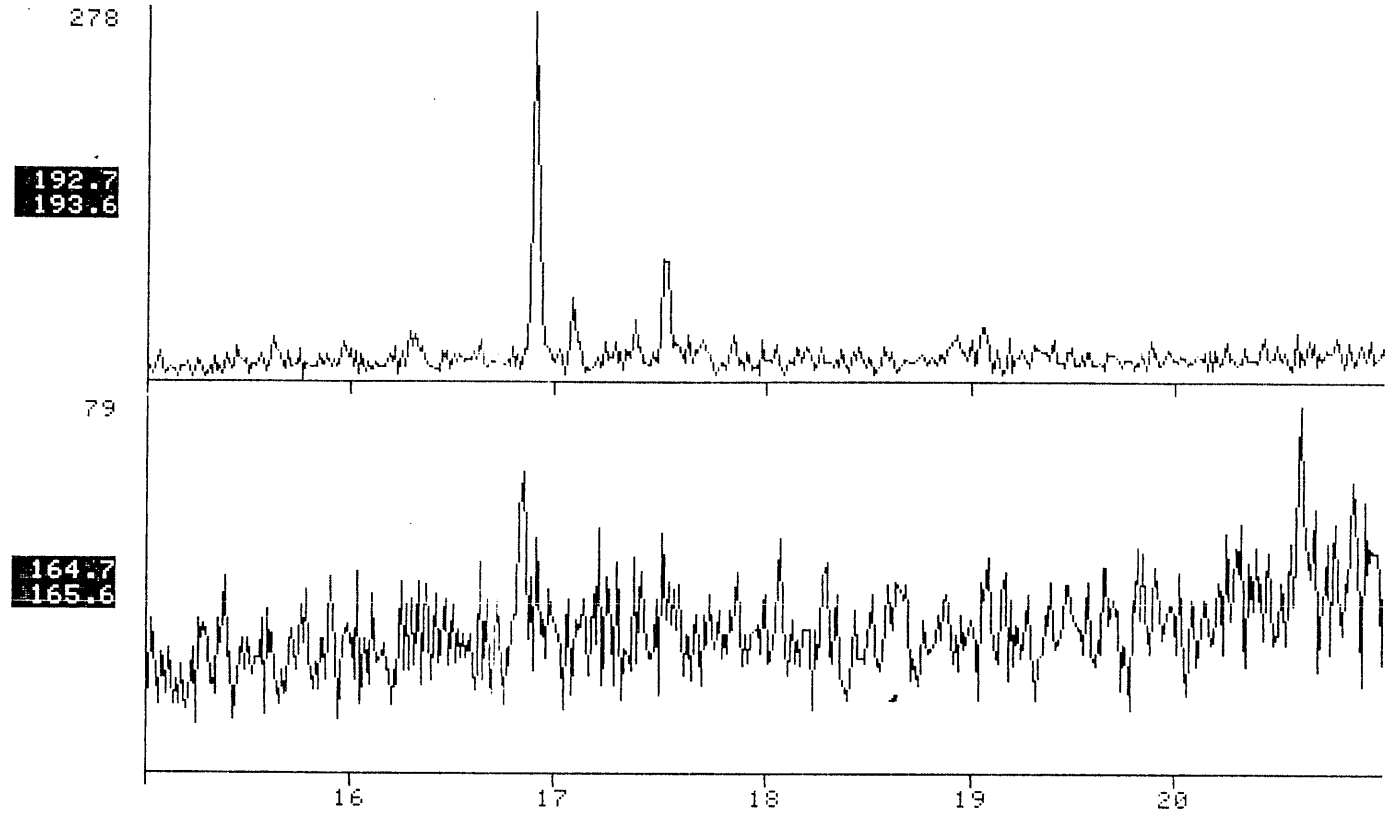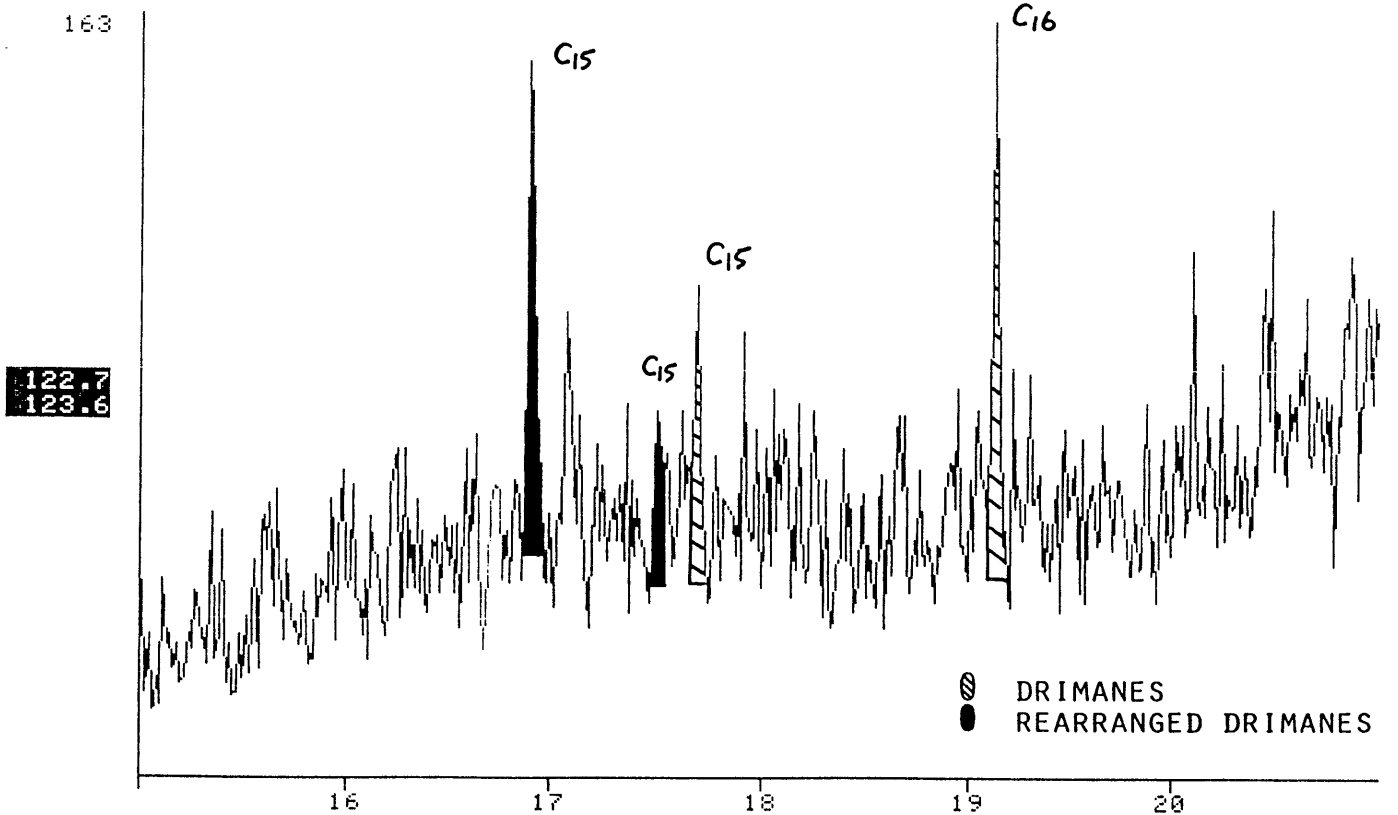
FIGURE 2-3h

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM.　FRN 6164
MISC 16-1-87. GEC. 0.2/70ul. COL#72@$
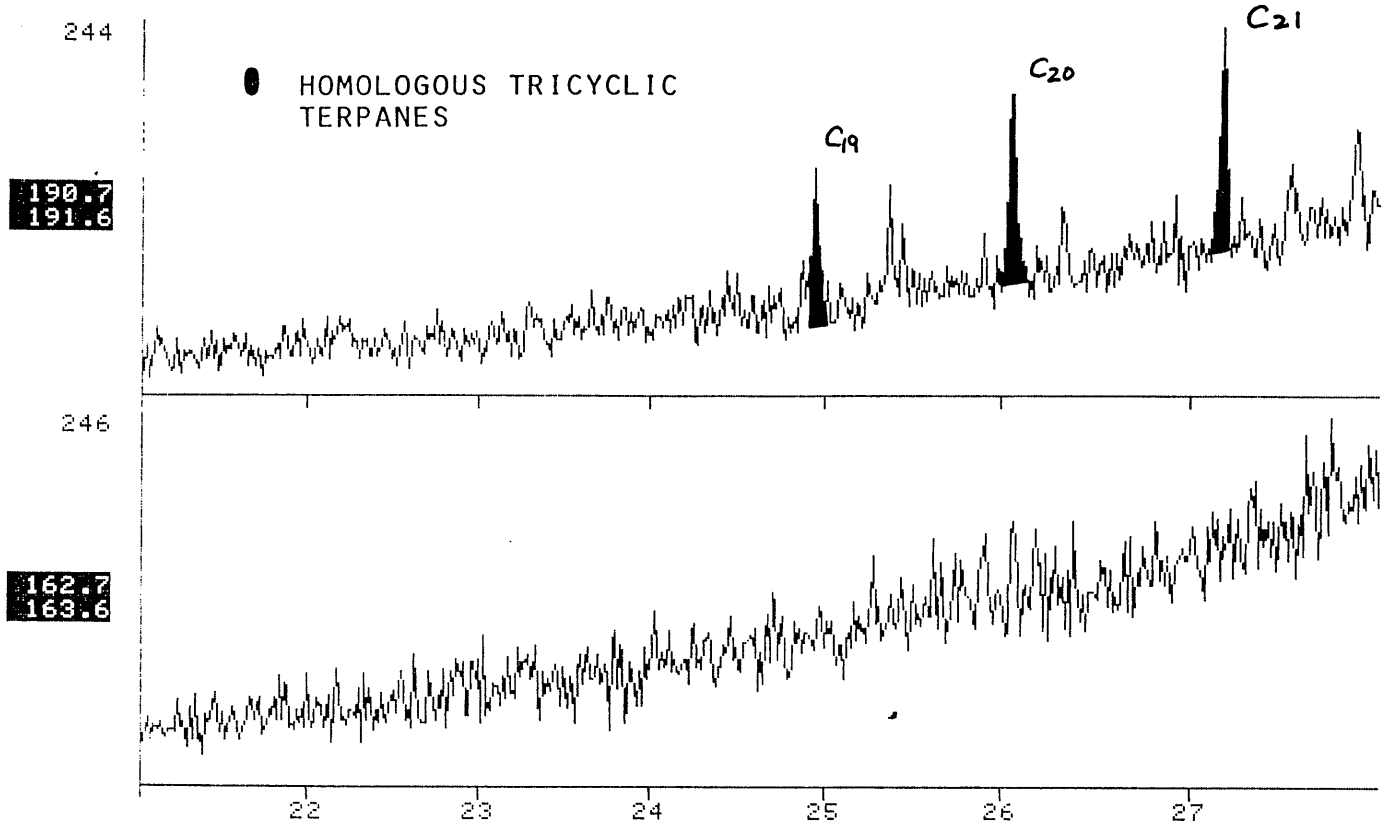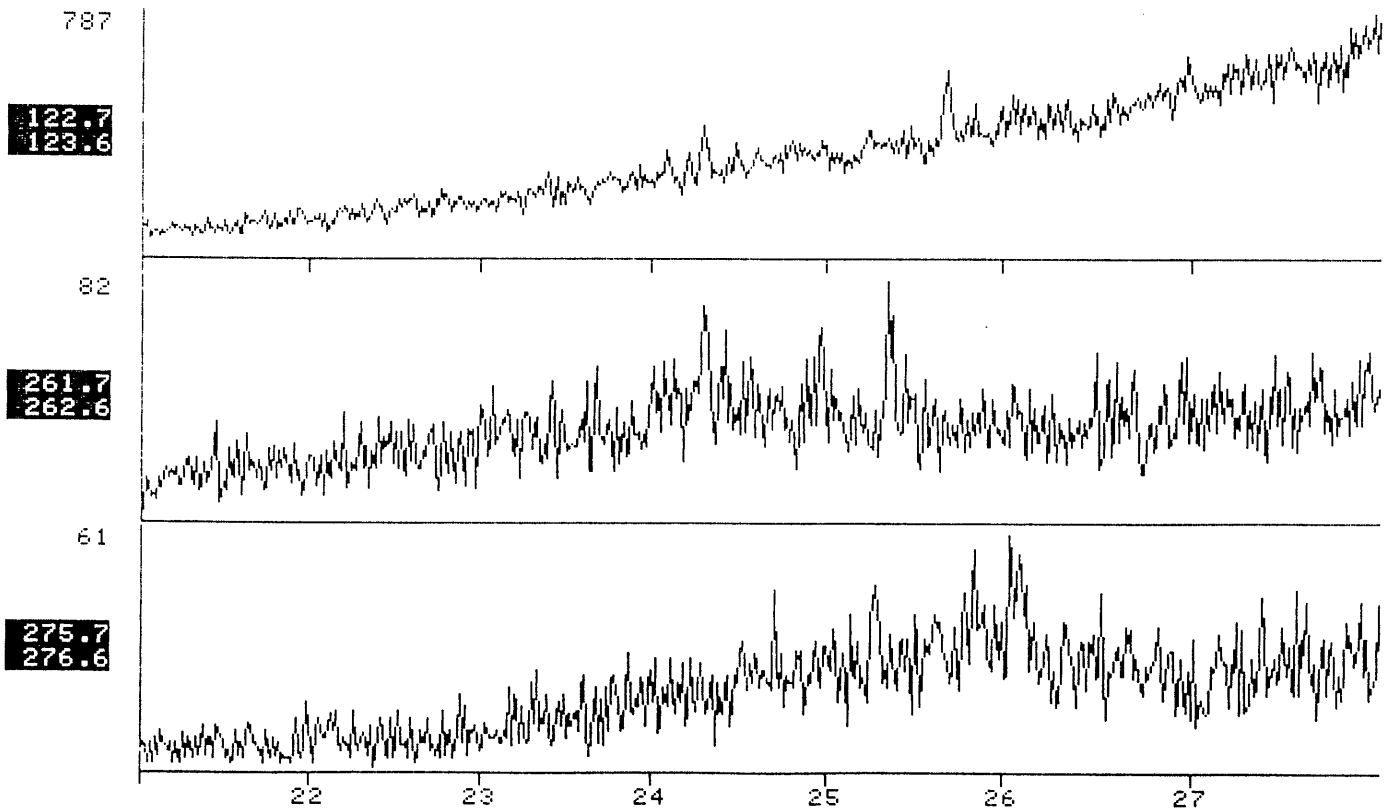
FIGURE 2-3i

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM. FRN 6164
MISC 16-1-87. GEC. 0.2/70ul. COL#720$
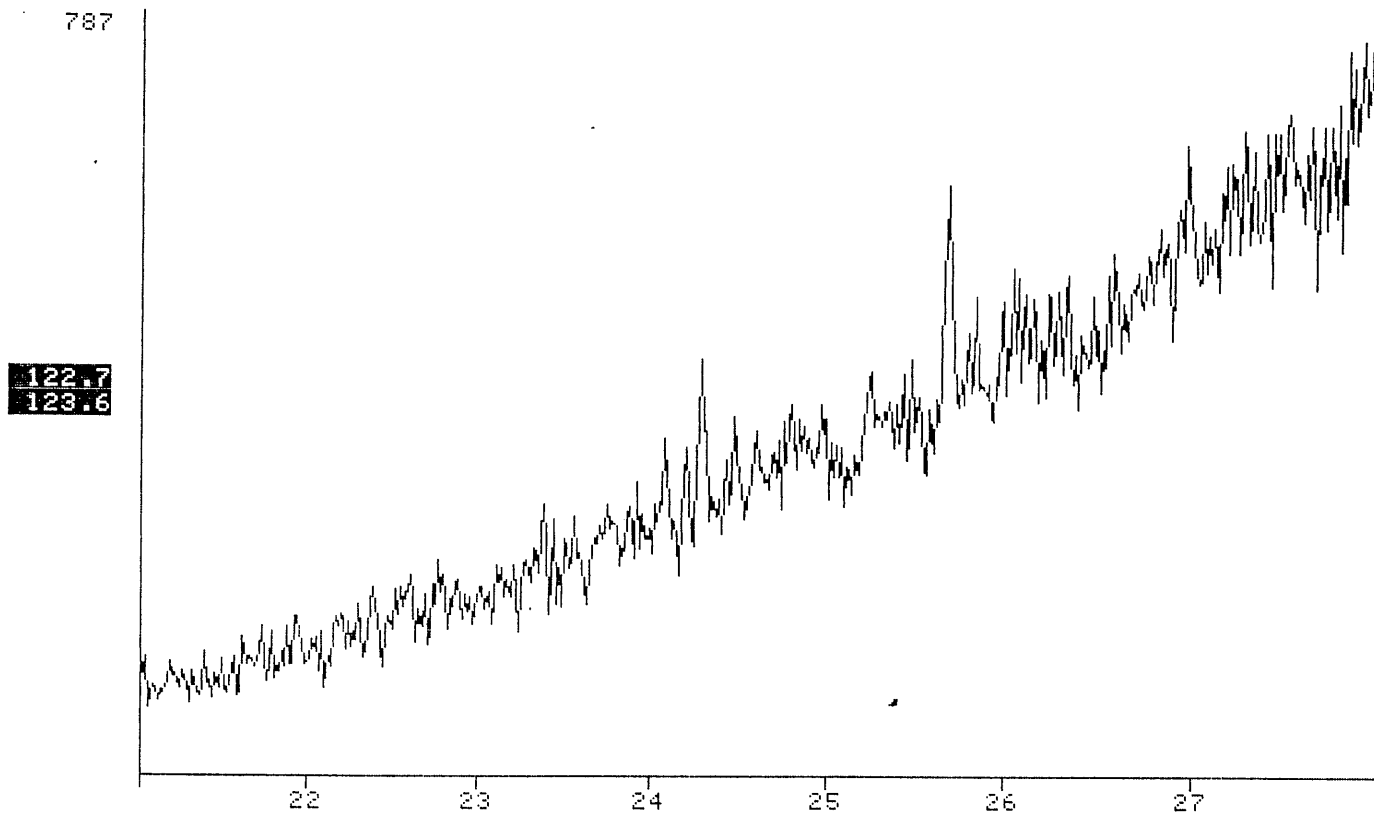
787

122.7
123.6

NAME ANGLESEA#1, 6239'. BRANCHED CYCLIC FRAGMENTOGRAM. FRN 6164
MISC 16-1-87. GEC. 0.2/70ul. COL#720$

75

258.7
259.6

48

273.7
274.6

FIGURE 3-1a

MONOAROMATIC STERANES
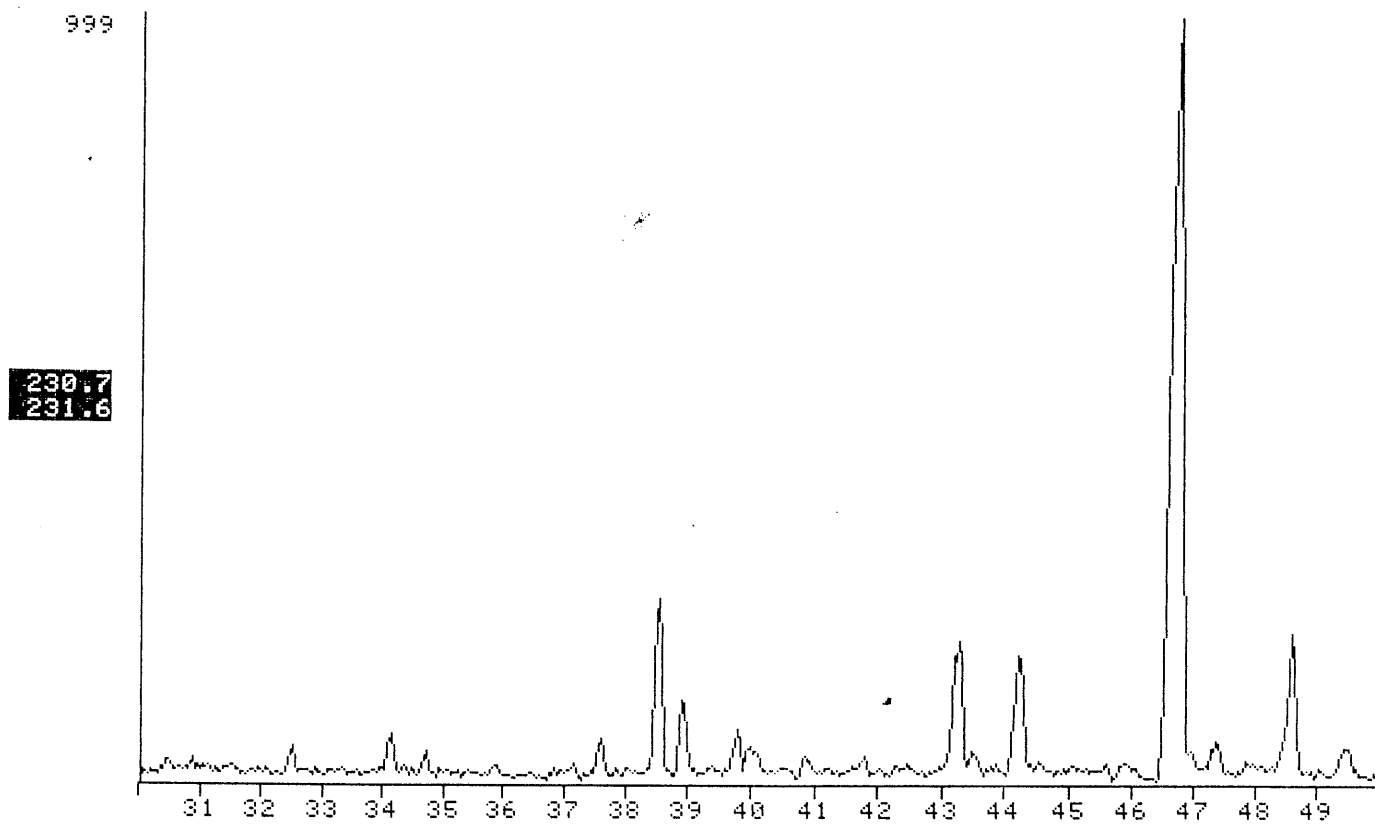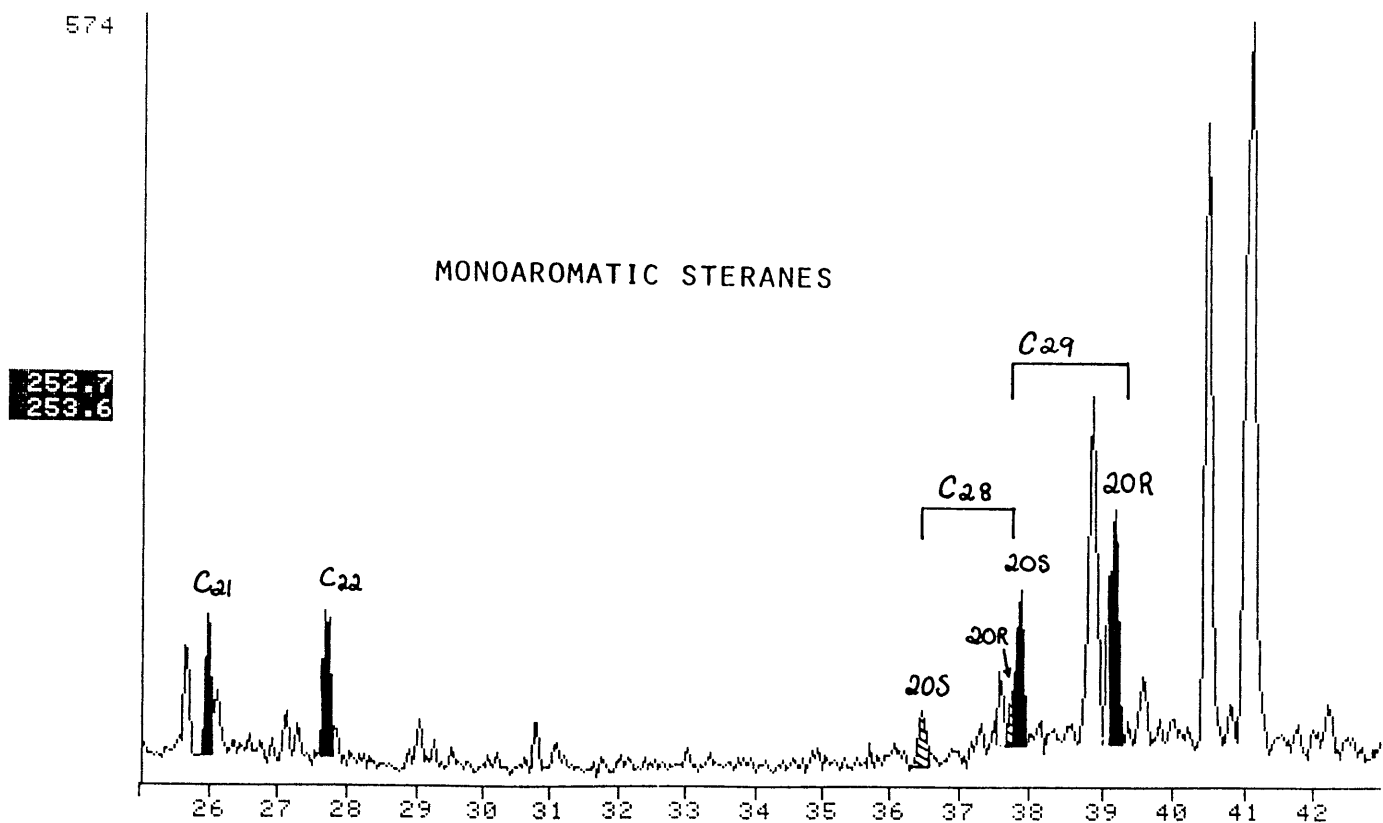
FIGURE 3-1b
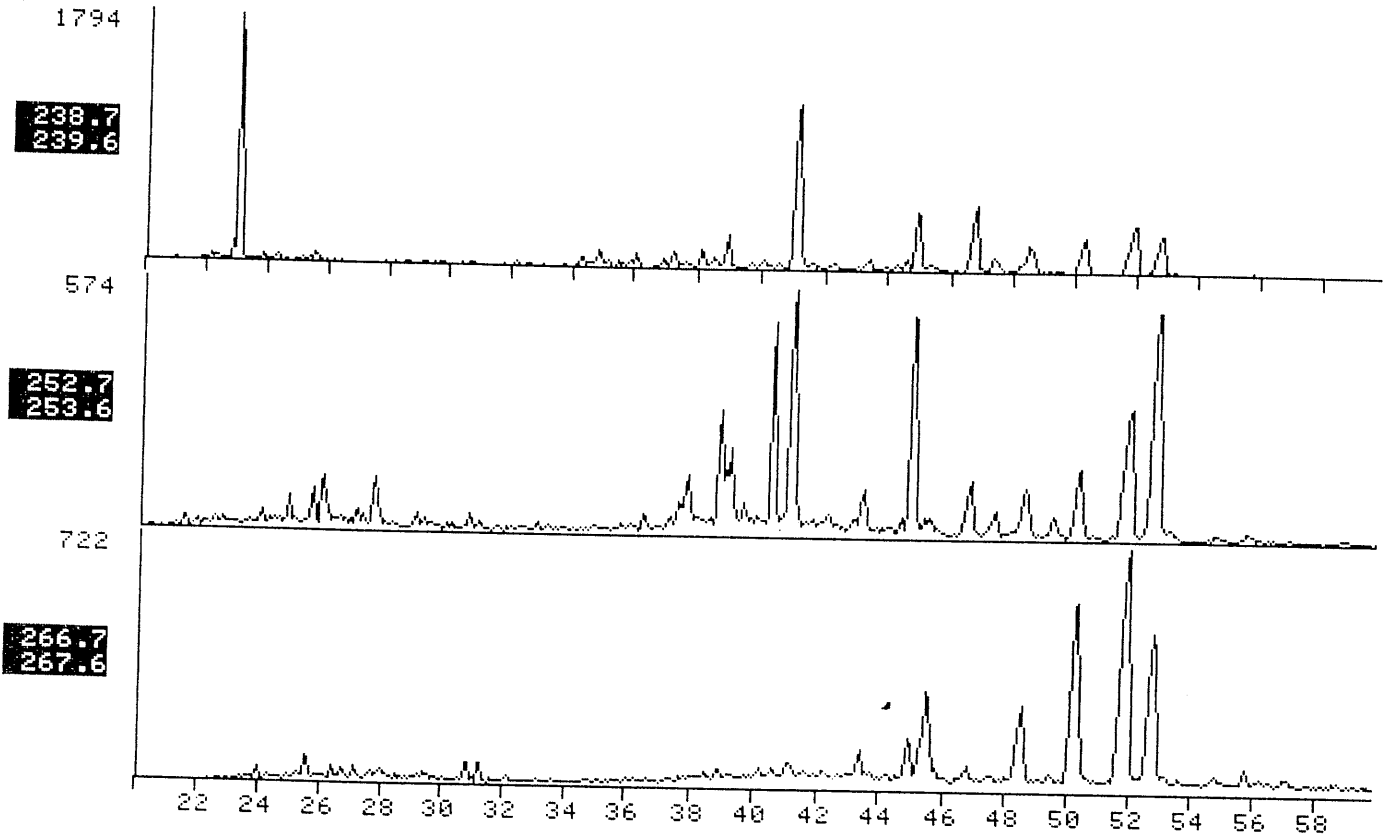
NAME ANGLESEA#1, 497'. AROMATIC FRAGMENTOGRAM.
MISC 19-2-87. GEC. 0.2/50ul. COL#72.
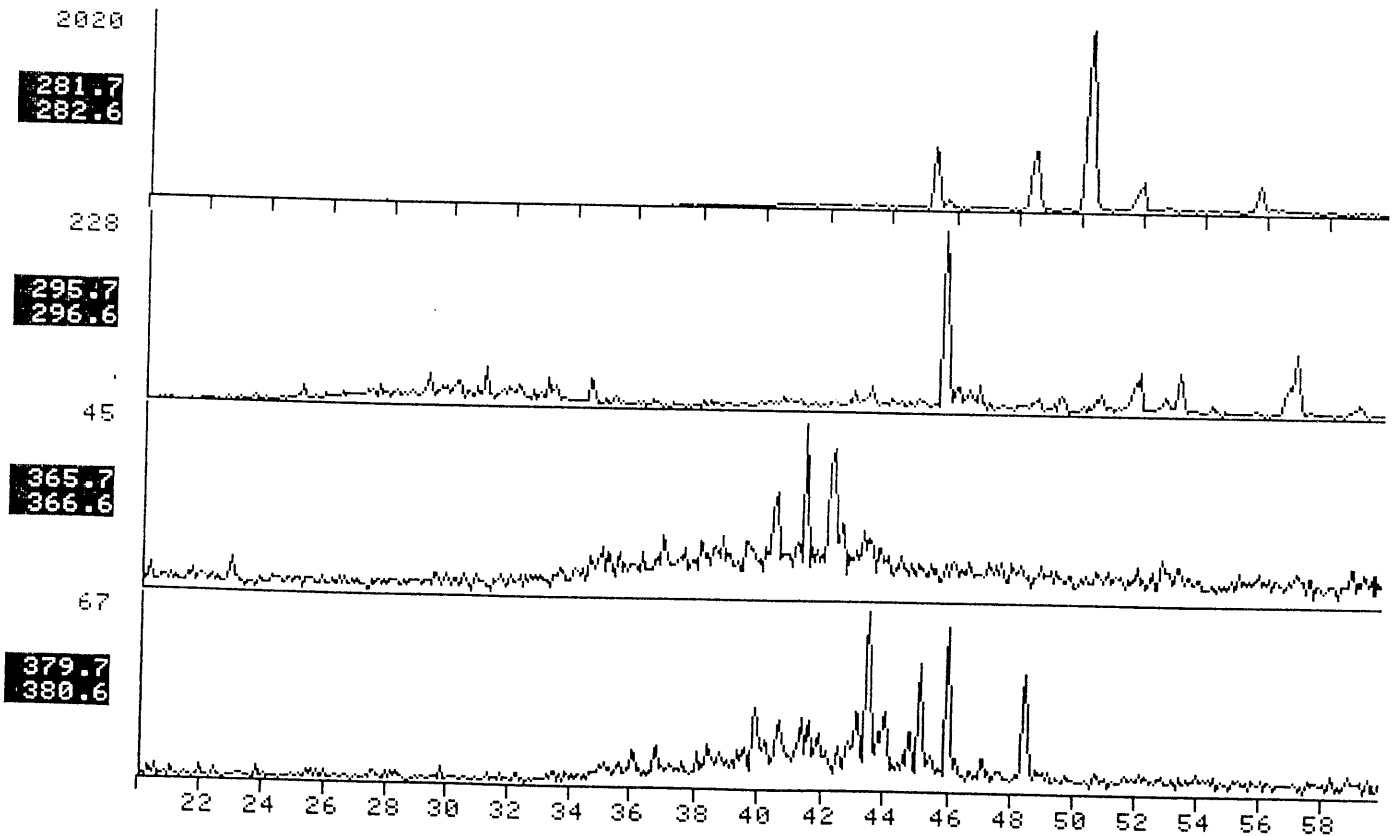
FRN 6185

FIGURE 3-1c
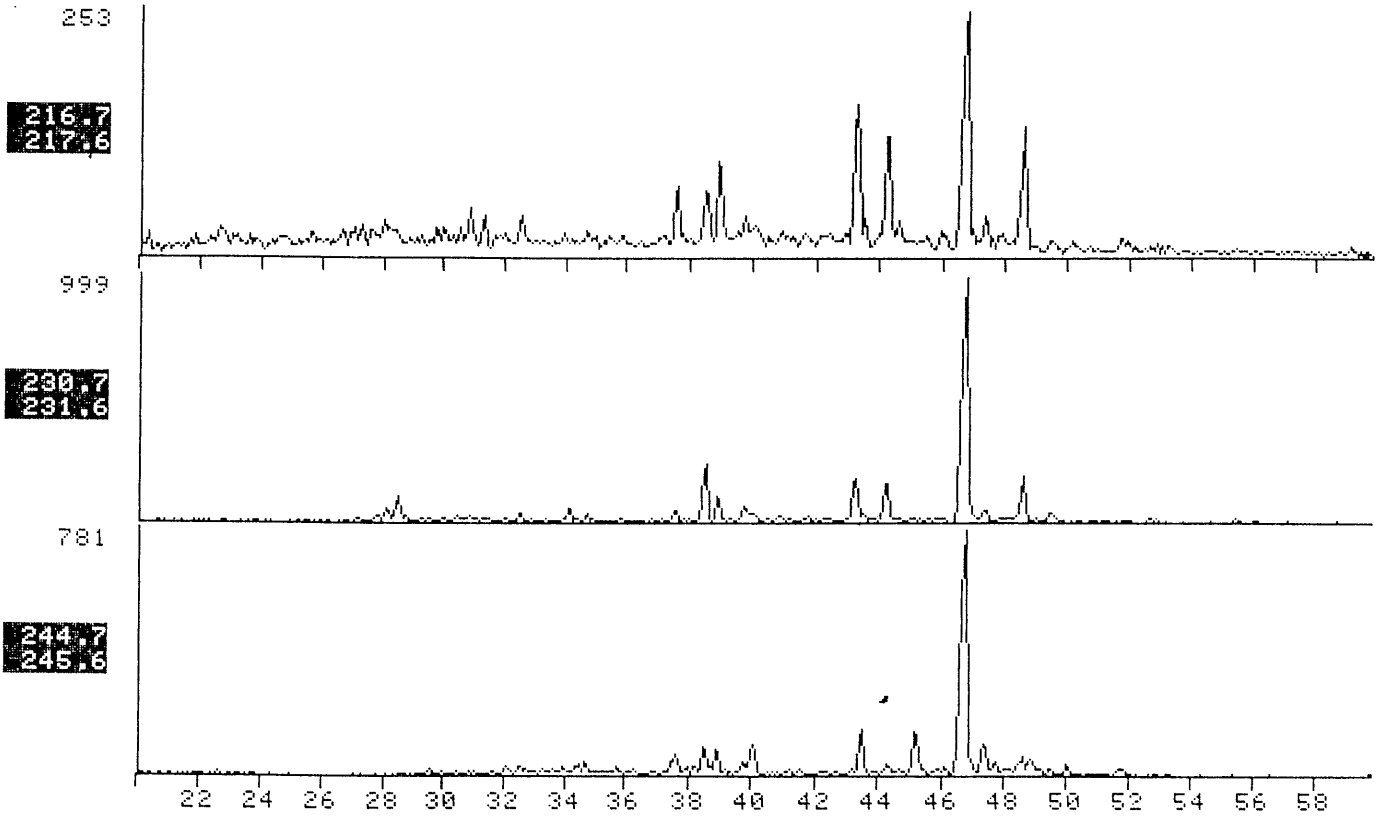
NAME ANGLESEA#1, 497'. AROMATIC FRAGMENTOGRAM.
MISC 19-2-87. GEC. 0.2/50ul. COL#72.

FRN 6185

FIGURE 3-2a

43

231.2
231.2

31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49

1676

253.2
253.2

● MONOAROMATIC STERANES

C29α20R

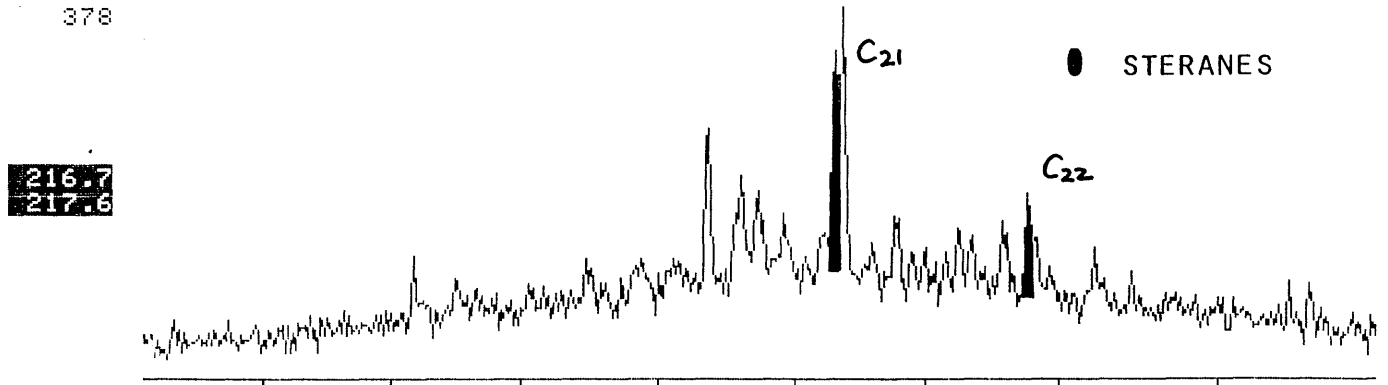26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
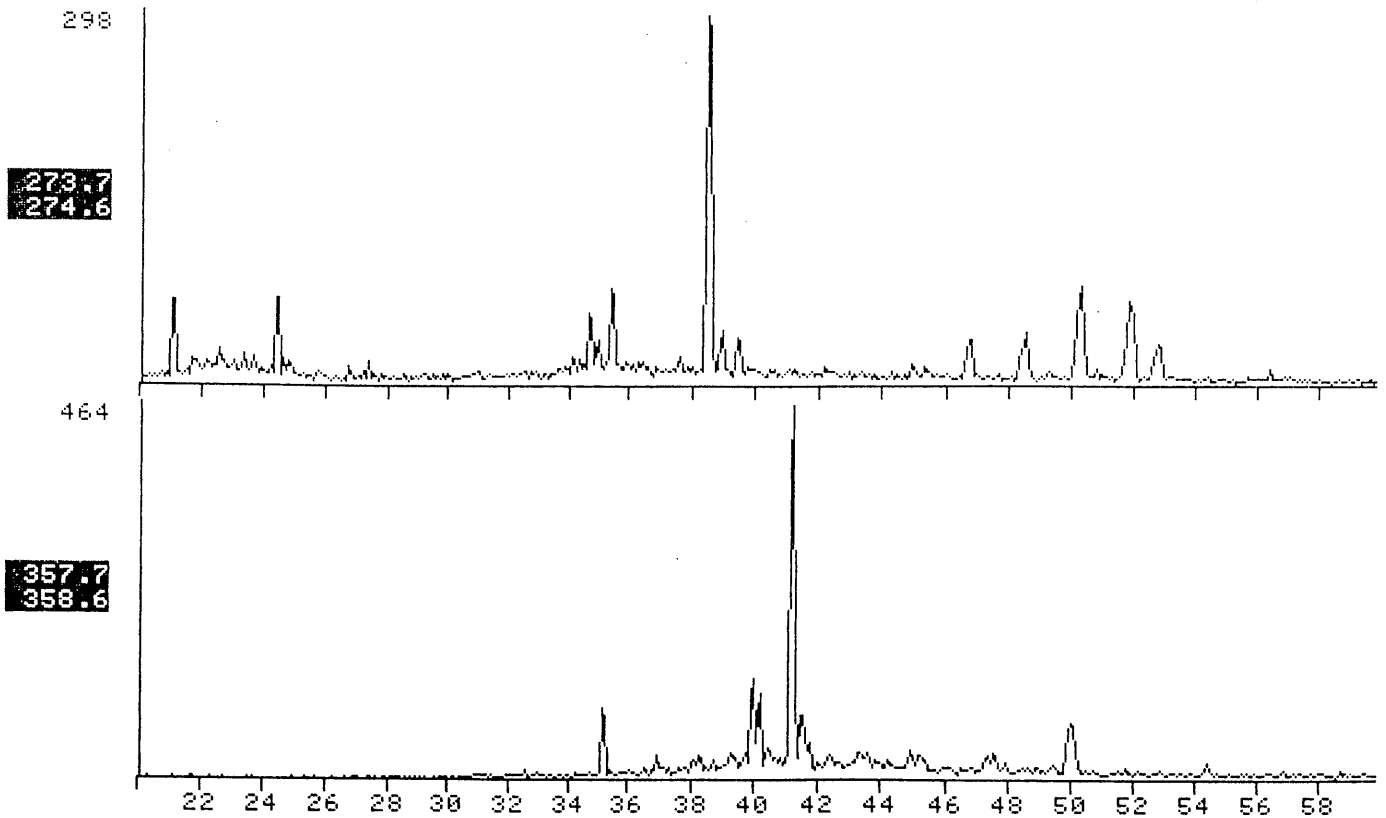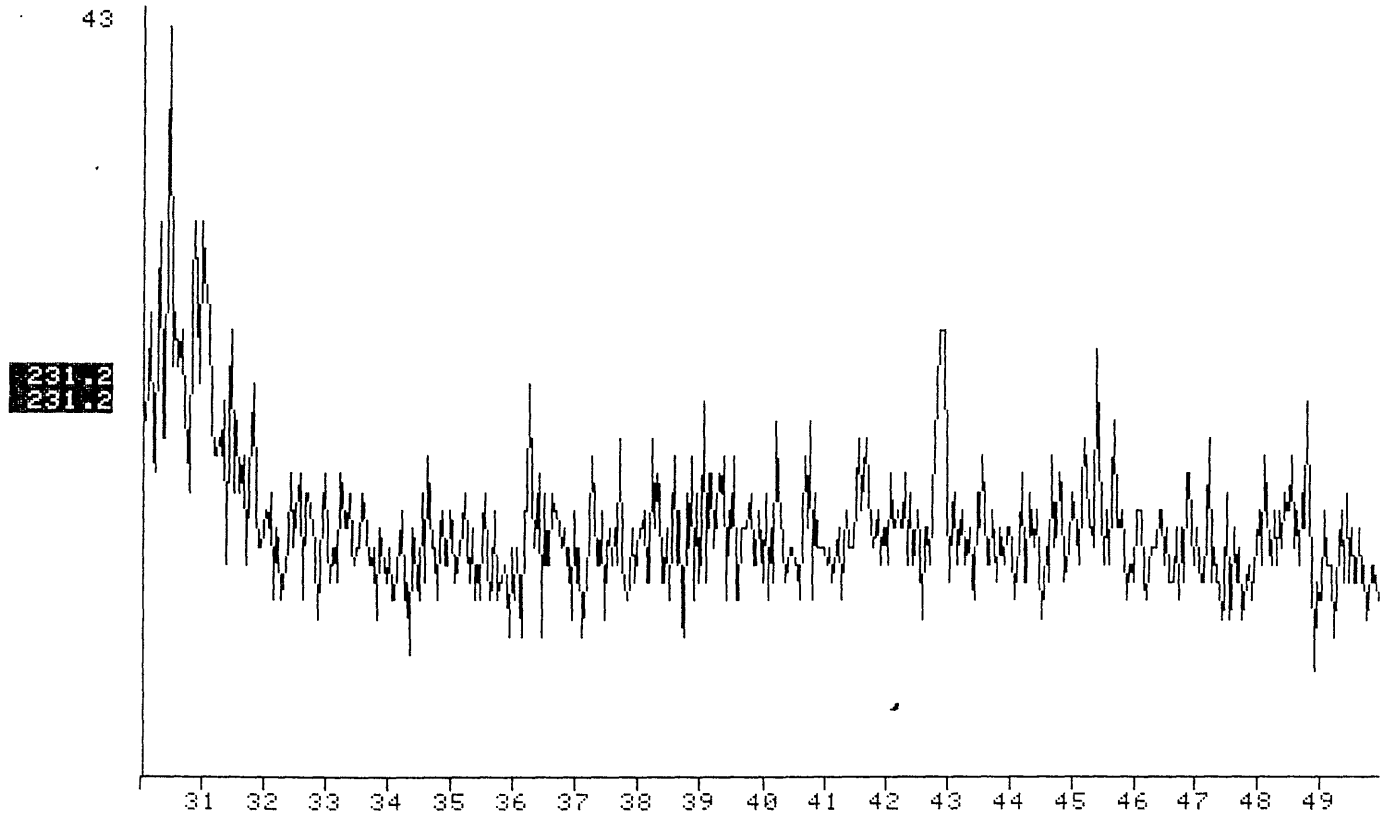
FIGURE 3-2b

FIGURE 3-2c

NAME ANGLESEA#1, 2565'. AROMATIC FRAGMENTOGRAM.
MISC 19-2-87. GEC. 0.250ul. COL#72.   FRN 6166
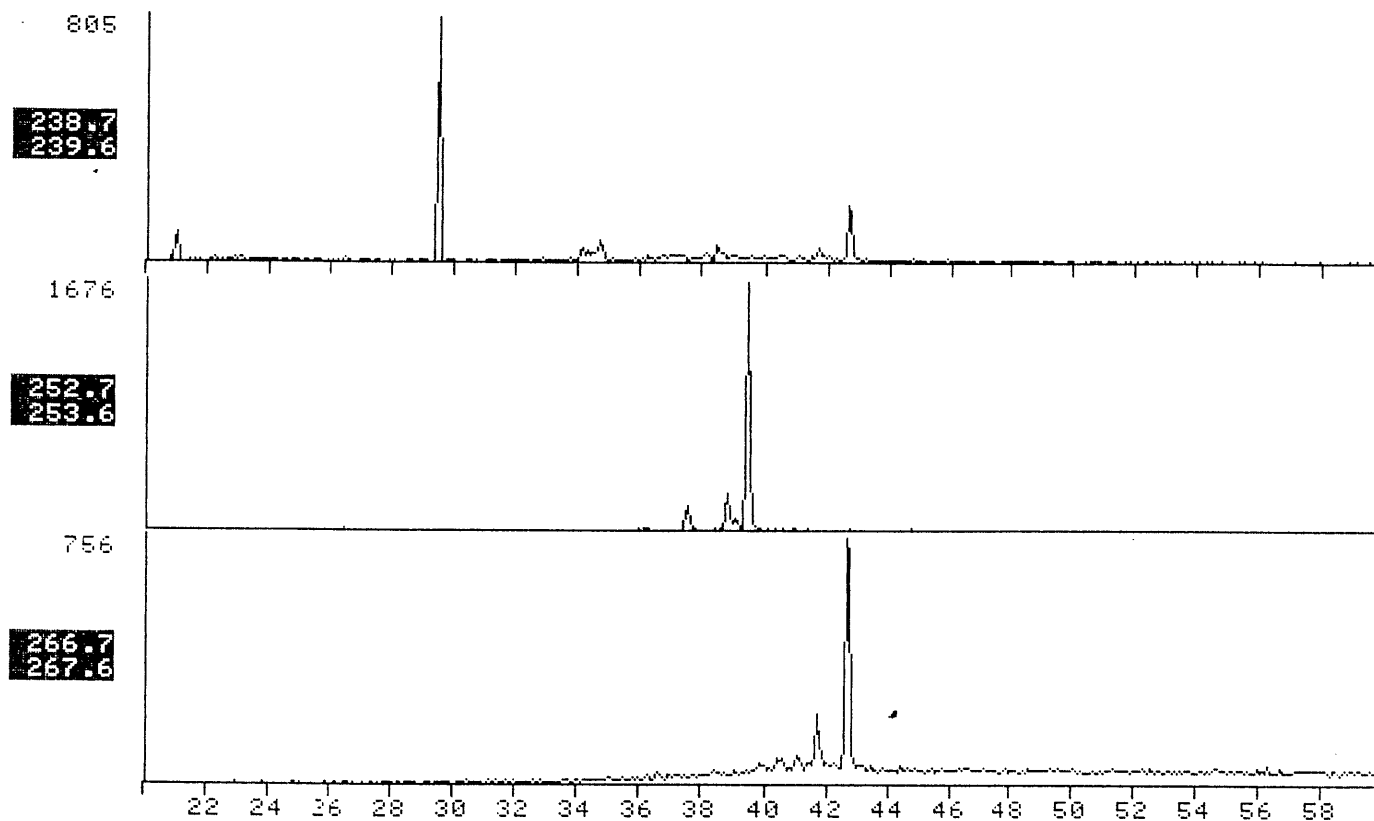
NAME ANGLESEA#1, 2565'. AROMATIC FRAGMENTOGRAM.
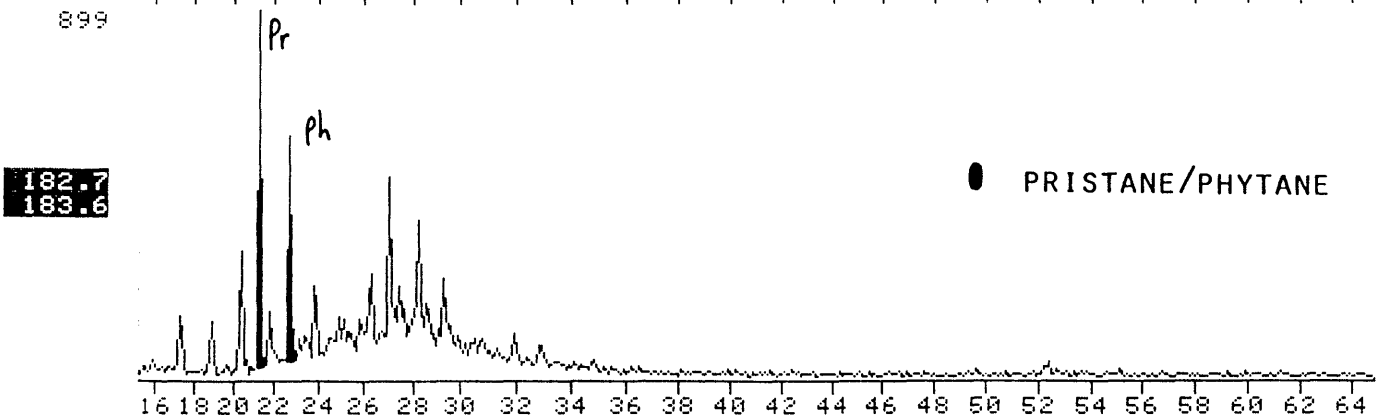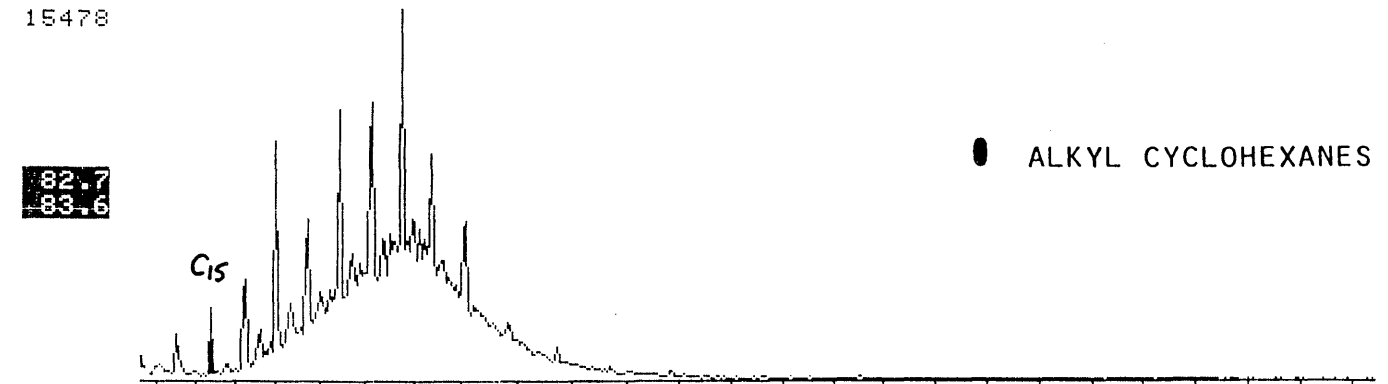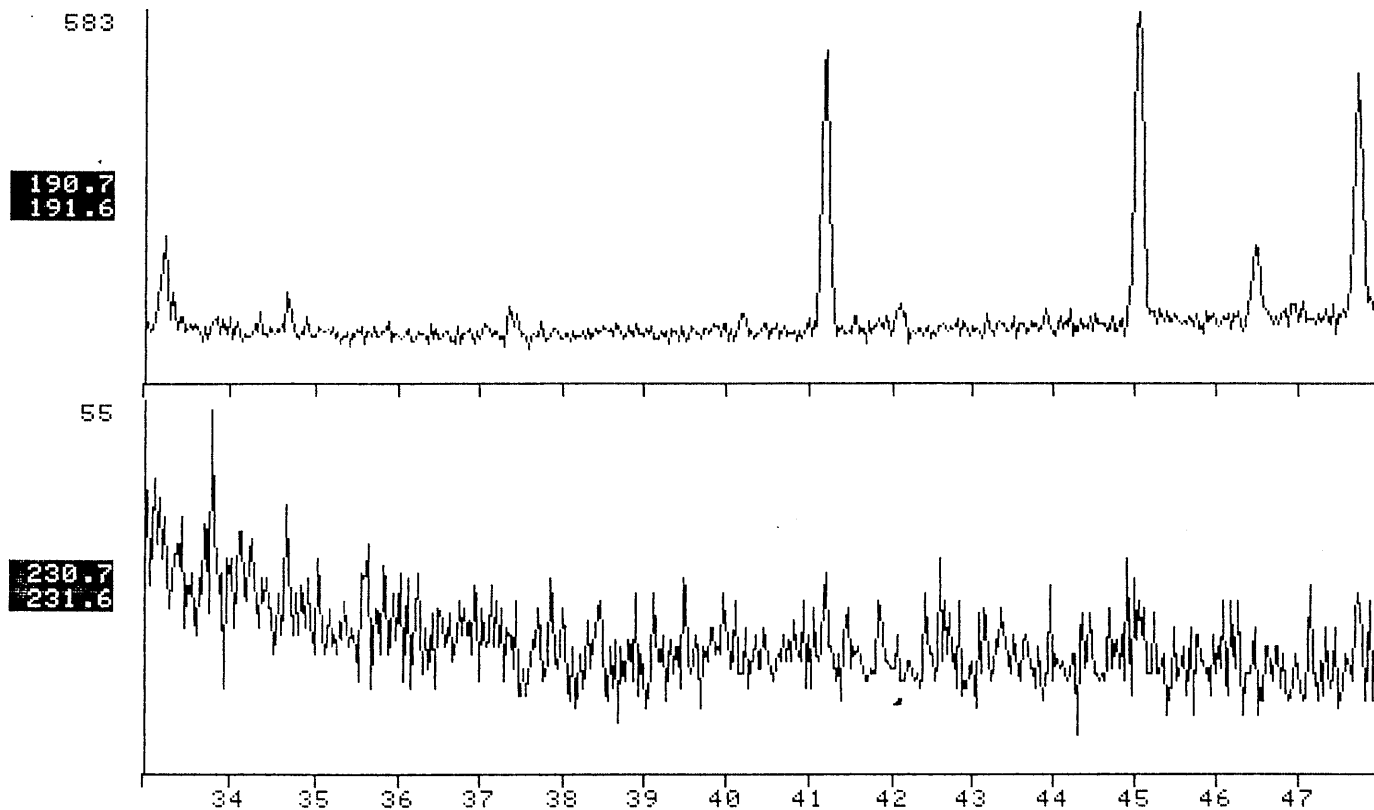MISC 19-2-87. GEC. 0.250ul. COL#72.   FRN 6166
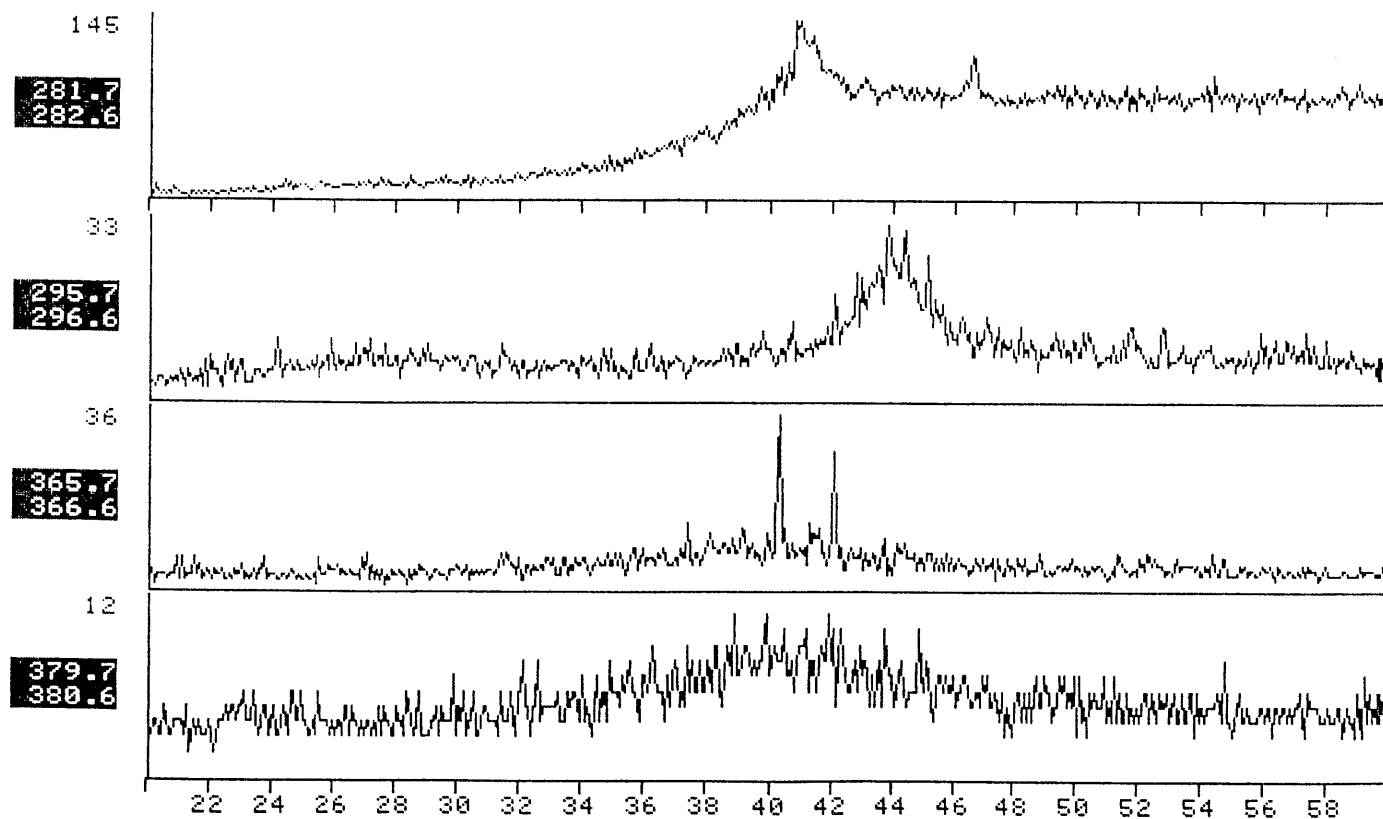
FIGURE 3-3a

NAME ANGLESEA#1, 6239'. AROMATIC FRAGMENTOGRAM.
MISC 19-2-87. GEC. 0.2/120ul. COL#72.
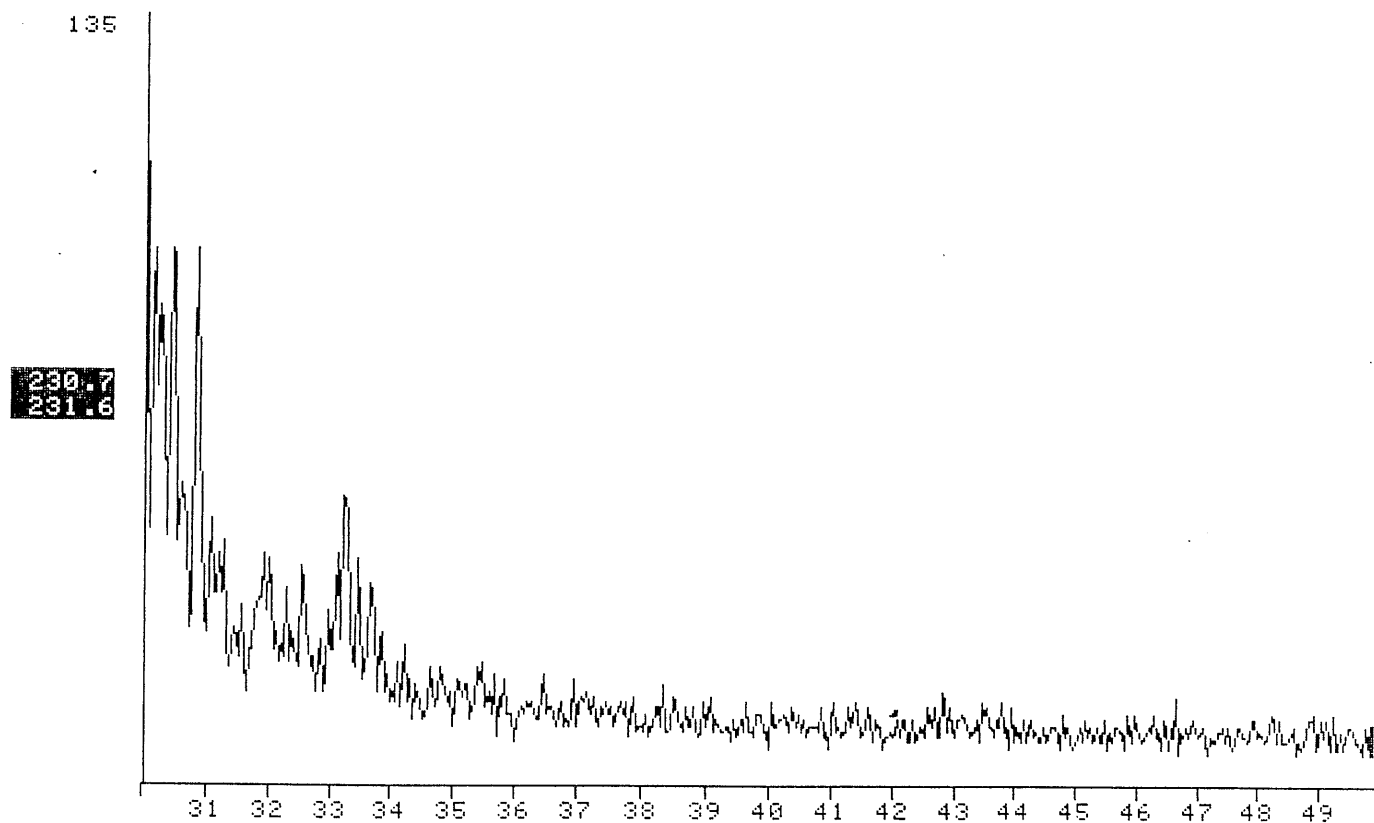
FRN 6168

NAME ANGLESEA#1, 6239'. AROMATIC FRAGMENTOGRAM.
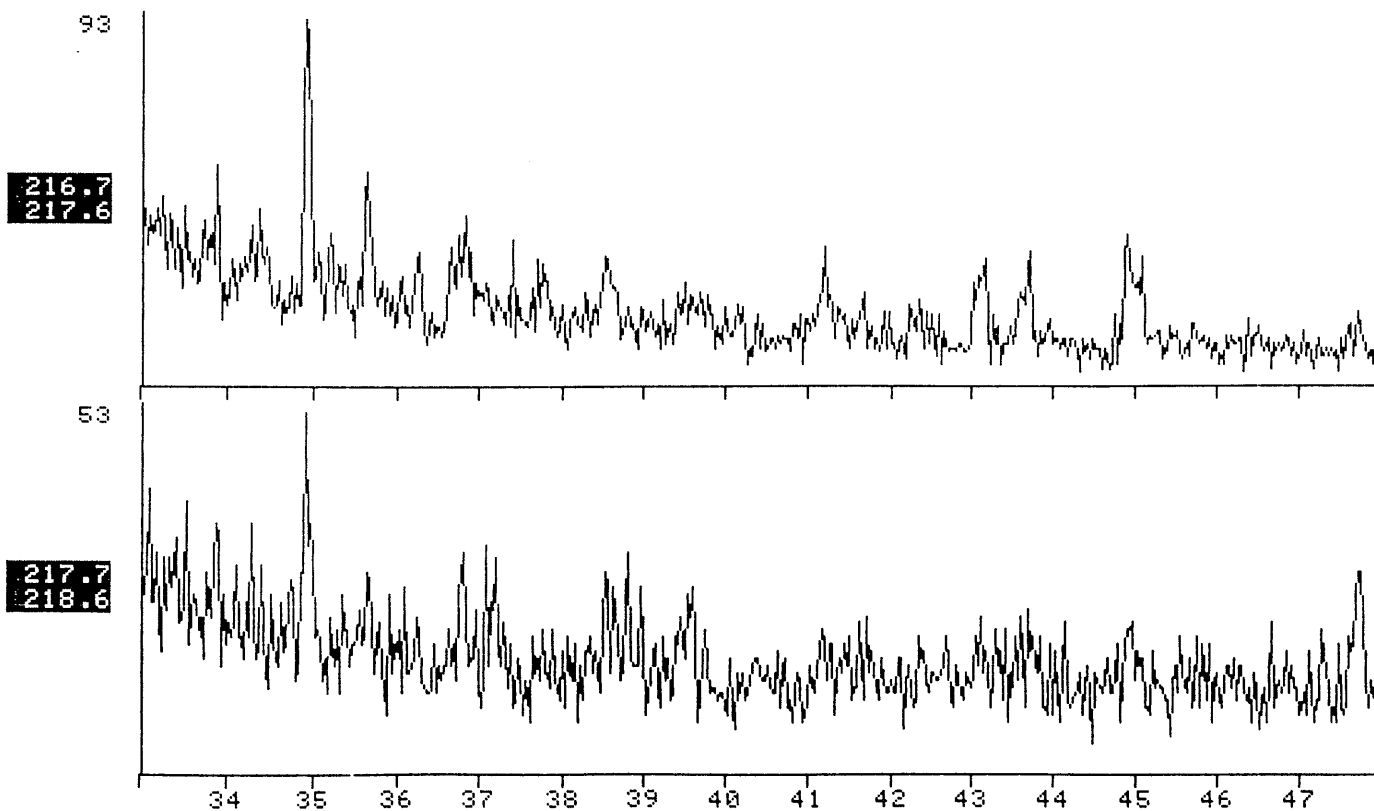MISC 19-2-87. GEC. 0.2/120ul. COL#72.

FRN 6168

MONOAROMATIC STERANES
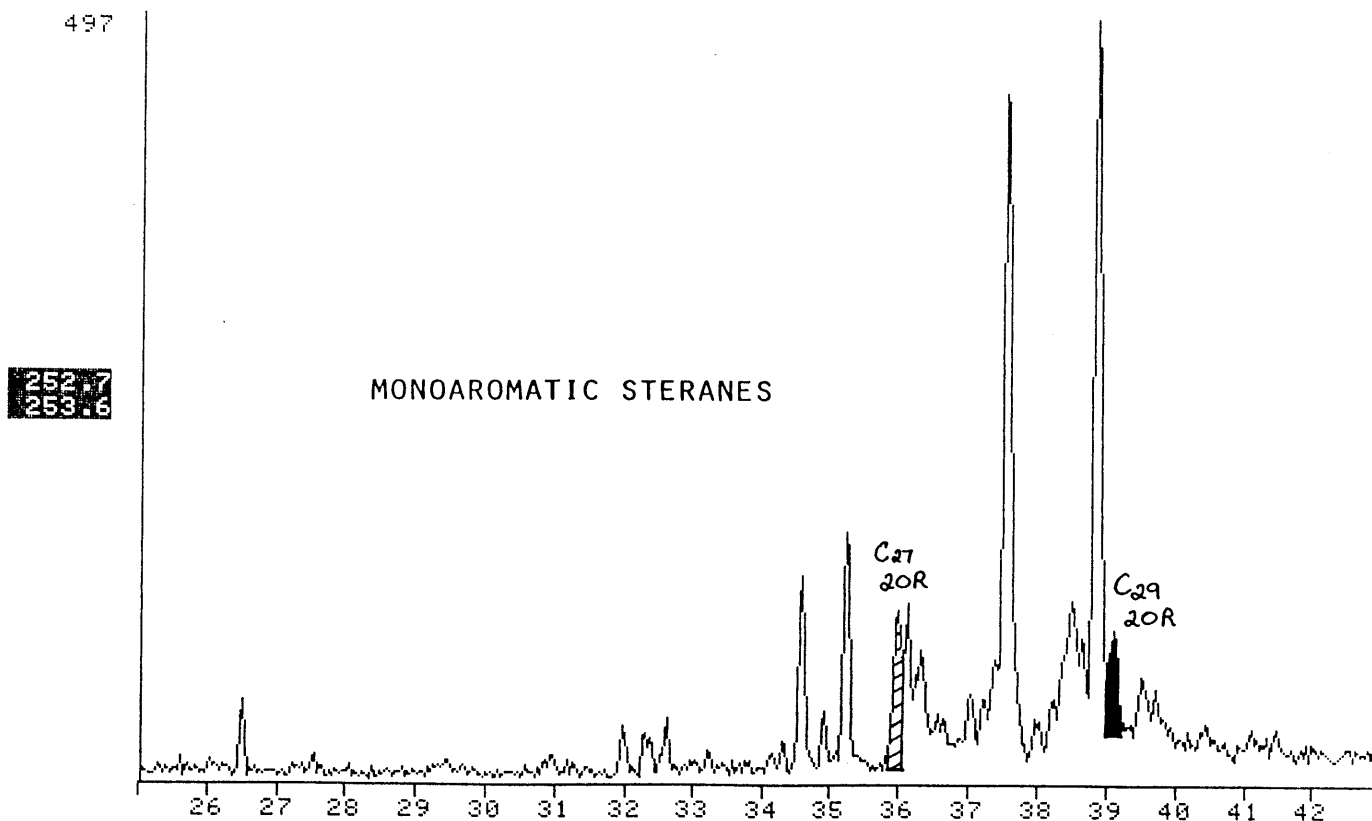
FIGURE 3-3b

NAME ANGLESEA#1, 6239'. AROMATIC FRAGMENTOGRAM.
MISC 19-2-87. GEC. 0.2/120ul. COL#72.   FRN 6168

599

216.7
217.6

274

230.7
231.6

196

244.7
245.6

22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58

NAME ANGLESEA#1, 6239'. AROMATIC FRAGMENTOGRAM.
MISC 19-2-87. GEC. 0.2/120ul. COL#72.   FRN 6168

163

273.7
274.6

48

357.7
358.6

22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58

FIGURE 3-3c
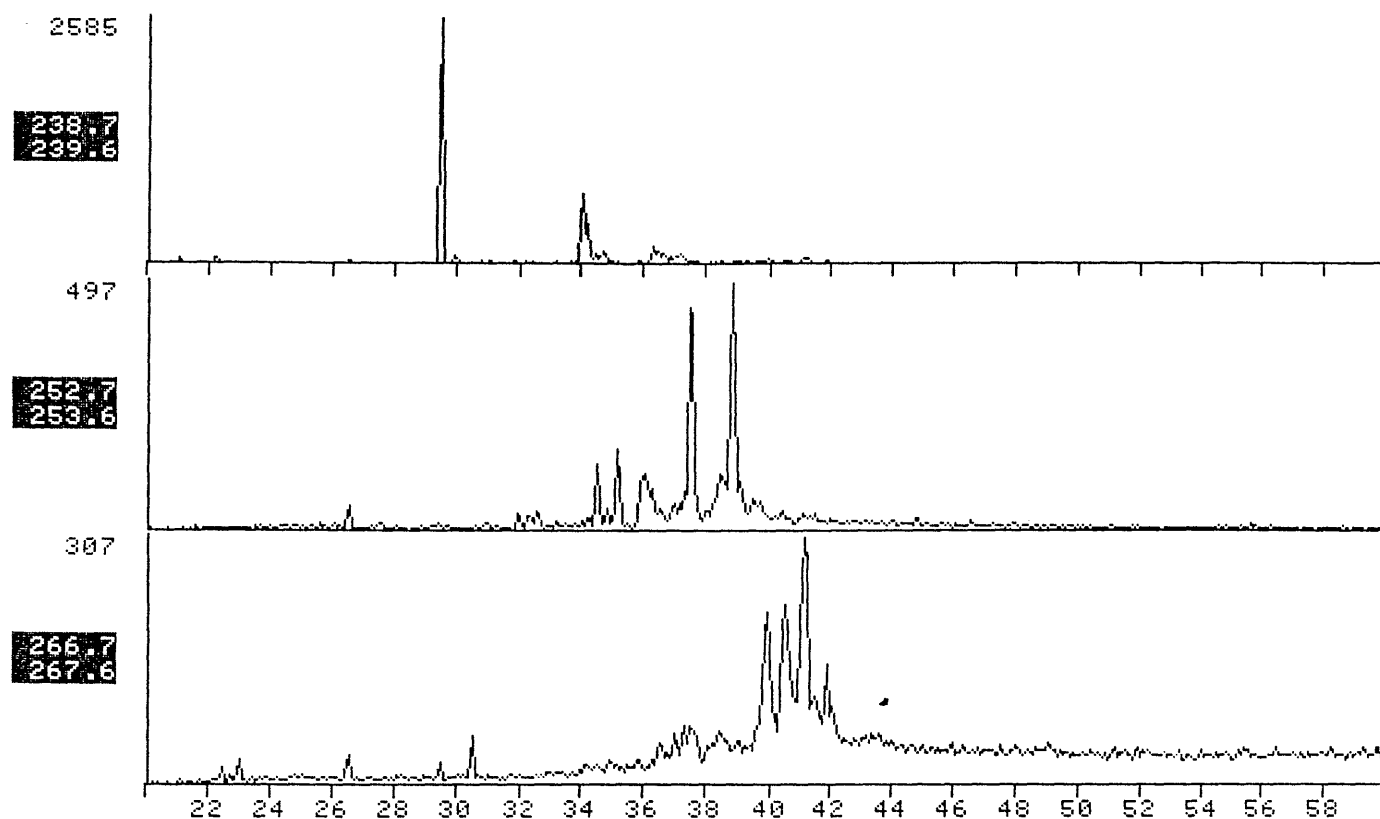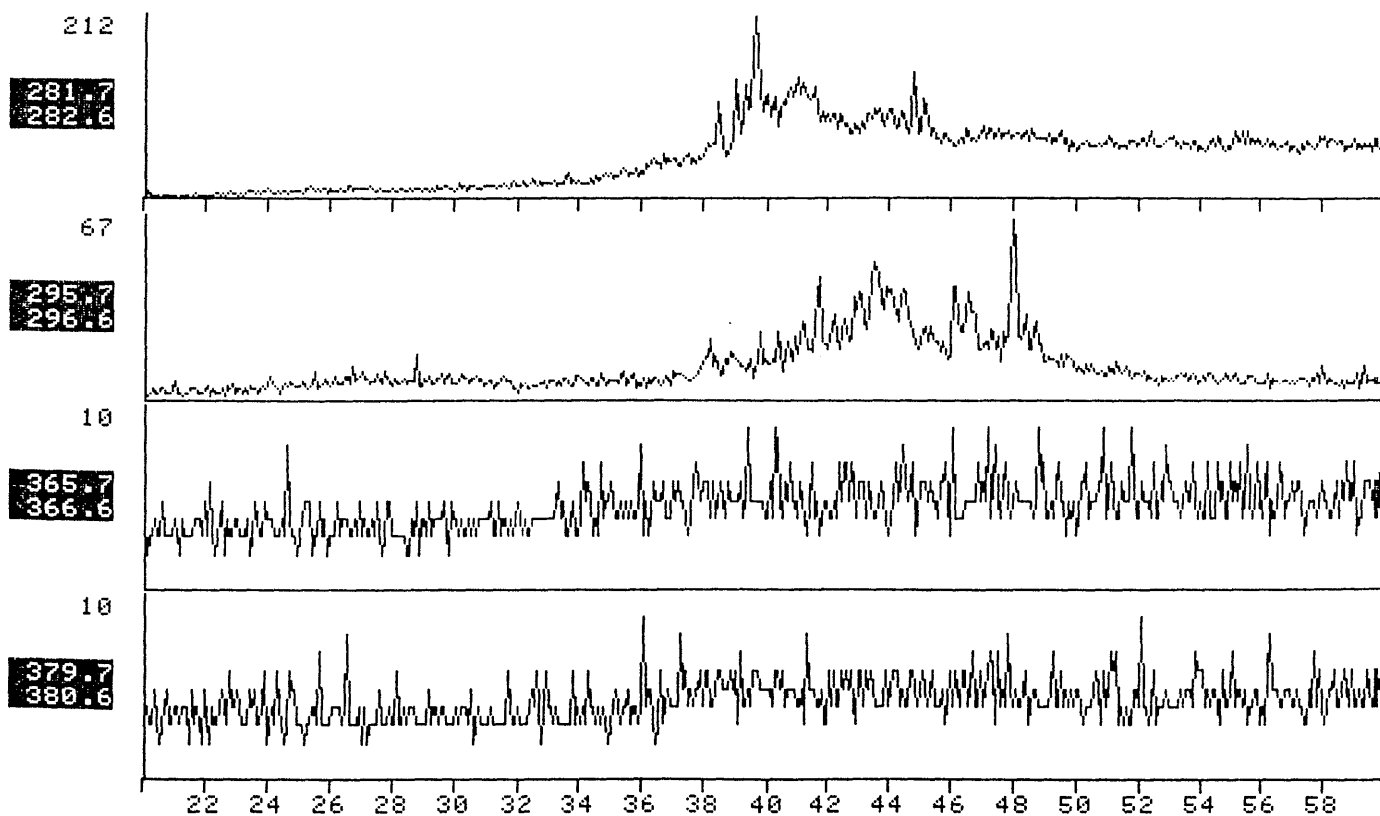
TABLE 1

ROCK-EVAL PYROLYSIS DATA (one run)

WELLNAME = ANGLESEA 1   DATE OF JOB = JANUARY 1987

SAMPLES	TMAX	S1	S2	S3	S1+S2	S2/S3	PI	PC	TOC	HI	OI
497ft Core 1	422	6.98	115.07	31.11	122.05	3.70	0.06	10.13	47.71	241	65
2565ft Core 10	440	0.04	0.31	0.53	0.35	0.58	0.11	0.03	0.83	37	63
6239ft Core 23	493	0.05	0.24	0.16	0.29	1.50	0.17	0.02	0.86	27	18
10060ft Core 33	nd	nd	nd	nd	nd	nd	nd	nd	0.40	nd	nd

TMAX	= Max. temperature S2	S1	= Volatile hydrocarbons (HC)	S2	= HC generating potential
S1+S2	= Potential yield	S3	= Organic carbon dioxide	PI	= Production index
PC	= Pyrolysable carbon	TOC	= Total organic carbon	HI	= Hydrogen index
OI	= Oxygen Index	nd	= no data		

TABLE 2

Summary of Extraction and Liquid Chromatography

Wellname: ANGLESEA 1   Date of Job: FEBRUARY 1987

A. Concentrations of Extracted Material

Depth(ft)	Weight of Rock Extd. (grams)	Total Extract (ppm)	Loss on Column (ppm)	Saturates (ppm)	Aromatics (ppm)	HC Total (ppm)	NSO's (ppm)	Asphaltenes (ppm)	NonHC Total (ppm)
				-------Hydrocarbons--------			-----Nonhydrocarbons-----		
497.0 Core 1	8.9	11674.2	4568.5	679.2	1724.2	2403.4	4702.2	nd	4702.2
2565.0 Core 10	30.3	343.2	75.9	145.2	19.8	165.0	102.3	nd	102.3
6239.0 Core 23	73.1	243.5	43.8	53.4	52.0	105.3	94.4	nd	94.4

B. Compositional Data

Depth(ft)	%SAT.	%AROM.	%HC's	%NSO's	%ASPH.	%Non HC's	EOM(mg) TOC(g)	SAT(mg) TOC(g)	SAT AROM	ASPH NSO	HC Non HC
	-----Hydrocarbons------			-----Nonhydrocarbons------							
497.0 Core 1	9.6	24.3	33.8	66.2	nd	66.2	24.5	1.4	.39	nd	.5
2565.0 Core 10	54.3	7.4	61.7	38.3	nd	38.3	41.4	17.5	7.33	nd	1.6
6239.0 Core 23	26.7	26.0	52.7	47.3	nd	47.3	28.3	6.2	1.03	nd	1.1

na = not applicable   nd = no data

TABLE 3

Summary of Gas Chromatography Data

Wellname: ANGLESEA 1   Date of Job:FEBRUARY 1987

A. Alkane Compositional Data

Depth(ft)	Prist./Phyt.	Prist./n-C17	Phyt./n-C18	CPI(1)	CPI(2)	(C21+C22)/(C28+C29)
497.0 Core 1	.86	.50	.68	3.17	3.99	.29
2565.0 Core 10	.99	.46	.58	1.46	1.74	4.88
6239.0 Core 23	.90	.63	.85	nd	nd	nd

TABLE 3

Summary of Gas Chromatography Data

Wellname: ANGLESEA 1   Date of Job:FEBRUARY 1987

B. n-Alkane Distributions

Depth(ft)	nC12	nC13	nC14	nC15	nC16	nC17	iC19	nC18	iC20	nC19	nC20	nC21	nC22	nC23	nC24	nC25	nC26	nC27	nC28	nC29	nC30	nC31
497.0 Core 1	3.5	4.3	4.4	3.6	3.9	5.1	2.6	4.4	3.0	2.8	1.6	1.5	1.7	3.0	2.1	12.3	3.3	12.4	2.3	8.7	4.7	8.8
2565.0 Core 10	5.3	6.8	9.3	6.5	8.5	12.3	5.6	9.8	5.6	6.5	4.1	2.7	4.6	1.9	1.4	2.9	1.1	1.3	.6	.9	1.3	1.2
6239.0 Core 23	7.7	8.2	15.9	7.4	8.5	9.2	5.8	7.6	6.5	8.4	3.7	2.4	5.2	3.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

na = not applicable   nd = no data

TABLE 4-1

SELECTED PARAMETERS FROM GC/MS ANALYSIS

Sample: ANGLESEA 1, 497ft, Core 1

	Parameter	Ion(s)	Value
1.	$18\alpha(H)$-hopane/$17\alpha(H)$-hopane (Ts/Tm)	191	0.32
2.	C_{30} hopane/C_{30} moretane	191	2.03
3.	C_{31} 22S hopane/C_{31} 22R hopane	191	0.03
4.	C_{32} 22S hopane/C_{32} 22R hopane	191	n.d.
5.	C_{29} 20S $\alpha\alpha\alpha$ sterane/C_{29} 20R $\alpha\alpha\alpha$ sterane	217	0.05
6.	$\dfrac{C_{29} \; \alpha\beta\beta \text{ steranes}}{C_{29} \; \alpha\alpha\alpha \text{ steranes} + C_{29} \; \alpha\beta\beta \text{ steranes}}$	217	0.11
7.	C_{27}/C_{29} diasteranes	259	n.d.
8.	C_{27}/C_{29} steranes	217	n.d.
9.	$18\alpha(H)$-oleanane/C_{30} hopane	191	n.d.
10.	$\dfrac{C_{29} \text{ diasteranes}}{C_{29} \; \alpha\alpha\alpha \text{ steranes} + C_{29} \; \alpha\beta\beta \text{ steranes}}$	217	0.16
11.	$\dfrac{C_{30} \text{ (hopane + moretane)}}{C_{29} \text{ (steranes + diasteranes)}}$	191/217	5.40
12.	C_{15} drimane/C_{16} homodrimane	123	0.26
13.	Rearranged drimanes/normal drimanes	123	0.39
14.	C_{15} alkyl cyclohexane/C_{30} hopane	83/191	0.84
15.	C_{15} alkyl cyclohexane/C_{16} homodrimane	83/123	6.19

n.d. = not detectable

TABLE 4-2

SELECTED PARAMETERS FROM GC/MS ANALYSIS

Sample: ANGLESEA 1, 2565ft, Core 10

	Parameter	Ion(s)	Value
1.	$18\alpha(H)$-hopane/$17\alpha(H)$-hopane (Ts/Tm)	191	0.08
2.	C_{30} hopane/C_{30} moretane	191	1.84
3.	C_{31} 22S hopane/C_{31} 22R hopane	191	1.22
4.	C_{32} 22S hopane/C_{32} 22R hopane	191	3.28
5.	C_{29} 20S $\alpha\alpha\alpha$ sterane/C_{29} 20R $\alpha\alpha\alpha$ sterane	217	0.98
6.	$\dfrac{C_{29}\ \alpha\beta\beta\ \text{steranes}}{C_{29}\ \alpha\alpha\alpha\ \text{steranes} + C_{29}\ \alpha\beta\beta\ \text{steranes}}$	217	0.19
7.	C_{27}/C_{29} diasteranes	259	n.d.
8.	C_{27}/C_{29} steranes	217	n.d.
9.	$18\alpha(H)$-oleanane/C_{30} hopane	191	n.d.
10.	$\dfrac{C_{29}\ \text{diasteranes}}{C_{29}\ \alpha\alpha\alpha\ \text{steranes} + C_{29}\ \alpha\beta\beta\ \text{steranes}}$	217	n.d.
11.	$\dfrac{C_{30}\ (\text{hopane} + \text{moretane})}{C_{29}\ (\text{steranes} + \text{diasteranes})}$	191/217	7.29
12.	C_{15} drimane/C_{16} homodrimane	123	0.36
13.	Rearranged drimanes/normal drimanes	123	0.14
14.	C_{15} alkyl cyclohexane/C_{30} hopane	83/191	2.21
15.	C_{15} alkyl cyclohexane/C_{16} homodrimane	83/123	6.13

n.d.   =   not detectable

TABLE 4-3

SELECTED PARAMETERS FROM GC/MS ANALYSIS

Sample: ANGLESEA 1, 6239ft, Core 23

	Parameter	Ion(s)	Value
1.	$18\alpha(H)$-hopane/$17\alpha(H)$-hopane (Ts/Tm)	191	n.d.
2.	C_{30} hopane/C_{30} moretane	191	n.d.
3.	C_{31} 22S hopane/C_{31} 22R hopane	191	n.d.
4.	C_{32} 22S hopane/C_{32} 22R hopane	191	1.14
5.	C_{29} 20S $\alpha\alpha\alpha$ sterane/C_{29} 20R $\alpha\alpha\alpha$ sterane	217	0.42
6.	$\dfrac{C_{29}\ \alpha\beta\beta\ \text{steranes}}{C_{29}\ \alpha\alpha\alpha\ \text{steranes} + C_{29}\ \alpha\beta\beta\ \text{steranes}}$	217	0.47
7.	C_{27}/C_{29} diasteranes	259	1.92
8.	C_{27}/C_{29} steranes	217	1.38
9.	$18\alpha(H)$-oleanane/C_{30} hopane	191	n.d.
10.	$\dfrac{C_{29}\ \text{diasteranes}}{C_{29}\ \alpha\alpha\alpha\ \text{steranes} + C_{29}\ \alpha\beta\beta\ \text{steranes}}$	217	0.77
11.	$\dfrac{C_{30}\ (\text{hopane} + \text{moretane})}{C_{29}\ (\text{steranes} + \text{diasteranes})}$	191/217	n.d.
12.	C_{15} drimane/C_{16} homodrimane	123	0.54
13.	Rearranged drimanes/normal drimanes	123	0.94
14.	C_{15} alkyl cyclohexane/C_{30} hopane	83/191	n.d.
15.	C_{15} alkyl cyclohexane/C_{16} homodrimane	83/123	30.19

n.d. = not detectable

TABLE 5-1

AROMATIC FRACTION GC/MS DATA

Sample: ANGLESEA 1, 497ft, Core 1

COMPOUND ABUNDANCE

Compound		Ion Used	Relative Abundance (area counts)	(%)	Confirmed
C_{20} Triaromatic Sterane	(A)	231	–	nd	
C_{21} Triaromatic Sterane		231	–	nd	
C_{26} S Triaromatic Sterane	(B)	231	–	nd	
C_{26} R Triaromatic Sterane		231	–	nd	
C_{27} S Triaromatic Sterane		231	–	nd	
C_{27} R Triaromatic Sterane	(C)	231	–	nd	
C_{28} S Triaromatic Sterane	(D)	231	–	nd	
C_{28} R Triaromatic Sterane	(E)	231	–	nd	
C_{21} Monoaromatic Sterane		253	541	13.8	*
C_{22} Monoaromatic Sterane		253	816	20.8	*
C_{27} S Monoaromatic Sterane		253	–	nd	
C_{27} R Monoaromatic Sterane		253	–	nd	
C_{28} S Monoaromatic Sterane		253	294	7.5	*
C_{28} R Monoaromatic Sterane		253	139	3.5	*
C_{29} S Monoaromatic Sterane		253	833	21.2	*
C_{29} R Monoaromatic Sterane	(F)	253	1299	33.1	*

CALCULATED VALUES

Parameter	Value
E/(E+F)	nd
A/(A+E)	nd
B/D	nd
C/E	nd

NOTES: Confirmed samples (*) are those which have been reliably
identified and integrated.

% = % of all compounds integrated.

nd = no data.

TABLE 5-2

AROMATIC FRACTION GC/MS DATA

Sample: ANGLESEA 1, 2565ft, Core 10

COMPOUND ABUNDANCE

Compound		Ion Used	Relative Abundance (area counts)	(%)	Confirmed
C_{20} Triaromatic Sterane	(A)	231	−	nd	
C_{21} Triaromatic Sterane		231	−	nd	
C_{26} S Triaromatic Sterane	(B)	231	−	nd	
C_{26} R Triaromatic Sterane		231	−	nd	
C_{27} S Triaromatic Sterane		231	−	nd	
C_{27} R Triaromatic Sterane	(C)	231	−	nd	
C_{28} S Triaromatic Sterane	(D)	231	−	nd	
C_{28} R Triaromatic Sterane	(E)	231	−	nd	
C_{21} Monoaromatic Sterane		253	−	nd	
C_{22} Monoaromatic Sterane		253	−	nd	
C_{27} S Monoaromatic Sterane		253	−	nd	
C_{27} R Monoaromatic Sterane		253	−	nd	
C_{28} S Monoaromatic Sterane		253	−	nd	
C_{28} R Monoaromatic Sterane		253	−	nd	
C_{29} S Monoaromatic Sterane		253	−	nd	
C_{29} R Monoaromatic Sterane	(F)	253	84	100.0	*

CALCULATED VALUES

Parameter	Value
E/(E+F)	nd
A/(A+E)	nd
B/D	nd
C/E	nd

NOTES: Confirmed samples (*) are those which have been reliably
identified and integrated.

% = % of all compounds integrated.

nd = no data.

TABLE 5-3

AROMATIC FRACTION GC/MS DATA

Sample: ANGLESEA 1, 6239ft, Core 23

COMPOUND ABUNDANCE

Compound		Ion Used	Relative Abundance		Confirmed
			(area counts)	(%)	
C_{20} Triaromatic Sterane	(A)	231	–	nd	
C_{21} Triaromatic Sterane		231	–	nd	
C_{26} S Triaromatic Sterane	(B)	231	–	nd	
C_{26} R Triaromatic Sterane		231	–	nd	
C_{27} S Triaromatic Sterane		231	–	nd	
C_{27} R Triaromatic Sterane	(C)	231	–	nd	
C_{28} S Triaromatic Sterane	(D)	231	–	nd	
C_{28} R Triaromatic Sterane	(E)	231	–	nd	
C_{21} Monoaromatic Sterane		253	–	nd	
C_{22} Monoaromatic Sterane		253	–	nd	
C_{27} S Monoaromatic Sterane		253	–	nd	
C_{27} R Monoaromatic Sterane		253	921	57.4	*
C_{28} S Monoaromatic Sterane		253	–	nd	
C_{28} R Monoaromatic Sterane		253	–	nd	
C_{29} S Monoaromatic Sterane		253	–	nd	
C_{29} R Monoaromatic Sterane	(F)	253	684	42.6	*

CALCULATED VALUES

Parameter	Value
E/(E+F)	nd
A/(A+E)	nd
B/D	nd
C/E	nd

NOTES: Confirmed samples (*) are those which have been reliably

identified and integrated.

% = % of all compounds integrated.

nd = no data.

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 to 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.

i

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 = $\dfrac{S2}{TOC} \quad x \quad \dfrac{100}{1}$

Oxygen Index   = $\dfrac{S3}{TOC} \quad x \quad \dfrac{100}{1}$

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:

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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:

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

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

The following scale is used to classify the source rock richness of samples based on 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.

$$< \ 50 \quad \text{Low maturity}$$
$$50 - 100 \quad \text{Moderate maturity}$$
$$> \ 100 \quad \text{High maturity}$$

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:

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

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

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:

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

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.

Cl-C31 analysis data can be used to obtain the same information as that obtained from Cl2+ GC but further provides detailed compositional data on the Cl-Cll 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

$$C29 \quad \frac{\alpha\alpha\alpha \ (20S)}{\alpha\alpha\alpha \ (20R)+ \ \alpha\alpha\alpha \ (20S)}$$

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 ratio 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 α(H) trisnorhopane to 17 α(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 18α (H) + C27 17α (H) triterpanes to C30 17α ,21β 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

x

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

$$\frac{C27(20R)}{C29(20R)} \quad \text{and} \quad \frac{C27(20R+20S)}{C29(20R+20S)} \quad \text{should reflect the nature of the organic}$$

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):

δ13C (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.

REFERENCES

Alexander, R., Kagi, R. I. and Woodhouse, G. W. "Measurement of thermal maturation of petroleum by proton magnetic resonance spectroscopy". Nature, 276, 1978, 598.

Alexander, R., Kagi, R. I. and Woodhouse, G. W. "A new method for measuring the maturity of petroleum in source rocks". APEA J., 19, 1979, 90-93.

Alexander, R., Kagi, R. I. and Woodhouse, G. W. "Variation in the Ratio of Isomeric Butanes in the Carnarvon Basin of Western Australia". Adv. in Org. Geochem., 1981, pp 76-79.

Cooper, J. E. and Bray, E. E. "A postulated role of fatty acids in petroleum formation". Geochim. Cosmochim. Acta, 27, 1963, 1113-1127.

Fuex, A.N., 1977. "The Use of Stable Carbon Isotopes in Hydrocarbon Exploration". J. Geochem. Expl., 7, 155-188.

Gransch, J. A. and Eisma E. "Characterization of the insoluble organic matter of sediments by pyrolysis". Advances in Organic Geochemistry, 1966, 407-426.

Hunt, J. M. "Geochemistry of Petroleum". Am. Assoc. Pet. Geol. Continuing Education Lecture Series.

LeTran, K., 1975. "Analyse et Etude des Hydrocarbures Gazeux Occlus dans le Sediments: Examples d'Application a l'exploration petroliere". Bull. Centre Rech. Pau. 9, 223-243.

LeTran, K., Connan J. and Van der Weide, B. "Diagenesis of organic matter and occurrence of hydrocarbons and hydrogen sulphide in the S. W. Aquitaine Basin". Bull. Centre Rech., Pau-SNPA, 8, 1974, 111.

Lijmbach, G. W. M. "On the origin of petroleum". Proc. 9th World Petroleum Congress, 2, 195, 357-369.

Mackenzie, A. S. et. al., 1980. Molecular parameters of maturation in the Toarcian Shales, Paris Basin, France-1. Changes in the configurations of acyclic isoprenoids, steranes and triterpanes. Geochim. Cosmochim. Acta, 44:1709:1721.

Philippi, G. T. "The influence of marine and terrestrial source material on the composition of petroleum". Geochim. Cosmochim. Acta, 38, 1974, 947.

Powell, T. G. and McKirdy, D. M. "Geological factors controlling crude oil composition in Australia and Papua New Guinea". Amer. Assoc., Petrol. Geol., 59, 1975, 1176.

Scalan R. S. and Smith J. E. "An improved measure of the odd-even predominance in the normal alkanes of sediment extracts and petroleum". Geochim. Cosmochim. Acta, 34, 1970, 611-620.

Seifert, W. K. 1978. Steranes and terpanes in kerogen pyrolysis for correlation of oils and source rocks. Geochim. Cosmochim. Acta, 42:473-484.

Seifert, W. K. and Moldowan, J. M. 1979. "Application of biological marker chemistry to petroleum exploration". Special paper, 10th World Petroleum Congress, Bucharest.

Seifert, W. K. and Moldowan, J. M. 1978. "Application of steranes, terpanes and monoaromatics to the maturation, migration and source of crude oils". Geochim. Cosmochim. Acta, 42:77-95.

Seifert, W. K. and Moldowan, J. M. 1979. "The effect of biodegradation on steranes and terpanes in crude oils". Geochim. Cosmochim. Acta 43:111-126.

Seifert, W. K. and Moldowan, J. M. 1981. "Paleoreconstruction by biological markers". Geochim. Cosmochim. Acta, 45:783-794.

Stahl, W. J. "Carbon and nitrogen isotopes in hydrocarbon research and exploration". Chem. Geol., 20, 1977, 121-149.

Stahl, W. J. "Source rock-crude oil correlation by isotopic type-curves". Geochim. Cosmochim. Acta, 42, 1978, 1573-1577.

Tissot, B. et. al. "Origin and evolution of hydrocarbons in early Toarcian shales, Paris Basin, France". Amer. Assoc. Petrol. Geol., 55, 1971, 2177.

Tissot, B. et. al. Influence of nature and diagenesis of organic matter in the formation of petroleum". Amer. Assoc. Petrol. Geol., 58, 1974, 499.

Tissot, B. and Welte, D. H. "Petroleum Formation and Occurrence". Springer-Verlag. Berlin, Heidelberg, New York, 1978.

Welte, D. H., et. al. "Correlation between petroleum and source rock". Proc. 9th World Petroleum Congress, 2, 1975, 179-191.