

R4997
Copy 8 of 12

DEPT. NAT. RES & ENV



PE800947

GIPPSLAND BASIN
HYDROCARBON REPORT

PETROLEUM GEOCHEMISTRY

HYDROCARBON SOURCE ROCK

EVALUATION STUDY

BIGNOSE NO. 1

W832

OIL and GAS DIVISION

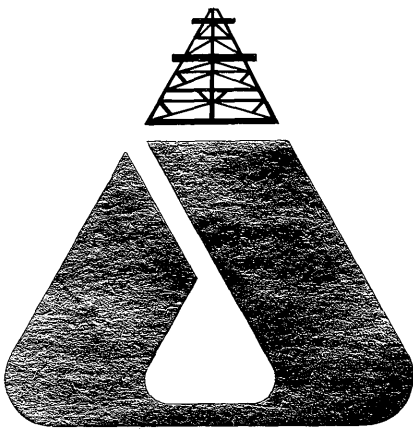
22 MAR 1984

ANALABS
BIGNOSE-1.

Prepared for

SHELL DEVELOPMENT (AUST.) PTY. LTD.

January, 1984.



ANALABS

A Division of Macdonald Hamilton & Co. Pty. Ltd.

52 MURRAY ROAD, WELSHPOOL, W.A. 6106.

Telephone (09) 458 7999

Telex: ANALAB AA92560

911
M/C Box
BAY B.

HYDROCARBON SOURCE ROCKEVALUATION STUDYBIGNOSE NO. 1SUMMARY

Organic geochemical analyses performed on twenty-three (23) side wall cores and two crude oil samples, taken from 2822.5m to 3939m in the Shell Development (Australia) Pty. Ltd. Bignose No. 1 well, drilled offshore Victoria, Australia have indicated the following:

- ° The maturity of the sediments range from marginally mature, at 2822.5m, to moderately mature levels at 3939m. The rocks between 2822.5m to 3747m are marginally mature and interpreted to be in the initial stages of oil and gas generation. The sediments from 3796m to 3939m are moderately mature, within the upper portions of the oil window.
- ° These sediments are interpreted to be too immature to have generated significant quantities of insitu hydrocarbons. However these rocks are organic rich with the potential of generating large amounts of petroleum at higher levels of thermal maturity. The following lists the organic facies present within this analysed interval, along with an interpretation of their hydrocarbon generating source potential at higher levels of maturation.

<u>Facies</u>	<u>Depth</u>	<u>Hydrocarbon Source Potential</u>
1	2822.5-3212m	Marginal to excellent
2	3318.5-3542m	Excellent
3	3567-3569m	Good
4	3591-3796m	Excellent
5	3863-3939m	Moderate

- ° The crude oil recovered at 3557.5m, from this well is characterised as a mature to very mature, good quality, saturate rich, migrated out-of-place hydrocarbon, which may have been sourced from more thermally mature equivalents to the very organic-rich rocks penetrated, and analysed from this well.

Paul Tybor

PAUL TYBOR

INTRODUCTION

Organic geochemical analyses have been performed on twenty-three (23) side wall core samples, from 2822.5m to 3939m, and two light crude oil samples from 3557.5m, in the Shell Development (Aust.) Pty. Ltd. Bignose No. 1 well, drilled offshore Victoria, Australia.

The purpose of this study has been to evaluate the hydrocarbon source quality (oil vs gas), richness and state of thermal maturity (pre oil, oil generative, post oil generative) of the sediments penetrated and analysed from this well. In addition, the oil recovered from this well, at 3557.5m, has been characterised and compared to the rocks analysed, to determine if any genetic relationships exist between the sediments and the oil.

ANALYTICAL

Upon arrival at Analabs, the samples from this well were assigned the Analabs Job Number 31194. The twenty-three cores were air-dried, ground and submitted to % total organic carbon determination, followed by Rock Eval pyrolysis analysis. Based on these screen analyses, Shell Development (Aust.) Pty. Ltd. personnel chose ten (10) of the samples for extraction, liquid chromatography and C₁₂⁺ saturate gas chromatography.

The two oil samples were submitted to liquid chromatographic separation, C₁₂⁺ saturate gas chromatography and whole oil gas chromatography. The results of these analyses are located in the following:

<u>Type of Analysis</u>	<u>Figure</u>	<u>Table</u>
<u>Side Wall Core Samples</u>		
% Total organic carbon determination	1	1
Pyrolysis Rock Eval Analysis	1	1
Extraction and liquid chromatography	2	2

<u>Type of Analysis (cont.)</u>	<u>Figure</u>	<u>Table</u>
C ₁₂ ⁺ saturate gas chromatography	3,4A to 4J	3
<u>Crude Oil Samples</u>		
Liquid chromatography		4
C ₁₂ ⁺ saturate gas chromatography	5A, 5B	5
C ₄ -C ₃₁ Whole oil gas chromatography	6A, 6B	6

Descriptions of the analyses performed on the rocks and crude oils recovered from this well are presented in the Theory and Methods Section located at the back of this report.

Copies of this report have been sent to Mr. J. G. Stainforth of Shell Development (Aust.) Pty. Ltd., located in Perth, Western Australia. Any questions regarding this study can be directed to either Mr. Paul Tybor or Dr. Garry Woodhouse of Analabs in Perth, Western Australia.

All data and interpretations given herein are proprietary to the Shell Development (Aust.) Pty. Ltd., and are treated as highly confidential material by all Analabs personnel.

RESULTS AND INTERPRETATIONS

A. Thermal Maturity of Sediments

The rocks analysed from this well have thermal maturities that range from marginally mature at 2822.5m, to moderately mature at 3939m. Between 2822.5m to 3765m, the sediments are interpreted to be marginally mature, in the initial stages of petroleum generation. The rocks from 3796m to 3939m are interpreted to be moderately mature, within the upper portions of the oil window.

This interpretation is based on Tmax pyrolysis temperatures and Production index values (P.I.; Figure 1; Table 1) obtained from the pyrolysis analyses performed on these samples. The samples from 2822.5m to 3765m have Tmax temperatures generally below 435°C, the temperature held to represent the boundary between marginally and moderately mature. The P.I. values for these samples are all, with the exception of the sample at 3212m with a 0.19 PI value, below 0.10, and suggest a low degree of thermal maturity for these rocks. The moderately mature samples between 3796m to 3939m have Tmax temperatures of 437°C and 438°C, with two of the three samples having P.I. values of 0.11 and 0.12. These parameters indicate a moderately mature level of thermal maturation has been achieved by these lower-most sediments. Also the CPI index values of the two samples from 3796m and 3939m are 1.34 and 1.35 respectively, which are significantly lower than the CPI values computed from the overlying samples. This suggests that the rocks between 3796m to 3939m have experienced a slightly more mature geothermal history than the overlying sediments.

B. Hydrocarbon Source Characterisation

All of the samples analysed between 2822.5m to 3939m contain at least good amounts of organic matter (>1.0% TOC; Figure 1; Table 1), with the majority of the samples containing excellent amounts of organic richness (>4.00% TOC). Based on these variations in richness, this sedimentary sequence can be divided into five organic facies as shown by the following:

<u>Organic Facies</u>	<u>Depth</u>	<u>%T.O.C.</u>	<u>Hydrogen Index</u>
1	2822.5-3212m	1.10-11.10 4.24mean	74-327 171mean
2	3318.5-3542m	12.16-55.82 31.50mean	259-744 420mean
3	3567-3569m	3.84-5.77 4.80mean	135-136 145mean
4	3591-3796m	8.80-43.40 25.74mean	274-615 421mean
5	3863-3939	1.35-1.68 1.51mean	124-205 164mean

It should be noted that the number of samples analysed from these facies are in some cases limited, and as a result care should be taken in determining just how significant the data is to a true representation of that facies. At any rate, the maturity of these sediments is considered too low for any significant amount of insitu hydrocarbon to have been generated. This is evidenced by the low Production Index values determined for these samples. However, at slightly more mature levels of maturation certain portions within all of the above identified facies would be capable of generating oil and gas. The following lists these facies in order of hydrocarbon generating potential.

<u>Facies</u>	<u>Potential Yield</u>	<u>Hydrocarbon Source Potential</u>
2- 3318.5-3542m	46.02-208.12mg/g 129.80mg/gmean	Excellent
4- 3591-3745.5m	36.84-198.29mg/g 114.12mg/gmean	Excellent
1- 2822.5-3212m	1.08-18.95mg/g 7.73mg/gmean	Marginal to Excellent
3- 3567-3569m	5.57-9.67mg/g 7.63mg/gmean	Good
5- 3863-3939m	2.35-3.13mg/g 2.74mg/gmean	Moderate

Extraction, liquid chromatography and C₁₂⁺ saturate gas chromatography was carried on samples from Facies 1, 2, 4 and 5. The results confirm that Facies 2 and 4 are the most organic rich, with EOM levels ranging between very good to excellent amounts (Figure 2; Table 2). However, the extracts contain high amounts of aromatic hydrocarbon, which is reflecting the low degree of thermal maturity of this sequence.

In summation, the rocks between 2822.5m to 3939m contain organic richness levels ranging between good to excellent, with moderate to excellent hydrocarbon generating potential at more mature levels of thermal alteration.

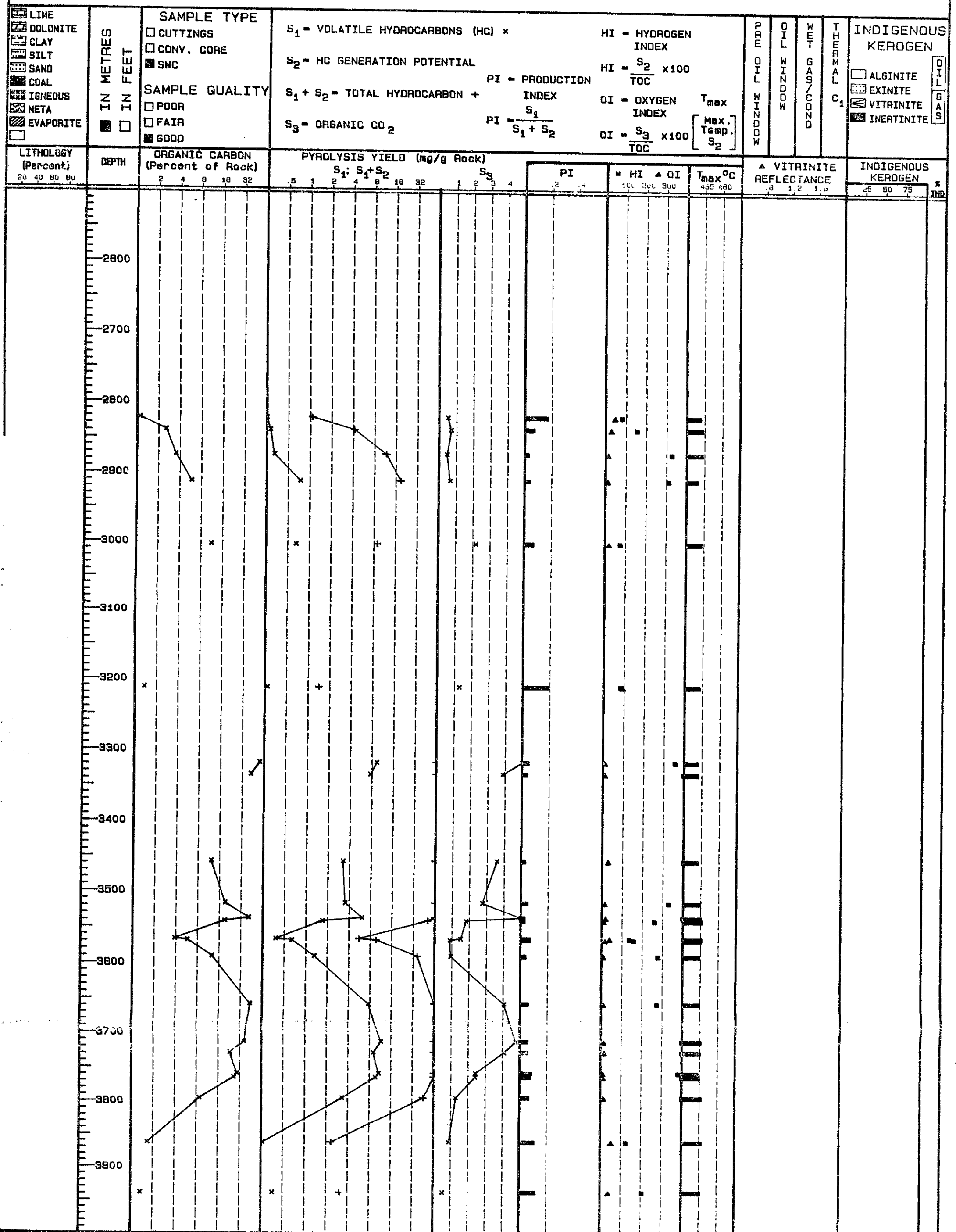
C. Crude Oil Characterisation

A crude oil was recovered at 3557.5m from this well, and two samples of it were sent for analysis. Based on the results of the analyses performed on the two samples, this crude oil is characterised as a mature to very mature, good quality, saturate rich, migrated out-of-place light hydrocarbon.

The high maturity of this hydrocarbon is based on the skewing of the normal alkanes in the whole oil GLC, towards the lighter molecules (n-C₇ - n-C₉; Figures 6A, 6B; Table 6A, 6B). Also, the hydrocarbon fraction is comprised of greater than 90% saturates (Table 4), with resulting in extremely high SAT/AROM ratios (16.75, 18.82; Figure 2; Table 4). As a result this light crude oil is interpreted to be migrated, out-of-place, reservoired within marginally mature sediments. This crude may have originated from more thermally mature equivalents to the very organic rich sediments penetrated and analysed from this well.

ANA-LOG

HYDROCARBON SOURCE ROCK EVALUATION



ANA-LOG

HYDROCARBON SOURCE ROCK EVALUATION

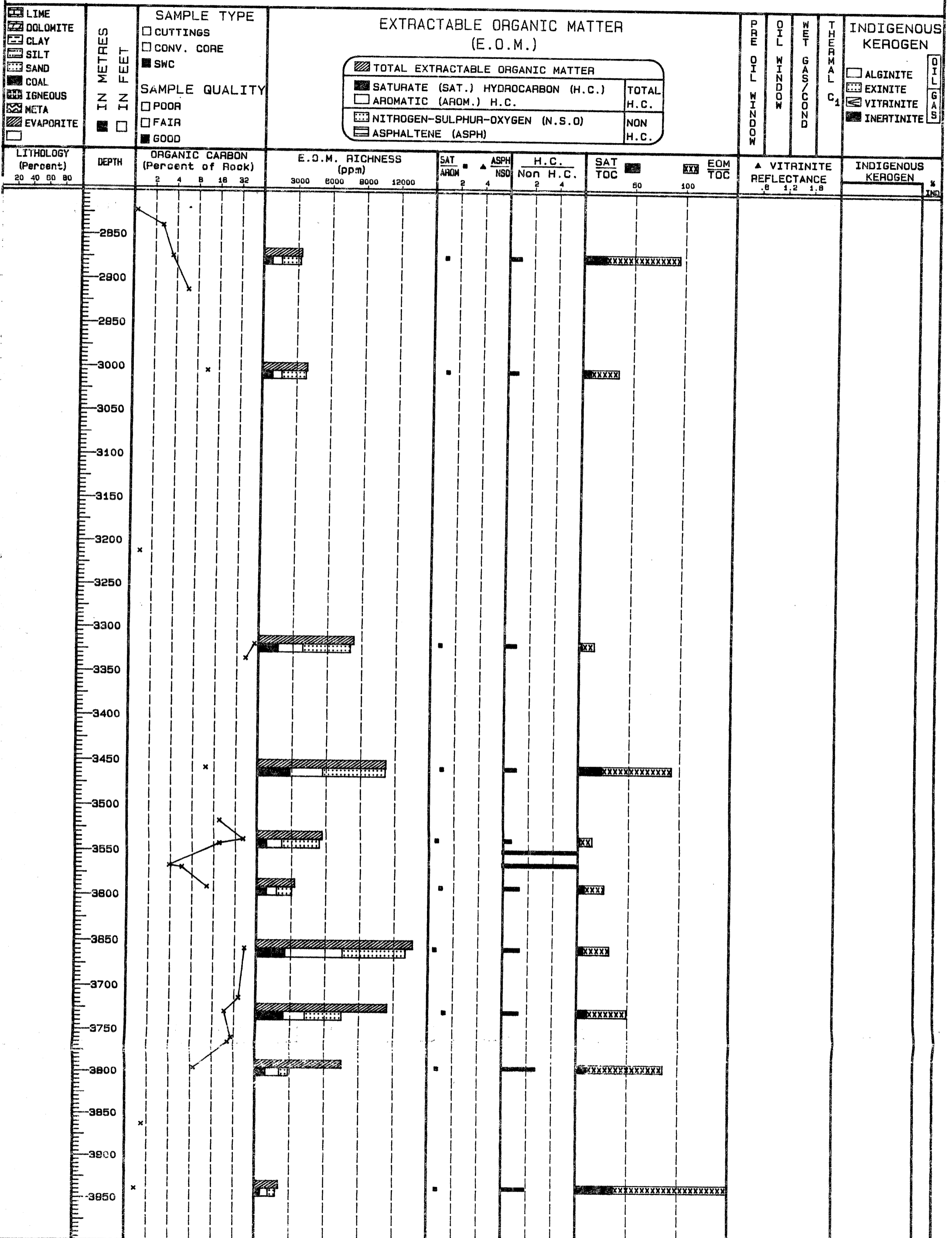


FIGURE 4A
BIGNOSE #1 2874.0m
Saturated Fraction
C₁₂+ G.L.C.

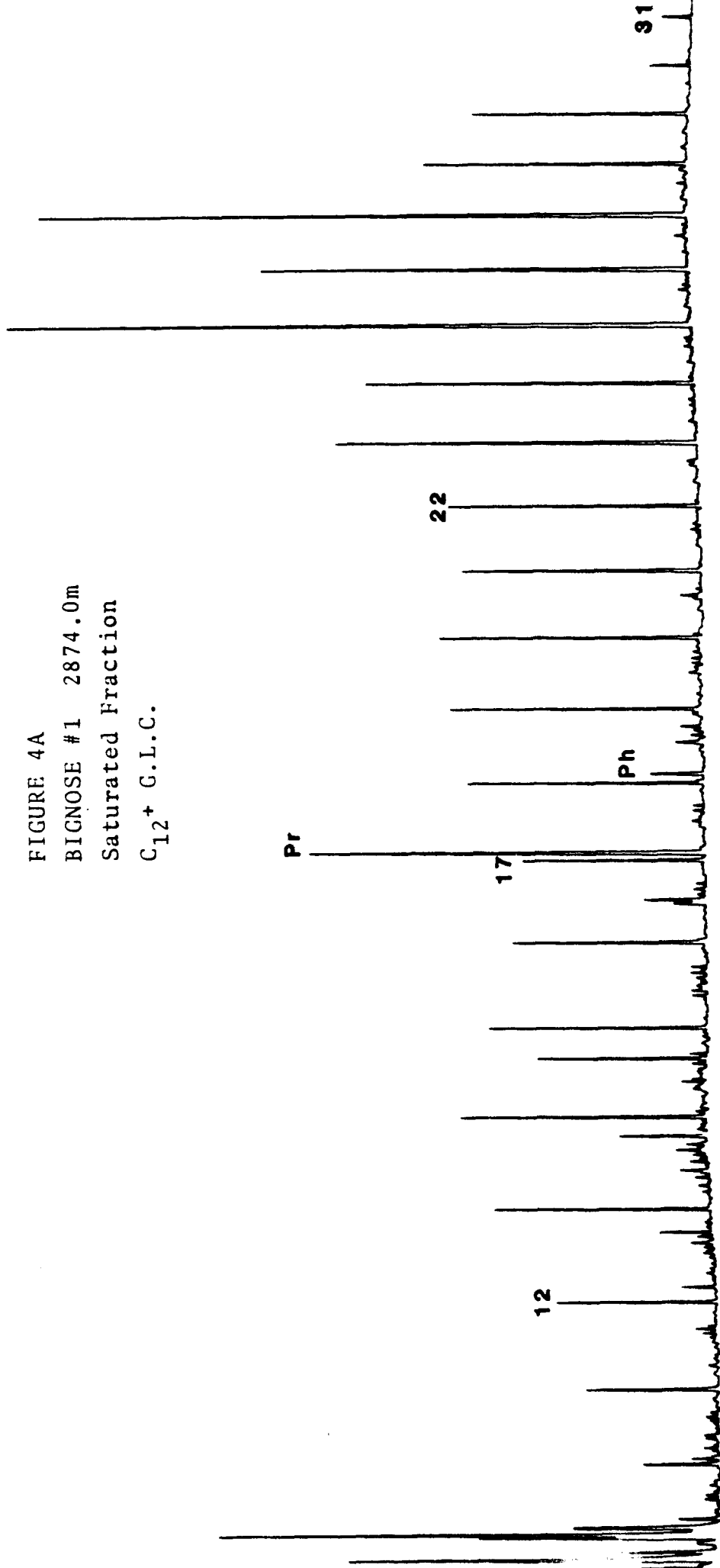


FIGURE 4B
BIGNOSE #1 3004.0m
Saturated Fraction
C₁₂+ G.L.C.

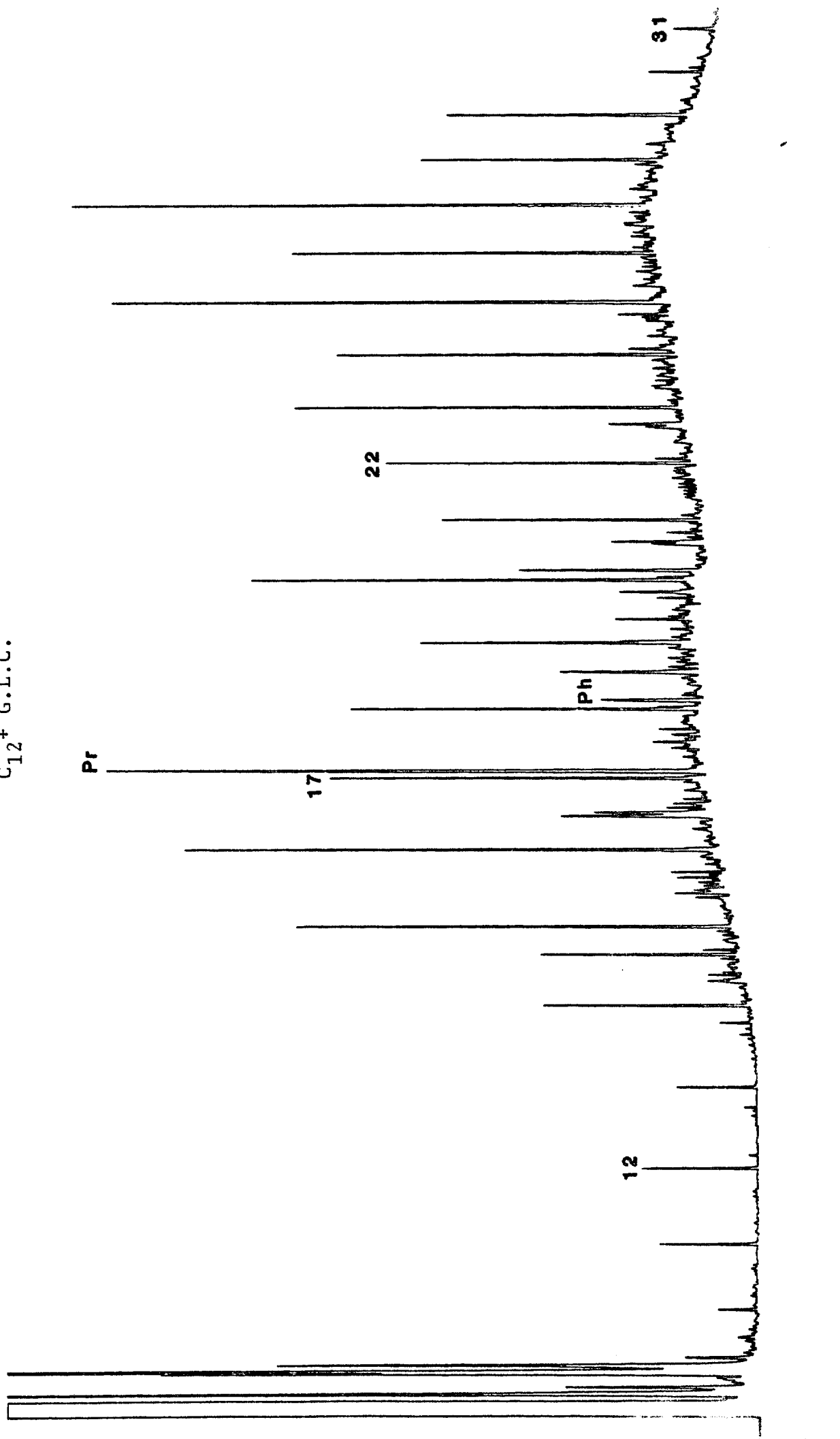


FIGURE 4C
BIGNOSE #1 3318.5m
Saturated Fraction
C₁₂+ G.L.C.

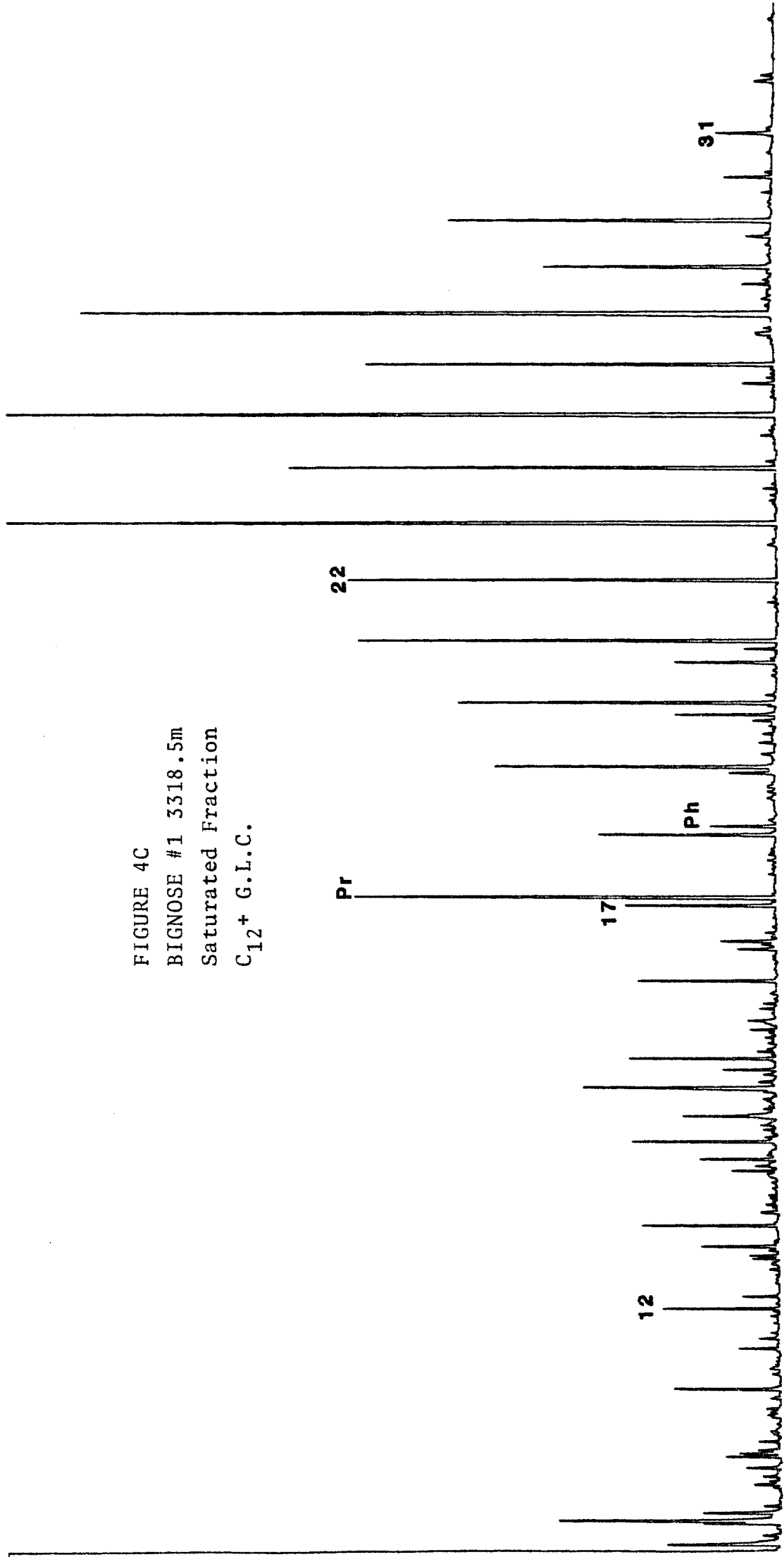


FIGURE 4D
BIGNOSE #1 3458.0m
Saturated Fraction
C₁₂+ G.L.C.

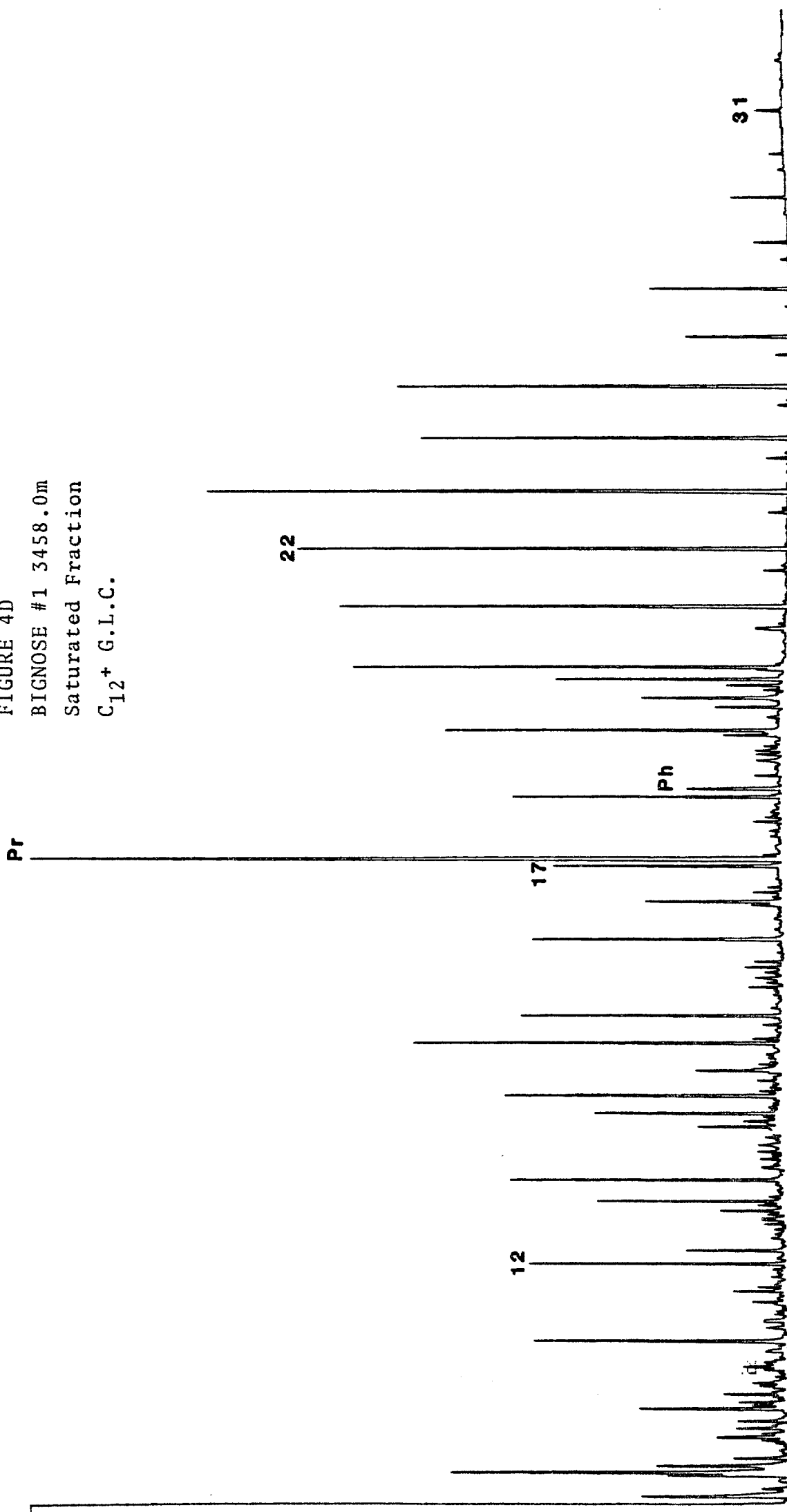


FIGURE 4E
BIGNOSE #1 3537.5m
Saturated Fraction
C₁₂+ G.L.C.

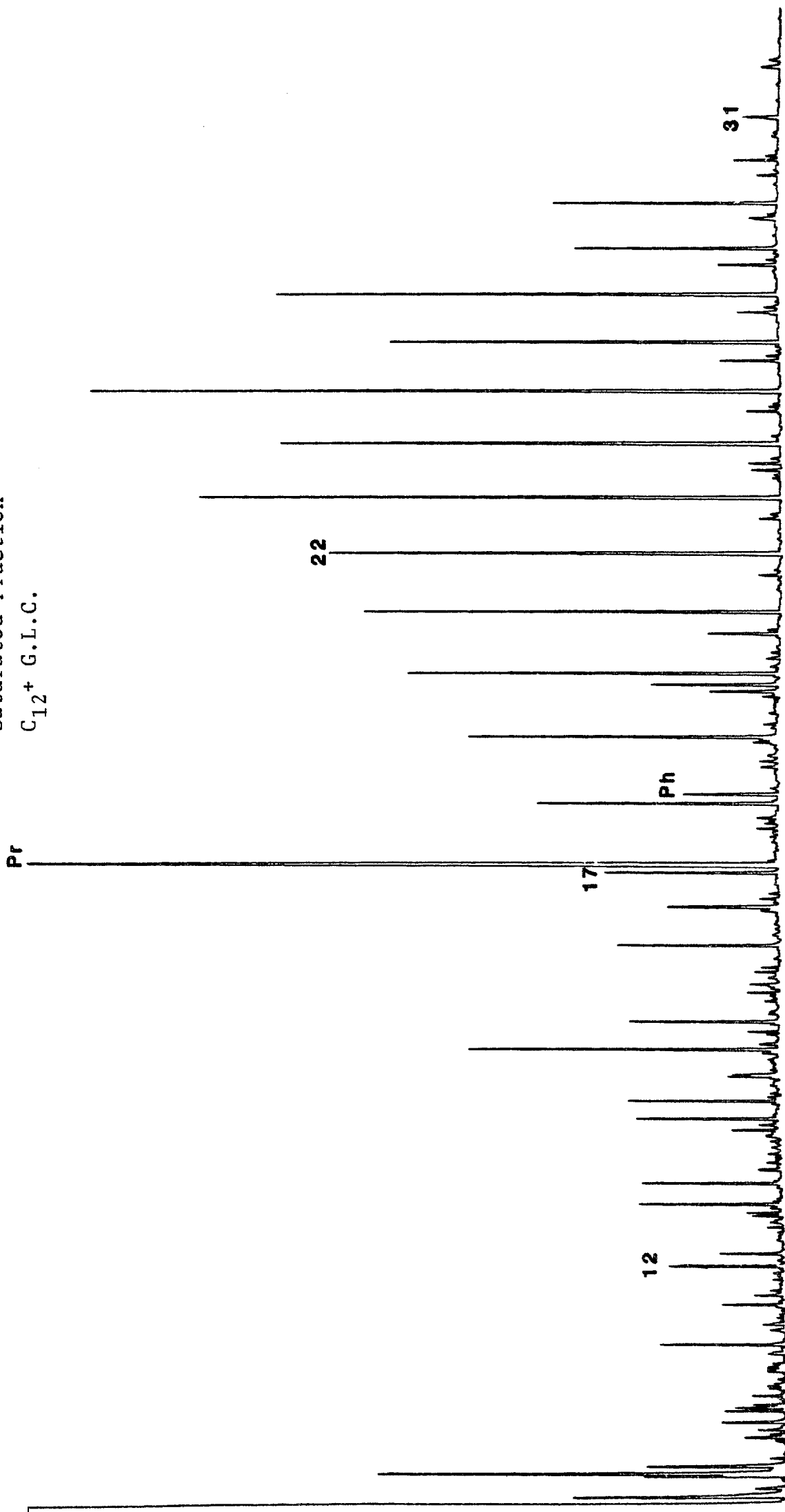


FIGURE 4F
BIGNOSE #1 3591.0
Saturated Fraction
C₁₂+ G.L.C.

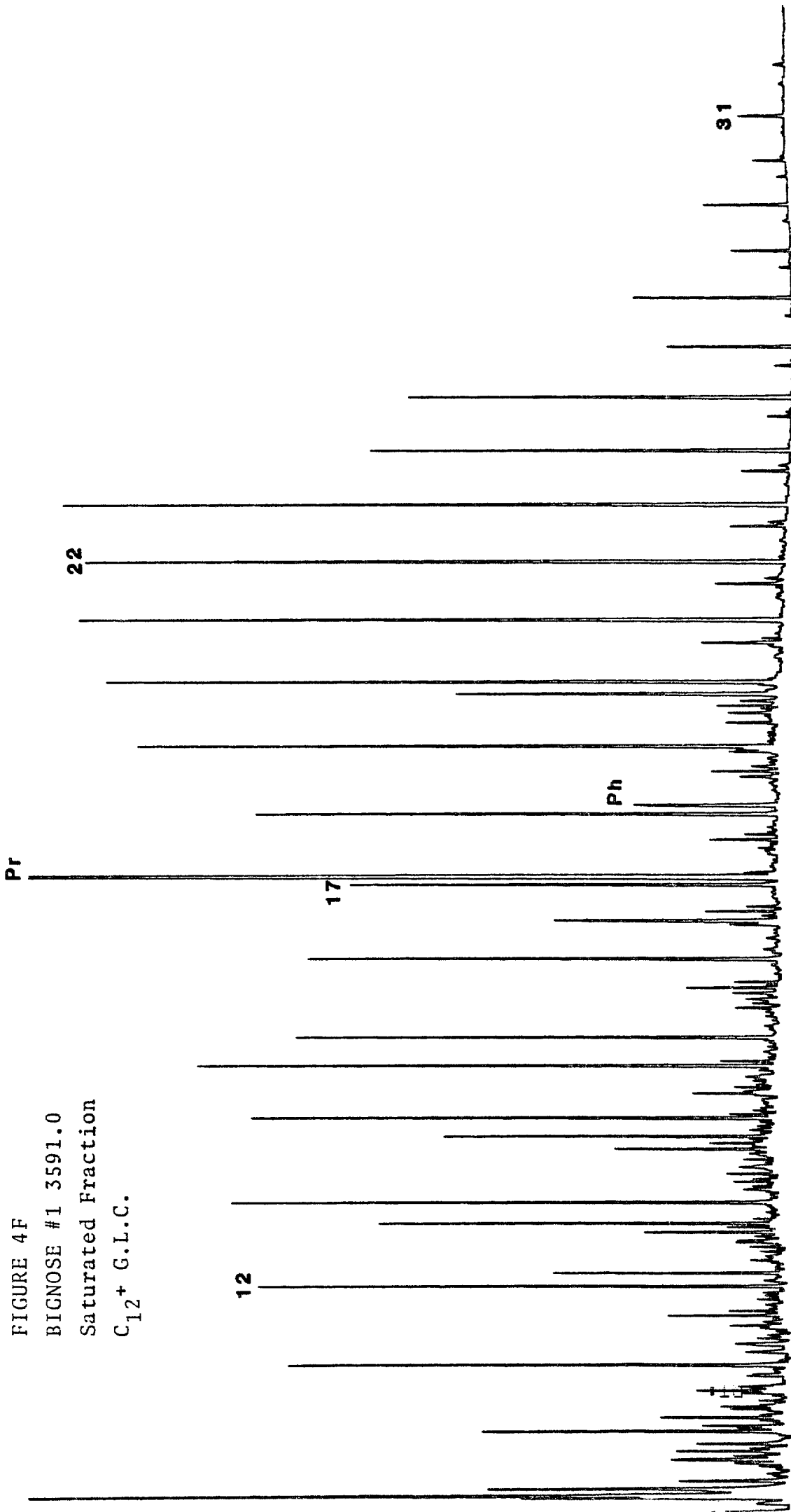


FIGURE 4G
BIGNOSE #1 3658.0m
Saturated Fraction
C₁₂+ G.L.C.

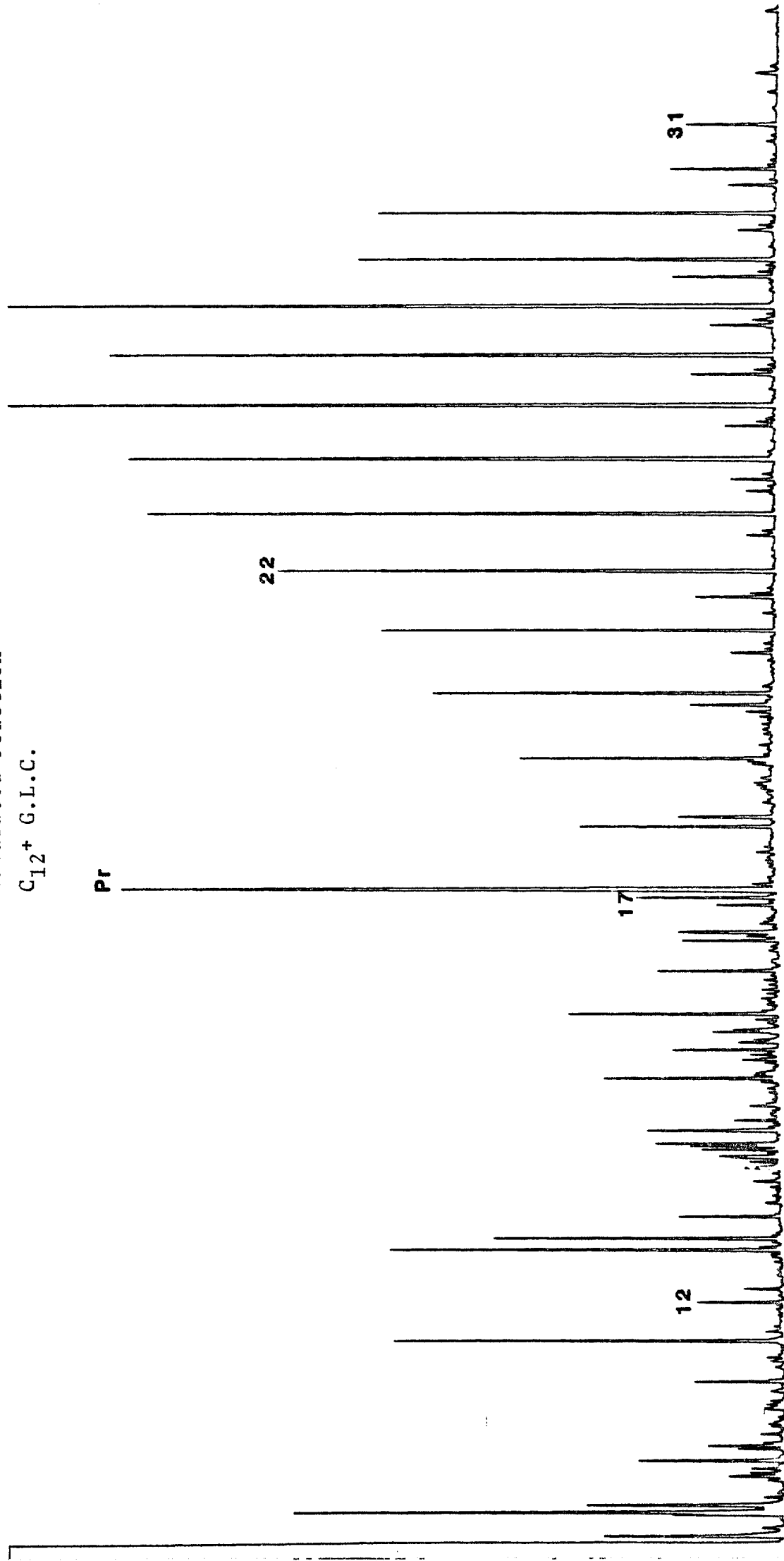


FIGURE 4H
BIGNOSE #1 3729.0m
Saturated Fraction
C₁₂+ G.L.C.

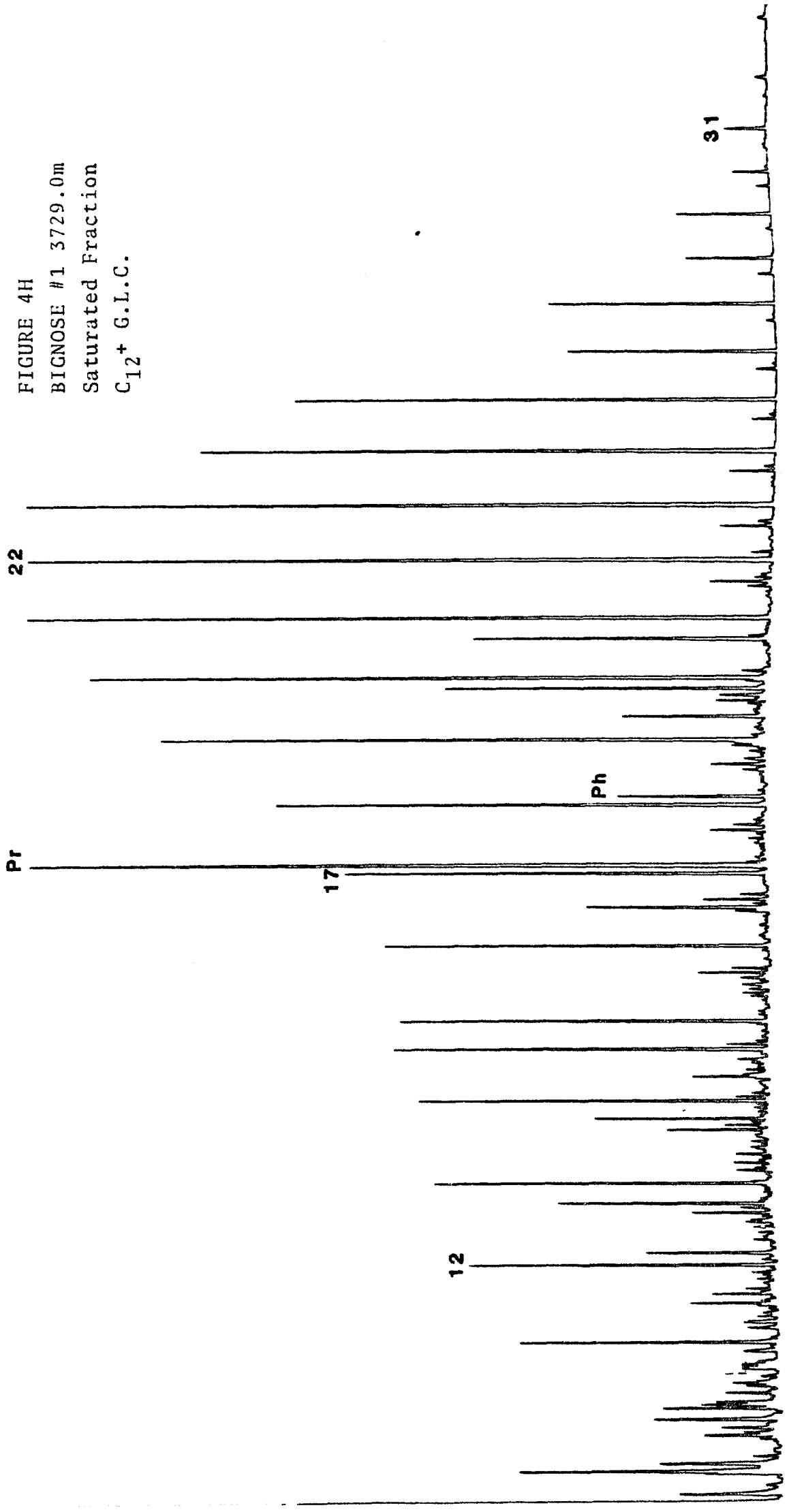


FIGURE 4I
BIGNOSE #1 3796.0m
Saturated Fraction
C₁₂+ G.L.C.

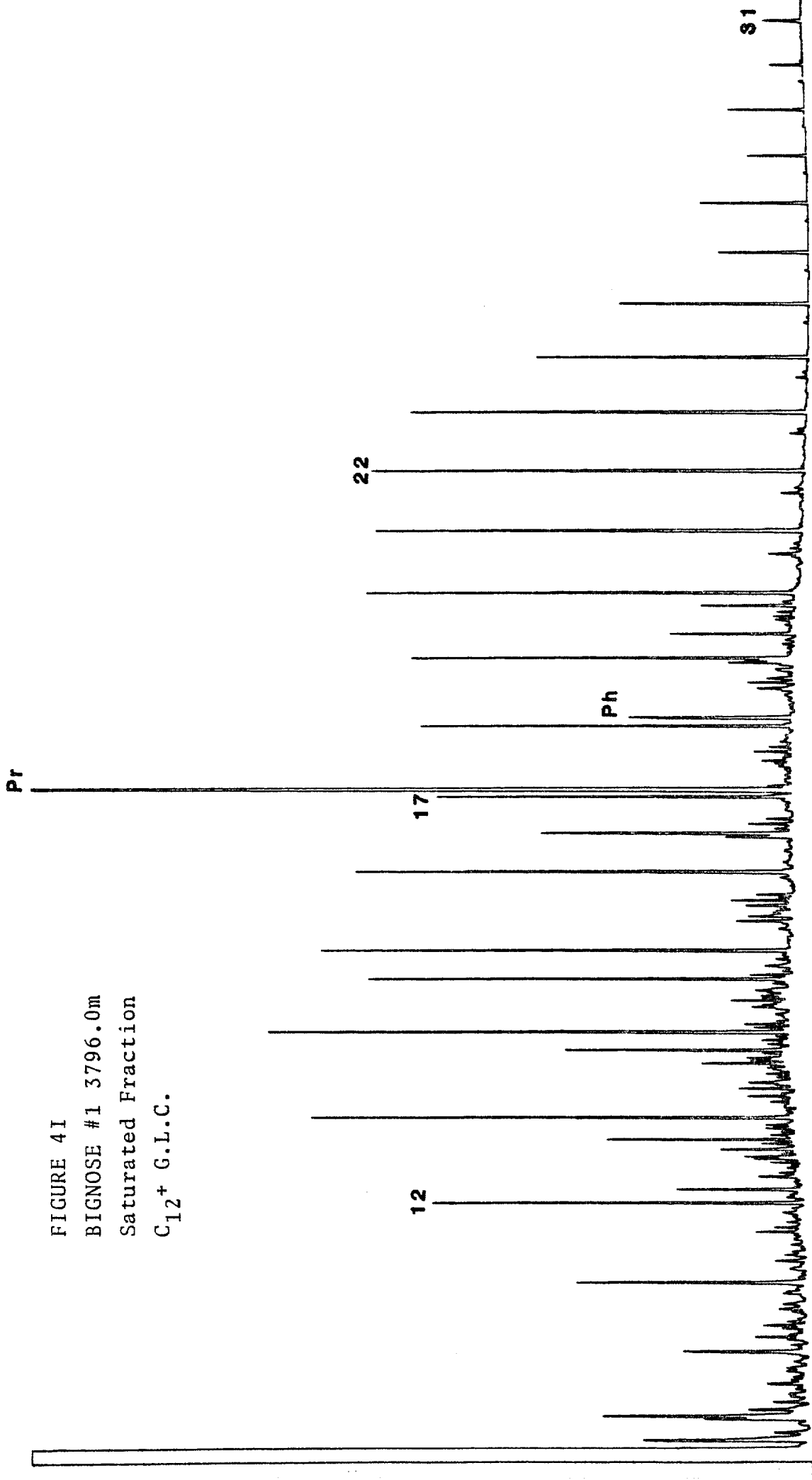


FIGURE 4J
BIGNOSE #1 3939.0m
Saturated Fraction
C₁₂+ G.L.C.

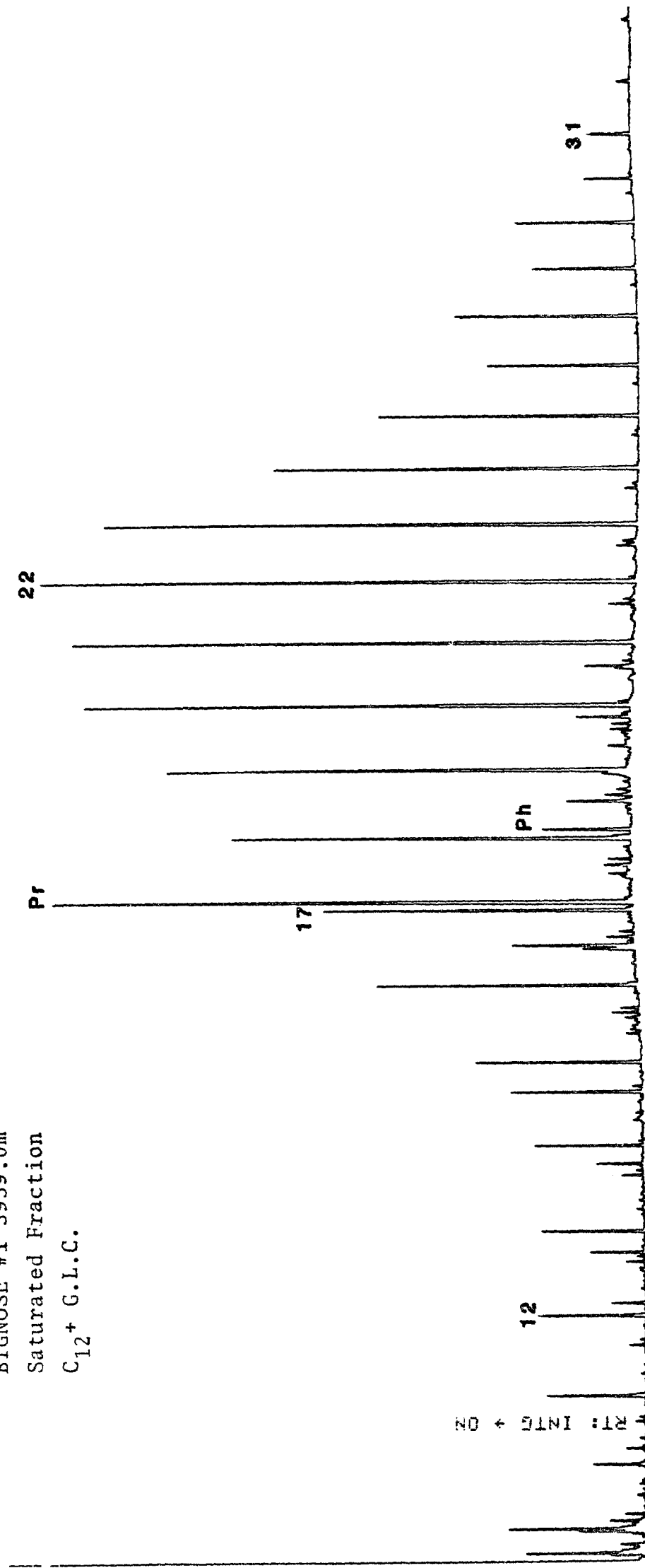


FIGURE 5A
BIGNOSE #1 3557.5m
Sample A
Saturated Fraction
C₁₂+ G.L.C.

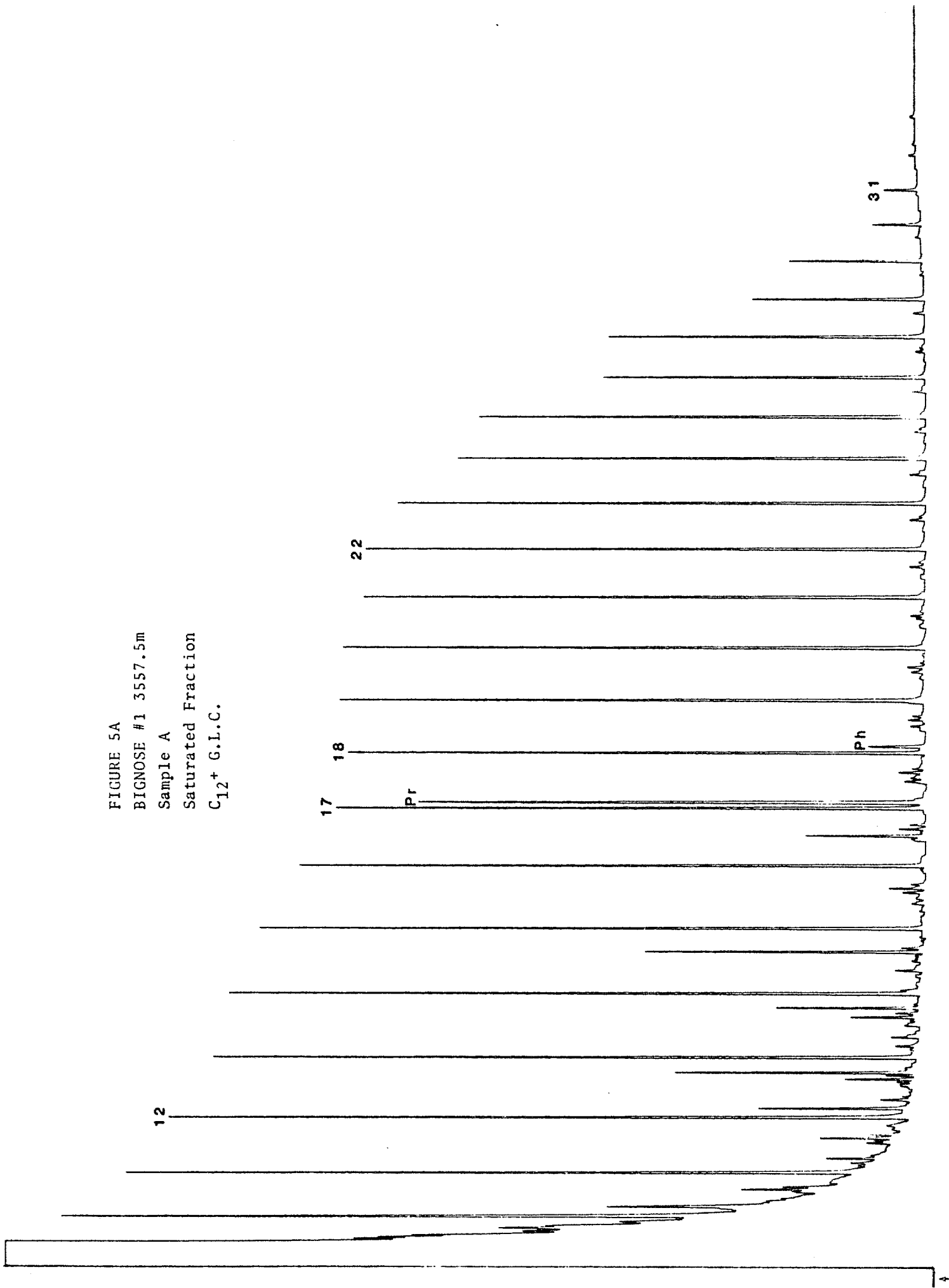


FIGURE 5B
BIGNOSE #1 3557.5m
Sample B
Saturated Fraction
C₁₂+ G.L.C.

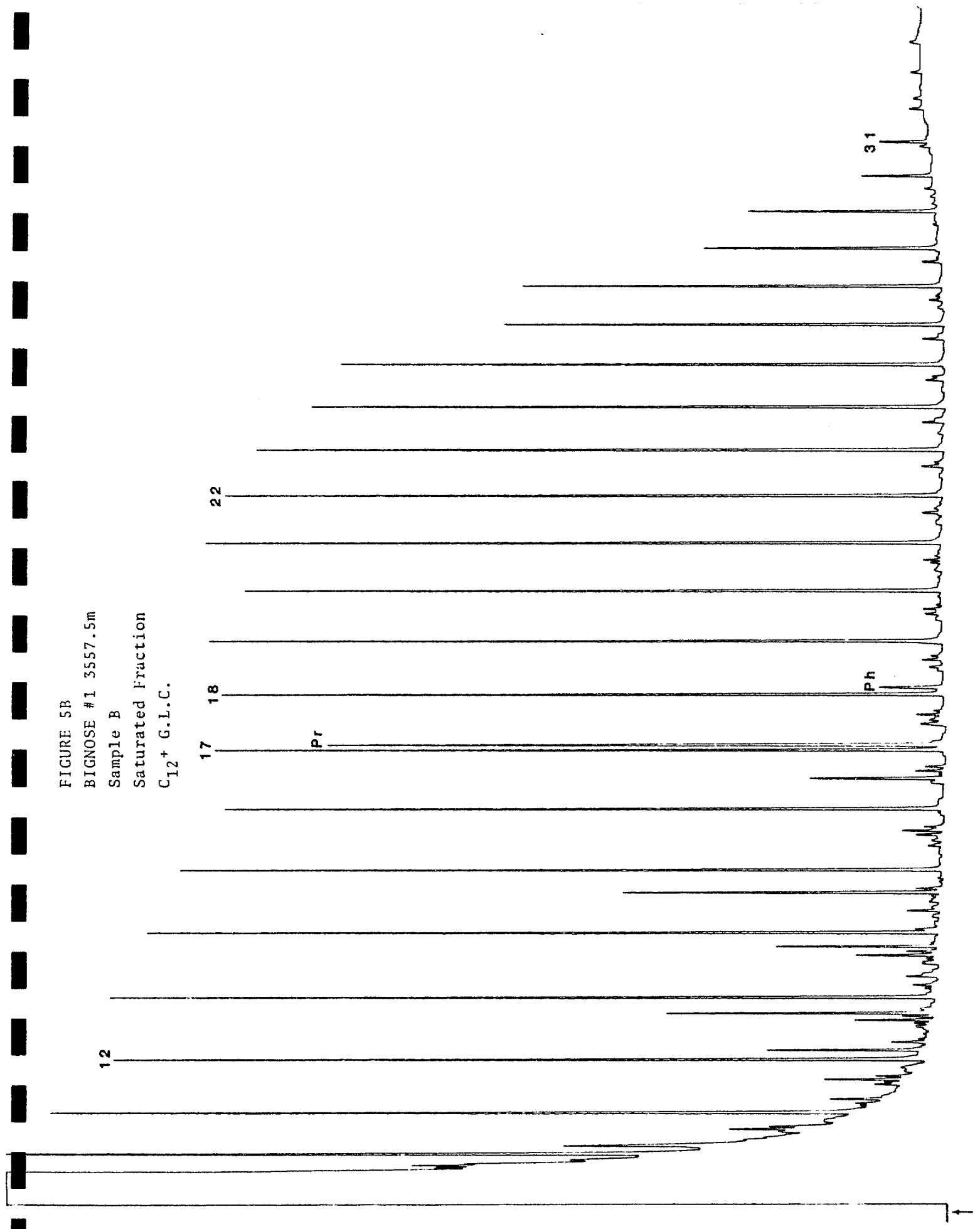


FIGURE 6A
BIGNOSE #1 3557.5m (A)
WHOLE OIL GLC

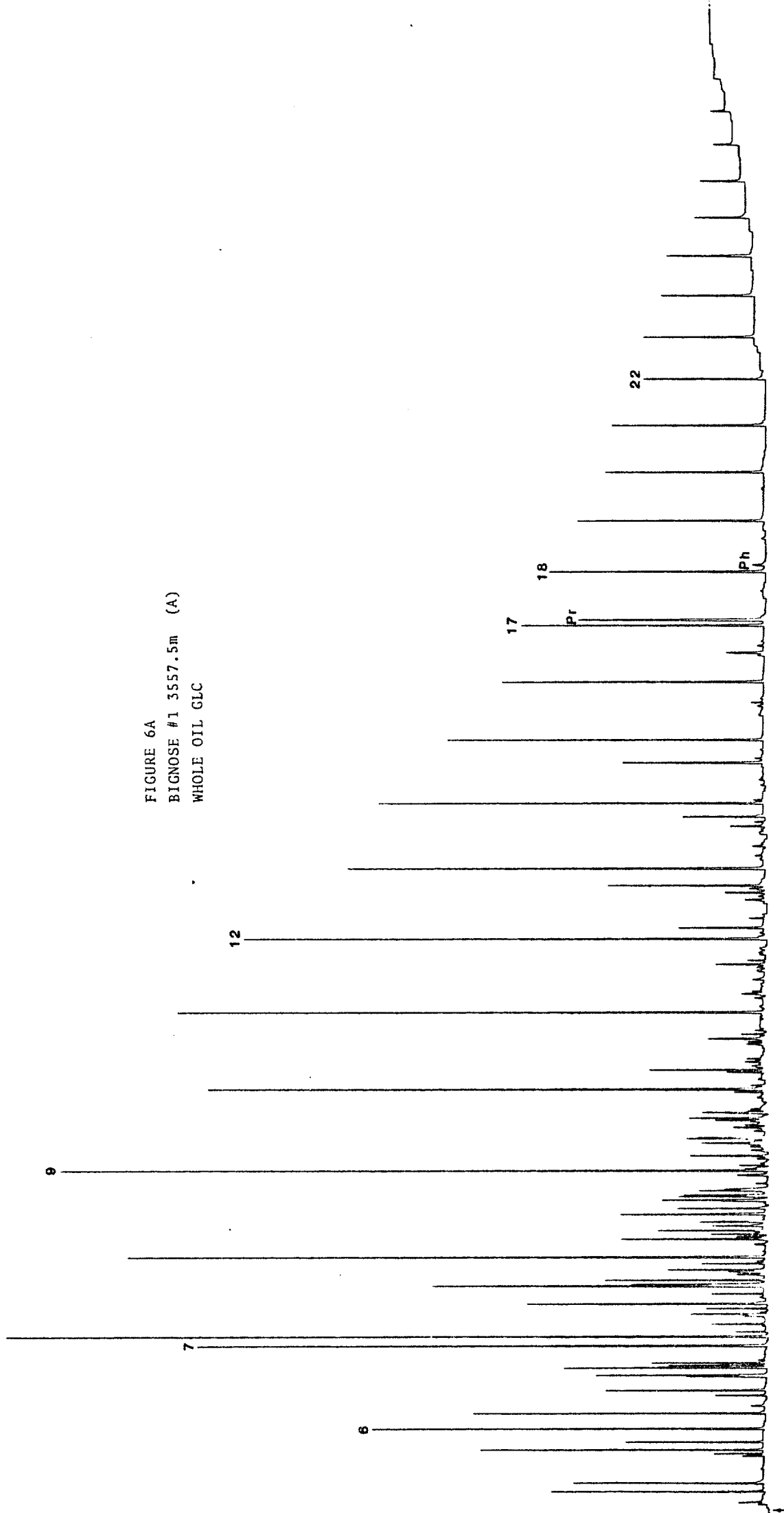


FIGURE 6B
BIGNOSE #1 3557.5m (B)
WHOLE OIL GLC

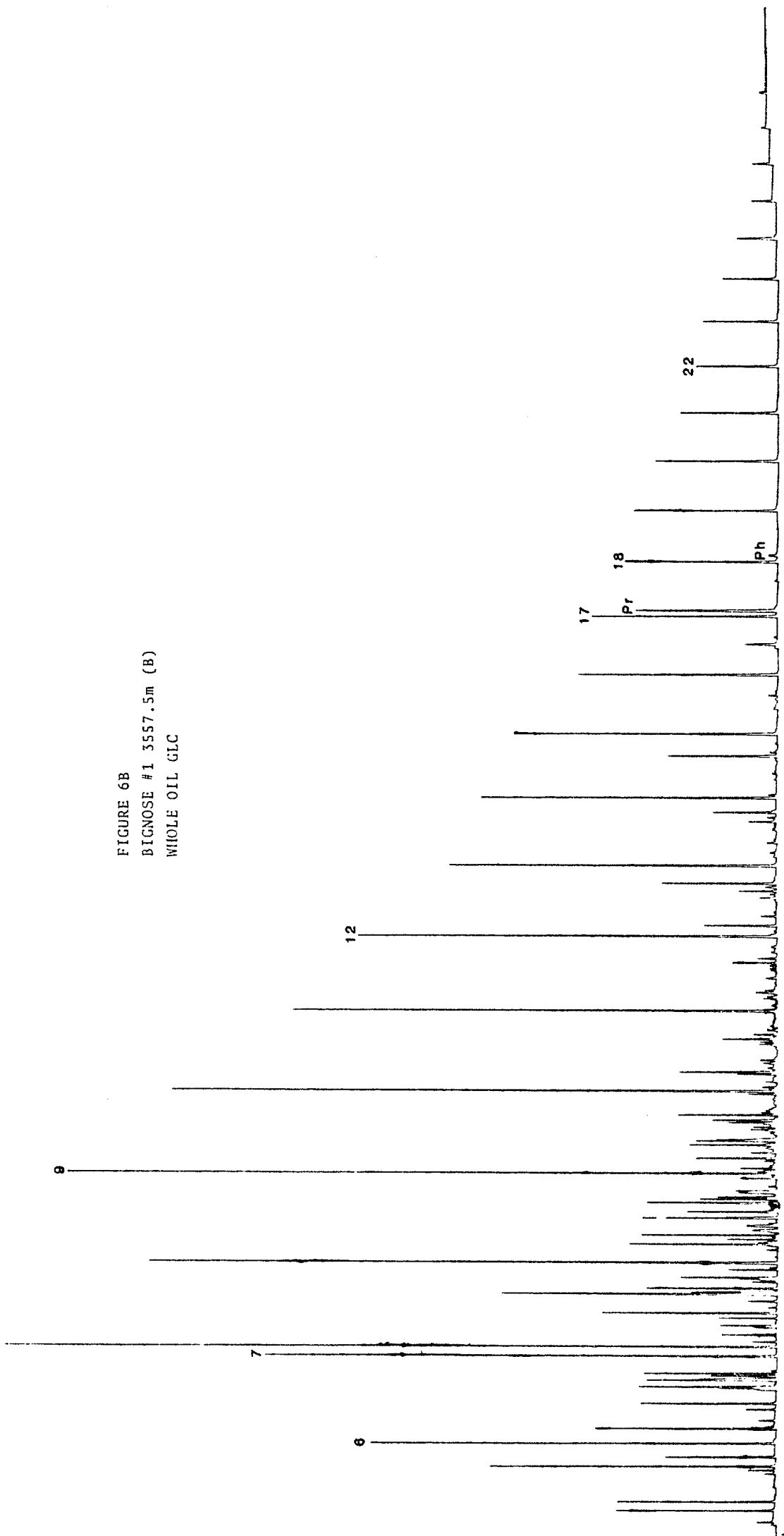


TABLE 1

ROCK-EVAL PYROLYSIS DATA (one run)

WELLNAME = BIGNOSE #1

DATE OF JOB = NOVEMBER 1983

DEPTH(m)	TMAX	S1	S2	S3	S1+S2	S2/S3	PI	PC	TOC	HI	OI
2822.5	430	0.18	0.90	0.51	1.08	1.76	0.17	0.09	1.10	81	46
2839.5	433	0.28	3.91	0.69	4.19	5.67	0.07	0.35	2.55	153	27
2874.0	433	0.32	11.49	0.46	11.81	24.98	0.03	0.98	3.51	327	13
2912.5	426	0.74	18.21	0.65	18.95	28.02	0.04	1.57	5.82	312	11
3004.0	433	0.65	8.32	2.18	8.97	3.82	0.07	0.74	11.10	74	19
3212.0	432	0.27	1.15	1.28	1.42	0.90	0.19	0.12	1.36	84	94
3318.5	430	9.37	198.75	5.46	208.12	36.40	0.05	17.27	55.82	356	9
3335.0	431	7.67	168.62	3.87	176.29	43.57	0.04	14.63	42.18	399	9
3458.0	431	3.26	90.52	3.57	93.78	25.36	0.03	7.78	12.16	744	29
3517.0	434	3.51	62.51	2.74	66.02	22.81	0.05	5.48	19.09	327	14
3537.5	436	6.10	177.45	7.45	183.55	23.82	0.03	15.23	40.76	435	18
3542.0	437	1.70	49.37	1.81	51.07	27.28	0.03	4.24	19.00	259	9
3567.0	437	0.38	5.19	1.49	5.57	3.48	0.07	0.46	3.84	135	38
3569.0	436	0.64	9.05	0.87	9.69	10.40	0.07	0.80	5.77	156	15
3591.0	434	1.32	35.52	0.94	36.84	37.79	0.04	3.06	12.74	278	7
3658.0	434	7.64	119.15	4.05	126.79	29.42	0.06	10.52	43.40	274	9
3713.5	437	11.58	186.70	4.75	198.26	39.31	0.06	16.46	36.50	511	13
3729.0	436	9.08	143.06	4.08	152.14	35.06	0.06	12.63	23.26	615	17
3759.5	433	10.80	111.00	2.41	121.80	46.06	0.09	10.11	29.10	381	8
3765.5	435	9.71	107.42	2.40	117.13	44.76	0.08	9.72	26.40	406	9
3796.0	438	3.34	42.58	1.27	45.92	33.53	0.07	3.81	8.80	483	14
3863.0	438	0.26	2.09	0.89	2.35	2.35	0.11	0.20	1.68	124	52
3939.0	437	0.36	2.77	0.53	3.13	5.23	0.12	0.26	1.35	205	39

TMAX = Max. temperature S2
 S1+S2 = Potential yield
 PC = Pyrolysable carbon
 OI = Oxygen Index

S1 = Volatile hydrocarbons (HC)
 S3 = Organic carbon dioxide
 TOC = Total organic carbon
 nd = no data

S2 = HC generating potential
 PI = Production index
 HI = Hydrogen index

TABLE 2

Summary of Extraction and Liquid Chromatography

Wellname: BIGNOSE #1

Date of Job: JANUARY 1984

A. Concentrations of Extracted Material

Depth(m)	Weight of Rock Extd. (grams)	Total Extract (ppm)	Loss on Column (ppm)	-----Hydrocarbons-----			-----Nonhydrocarbons-----		
				Saturates (ppm)	Aromatics (ppm)	HC Total (ppm)	NSO's (ppm)	Asphaltenes (ppm)	NonHC Total (ppm)
2874.0	14.3	3321.7	90.9	762.2	811.2	1573.4	1657.3	nd	1657.3
3004.0	8.7	3931.0	126.4	896.6	793.1	1689.7	2114.9	nd	2114.9
3318.5	11.5	8304.3	300.9	1695.7	2153.5	3849.1	4154.3	nd	4154.3
3458.0	7.7	11207.8	61.8	2842.6	2842.6	5685.2	5460.8	nd	5460.8
3537.5	7.4	5662.2	243.2	824.3	1324.3	2148.6	3270.3	nd	3270.3
3591.0	11.3	3283.2	256.6	831.9	876.1	1708.0	1318.6	nd	1318.6
3658.0	8.4	13631.0	634.0	2499.4	4996.8	7496.2	5498.7	nd	5498.7
3729.0	11.2	11446.4	3971.4	2415.0	1856.4	4271.4	3203.6	nd	3203.6
3796.0	11.2	7517.9	4662.5	893.8	1195.5	2089.3	766.1	nd	766.1
3939.0	7.4	2067.6	270.3	500.0	675.7	1175.7	621.6	nd	621.6

TABLE 2

Summary of Extraction and Liquid Chromatography

Wellname: BIGNOSE #1

Date of Job: JANUARY 1984

B. Compositional Data

Depth(m)	-----Hydrocarbons-----			-----Nonhydrocarbons-----			EDM(mg) TOC(a)	SAT(mg) TOC(a)	SAT AROM	ASPH NSO	HC Non HC
	%SAT.	%AROM.	%HC's	%NSO's	%ASPH.	%Non HC's					
2874.0	23.6	25.1	48.7	51.3	nd	51.3	94.6	21.7	.94	nd	.9
3004.0	23.6	20.8	44.4	55.6	nd	55.6	35.4	8.1	1.13	nd	.8
3318.5	21.2	26.9	48.1	51.9	nd	51.9	14.9	3.0	.79	nd	.9
3458.0	25.5	25.5	51.0	49.0	nd	49.0	92.2	23.4	1.00	nd	1.0
3537.5	15.2	24.4	39.7	60.3	nd	60.3	13.9	2.0	.62	nd	.7
3591.0	27.5	28.9	56.4	43.6	nd	43.6	25.8	6.5	.95	nd	1.3
3658.0	19.2	38.5	57.7	42.3	nd	42.3	31.4	5.8	.50	nd	1.4
3729.0	32.3	24.8	57.1	42.9	nd	42.9	49.2	10.4	1.30	nd	1.3
3796.0	31.3	41.9	73.2	26.8	nd	26.8	85.4	10.2	.75	nd	2.7
3939.0	27.8	37.6	65.4	34.6	nd	34.6	153.2	37.0	.74	nd	1.9

na = not applicable nd = no data

TABLE 3

Summary of Gas Chromatography Data

Wellname: BIGNOSE #1

Date of Job: JANUARY 1984

A. Alkane Compositional Data

Depth(m)	Prist./Phvt.	Prist./n-C17	Phvt./n-C18	CPI(1)	CFI(2)	(C21+C22)/(C28+C29)
2874.0	7.82	3.44	.35	2.01	1.97	.97
3004.0	5.97	2.51	.44	1.69	1.61	1.03
3318.5	7.50	4.62	.53	2.56	2.48	1.59
3458.0	10.54	5.96	.50	2.10	2.06	13.00
3537.5	12.25	9.19	.55	1.68	1.62	2.16
3591.0	9.95	4.06	.36	1.72	1.71	13.77
3658.0	9.09	8.33	.69	1.51	1.45	.99
3729.0	7.33	2.93	.33	1.44	1.42	13.24
3796.0	7.68	4.57	.63	1.34	1.32	8.18
3939.0	7.15	2.92	.31	1.35	1.32	6.54

TABLE 3

Summary of Gas Chromatography Data

Wellname: BIGNOSE #1

Date of Job: JANUARY 1984

B. n-Alkane Distributions

DEPTH(m)	nC12	nC13	nC14	nC15	nC16	nC17	iC19	nC18	iC20	nC19	nC20	nC21	nC22	nC23	nC24	nC25	nC26	nC27	nC28	nC29	nC30	nC31
2874.0	2.1	2.7	3.3	3.0	2.6	2.6	8.9	3.3	1.1	3.6	3.9	3.6	3.8	5.9	5.3	14.8	7.4	13.6	4.1	3.5	.6	.4
3004.0	1.3	.9	2.4	5.5	7.1	4.8	12.0	4.6	2.0	3.4	6.8	3.4	4.1	5.5	4.7	8.3	5.3	9.0	3.6	3.6	.7	.8
3318.5	1.1	1.3	1.5	1.5	1.4	1.6	7.5	1.9	1.0	3.1	3.9	5.4	5.8	13.4	6.8	16.2	5.7	12.7	2.8	4.3	.5	.6
3458.0	3.2	3.5	3.6	3.3	3.3	3.3	19.9	3.8	1.9	4.8	6.7	7.1	8.0	10.9	5.1	6.3	1.3	2.0	.4	.7	.1	.4
3537.5	1.1	1.4	1.5	1.6	1.7	2.0	18.4	2.7	1.5	3.6	4.9	5.2	6.4	9.0	7.4	11.5	5.7	7.9	2.5	2.9	.5	.6
3591.0	4.1	4.4	4.5	4.2	4.1	4.3	17.5	4.9	1.8	6.3	7.8	7.8	7.9	8.5	4.1	3.5	1.0	1.3	.4	.7	.3	.4
3658.0	.7	.8	1.8	.8	1.1	1.2	10.3	1.7	1.1	2.5	3.4	4.0	5.5	7.8	8.8	13.4	9.5	13.8	4.9	4.7	1.0	1.0
3729.0	2.5	2.6	2.9	3.0	3.4	4.0	11.8	4.8	1.6	6.1	8.3	9.3	10.8	11.0	6.8	5.2	1.8	2.0	.7	.8	.3	.4
3796.0	4.2	5.5	6.4	5.7	5.4	4.9	22.2	4.6	2.9	4.9	5.8	5.8	6.1	5.5	3.3	2.2	1.1	1.2	.7	.8	.4	.5
3939.0	1.4	1.2	1.3	2.1	3.4	4.5	13.0	5.9	1.8	7.2	8.9	10.0	10.7	9.4	5.7	4.0	2.1	2.7	1.5	1.7	.7	.8

na = not applicable nd = no data

TABLE 4

Summary of Physical Property and Sulphur Data

Date of Job: NOVEMBER 1983

Sample	API Gravity	%Sulphur(w/w)	Viscosity(0°C)	Viscosity(0°C)
BIGNOSE #1 3557.5m A	nd	nd	nd	nd
BIGNOSE #1 3557.5m B	nd	nd	nd	nd

TABLE 4

Summary of Liquid Chromatography(Compositional Data)

Date of Job: NOVEMBER 1983

Sample	-----Hydrocarbons-----			-----Nonhydrocarbons-----			SAT	ASPH	HC
	%SAT.	%AROM.	%HC's	%NSO's	%ASPH.	%Non HC's	AROM	NSO	Non HC
BIGNOSE #1 3557.5m A	92.4	5.5	97.9	2.1	nd	2.1	16.75	nd	47.3
BIGNOSE #1 3557.5m B	93.9	5.0	98.9	1.1	nd	1.1	18.82	nd	92.5

na = not applicable nd = no data

TABLE 5

Summary of Gas Chromatography Data

A. Alkane Compositional Data

Date of Job: NOVEMBER 1983

Sample	Prist./Phyt.	Prist./n-C17	Phvt./n-C18	CPI(1)	CPI(2)	(C21+C22)/(C28+C29)
BIGNOSE #1 3557.5m A	9.00	1.07	.12	1.17	1.15	3.71
BIGNOSE #1 3557.5m B	8.95	1.07	.12	1.16	1.13	3.28

TABLE 5

Summary of Gas Chromatography Data

B. n-Alkane Distributions

Date of Job: NOVEMBER 1983

Sample	nC12	nC13	nC14	nC15	nC16	nC17	iC19	nC18	iC20	nC19	nC20	nC21	nC22	nC23	nC24	nC25	nC26	nC27	nC28	nC29	nC30	nC31
BIGNOSE #1 3557.5m A	6.9	6.9	6.7	6.3	6.0	5.9	6.3	5.9	.7	6.1	5.8	5.8	5.6	5.4	4.7	4.5	3.2	3.1	1.7	1.4	.5	.4
BIGNOSE #1 3557.5m B	6.3	6.3	6.2	5.9	5.7	5.6	6.0	5.7	.7	6.0	5.8	5.9	5.9	5.9	5.2	5.1	3.7	3.5	2.0	1.6	.6	.4

na = not applicable nd = no data

TABLE 6A

COMPOSITIONAL DATA - BIGNOSE # 1 3557.5m (A)

<u>Carbon Number</u>	<u>Weight %</u>
1 - 3	nd
4	0.16
5	2.24
6	6.65
7	20.99
8	12.61
9	11.50
10	7.86
11	6.40
12	5.74
13	4.19
14	4.29
15	2.52
16	2.37
17	3.51
18	1.60
19	1.33
20	1.11
21	0.92
22	0.86
23	0.78
24	0.63
25	0.67
26	0.33
27	0.33
28	0.15
29	0.11
30	0.06
31	nd

TABLE 6B

COMPOSITIONAL DATA - BIGNOSE # 1 3557.5m (B)

<u>Carbon Number</u>	<u>Weight %</u>
1-3	nd
4	0.10
5	1.82
6	6.59
7	21.87
8	12.60
9	11.73
10	8.72
11	6.46
12	6.30
13	4.39
14	4.21
15	2.54
16	2.26
17	3.12
18	1.45
19	1.16
20	1.01
21	0.86
22	0.71
23	0.58
24	0.41
25	0.50
26	0.21
27	0.19
28	0.09
29	0.07
30	0.02
31	nd

July, 1983

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 1cm^2 of the container lid with liquid 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°C ; carrier gas = nitrogen at 23mls/min; injector temperature = 120°C ; detector temperature = 120°C ; analysis cycle = C_1 - C_4 components are flushed from the column in the forward direction and then the C_5 - C_7 compounds are removed from the column by backflushing.

The integrated areas of peaks representing each of the C_1 - C_7 components of the headspace gas are compared to the areas of the 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 (C_2 - C_4/C_1 - C_4) expressed as a % against sediment burial depth. Gas containing appreciable quantities of C_2 - C_4 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°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 1 a).

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, cuttings 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 level of drilling mud and the 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 hand-crushed 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°C (Leco Induction Furnace CS-044) in a 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:

<u>Classification</u>	<u>Clastics</u>	<u>Carbonates</u>
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 S_3 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°C for 3 minutes to liberate free petroleum (S_1 peak);
- Stage (iii) - Sample heated from 300°C to 550°C at 25°C/minute to produce petroleum from kerogen (S_2 peak). The furnace is maintained at 550°C for one minute. Carbon dioxide produced during this pyrolysis up to 390°C in the case of "one run" and 550°C for "two run" is absorbed on a molecular sieve trap;
- Stage (iv) - During cool-down period the carbon dioxide produced during pyrolysis is measured (S_3 peak).

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

$$S_1, S_2, S_3 = \text{kg/tonne or mg/g of rock}$$

$$T_{\text{max}} = \text{°C}$$

$$\text{Hydrogen Index} = \frac{S_2}{\text{TOC}} \times 100$$

$$\text{Oxygen Index} = \frac{S_3}{\text{TOC}} \times 100$$

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

- (i) S_1 - indicates the level of oil and/or gas already generated by the sample according to the following scale:

<u>S_1 (mg/g or kg/tonne)</u>	<u>Classification</u>
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) S_1+S_2 - referred to as the genetic potential this parameter is used for source rock classification according to the following criteria:

<u>S_1+S_2 (mg/g or kg/tonne)</u>	<u>Classification</u>
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) $S_1/(S_1+S_2)$ - 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 overmaturity. For gas prone sediments, the PI data shows a relatively smaller change with increasing maturity.
- (iv) T_{max} - the temperature corresponding to the S_2 maxima. This temperature increases with increasingly mature sediments. Values less than 430°C are indicative of immaturity while values from 430/435 to 460°C represent the maturity range of the oil window. T_{max} values greater than 460°C are indicative of overmaturity.
- (v) HI, OI - the hydrogen ($[S_2 \times 100]/TOC$) and oxygen ($[S_3 \times 100]/TOC$) 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 sample 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 formulas:

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

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

The following scale is used to classify the source rock richness of samples based on C_{12}^+ 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 petroleum and the ppm 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 + 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. 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°C to 280°C at 4°C/min; injection system = Grob splitless using a 30 sec. dump time and split ratio of 25:1; carrier gas = hydrogen at 2mls/min; injector temperature = 300°C; detector temperature = 310°C; recorder/integrator speed = 0.5cm/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:

$$CPI(1) = \frac{(C_{23} + C_{25} + C_{27} + C_{29})Wt\% + (C_{25} + C_{27} + C_{29} + C_{31})Wt\%}{2 \times (C_{24} + C_{26} + C_{28} + C_{30})Wt\%}$$

$$CPI(2) = \frac{(C_{23} + C_{25} + C_{27})Wt\% + (C_{25} + C_{27} + C_{29})Wt\%}{2 \times (C_{24} + C_{26} + C_{28})Wt\%}$$

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 irrespective of maturity whereas values for terrestrial extracts decrease with maturity from values as high as 20 but don't usually reach a value of 1.

(c) C₂₁+C₂₂/C₂₈+C₂₉ - This parameter provides information about the source of the organic matter (Philippi, 1974). Generally, a terrestrial source gives values <1.2 whereas a marine source 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/nC₁₇Ratio - 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 - C_{18} 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 marine petroleum.

9. API/SPECIFIC GRAVITY

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

$$\text{API Gravity} = \left(\frac{141.5}{\text{SG}_{(60^\circ\text{F})}} \right) - 131.5$$

The reported gravity value is the average of duplicate determinations.

10. 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 processes such as bacterial alteration.

11. C_1 - C_{31} 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 C_{12}^+ saturate fraction GC data for oil or condensate samples.

The analysis is carried out under the same conditions as for the C_{12}^+ GC analysis with the following exceptions: column temperature = programmed from -20°C to 280°C at 4°C/min (uses cryogenic mode); injection is carried out in split mode; sample = 0.1 μ l of neat petroleum.

C_1 - C_{31} analysis data can be used to obtain the same information as that obtained from C_{12}^+ GC but further provides detailed compositional data on the C_1 - C_{11} fraction and enables calculation of the distillation range of the sample.

12. MOLECULAR SIEVE EXTRACTION

This technique is used to isolate the branched/cyclic alkanes from the saturate fraction for gas chromatography/mass spectrometry 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 sieves are filtered from the liquid phase and are washed with 4 x 10ml aliquots of benzene. The liquid phase plus washings are freed of benzene by distillation yielding the branched/cyclic compounds.

13. COMPUTERIZED GAS CHROMATOGRAPHY/MASS SPECTROMETRY (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 memorized by the data system. Since any given class of molecules will break down in the analyser tube 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 following two modes of operation:

- (i) Acquire mode - in which all ions in each mass spectrum are memorized by the data system;
- (ii) Selective ion monitoring (SIM) mode - in which only selected ions of interest are memorized by the data system.

At present the sterane/triterpane 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 ions which are pertinent to the sterane/triterpane fraction.

<u>Ion</u>	<u>Molecular Type</u>
177	Demethylated triterpanes
191	Normal triterpanes
205	Methyl triterpanes
163	Specific deethylated triterpanes
356	Parent ion - C ₂₆ triterpanes
370	Parent ion - C ₂₇ triterpanes
384	Parent ion - C ₂₈ triterpanes
398	Parent ion - C ₂₉ triterpanes
412	Parent ion - C ₃₀ triterpanes
426	Parent ion - C ₃₁ triterpanes
183	Isoprenoids
217	Normal steranes
218	Normal steranes
231	4-methyl steranes
259	Diasteranes
358	Parent ion - C ₂₆ steranes
372	Parent ion - C ₂₇ steranes
386	Parent ion - C ₂₈ steranes
400	Parent ion - C ₂₉ steranes
414	Parent ion - C ₃₀ steranes

GC/MS/DS analysis of the sterane/triterpane fraction can often provide information about the maturity and source type of petroleum and whether it has been affected by microorganisms. 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 sediments to a mixture of the $\alpha\alpha\alpha(20R)$ and $\alpha\alpha\alpha(20S)$ compounds. The ratio of $C_{29} \frac{\alpha\alpha\alpha(20S)}{\alpha\alpha\alpha(20R) + \alpha\alpha\alpha(20S)}$ expressed as a percentage is about 25% at the onset of oil generation and increases almost linearly to a value of about 50% at the peak of oil generation.
- (b) The biologically produced $\alpha\alpha\alpha$ steranes are partially converted during catagenesis to the corresponding $\alpha\beta\beta$ series. The percentage of the C₂₉ $\alpha\beta\beta$ component in the total C₂₉ steranes is another measure of maturation. The value of this parameter is about 25% at the onset of oil generation and it increases exponentially to a value of about 70% 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 β ,21 β hopanes to the corresponding 17 α ,21 β and 17 β ,21 α compounds is also maturation dependent. For C₃₀ triterpanes the ration of $\frac{17\beta,21\alpha}{17\alpha,21\beta}$ 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 the C₃₀ 17 α ,21 β triterpane is maturity dependent. The

ratio decreases 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 C_{27} compounds are more abundant than the C_{29} compounds. General marine organic matter has approximately equivalent amounts of the C_{27} and C_{29} compounds while organic matter rich in land-plants usually has more of the C_{29} 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 C_{27} - C_{35} hopanes and moretanes whereas the higher plant triterpanes are compounds other than hopanes or moretanes and are commonly C_{30} compounds.
- (iii) Based on Diasteranes
The diasteranes are not produced biologically but are formed during early diagenesis from sterane precursors. The diasterane ratios $\frac{C_{27}(20R)}{C_{29}(20R)}$ and $\frac{C_{27}(20R+20S)}{C_{29}(20R+20S)}$ 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 C_{29} $\alpha\alpha\alpha(20R)$ 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 177, 191, 217, 218, 259 and 400 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, 4-methyl steranes, bisnor-hopane and botryococcane can often prove very useful for this purpose.

14. 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°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 to oil and oil to source rock correlation its most significant application is the identification of source of gas according to following criteria (Fuex, 1977):

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

15. 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 emersed 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 1.6% Ro. Very mature values are between 1.6% Ro and 2.4% Ro, while severely altered rocks have reflectances above 2.5% 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 matter. Also vitrinite reflectance cannot be performed on rocks older than Devonian Age, due to the absence of land plants in the older geologic time periods.

16. 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 color of the kerogen is related to the thermal maturity of the sediments and is often used as a maturation indicator.

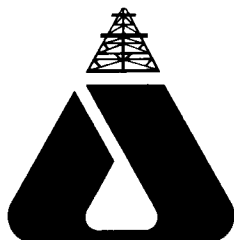
The preparation of slides for visual kerogen assessment by the palynologist firstly involves concentration of the organic matter by removal of the rock matrix using hydrochloric and hydrofluoric acid treatment and heavy liquid separation. The organic concentrate is then mounted on a glass slide using 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 Étude des Hydrocarbures Gazeux Occlus dans le Sédiments: Exemples d'Application à l'exploration pétrolière". *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, 1975, 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. Applications 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 reasearch 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.

ANALABS
A Division of Macdonald Hamilton & Co. Pty. Ltd.



OIL AND GAS DIVISION

PERTH, WESTERN AUSTRALIA

52 Murray Road,
Welshpool, W.A. 6106

Telephone: (09) 458 7999
Telex: ANALAB AA92560

Samples can be forwarded to Perth from any of the following Analabs Centres:

BRANCH ADDRESSES

WESTERN AUSTRALIA

PERTH — HEAD OFFICE

52 Murray Road,
Welshpool, Western Australia, 6106
Telephone (09) 458 7999, 458 7154
(P.O. Box 210, Bentley, W.A. 6102)
Telex ANALAB AA 92560

KALGOORLIE

Gt. Eastern Highway,
Kalgoorlie, Western Australia, 6430
Telephone (090) 21 1416
(P.O. Box 174, Kalgoorlie, W.A., 6430)
Telex KALAB AA 91784

NORTHERN TERRITORY

DARWIN

Cnr. Coonawarra & Mataram Roads,
Winnellie, N.T., 5789
Telephone (089) 84 3849
(P.O. Box 39344, Winnellie, N.T., 5789)
Telex NTLAB AA 85765

QUEENSLAND

BRISBANE

53 Suscatand Street,
Rocklea, Queensland, 4106
Telephone (07) 277 1668
Telex QLDLAB AA 44030

CAIRNS

1 Ogden Street,
Cairns, Queensland, 4870
Telephone (070) 51 5518, 51 7829
Telex TETLAB AA 48423

MT. ISA

15 Traders Way,
Mt. Isa, Queensland, 4825
Telephone (077) 43 6837
(P.O. Box 2401, Mt. Isa, Qld., 4825)
Telex ISALAB AA 46850

TASMANIA

BURNIE

14 Thirkell Street,
Cooee, Tasmania, 7320
Telephone (004) 31 6837
(P.O. Box 929, Burnie, Tas., 7320)
Telex TASLAB AA 59224

INDONESIA

JAKARTA

15th Floor
Arthaloka Building
Jl Jend Sudirman 2
Jakarta
Telephone 58 3533
Telex FRANKI 46441

BALIKPAPAN

Room 315
Hotel Benakutai
Jalan P. Antasari
Telephone 2 1811
(P.O. Box 200, Balikpapan)
Telex BEAUTX IA 37102

FIJI

SUVA

C/- Marine Pacific Ltd.
Stinson Building
Tofua Street, Walu Bay
Telephone 31 2488
(P.O. Box 1342, Suva, Fiji)
Telex TUGBOAT 2202