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REPORT TITLE

Source Rock Evaluation of Well 30/7-6A.
Section II.

CONTRACTOR

Norsk Hydro A/S.

CONTRACTORS REF.:

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JOB NO.:

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SUMMARY

KEY WORDS

Source Rock.

CONTENTS

Summary.

On the basis of the light hydrocarbons, the analysed sequence was divided into five zones. A: 3714-3775 m, B: 3800-3825 m, C: 3850-3900 m, D: 3925-4050 m and E: 4075 m.

Zone A is a rich source rock for oil with an oilwindow maturity. Zone B, which consists mainly of sandstone, shows signs of reservoired oil and gas. Zone C contains large quantities of coal and has an oilwindow maturity. Zone D is again a zone with a large proportion of sandstone and shows signs of reservoired oil and gas. Zone E is a rich source rock for gas with an oilwindow maturity.

EXPERIMENTAL

One ml. of the headspace gas from each of the cans was analysed gaschromatographically for light hydrocarbons. The results are shown in Table I.a. The canned samples were washed with temperated water on a 0,125 mm sieve to remove drilling mud and thereafter dried at 35°C.

Light Hydrocarbons

Aliquotes of the samples were dried at room temperature after washing and sieving. The cuttings with a grain size between 1 and 2 mm were used for light hydrocarbon determination. These were treated with 6N HCl in a closed evacuated system, thereafter flushed with water and the released gas analysed gaschromatographically. The results are shown in Table I.b.

Total Organic Carbon (TOC)

Aliquotes of the samples were treated with hot 6N HCl to remove carbonates, and then analysed on a Leco 12 carbon determinator, to determine the total organic carbon (TOC). Table II.

Extractable Organic Matter (EOM)

From the TOC results, samples were selected and extracted with DCM in soxhlet apparatus for 48 h., and the amount of extractable organic matter was determined. Table III.

Chromatographic Separation

The extracts were separated on columns packed with 2/3 silica and 1/3 alumina, by eluting with hexane, benzene and methanol. Table III. The saturated fractions were analysed gaschromatographically on a

25 mm glass capillary column, using a Carlo Erba FV 2150 Chromatograph. The measurements from the gaschromatograms are shown in Table VII.

Vitrinite Reflectance

Five sidewall cores and six cutting samples were sent for vitrinite reflectance measurements at Geoconsultants, Newcastle upon Tyne. Upon receipt, the samples were soaked in warm water and sieved through 72 mesh to remove drilling mud. After oven drying av 40°C, they were mounted in Bakelite resin blocks; care being taken during the setting in the plastic to avoid temperatures in excess of 100°C. The samples were then ground, initially on a diamond lap followed by two grades of corundum paper. All grinding and subsequent polishing stages in the preparation were carried out using isopopyl alcohol as lubricant, since water leads to the swelling and disintegration of the clay fraction of the samples.

Polishing of the samples was performed on Selvyt cloths using three grades of alumina, 5/20, 3/50 and Gamma, followed by careful cleaning of the surface.

Reflectance determinations were carried out on a Leitz M.P.V. microphotometer under oil immersion, R.I. 1.516 at a wavelength of 546 nm. The field measured was varied to suit the size of the organic particle, but was usually of the order of 2 micron diameter.

The surface of the polished block was searched by the operator for suitable areas of vitrinitic material in the sediment. The reflectance of the organic particle was determined relative to optical glass standards of known reflectance. Where possible, a minimum of twenty individual particles of vitrinite was measured, although in many cases this number could not be achieved. The search for vitrinitic material was maintained for approximately 45 minutes on each sample before termination, if the operator considered that no more vitrinitic particles were likely to be located.

Visual Kerogen

Samples for visual kerogen were picked from the screening analyses. The samples were crushed, treated with HCl and HF to remove the rock matrix, centrifuged and mounted on slides.

Maturity of the individual samples was determined by visual estimation of the colours of pollen, spores, cuticles, wood remains, and finely dispersed organic matter.

The colour tones are given according to Burgess' index (Burgess, J.D., 1974. Geol. Soc. Amer. Spec. Paper, 153, 19-30).

RESULTS AND DISCUSSION

Light Hydrocarbons

From the C_1-C_4 hydrocarbon abundance, wetness of the gas and the isobutane/n butane (iC_4/nC_4) ratio, the analysed section 3714-4075 can be divided into five zones:

A: 3714-3775 m
B: 3800-3825 m
C: 3850-3900 m
D: 3925-4050 m
E: 4075 m

These zones have been found on the basis of the headspace analyses plus the absorbed gas in the cuttings.

A: 3714-3775 m: This zone shows a fair potential and a decreasing wetness with increasing depth.

B: 3800-3825 m: This zone consists of only two samples. The headspace shows a high abundance of light hydrocarbons, but the gas is rather dry. The zone consists mainly of sand, and the analyses indicate accumulated gas.

C: 3850-3900 m: This zone has again a fair potential with a very wet gas. The lithological analysis shows this zone to consist mainly of coal.

D: 3925-4050 m: Again a zone with very high abundance of C_1-C_4 hydrocarbons in the headspace. Lithological analysis shows the zone to consist mainly of sand, and the analyses indicate accumulated hydrocarbons. There is a drop in the abundance in the middle of the zone. However, the wetness and iC_4/nC_4 ratio are rather constant, so it was decided not to divide it into another zone.

E: 4075 m: This sample gave again a marked drop in the C_1-C_4 hydro-

carbon abundance, and an increase in wetness together with decrease in the iC_4/nC_4 ratio. This separates it out from the overlying zone. This zone has a fair potential.

Total Organic Carbon (TOC)

Total organic carbon (TOC) was measured on all the samples. Where significant amounts of different lithologies were found, TOC was measured on the different lithologies.

A: 3714-3775 m: Mainly claystone with the exception of 3725 m, which consists of approximately 80 % siltstone and 20 % claystone. The claystone shows a good to rich potential.

B: 3800-3825 m: This zone consists mainly of sandstone and silty sandstone. The sample from 3825 m shows a rather high TOC value for a silty sandstone. This could indicate migrated oil in the sandstone.

C: 3850-3900 m: In this zone the samples contain large amounts of coal, and it was difficult to separate all the coal particles. We must therefore accept that the results are high.

D: 3925-4050 m: Again a zone with mixed lithologies, mainly sandstone, but also some samples with significant amounts of claystone. The claystone shows a good to rich potential, and the sandstone shows a rather high TOC value which could be an indication of migrated oil.

E: 4075 m: This zone consists of only one sample, mainly claystone with a rich potential.

Extractable Organic Matter (EOM) and Chromatographic Separation

A: 3714-3775 m: Three samples, 3714, 3750 and 3775 m, were extracted from this zone, and all show a high abundance of EOM with a rich potential of hydrocarbons. The percentage of hydrocarbons is so high

that it indicates migrated hydrocarbons in the claystone. The gaschromatograms show all samples to be front biased with an indication of a sterane hump in the sample from 3714 m.

B: 3800-3825 m: One sample from this zone, 3800 m, was extracted. The sample was mainly sand, but gave a rather high abundance of EOM, which indicates migrated oil. The gaschromatogram shows a front biased distribution with a CPI less than 1.0.

C: 3850-3900 m: One sample from this zone, 3875 m, was extracted. The sample was mainly claystone, but the TOC result indicates the probability of coal. The gaschromatogram shows a front biased distribution and a large sterane hump. The CPI value is less than 1.0.

D: 3925-4050 m: One sample, 3975 m, from the sand in this interval was ectracted, and the results indicate migrated hydrocarbons. The gaschromatogram is front biased with a CPI value close to unity.

E: 4075 m: The claystone from the one sample in this zone was extracted and showed a high abundance of EOM. However, the gaschromatogram indicates contamination from diesel in the drilling mud.

Vitrinite Reflectance

Six samples were analysed for vitrinite reflectance. In the following we will describe the individual samples, and, together with the reflectance values, other information from the analyses will be given.

3714 m: Mixed lithologies, Ro=0.39(13), Ro=1.43(6). The sample has a low organic content, apart from some coal cuttings. A little interstitial material of high reflectance in limestone, otherwise barren. UV light shows variable carbonate fluorescence and no exinite. The Ro=0.39 is probably from a drilling additive, while the high Ro=1.43 will be from reworked material.

3775 m: Shale, siltstone, pyrite and cement, Ro=0.99(15). The sample

has a moderate organic content with inertinite as the dominant maceral. A few vitrinite wisps and particles. UV light shows a few deep orange and orange/red fluorescence from spores and a low exinite content.

3850 m: Shale, siltstone, sandstone, coal and carbargillite, Ro=1.00 (22). The sample has a low organic content confined to coal and shale lithologies. Mainly inertinite particles and a few vitrinite wisps. UV light shows a few red specks of probable hydrocarbons, and no exinite.

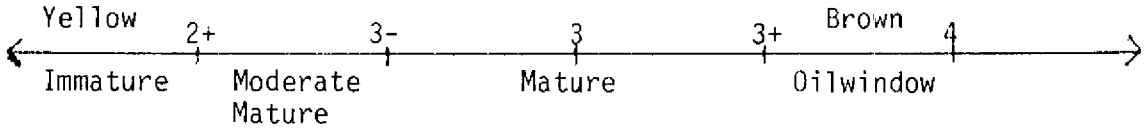
3900 m: Coal, siltstone, shale and lignite, Ro=0.99(25). The sample has a variable organic content with lithology. Vitrinite is predominant with inertinite as subordinant. The coal is barren. UV light shows fluorescence from hydrocarbons which dissolve in the immersion oil.

4000 m: Coal, carbargillite, shale, sandstone and lignite, Ro=1.03 (25). The sample has a variable organic content with lithology. Vitrinite is predominant with inertinite as subordinate. UV light shows fluorescence from hydrocarbons plus resin traces.

4075 m: Mixed lithologies, shale, sandstone, coal and cement, Ro=0.43 (3), Ro=1.19(20). The sample has a moderate organic content with a few particles of low Ro. Some wisps and particles of vitrinite are recorded in the shale, and these appear reliable. UV light shows red fluorescence from hydrocarbon traces.

Visual Evaluation of Kerogen

Samples were treated for visual kerogen analysis. In the analyses of this well, the colour index is given for the dominant organic debris unless otherwise stated. The following interpretation has been used for the qualitative colour index:



In the following individual samples are discussed separately, and different kerogen components are expressed in terms of percentages of total kerogen. These are based on visual estimates and are not quantitative measurements.

3714 m: The sample contains approximately equal amounts of amorphous material and wood remains, with a colour index of 3-. This indicates a mature source rock for oil and gas.

3750 m: Finely dispersed amourphous debris dominates completely. This together with a colour index of 3/3+ indicates a mature/oil-window source rock for oil.

3775 m: The composition and colour index as the sample above.

3825 m: Undifferentiated dispersed herbaceous material and wood remains dominate this sample together with approximately 20 % herbaceous material. The sample shows a colour index of 3+.

3875 m: The composition and colour index as the sample above.

3900 m: Undifferentiated dispersed herbaceous material and wood remains dominate completely, with a colour index of 4-. This indicates a source rock for gas with an oilwindow maturity.

3975 m: Undifferentiated dispersed herbaceous material and wood remains dominate together with approximately 20 % amorphous material. The sample has a colour index of 4-.

4025 m: The composition and colour index as the samples above.

4075 m: Undifferentiated herbaceous material and wood remains dominate with only small amounts of amorphous material. The sample has a colour index of 4-. This indicates a source rock for gas with an oil-window maturity.

CONCLUSION

On the basis of the light hydrocarbon data, the analysed sequence of the well was divided into five zones; A: 3714-3775 m, B: 3800-3825 m, C: 3850-3900 m, D: 3925-4050 m and E: 4075 m.

In our evaluation of the well we have based our richness rating on the light hydrocarbon, total organic carbon (TOC) and extracted organic matter (EOM) data. The maturation is mainly based on the vitrinite reflectance and visual kerogen data.

A: 3714-3775 m: This zone consists mainly of claystone and is rated as a rich source rock on the basis of the light hydrocarbons, TOC and EOM data. However, the relative high percentage of hydrocarbons in the EOM indicates some migrated hydrocarbons. The vitrinite reflectance measurements indicate an oilwindow maturity. The visual kerogen analysis shows a marginally lower maturity and that the zone is oil-prone. On the basis of this we will rate it as a rich source rock for oil with an oilwindow maturity.

B: 3800-3825 m: This zone consists mainly of sandstone, and the different analyses indicate reservoired oil and gas.

C: 3850-3900 m: This zone contains large quantities of coal. A general richness rating is therefore not performed. However, the maturity measurements show the zone to be in the middle of the oil-window.

D: 3925-4050 m: Again a zone with a large proportion of sandstone. The different analyses indicate reservoired oil and gas.

E: 4075 m: This zone consists mainly of claystone, and the light hydrocarbons, TOC and EOM indicate the zone to be a rich source rock. The maturity measurements indicate a maturity towards the lower end of the oilwindow. However, the visual kerogen indicates the zone to be mainly gasprone, and we therefore rate this zone to be a rich source rock for gas.

Table I.a.

Concentration (µl gas/kg rock) Light Hydrocarbons, Headspace Gas.							
Depth (m)	C_1	C_2	C_3	iC_4	nC_4	ΣC_1-C_4	ΣC_2-C_4
3714	580	160	102	30	27	899	319
3725	790	104	80	9	40	1023	233
3750	290	34	22	5	14	365	75
3775	2340	141	100	12	31	2624	284
3800	25240	2230	1210	121	363	29164	3924
3825	36420	5020	3820	214	582	46056	9636
3850	1430	910	892	64	192	3488	2058
3875	520	171	182	25	94	992	472
3900	120	454	174	31	103	882	762
3925	16240	2890	214	41	124	19509	3269
3950	10240	2340	1260	38	89	13967	3727
3975	4020	526	432	41	92	5111	1091
4000	3256	474	316	71	161	4278	1022
4025	9240	1384	952	179	426	12151	2911
4050	11320	2120	1052	53	96	14641	3221
4075	2420	652	412	7	18	3509	1089

Table I.b.

Concentration (µl gas/kg rock). Light Hydrocarbons, Absorbed Gas.

Depth (m)	C_1	C_2	C_3	iC_4	nC_4	ΣC_1-C_4	ΣC_2-C_4
3714	1025	310	220	55	50	1720	635
3725	1255	223	150	17	74	1719	463
3750	261	31	20	3	8	322	61
3775	1347	87	58	7	20	1520	172
3800	516	42	20	2	6	586	69
3825	748	93	75	4	11	933	184
3850	153	89	87	7	20	357	204
3875	64	20	28	3	11	127	63
3900	42	142	82	7	32	270	228
3925	82	14	5	0.2	0.6	104	20
3950	205	44	29	0.7	1.5	281	75
3975	79	11	8	0.6	1.2	99	20
4000	191	28	17	4	8	247	57
4025	185	25	15	3	12	239	55
4050	212	46	22	1	2	283	72
4075	236	64	40	0.6	1.6	342	106

Table I.c.

Concentration (µl gas/kg rock). Light Hydrocarbons, Headspace + Absorbed Gas.									
Depth (m)	C_1	C_2	C_3	iC_4	nC_4	ΣC_1-C_4	ΣC_2-C_4	% wetness	$\frac{iC_4}{nC_4}$
3714	1605	470	322	85	77	2619	868	33.1	1.1
3725	2045	327	230	26	114	2742	696	25.4	0.23
3750	551	65	42	8	22	687	136	19.8	0.36
3775	3687	228	158	19	51	4144	456	11.0	0.37
3800	25756	2272	1230	123	369	29752	3993	13.4	0.33
3825	37168	5113	3895	218	593	46989	9820	20.9	0.37
3850	1583	999	979	71	212	3845	2262	58.8	0.33
3875	584	191	210	28	105	1119	535	47.8	0.27
3900	162	596	256	38	135	1052	990	94.1	0.28
3925	16322	2904	219	41	125	19613	3497	17.8	0.33
3950	10445	2388	1289	39	90	14248	3702	26.7	0.43
3975	4099	537	440	42	93	5210	1111	21.3	0.45
4000	3447	502	333	75	169	4525	1069	23.6	0.44
4025	9425	1409	967	182	438	12390	3966	23.9	0.42
4050	11532	2166	1074	54	98	14924	3293	22.1	0.55
4075	2656	716	452	8	20	3851	1195	31.0	0.40

Table II.

Lithology and Total Organic Carbon (TOC) Measurements.

Depth (m)	TOC		Lithology
3714	1.19	80%	Claystone, partly silty, grey, light grey, greenish grey, brownish grey.
	0.68	20%	Siltstone, clayey, occasionally sandy, light grey to clear.
3725	0.76	80%	Siltstone, clayey, occasionally sandy (very fine to fine), light grey.
	1.72	20%	Claystone, grey.
		Obs.	Pyrite.
3750	2.14	100%	Claystone to silty Claystone, grey, brownish grey, light grey.
3775	2.07	100%	Claystone to silty Claystone, brownish grey, grey.
		Sm.am.	Pyrite.
3800	0.44	95%	Quartz Sand, very fine to coarse, subangular to subrounded, clear.
		5%	Claystone.
3825	1.51	95%	Silty Sandstone, very fine, brownish grey to clear.
		5%	Claystone, grey.
3850		65%	Coal.
	6.75	35%	Silty Claystone, light brown, from bore mud.
3875	14.75	50%	Silty Claystone, light brown, from bore mud.
		25%	Coal.
		25%	Sand (15%), fine to coarse, clear; and silty Sandstone (10%), very fine, brownish grey to clear.

Table II - p.2.

Depth (m)	TOC	Lithology	
3900		80%	Coal.
	6.67	20%	Silty Claystone, light brown, from bore mud.
3925	0.75	95%	Sandstone (65%), very fine to fine, light grey to clear, brownish; and Sand (30%), medium to coarse, clear.
		5%	Claystone, grey.
		Obs.	Pyrite.
3950	0.42	65%	Sandstone, very fine to fine, brownish light grey to clear, some medium, clear Sand grains.
	1.56	35%	Claystone, grey.
		Sm.am.	Coal.
		Obs.	Pyrite.
3975	0.45	91%	Sandstone, very fine to fine, brownish light grey to clear.
	3.33	7%	Claystone, grey.
		2%	Coal.
		Obs.	Pyrite.
4000		70%	Coal.
	0.55	30%	Sandstone, very fine to fine, brownish light grey to clear.
4025	1.03	97%	Sand/Sandstone, very fine to coarse, angular to subangular, clear, partly brownish.
		3%	Claystone, grey.
		Sm.am.	Coal.
		Obs.	Pyrite.

Table II - p.3.

Depth (m)	TOC		Lithology
4050	0.49	100%	Sand, very fine to coarse, very angular to subangular, clear to brownish.
4075	4.73	80%	Claystone, grey.
		20%	Silty Claystone, light brown, from bore mud.
		Sm.am.	Quartz Sand; Coal.
		Obs.	Pyrite.

The lithological description is done on the fraction between 0.125 and 2.0 mm.

Abbreviations used in the table: Sm.am.: Small amounts.
Obs.: Observed.

Table III

Weight (mg) of EOM and chromatographic fractions.

Depth (m)	Rock extracted (g)	EOM	Sat	Aro	Hydrocarbons HC	Non Hydrocarb.	TOC
3714	100.7	185.1	78.1	49.0	127.1	41.9	1.19
3750	99.97	315.6	120.7	99.5	220.2	87.6	2.14
3775	100.3	286.6	101.7	85.4	187.1	81.3	2.07
3800	45.61	24.9	6.5	8.2	14.7	8.2	0.44
3875	100.4	982.5	400.7	284.8	685.5	243.9	14.46
3975	100.2	203.7	37.3	68.9	106.2	86.1	3.33
4075	54.24	170.1	46.6	55.7	102.3	63.2	4.73

Table IV

Concentration of EOM and chromatographic fractions (Weight ppm of rock).

Depth (m)	EOM	Sat	Aro	Total hydrocarb.	Non hydrocarb.
3714	1838	776	486	1262	416
3750	3157	1207	995	2202	876
3775	2857	1014	1851	1865	811
3800	546	143	180	323	180
3875	9786	3991	2837	6828	2429
3975	2033	372	688	1060	859
4075	3136	859	1027	1886	1165

Table V

Concentration of EOM and chromatographic fractions (mg/gTOC).

Depth (m)	EOM	Sat	Aro	Total hydrocarb.	Non hydrocarb.
3714	154.46	65.17	40.89	106.06	34.97
3750	147.52	56.42	46.51	102.93	40.95
3775	138.04	48.98	41.13	90.12	39.16
3800	124.08	32.39	40.86	73.25	40.86
3875	67.68	27.62	19.62	47.22	16.80
3975	451.77	82.73	152.81	235.53	190.92
4075	66.30	18.16	21.71	39.87	24.63

Table VI

Composition in % of the organic material extracted from the rock.

Depth (m)	$\frac{\text{Sat}}{\text{EOM}}$	$\frac{\text{Aro}}{\text{EOM}}$	$\frac{\text{HC}}{\text{EOM}}$	$\frac{\text{Sat}}{\text{Aro}}$	$\frac{\text{Non HC}}{\text{EOM}}$	$\frac{\text{HC}}{\text{Non HC}}$
3714	42.19	26.47	68.67	159.39	22.64	303.34
3750	38.24	31.53	69.77	121.31	27.76	251.37
3775	35.48	29.80	65.28	119.09	28.37	230.14
3800	26.10	32.93	59.04	79.27	32.93	179.27
3875	40.78	28.99	69.77	140.70	24.82	281.06
3975	18.31	33.82	52.14	54.14	42.27	123.34
4075	27.40	32.75	60.14	83.66	37.15	161.87

Table VII -

Tabulation of datas from the gaschromatograms.

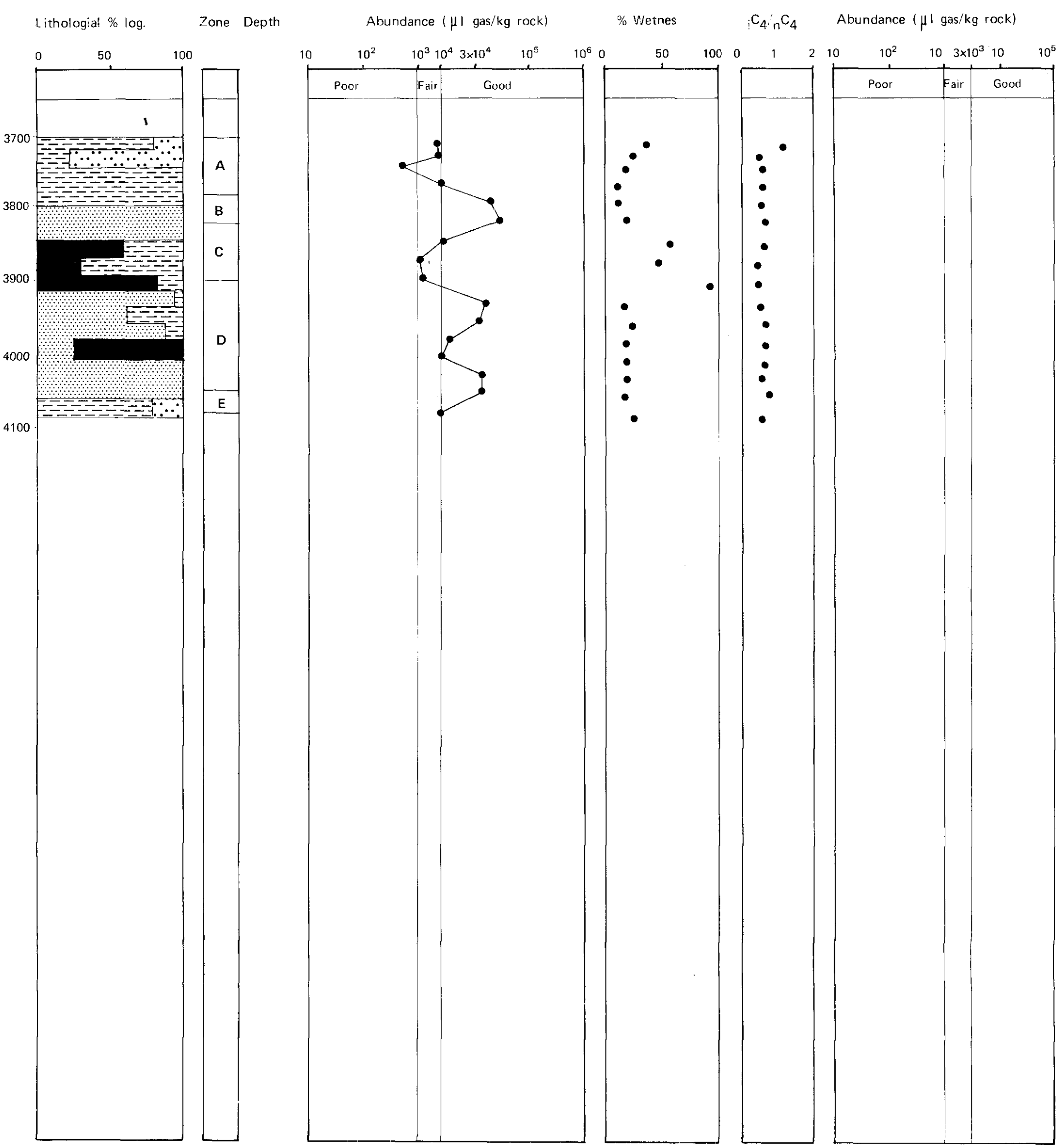
Depth (m)	Pristane/nC_{17}	Pristane/Phytane	CPI
3714	0.34	1.05	0.91
3750	0.31	1.47	1.02
3775	0.31	1.50	0.88
3800	0.31	1.42	0.90
3875	0.32	1.32	0.84
3975	0.27	1.86	1.04
4075	0.34	1.20	0.98

Table VIII

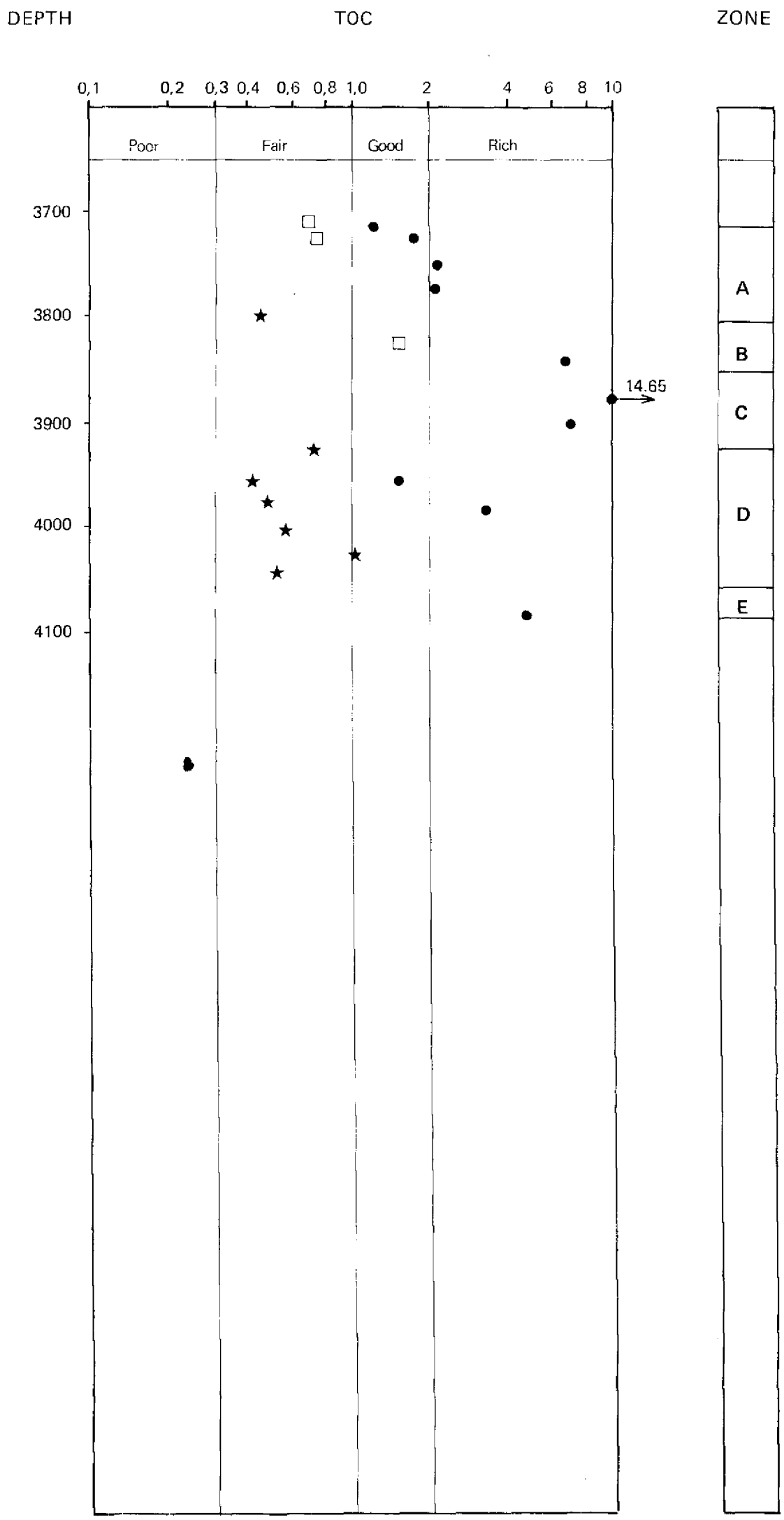
Vitrinite Reflectance and Visual Kerogen Estimation.

Depth (m)	Vitrinite Reflectance	Colour index	Type of organic matter
3714	0.39(13) 1.43(6)	3-	Am/W
3750		3/3+	Am
3775	0.99(15)	3/3+	Am
3825		3+	H/W
3850	1.00(22)		
3875		3+	H/W
3900	0.99(25)	4-	H/W
3975		4-	H/W/Am
4000	1.03(25)		
4025		4-	H/W/Am
4075	0.43(3) 1.19(20)	4-	H/W

$C_1 - C_7$ HYDROCARBONS
Presentation of Analytical Data



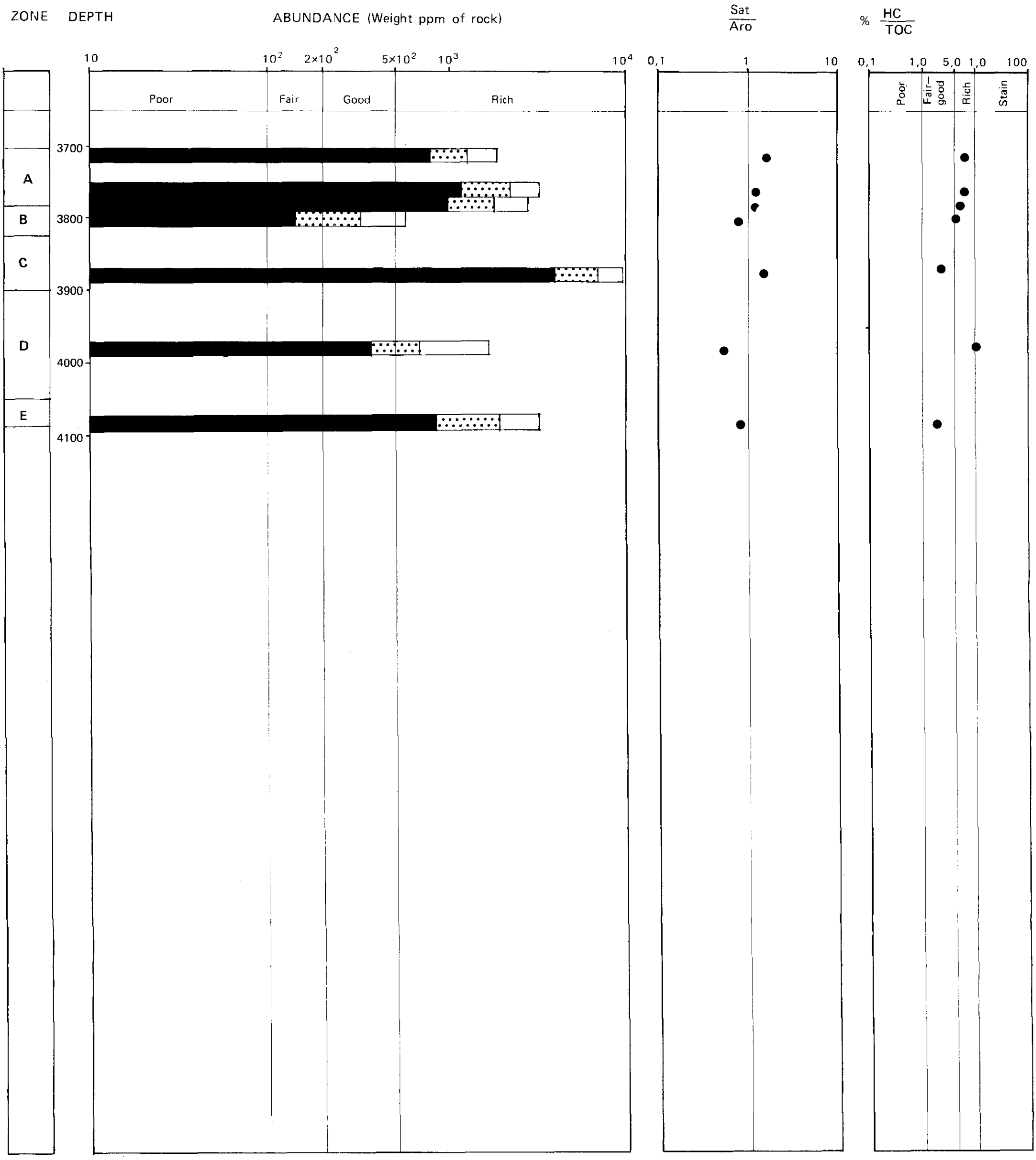
TOTAL ORGANIC CARBON (TOC)
Presentation of Analytical Data



TOC: Total Organic Carbon

- ● Claystone
- ★ Sandstone
- □ Siltstone

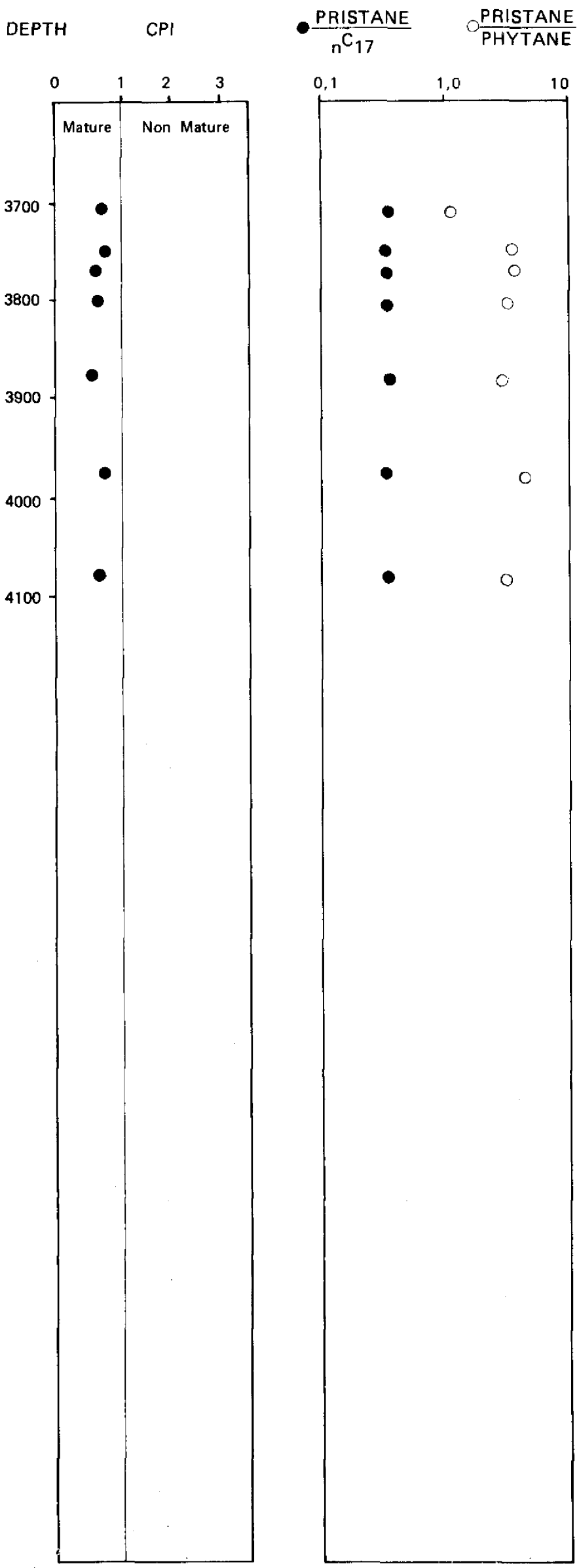
C_{15}^{+} HYDROCARBONS
Presentation af Analytical Data

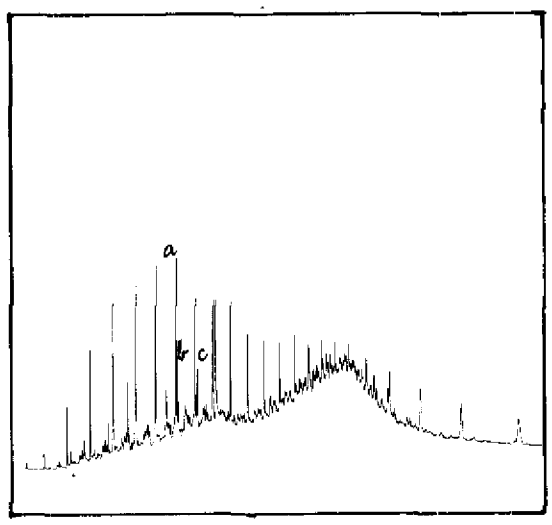


Sat: Saturated Hydrocarbons
Aro: Aromatic Hydrocarbons
NSO: Nitrogen, Sulphur and Oxygen containing compounds

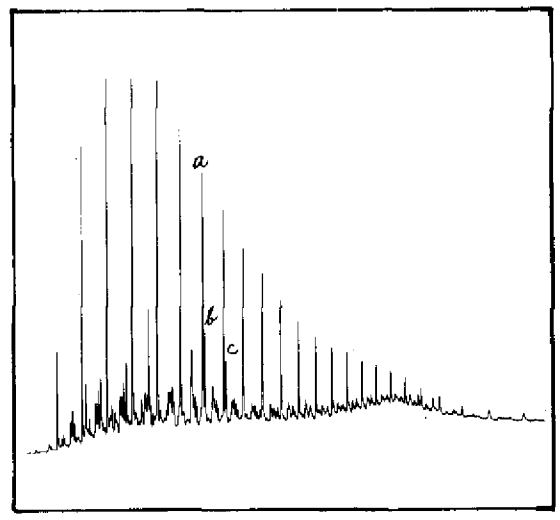
Asp: Asphaltenes
HC: C_{15}^{+} Hydrocarbons
TOC: Total Organic Carbon

C_{15}^{+} SATURATED HYDROCARBONS





3714



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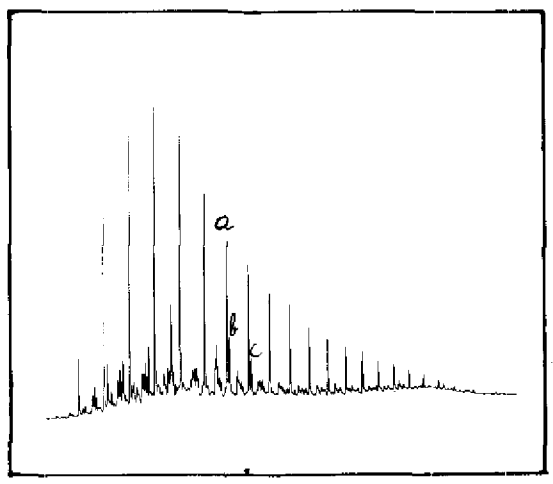

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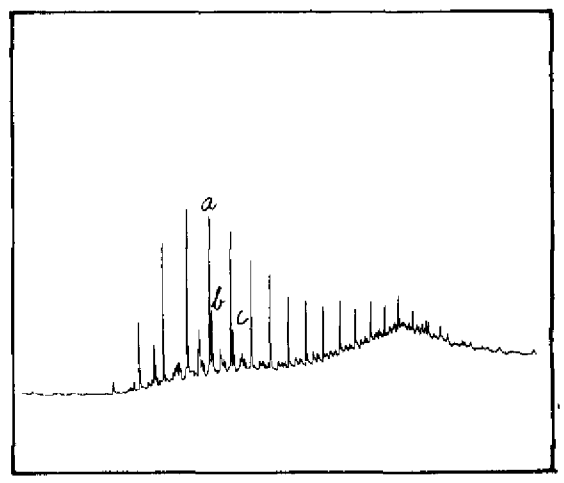

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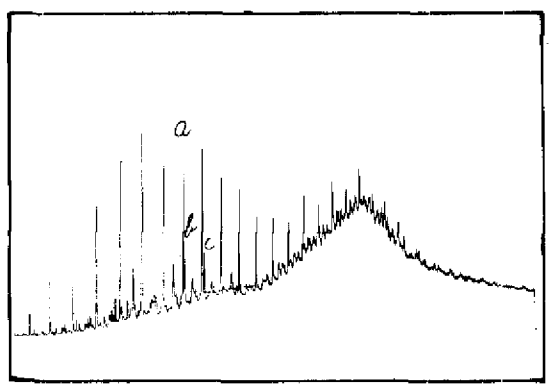

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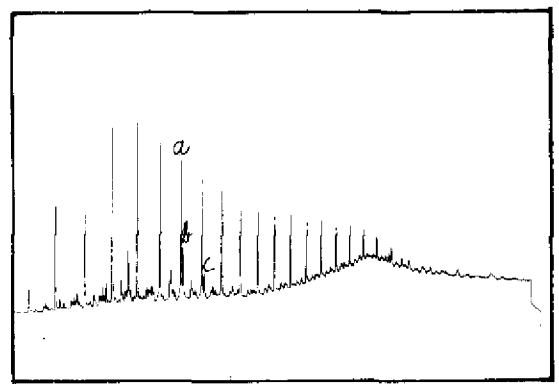
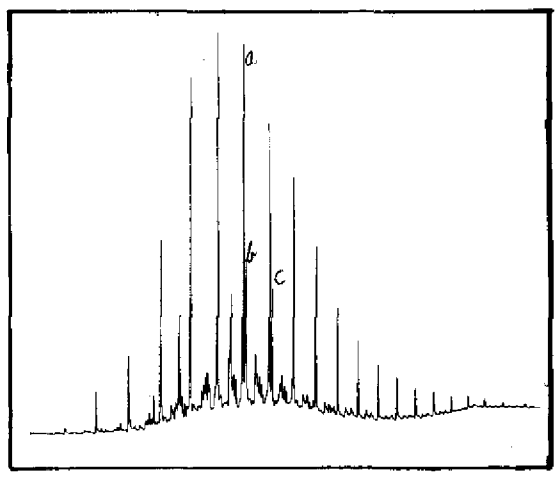


3970

a: $_{n}C_{17}$

b: Pristane

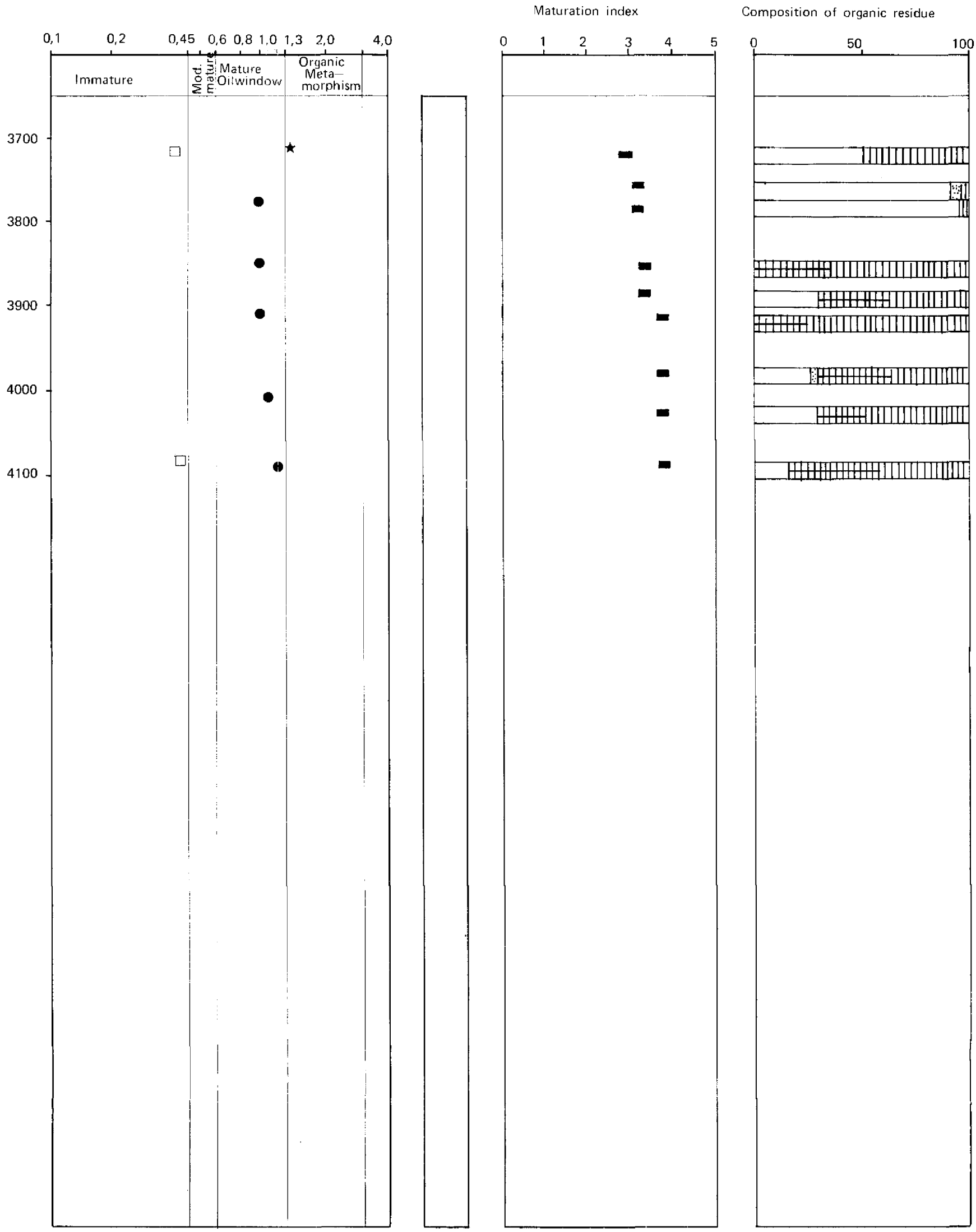
c: Phytane



4075

MATURATION

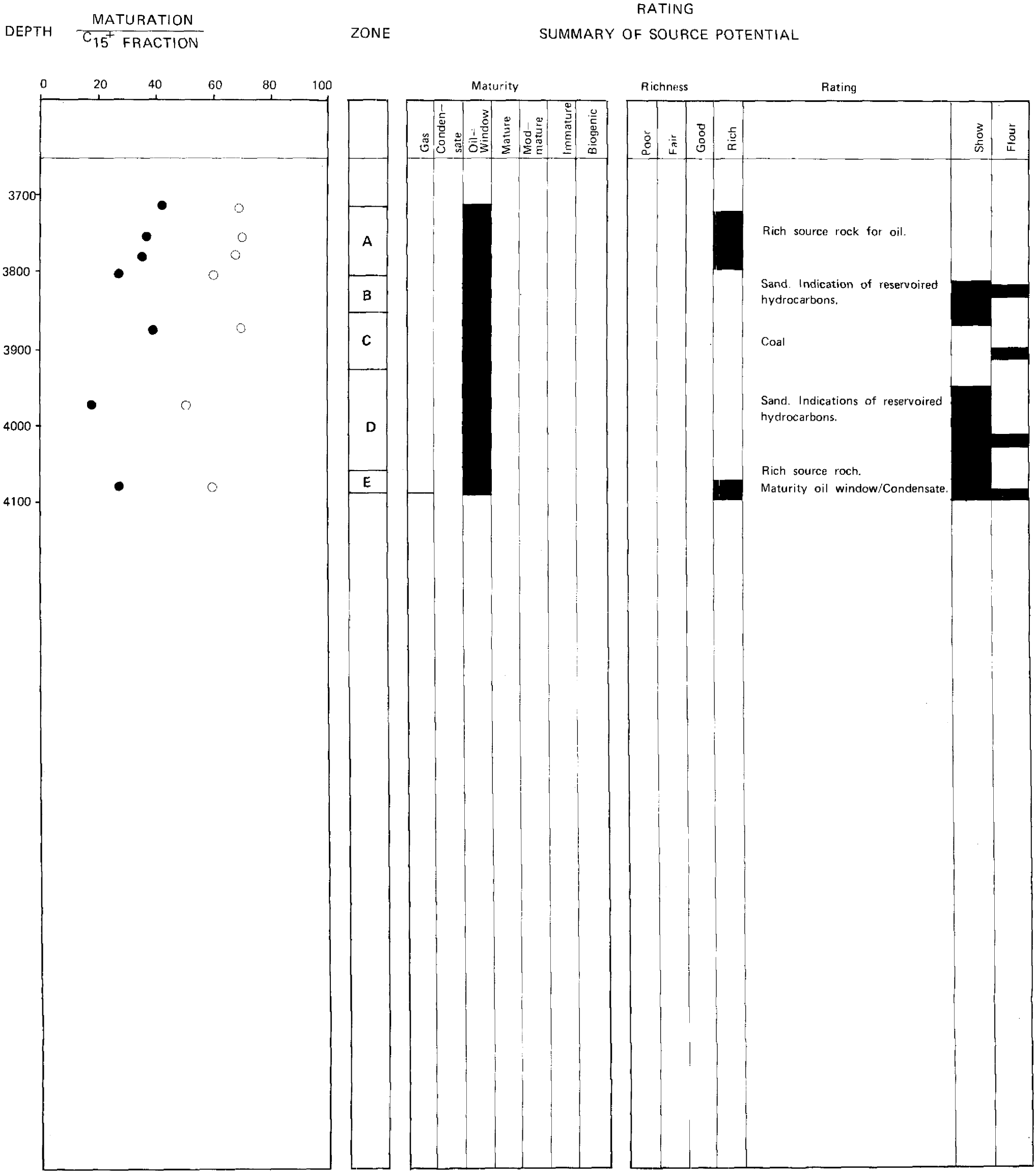
DEPTH | VITRINITE REFLECTANCE | ZONE | VISUAL KEROGEN COLORATION AND COMPOSITION OF ORGANIC RESIDUE



- ● True vitrinite
- □ Additive vitrinite
- ★ Reworked

- Amorphous material, Sapropel
- Algal
- Spores and pollen
- Cuticles
- Wood remains
- Undifferentiated disperse herbaceous material
- Black coal fragments

INTERPRETATION DIAGRAM



Sat: Saturated Hydrocarbons
HC: Hydrocarbons
EOM: Extractable Organic Matter