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ROBERTSON RESEARCH INTERNATIONAL LIMITED

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A PETROLEUM GEOCHEMICAL EVALUATION OF THE SECTION 2740m – 4585m OF THE NORSK HYDRO 15/2 - 1 WELL, NORWEGIAN NORTH SEA.

by

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SUMMARY

A petroleum geochemical study has been carried out on sediments chiefly of Cretaceous and Late to Middle Jurassic age in the 15/2-1 well. The early to middle mature Cretaceous sediments penetrated between 2740 and 3710 metres contain only small amounts of organic matter and no potential source rocks are identified. The Valhall Formation is indicated to be middle mature for oil generation and contains organically rich horizons, some of which have oil source potential. There appears to be a sharp increase in maturity level on entering the Kimmeridge Clay Formation which is late mature for oil generation. Oil generating kerogen is abundant in the upper part of the Kimmeridge Clay Formation and should have realised much of its hydrocarbon potential, while the deeper part of this formation appears more gas-prone. The Heather, Hugin and Sleipner Formations contain more humic kerogen and in the latter formation coals are present. These sediments are therefore principally potential sources of gas which at their present level of maturity are near the main gas generation stage.

The following numbers of analyses were carried out during the study of this well:

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RESULTS AND INTERPRETATION

A. MATURITY EVALUATION

i. Summary of Maturity Evaluation

Airspace gas data are only available for the interval 2740 to 3815 metres and suggest an early mature state with the middle mature stage for oil generation reached near the base of this interval. Vitrinite reflectance data also indicate a middle mature state for the earliest Cretaceous sediments. The data indicate a rapid increase in maturity level through the Kimmeridge Clay Formation which is late mature on the basis of microscopic examination. Pyrolysis temperatures indicate an early to middle level of maturity and turbo drilling may have had an adverse effect of darkening the colour of the organic matter and apparently modifying its maturity level. In the deeper part of the Heather Formation and in the Hugin and Sleipner sediments there is far better agreement between the maturity indicators and a late to post-mature stage for the oil generation is seen at the base of the analysed well section. The main gas generation stage of maturity has not been reached for the Jurassic sediments in this section.

ii. Airspace Gaseous Hydrocarbon Analysis (Table 1 and Figure 1).

The total amount of airspace gas in the organically lean Cretaceous sediments between 2740 and 3875 metres is low and variable. Over this interval the proportion of wet gas is seen to rise from about 10%, indicative of early maturity to about 30%, a value normally associated with middle maturity for oil-prone organic matter. On passing into the Kimmeridge Clay Formation both total gas abundance and the proportion of wet gas increase sharply to high levels, which may be indicative of the presence of migrant gaseous hydrocarbons in addition to copious gas generation. Between 4235 and 4365 metres there is a decrease in total gas abundance, but little change in total gas composition in the sediments of the Heather Formation. Below 4435 metres, gas abundance of mostly methane, increases to very high values as the coaly sediments of the Hugin and Sleipner Formations are encountered, which maybe partly generated from the coals.

iii. Cuttings Gas Analysis (Table 2 and Figure 2).

In view of the low amounts of airspace gas present in the upper half of the section, this analysis was restricted to the samples below 3710 metres. The results of this analysis show similar trends to those shown by airspace gas, with high gas abundances in the Kimmeridge Clay and Hugin/Sleipner Formations and a lower total gas abundance in the Heather Formation. Wet gas is prevalent throughout the interval examined and much of this may be migrant as well as indigenously generated. After allowing for the presence of migrant gas, it seems likely that the sediments are well matured for oil and gas generation.

iv. Vitrinite Reflectance Analysis (Table 3 and Figure 3).

Vitrinite reflectance analysis was carried out on hand-picked lithologies in order that values on in situ rather than caved vitrinite could be recognised for maturity interpretation. However, it has been found that nearly all the samples contained several populations of vitrinite of differing reflectivity. Furthermore, the vitrinite particles are sparse and the grains difficult to measure. It is thought that the poor quality of the vitrinite particles may be partly due to turbo drilling.

The only reliable data appear to be from below 4365 metres where vitrinite is more abundant and coals occur. Between 4365 and 4525 metres, reflectivities lie in the range 0.88% to 1.32% and though not showing any defined increase with depth, are highest in the coals and shales at the base of the analysed section.

Above 4365 metres the numbers of particles in each reflectance population are about equal, though a trend of increasing values within the ranges is seen in Figure 3. It is know that substantial amounts of caved Cretaceous material are present in the Jurassic samples. Values of around 0.56% to 0.66%, which are seen in the Cretaceous and Jurassic, may therefore be derived from caved Cretaceous material. Between 4025 and 4355 metres, within the Jurassic, reflectivity values appear to be in the range of 0.72% to 0.87%.

Over the analysed interval 3815 to 4525 metres, reflectivity values appear to increase from about 0.6% to about 1.1% and possibly upto 1.3%. Such a rapid increase in maturity is unusual and while such marked increases have been previously seen in wells in this part of the Norwegian North Sea, the reason is not yet clear. Proximity to a high temperature source seem likely.

v. Spore Colour Index Analysis (Table 3 and Figure 4).

Spore colour index analysis was carried out on hand-picked lithologies containing more than 2.0% organic carbon. Palynomorphs were found to be sparse in all the analysed samples above 4365 metres. Caved sporomorphs were noted in several samples and allowances made for their presence. In general, all in situ sporomorphs show high indices of mainly 7.5 to 8.5 throughout the analysed section. The data show similar features to the vitrinite reflectance data in that high values are most frequent and there is a strong suggestion that sporomorph colours could have been darkened due to turbo-drilling. Indices below 4465 metres do, however, fit well with vitrinite reflectance data and the data are more abundant. The data for the interval 3815 to 4355 metres are not considered of sufficient quality to reliably interpret the maturity level.

B. HYDROCARBON SOURCE ROCK EVALUATION

i. Organic Carbon Content (Table 4 and Enclosure).

In the upper part of the section, Cretaceous sediments between 2740 and 3710 metres have low organic carbon contents ranging from 0.27% to 0.45%. The underlying Valhall Formation includes lithologies of higher organic carbon content, up to 4.01%, though some caved lithologies also appear to be present. The sediments of the Kimmeridge Clay Formation are all organically rich with individual lithologies having between 5.13% and 9.25% organic carbon. The Heather Formation is rather leanner in organic matter than the Kimmeridge Clay, though still yields contents of around 3% to 7%. Shales in the Hugin and Sleipner Formations have good organic carbon contents of 4.23% and 4.29% respectively, the samples of mixed lithology from this part of the section often containing coals. From the deepest part of the section, where the Permian is encountered, only cavings from the Sleipner Formation are present.

ii. Kerogen Composition (Table 3).

The kerogen of the Valhall Formation sediments between 3815 and 3875 metres is humic with inertinite dominant over vitrinite. Amorphous kerogen dominates the Kimmeridge Clay and though non-fluorescing and dark in colour, it is probably sapropel rather than degraded vitrinite. Within the Heather Formation there is rather more variation in kerogen composition, though sapropel is frequently dominant. Inertinite is, however, common and waxy contaminant organic matter and Cretaceous caved material are noticed in several samples. Samples from the Hugin and Sleipner Formations contain little or no sapropel and are dominated by the humic materials vitrinite and inertinite.

iii. Pyrolysis Evaluation (Table 4 and Enclosure).

Lithologies analysed from the Valhall and Kimmeridge Clay Formations gave very variable hydrogen indices in relation to organic content and kerogen type. The higher values of between 264 and 362 in the interval 3905 to 4025 metres could relate to either a mixture of sapropelic and vitrinitic kerogen or waxy sapropelic kerogen at a late level of maturity, though this is not supported by the low pyrolysis temperatures. The remaining parts of these two formations gave low hydrogen indices of around 100 usually associated with vitrinitic kerogen rather than the amorphous material visually observed. Potential hydrocarbon yields are however good to very good particularly in the upper part of the Kimmeridge Clay. In the deeper part of the Kimmeridge Clay, high production indices suggest oil-staining. In the Heather Formation hydrogen indices and potential yields are very low reflecting the inertinitic nature of the kerogen. Hydrocarbon staining is seen in these sediments. Samples from the Hugin and Sleipner Formations have slightly higher hydrogen indices, reflecting a more vitrinitic kerogen composition than in the Heather Formation. Some oil-staining appears to persist into these deeper sediments. It is notable that pyrolysis temperatures show a rapid increase on passing from the Heather to the Sleipner Formations. The deepest sediments analysed give pyrolysis temperatures in fair agreement with the visual maturity indications, while the Kimmeridge Clay gave pyrolysis temperatures indicative of a far lower level of maturity.

iv. Extraction and Fractionation of Organic Matter (Table 4 and Enclosure). The amount of extractable organic matter in almost every sample analysed is high, though the greatest extract abundances are confined to the Kimmeridge Clay Formation. The amount of hydrocarbons present in the extract is high through most of the analysed section and at a level indicating some degree of hydrocarbon staining. The highest yields of hydrocarbons in relation to organic richness are in the Kimmeridge Clay.

v. Gas Chromatography of Alkane Fractions of Rock Extracts (Figures 5-18).

In general two types of hydrocarbon distribution can be seen from the chromatograms. The first group includes the sediments of the Valhall, Kimmeridge Clay and upper part of the Heather Formation from the interval 3815 to 4295 metres, as illustrated in Figures 5 to 13. The distribution of normal alkanes in each chromatogram shows derivation of the hydrocarbons from a similar organic facies. Occasionally this is modified by the addition of non-indigenous hydrocarbons often of mainly shorter chain length as seen at 3965 and 4085 metres, (Figures 7 and 9). The isoprenoids pristane and phytane are of lower abundance than neighbouring n-alkanes and steranes and triterpanes are virtually absent, showing that the hydrocarbons are generated from a middle to late mature source rock of marine facies, influenced by some contribution of terrestrially derived organic matter.

The deeper samples, from the lower part of the Heather Formation and the Hugin and Sleipner Formations between 4355 and 4525 metres give the second group of distinctive chromatograms. These show the presence of a larger proportion of long chain n-alkanes, particularly above n-C_{20}, and therefore derivation from more terrestrially influenced source facies containing humic kerogen. Isoprenoids are in low abundance and indicate hydrocarbon generation at a late stage of maturity. Staining by non-indigenous hydrocarbons is present and identified by the unusually high abundance of shorter chain n-alkanes as seen in the sample from 4435 metres, (Figure 17).

III

CONCLUSIONS

The following conclusions are drawn from the petroleum geochemical studies of the section 2740 to 4585 metres of the Norsk Hydro 15/2-1 well.

Thermal Maturity

i. The Cretaceous sediments between 2740 and 3815 metres appear to be at an early, increasing to middle level of maturity with respect to oil generation.

ii. The data indicate a rapid increase in maturity level on entering the sediments of the Kimmeridge Clay Formation, which are indicated to be late mature for oil generation.

iii. The underlying sediments in the deeper part of the Heather Formation and the Hugin and Sleipner Formations, are late to possibly post-mature for oil generation. The coals of the Sleipner Formation may be at optimum maturity for gas generation.

iv. There is some discordance in the maturity data chiefly in the Kimmeridge Clay Formation where turbo drilling may have affected the properties of the kerogen.

v. A high geothermal gradient seems likely through the Late and Middle Jurassic section.

Hydrocarbon Source Rocks

i. No hydrocarbon source rocks have been identified in the Cretaceous sediments between 2740 and 3710 metres on the basis of the samples analysed.

ii. Sediments from the Valhall Formation between 3815 and 3875 metres contain substantial quantities of organic matter which though visually appear mainly vitrinitic, are shown by pyrolysis to contain a significant amount of oil-prone organic matter in some lithologies.

iii. The Kimmeridge Clay Formation comprises sediments with a high content of predominantly oil-prone organic matter between 3905 and 4025 metres. In view of the late stage of maturity, oil generation from these sediments should be well advanced. The deeper part of the Kimmeridge Clay Formation does not appear to contain such high quality oil-prone organic matter, though it should have acted as a fair to good source of hydrocarbons.

iv. The Heather Formation though having a good content of organic matter, has acted as a less copious source of hydrocarbons than the Kimmeridge Clay by virtue of the more humic nature of the kerogen present.

v. Sediments of the Hugin and Sleipner Formations include argillaceous lithologies with vitrinitic kerogen and coals both of which appear to be acting as sources of mainly methane gas.

vi. An abundance of migrant wet gas is seen throughout the Kimmeridge Clay Formation and oil-staining by migrant liquid hydrocarbons, is common in the Late and Middle Jurassic sediments.

COMPANY: NORSK HYDRO **WELL:** 15/2-1 **LOCATION:** NORWEGIAN NORTH SEA

SAMPLE DEPTH (METRES)	RELATIVE GASEOUS HYDROCARBON COMPONENT ABUNDANCE (%)					TOTAL ABUNDANCE (ppm)	TOTAL C_2-C_4 (%)	RATIO *i*-Butane / *n*-Butane
	C_1	C_2	C_3	*i*-C_4	*n*-C_4			
2740	74.85	9.79	7.48	1.43	6.25	490	25.14	0.22
2840	90.91	5.81	1.98	0.34	0.95	750	9.08	0.36
2930	92.71	4.7	1.9	0.26	0.42	370	7.28	0.62
3020	94.08	4.02	1.48	0	0.42	90	5.91	0
3110	82.32	12.07	3.7	0.48	1.43	160	17.67	0.33
3200	87.99	7.29	3.49	0.31	0.92	190	12	0.33
3290	86	7.11	4.6	0.1	2.19	190	14	0.04
3350	80.58	7.8	6.27	0.15	5.2	260	19.41	0.02
3440	82.24	7.88	4.99	0.22	4.66	180	17.75	0.04
3530	57.28	16.12	13.91	1.92	10.76	760	42.72	0.17
3620	65.64	15.94	10.21	1.12	7.08	330	34.36	0.15
3710	66.67	18.38	8.25	1.03	5.67	110	33.33	0.18
3815	16.58	16.55	36.51	5.21	25.15	4980	83.42	0.20
3845	23.03	19.28	31.75	4.69	21.25	7240	76.97	0.22
3875	35.87	26.42	25.65	1.29	10.77	4560	64.13	0.12
3905	9.18	18.25	36.16	4.96	22.45	24370	80.82	0.22
3935	27.37	20.96	31.79	3.71	16.17	77150	72.63	0.22
3965	17.92	21.37	36.60	4.63	19.48	38310	82.08	0.23
3995	16.41	19.07	37.70	5.81	21.01	27660	83.59	0.27
4025	31.05	27.37	29.29	2.66	9.62	111500	68.95	0.27
4055	29.46	21.29	31.44	4.05	13.75	56900	70.54	0.29
4085	39.02	19.68	23.78	3.82	13.69	74720	60.98	0.27
4115	22.63	17.78	34.29	5.47	19.83	23460	77.37	0.27
4145	26.76	18.77	31.75	4.87	17.85	25130	73.24	0.27
4175	22.21	20.16	34.93	4.96	17.74	23030	77.79	0.27
4205	29.14	20.15	31.00	4.45	15.26	20740	70.86	0.29
4235	39.19	20.02	24.80	4.07	11.92	4670	60.81	0.34

Note: Total gaseous hydrocarbon abundance values are expressed as volume of hydrocarbon gases relative to volume of airspace

TABLE 1A Airspace Gaseous Hydrocarbon Analysis Data

COMPANY: NORSK HYDRO WELL: 15/2-1 LOCATION: NORWEGIAN NORTH SEA

SAMPLE DEPTH (METRES)	RELATIVE GASEOUS HYDROCARBON COMPONENT ABUNDANCE (%)					TOTAL ABUNDANCE (ppm)	TOTAL C_2-C_4 (%)	RATIO *i*-Butane / *n*-Butane
	C_1	C_2	C_3	*i*-C_4	*n*-C_4			
4265	55.22	19.39	19.70	0.82	4.87	5870	44.78	0.16
4295	40.85	19.63	28.48	1.53	9.51	3910	59.15	0.16
4325	18.14	14.57	39.10	6.60	21.58	9690	81.86	0.30
4355	30.64	30.54	30.39	2.31	6.12	17340	69.36	0.37
4365	30.63	17.12	30.57	6.13	15.55	4070	69.37	0.39
4435	66.80	21.18	9.07	1.19	1.76	165910	33.19	0.67
4465	76.81	17.38	4.73	0.45	0.64	137470	23.19	0.70
4495	75.42	18.86	4.66	0.47	0.58	139500	24.58	0.81
4525	76.81	17.81	4.47	0.41	0.50	137330	23.19	0.81
4555	73.48	19.89	5.43	0.57	0.63	149340	26.52	0.89
4585	82.22	12.66	4.04	0.48	0.61	90400	17.78	0.78

Note: Total gaseous hydrocarbon abundance values are expressed as volume of hydrocarbon gases relative to volume of airspace

TABLE 1B Airspace Gaseous Hydrocarbon Analysis Data

COMPANY: NORSK HYDRO **WELL:** 15/2-1 **LOCATION:** NORWEGIAN NORTH SEA

SAMPLE DEPTH METRES	RELATIVE GASEOUS HYDROCARBON COMPONENT ABUNDANCE (%)					TOTAL ABUNDANCE	TOTAL C_2-C_4 (%)	RATIO *i*-Butane / *n*-Butane
	C_1	C_2	C_3	*i*-C_4	*n*-C_4			
3815	0.91	1.37	20.55	10.5	66.67	3120	99.09	0.15
3845	6.45	6.45	22.58	8.06	56.45	860	93.55	0.14
3875	12.12	6.06	27.27	6.06	48.48	220	87.88	0.12
3905	0.17	2.42	28.2	10.37	58.83	27690	99.83	0.17
3935	0.26	3.88	30.56	10.08	55.22	76650	99.74	0.18
3965	1.30	2.29	26.11	10.71	59.59	57710	98.7	0.17
3995	1.85	2.95	27.68	10.33	57.2	7320	98.15	0.18
4025	0.54	11.01	44.61	7.49	36.35	71910	99.46	0.20
4055	0.41	4.84	33.78	10.62	50.34	70100	99.59	0.21
4085	0.18	3.39	28.4	11.6	56.43	36020	99.82	0.20
4115	0.16	2.47	24.81	12.64	59.92	36610	99.84	0.21
4145	0.14	2.2	24.24	12.67	60.74	25920	99.86	0.20
4175	0.25	3.17	28.06	12.29	56.24	56390	99.75	0.21
4205	0.29	3.17	27.65	12.6	56.3	44800	99.71	0.22
4235	2.46	8.45	33.1	10.56	45.42	8870	97.54	0.23
4265	2.37	9.47	35.5	11.24	41.42	6250	97.63	0.27
4295	1.82	5.45	34.19	11.27	47.27	8870	98.18	0.23
4325	5.56	3.03	20.96	14.14	56.31	14660	94.44	0.25
4355	1.19	8.57	41.19	11.9	37.14	33600	98.81	0.32
4365	23.26	5.92	32.56	9.09	29.18	18190	76.74	0.31
4435	11.49	25.50	37.25	6.74	19.02	29110	88.51	0.35
4465	22.05	35.45	29.37	3.53	9.61	36580	77.95	0.36
4495	20.59	39.29	29.65	2.94	7.53	40470	79.41	0.39
4525	19.13	38.48	30.43	3.48	8.48	15330	80.87	0.41
4555	12.27	35.21	37.02	4.63	10.87	19110	87.73	0.42
4585	5.88	27.75	41.13	7.40	17.85	27020	94.12	0.41

TABLE 2 CUTTINGS **Gaseous Hydrocarbon Analysis Data**

SAMPLE DEPTH (METRES)	SAMPLE TYPE	GENERALISED LITHOLOGY	SPORE COLOUR INDEX (1-10)	VITRINITE REFLECTIVITY IN OIL, R av %	KEROGEN COMPOSITION (%)		
					INERTINITE	VITRINITE	SAPROPEL
3815	Picked Ctgs	SH, med-dk gy	7.5(4)	0.56(1)	70	30	*
3875	"	A/a	-	0.51(1); 0.62(1); 0.80(9)	-	-	-
"	"	MDST, lt gy calc	-	*	-	-	-
3905	"	SH, gy-blk	8(3)	*	10	20	?70
3965	"	A/a	?8(Np)	0.65(1)	20	*	?80
4025	"	A/a	7.5-8(2)	0.56(5); 0.77(5); 0.93(3)	20	10	?70
4085	"	MDST, brn-blk	7.5-8(2)	0.65(5); 0.72(4); 0.92(4)	20	10	?70
4145	"	A/a	?6(1) 7.5-8(3)	0.61(5); 0.78(1); 0.93(5)	20	10	?70
4205	"	A/a	7-8(Np)	0.66(3); 0.85(2); 1.10(4)	20	10	?70
4265	"	A/a	8(2)	0.97(2); 1.09(3); 1.32(10)	70	10	?20
4295	"	MDST/SH, brn-gy/ brn-blk	8(1)	0.81(1)	20	10	?70
4355	"	A/a	8-8.5(2)	0.87(5); 1.00(3); 1.15(5); 1.33(6)	60	10	30
"	"	SH, gy-blk	4(2); 7-7.5(2); 8-8.5(7)	0.80(2); 0.93(1); 1.16(3)	30	10	60
4365	"	MDST, lt/med brn-gy	8(1)	0.88(1); 1.16(9)	?20	*	?80
"	"	SH, ol-blk	9(8)	0.77(2); 0.88(5); 1.02(9)	?50	?30	?20
4435	"	COAL	8(15)	0.86(15); 1.06(6)	60	30	10Sp

Note: Np = values obtained on kerogen colour alone.

TABLE 3A **Maturity Evaluation Data**

Note: Values in brackets refer to number of particles measured in each particular population.

COMPANY: NORSK HYDRO   WELL: 15/2-1   LOCATION: NORWEGIAN NORTH SEA

SAMPLE DEPTH (METRES)	SAMPLE TYPE	GENERALISED LITHOLOGY	SPORE COLOUR INDEX (1-10)	VITRINITE REFLECTIVITY IN OIL, R av %	KEROGEN COMPOSITION (%)		
					INERTINITE	VITRINITE	SAPROPEL
4435	Picked Ctgs	SH, ol-blk	8-8.5(7)	0.74(3); 0.91(11); 1.11(7)	30	50	10sp,df 10am
4525	"	COAL	8-8.5(2)	1.28(24)	?50	?50	*
"	"	SH, brn-gy/dk gy	8.5(20)	1.11(9); 1.32(11)	40	50	10sp

TABLE 3B Maturity Evaluation Data

Table 4A CHEMICAL ANALYSIS DATA

COMPANY: NORSK HYDRO **WELL:** 15/2-1 **LOCATION:** NORWEGIAN NORTH SEA

SAMPLE DEPTH (METRES)	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	PYROLYSIS: TEMP-ERATURE °C	HYDROGEN INDEX	OXYGEN INDEX	PRODUCTION INDEX	POTENTIAL YIELD (ppm)	SOLVENT EXTRACTION: TOTAL EXTRACT (ppm)	HYDRO-CARBONS (ppm)	EXTRACT % OF ORGANIC CARBON	HYDROCARBONS: mg/g OF ORGANIC CARBON	HYDROCARBONS: % OF EXTRACT	ALKANES % OF HYDRO-CARBONS
		MAASTRICHTIAN-TOR FM(top 2730m												
2740	Ctgs	MDST, lt gy, calc+30% SH, med-dk gy+20% SH, gy-blk	0.39											
2840	"	MDST, v lt gy, calc+10% SH, med-dk gy	0.33											
		FLOUNDER FM (2920m)												
2930	"	MDST, a/a+20%SH, a/a	0.27											
		CAMPANIAN-SANTONIAN (top 2935m)												
3020	"	MDST, a/a+50% MDST, pale red, calc+mnr SH, a/a	0.36											
3110	"	MDST, v lt gy, calc+20%SH,a/a	0.33											
3200	"	MDST, a/a+30% SH, a/a	0.35											
3290	"	MDST, a/a+40% SH, a/a	0.33											
3350	"	MDST, a/a+30% SH, a/a	0.45											
		CONIACIAN?-TURONIAN(top 3389m)												
3440	"	A/a	0.27											
		HERRING FM (top 3438m)												
3530	"	MDST, a/a+20% SH, a/a	0.29											
		CENOMANIAN-HIDRA FM (top 3551m												
3620	"	MDST, a/a+30% SH, a/a	0.27											
		ALBIAN(top 3660.5m)-?RODBY FM (top 3657m)												
3710	"	MDST, a/a+40% SH, a/a	0.40											
		VALHALL FM(top 3728m)												
3815	"	SH, a/a+40% SH, gy-brn+20% MDST, lt gy, calc	3.27											
	P	SH, med-dk gy	4.01	427	290	58	0.14	11700	3400	2180	8.5	54	64	52
	P	SH, gy-brn	1.57											
	P	MDST, lt gy calc	0.52											
		BARREMIAN-HAUTERIVIAN(top 3815m)												
3845	Ctgs	MDST, a/a+30% SH, a/a+mnr SH a/a	3.82											
3875	"	MDST, a/a+20% SH, a/a+10% SH a/a+mnr SH, blk, coaly	3.27											
	P	SH, med-dk gy	0.73											
	P	SH, gy-brn	0.58											
	P	MDST, lt gy calc	0.32											
		L. RYAZANIAN (top 3873m)-KIMMERIDGE CLAY Fm (top 3877m)												
3905	Ctgs	SH, gy-blk+mnr SH gy-brn	7.52											
	P	SH, gy-blk	7.14	429	362	39	0.14	25900	9430	6950	13.2	97	73	50

Table 4B CHEMICAL ANALYSIS DATA

COMPANY: NORSK HYDRO **WELL:** 15/2-1 **LOCATION:** NORWEGIAN NORTH SEA

GENERAL DATA			CHEMICAL ANALYSIS DATA											
				PYROLYSIS					SOLVENT EXTRACTION					
												HYDROCARBONS		
SAMPLE DEPTH (METRES)	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TEMP-ERATURE °C	HYDROGEN INDEX	OXYGEN INDEX	PRODUCTION INDEX	POTENTIAL YIELD (ppm)	TOTAL EXTRACT (ppm)	HYDRO-CARBONS (ppm)	EXTRACT % OF ORGANIC CARBON	mg/g OF ORGANIC CARBON	% OF EXTRACT	ALKANES % OF HYDRO-CARBONS
		E.RYAZANIAN-L.VOLGIAN(top 3908.5m)												
3935	Ctgs	SH, gy-blk+tr SH, gy-brn	5.54											
		M.VOLGIAN - OXFORDIAN (top 3948.5m)												
3965	"	A/a	4.40											
	P	SH, gy-blk	5.13	432	269	58	0.21	13800	9550	7240	18.6	141	76	62
3995	Ctgs	SH, gy-blk+mnr SH, gy-brn	4.00											
4025	"	A/a	5.28											
	P	SH, gy-blk	8.08	437	264	26	0.17	21400	8400	5480	10.30	68	65	43
4055	Ctgs	SH, gy-blk+mnr SH, gy-brn	5.77											
4085	"	MDST, brn-blk,calc+20%LST, lt gy+mnr SH, med gy, calc+tr SH, gy-brn, calc	6.03											
	P	MDST, brn-blk, calc	9.25	430	96	26	0.34	8900	12865	11060	13.9	120	86	66
4115	Ctgs	MDST, a/a+mnr LST, a/a+tr SH, a/a+mnr SH, a/a	6.02											
4145	"	A/a	5.44											
	P	MDST, brn-blk, calc	5.36	431	124	41	0.34	6700	8885	5175	16.6	97	58	69
4175	Ctgs	MDST, a/a+tr LST, a/a+tr SH, a/a+tr SH, a/a	5.77											
4205	"	MDST, a/a+tr LST, a/a+mnr SH, a/a+tr SH, a/a	5.55											
	P	MDST, brn-blk, calc	5.88	437	107	30	0.31	6400	6425	4370	10.9	74	68	67
		HEATHER FM (top 4204m)												
4235	Ctgs	MDST, brn-gy/blk, calc+tr SH, med gy, calc+tr SH, a/a+tr LST, a/a	3.19											
		E.OXFORDIAN (top 4234.5m)												
4265	"	MDST, a/a+mnr SH, a/a+tr SH, a/a+tr LST, a/a	3.88											
	P	MDST, brn-blk, calc	3.40	439	41	67	0.34	1500	2100	1050	6.2	31	50	61
4295	Ctgs	MDST/SH, brn-gy/brn-blk +mnr SH, a/a+tr SH, a/a+tr LST, a/a+tr LIG	3.08											
	P	MDST/SH, brn-gy/brn-blk	3.31	439	48	72	0.34	1600	2965	2045	9.0	62	69	61
		L.CALLOVIAN (top 4315m)												
4325	Ctgs	MDST, brn-gy, calc+tr SH, gy-brn, calc+tr SH, gy-blk+ tr LST, a/a+tr LIG	6.94											

Table 4C CHEMICAL ANALYSIS DATA

COMPANY: NORSK HYDRO **WELL:** 15/2-1 **LOCATION:** NORWEGIAN NORTH SEA

GENERAL DATA			CHEMICAL ANALYSIS DATA											
				PYROLYSIS					SOLVENT EXTRACTION			HYDROCARBONS		
SAMPLE DEPTH (METRES)	SAMPLE TYPE	ANALYSED LITHOLOGY	ORGANIC CARBON % OF ROCK	TEMP-ERATURE °C	HYDROGEN INDEX	OXYGEN INDEX	PRODUCTION INDEX	POTENTIAL YIELD (ppm)	TOTAL EXTRACT (ppm)	HYDRO-CARBONS (ppm)	EXTRACT % OF ORGANIC CARBON	mg/g OF ORGANIC CARBON	% OF EXTRACT	ALKANES % OF HYDRO-CARBONS
4355	Ctgs	MDST, brn-gy,calc+20% SH, gy-blk+tr SH, med-gy, calc+tr SH, gy-brn	4.93											
	P	MDST/SH, brn-gy/brn-blk	4.00	440	68	50	0.36	2800	3710	2205	9.3	55	59	67
	P	SH, gy-blk	5.96	445	92	28	0.31	5600	4200	2920	7.0	49	69	24
4365	Ctgs	MDST, lt/med brn-gy, calc +20% SH, ol-blk+mnr SH, med gy+tr SST, brn-gy	3.64											
	P	MDST, lt/med brn-gy	3.28	444	62	51	0.39	2100	3100	1080	9.5	33	35	52
	P	SH, ol-blk	3.73	449	54	26	0.36	2000	500	-	1.2	-	-	-
		E. CALLOVIAN (top 4424m)- HUGIN FM (top 4365m)												
4435	Ctgs	COAL+30% SH, ol-blk+30% SST, lt gy/brn-gy+tr SH, med gy	8.70											
	P	SH, ol-blk	4.23	448	89	19	0.27	3800	2765	1945	7.4	46	70	66
4465	Ctgs	COAL+30% SH, ol-blk+30% SST lt gy/brn-gy+tr SH, med gy	14.52											
		BATHONIAN-BAJOCIAN (Top 4485m) - SLEIPNER FM (top 4485m)												
4495	"	SH, ol-blk+30% COAL+30% SST, a/a+tr SH, a/a	16.76											
4525	"	SH, brn-gy/dk gy+30% COAL+mnr SST, a/a	10.68											
	P	COAL	59.31											
	P	SH, brn-gy/dk gy	4.29	454	108	13	0.26	4700	1850	1330	4.4	31	72	54
4555	Ctgs	SH, a/a+20% COAL+mnr SST,a/a	7.24											
		L.PERMIAN(top 4554.5m)												
4585	"	SH, a/a+40% SST, a/a+mnr COAL (caved)	7.06											

COMPANY: NORSK HYDRO WELL: 15/2-1 LOCATION: NORWEGIAN NORTH SEA

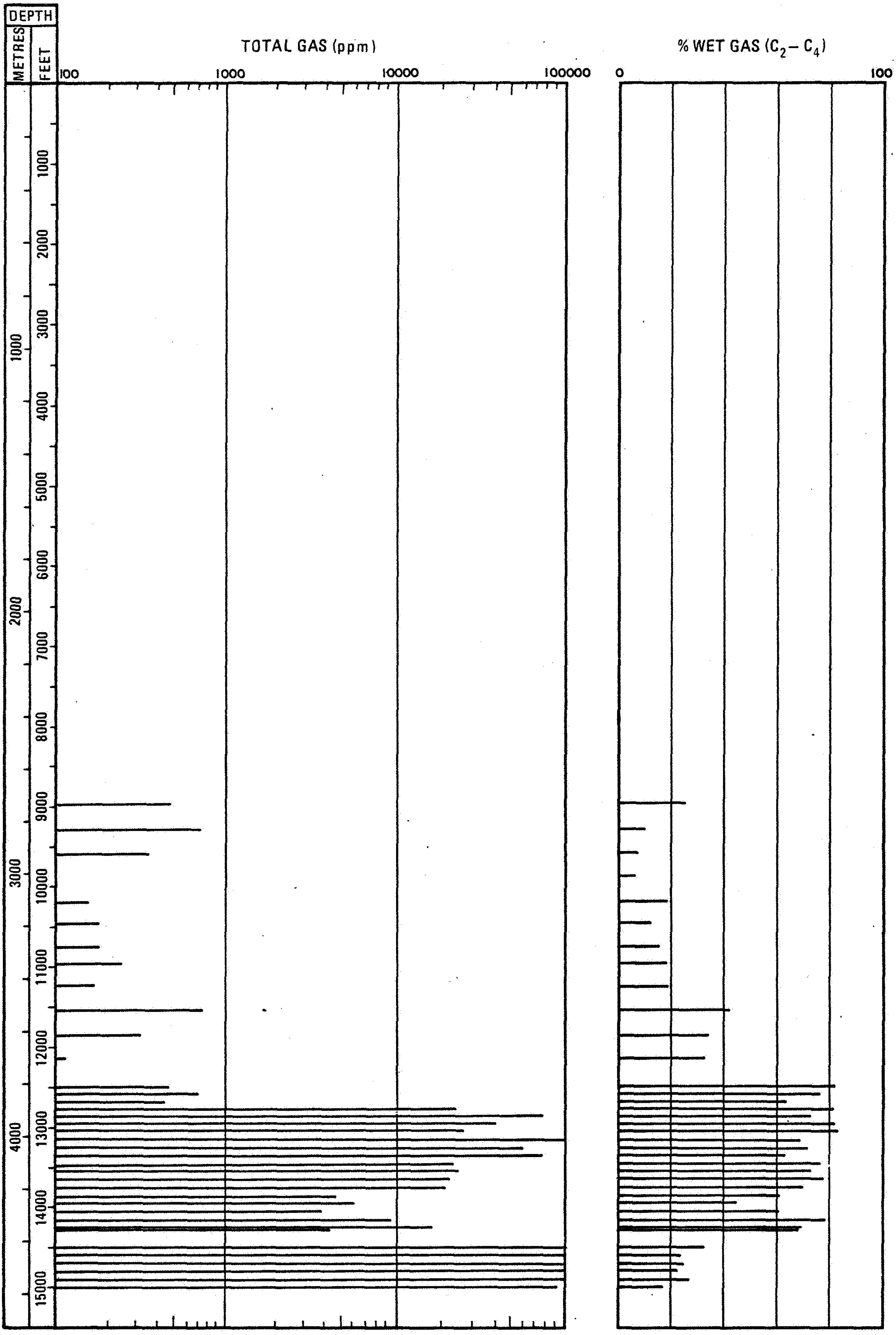


FIGURE 1 Airspace (C_1 - C_4) Hydrocarbons against Depth

COMPANY: NORSK HYDRO WELL: 15/2-1 LOCATION: NORWEGIAN NORTH SEA

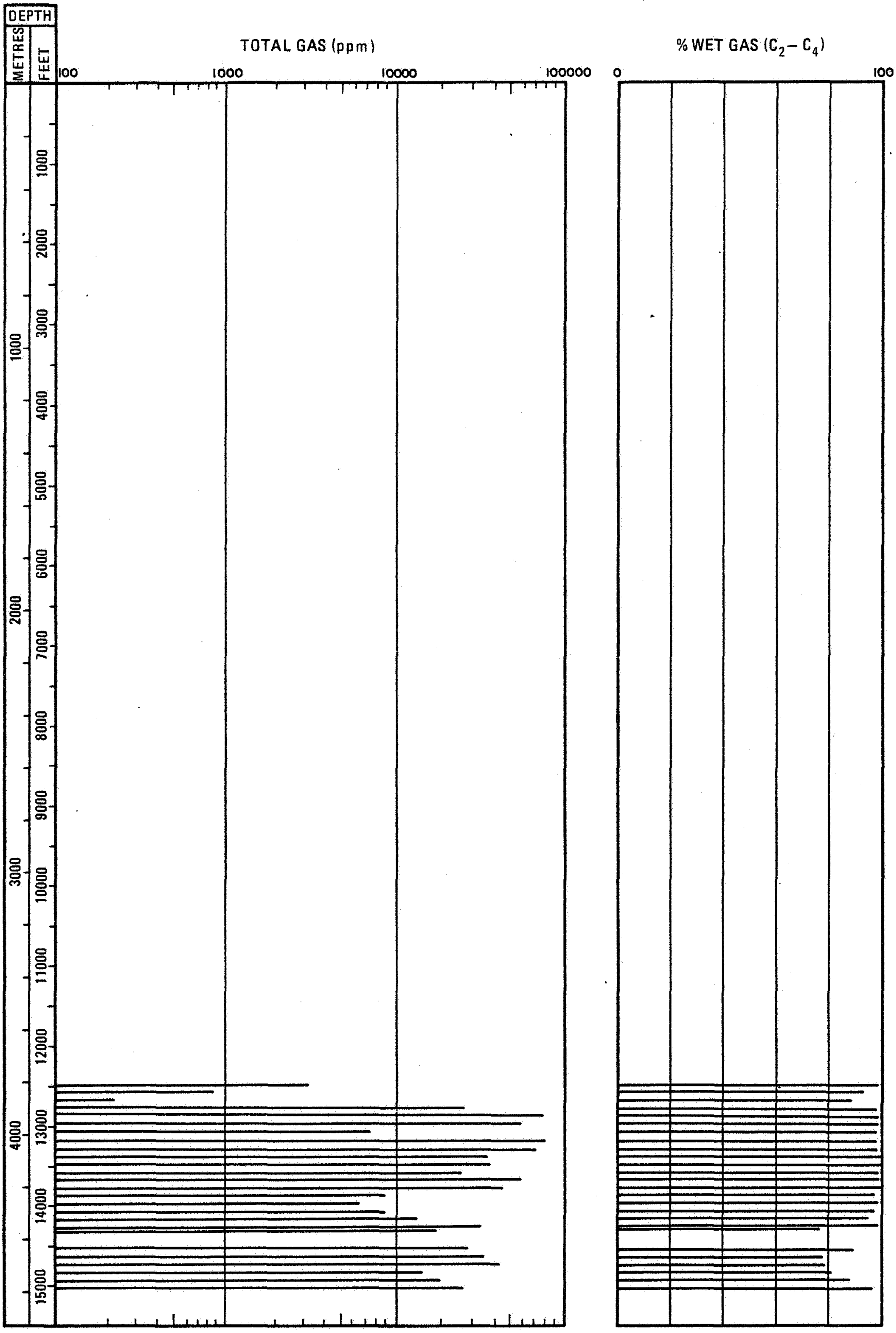


FIGURE 2 Cuttings (C_1 - C_4) Hydrocarbons against Depth

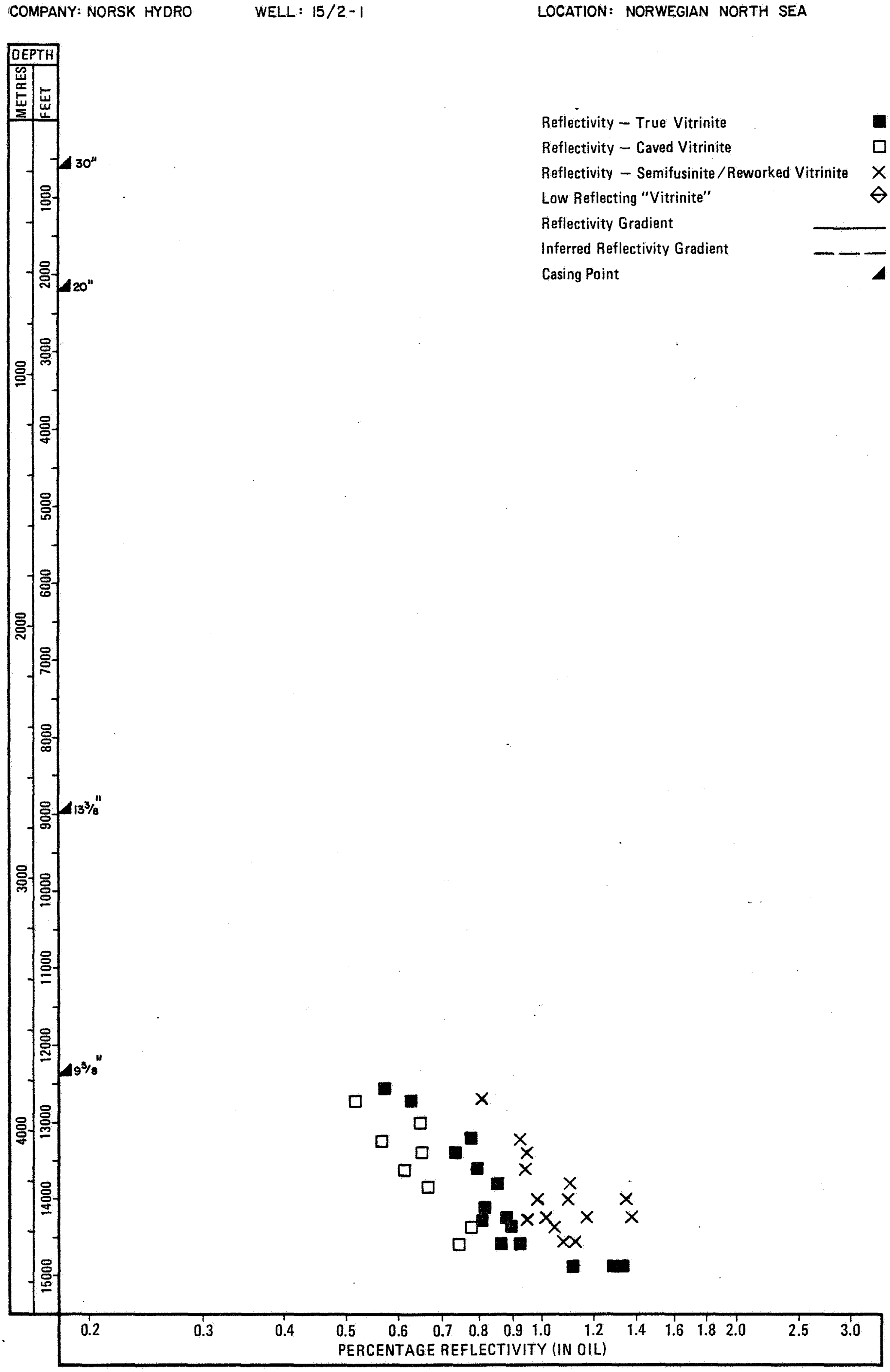


FIGURE 3 Vitrinite Reflectivity against Depth

COMPANY: NORSK HYDRO **WELL:** 15/2-1 **LOCATION:** NORWEGIAN NORTH SEA

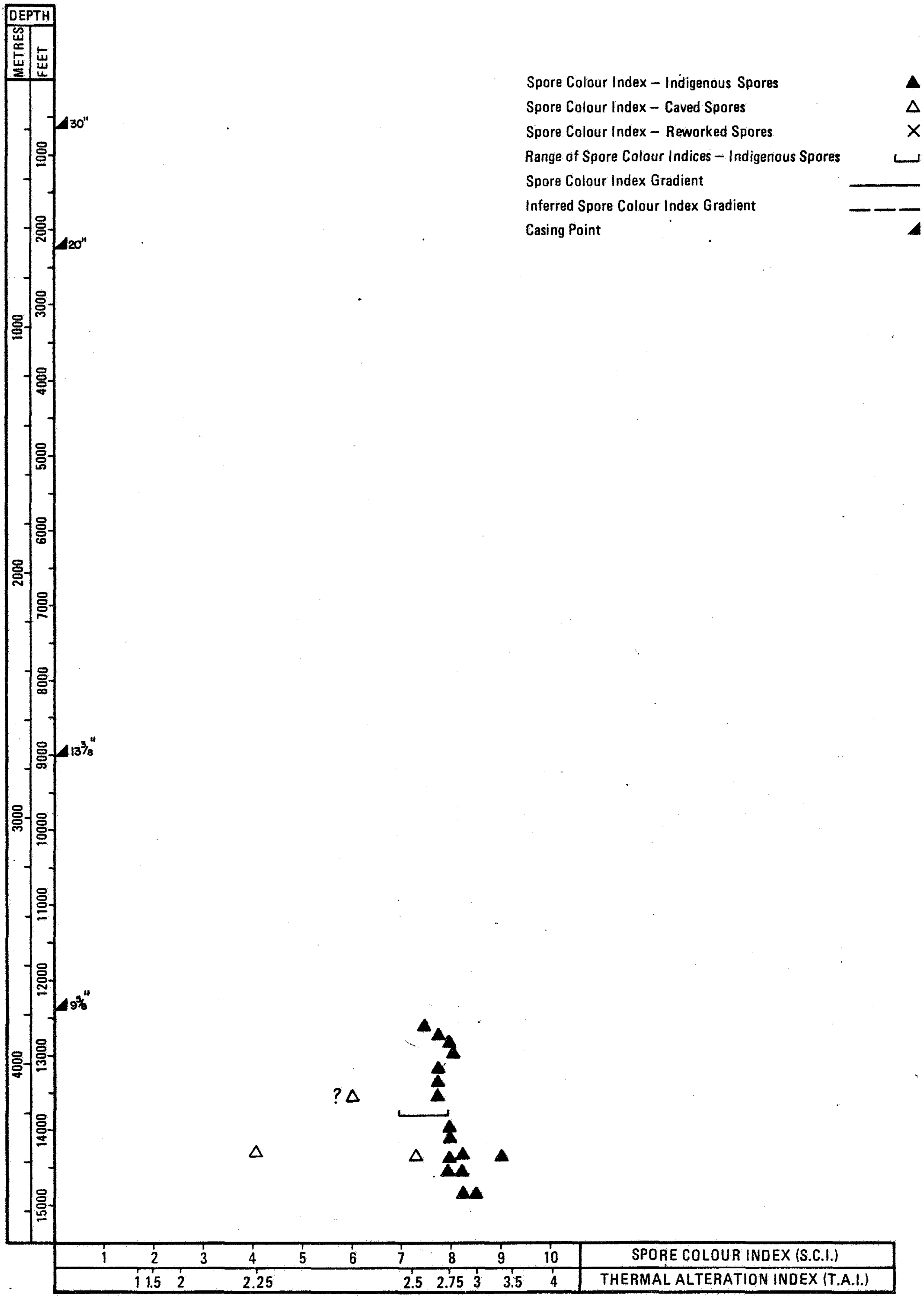


FIGURE 4 Spore Colour Indices against Depth

FIG.5 WELL: 15/2-1 3815m

Valhall Formation

Shale, medium - dark grey

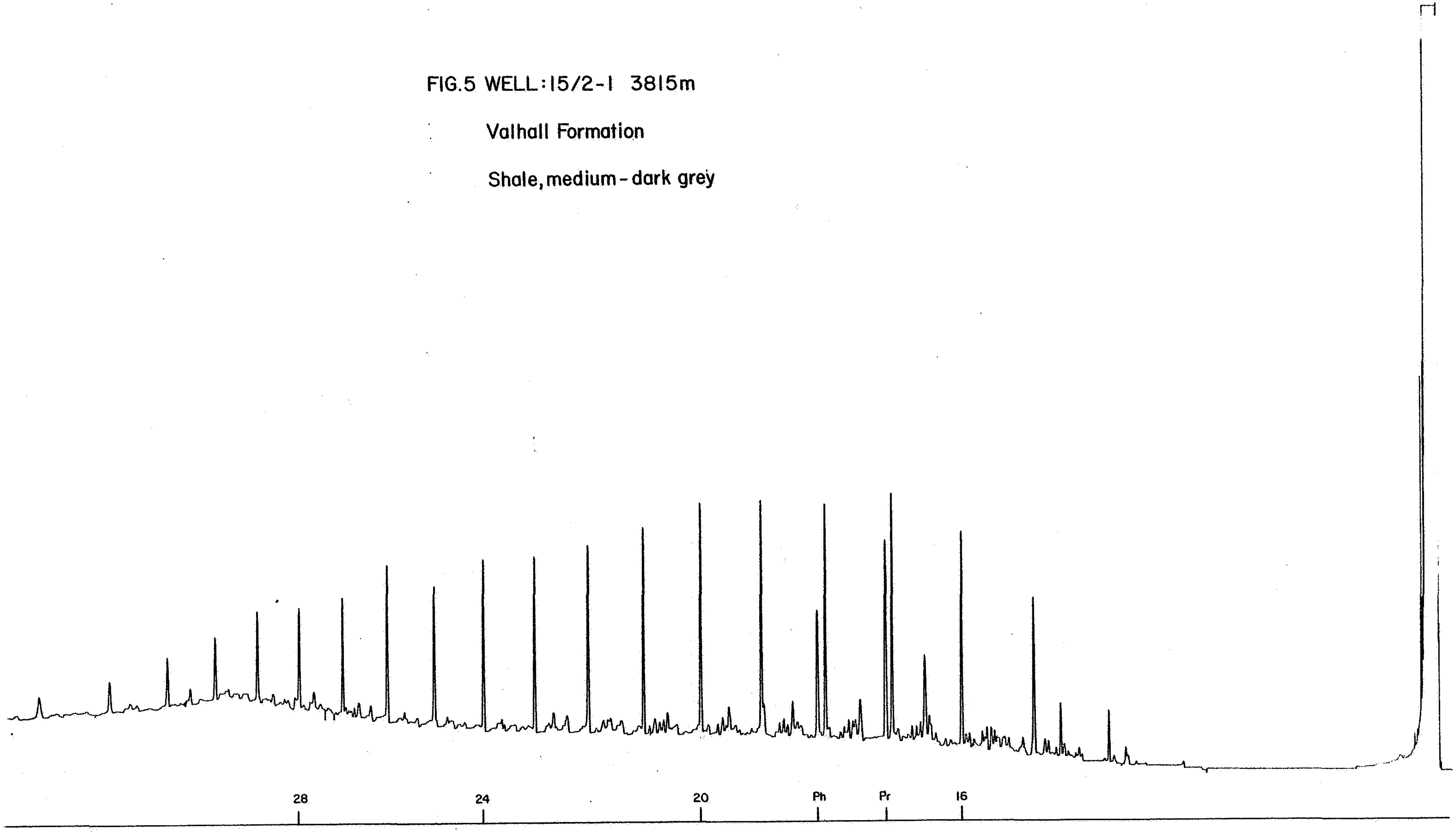


FIG.6 WELL: 15/2-1 3905m

Kimmeridge Clay Formation

Shale, grey - black

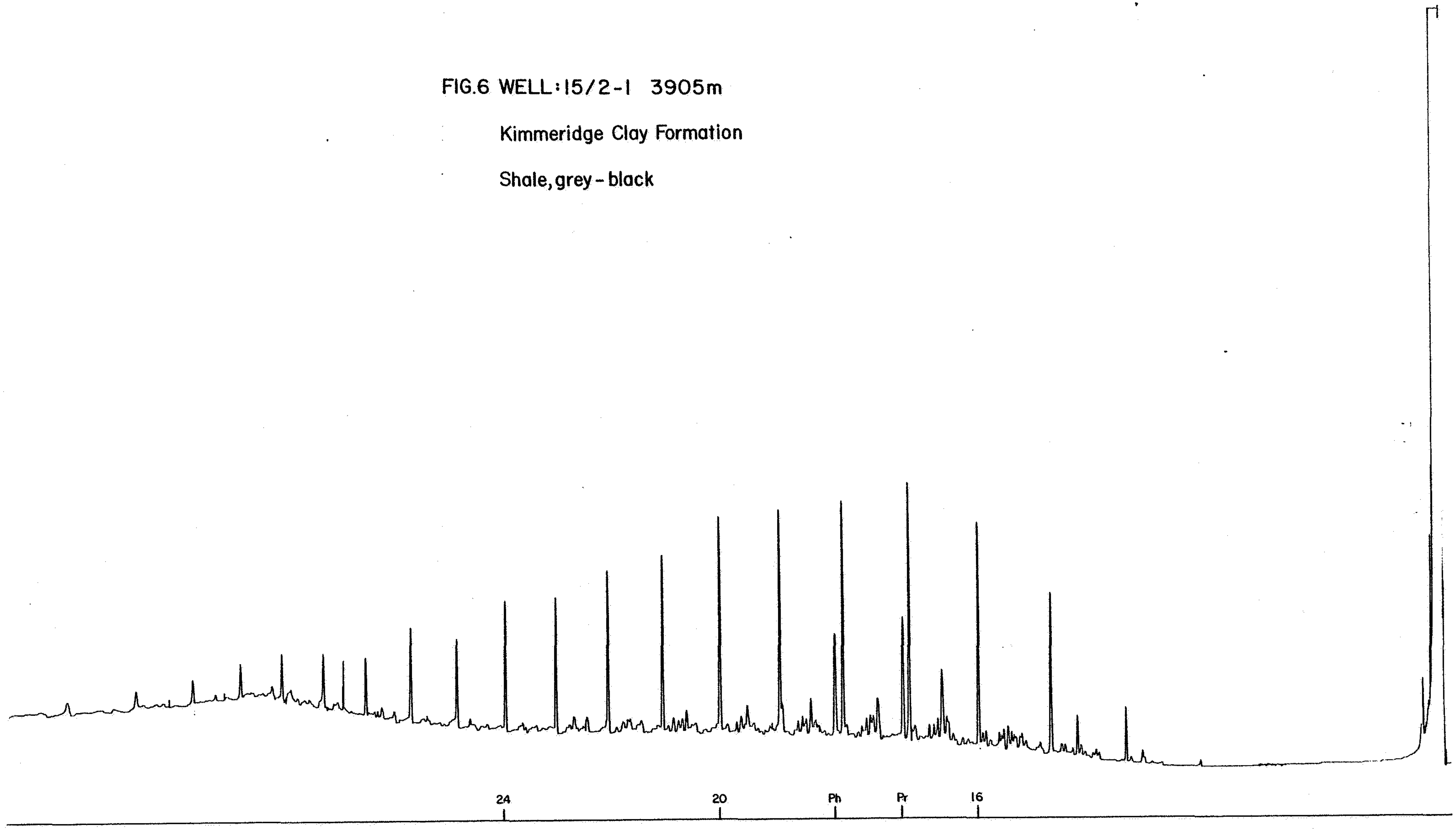


FIG.7 WELL: 15/2-1 3965m

Kimmeridge Clay Formation

Shale, grey - black

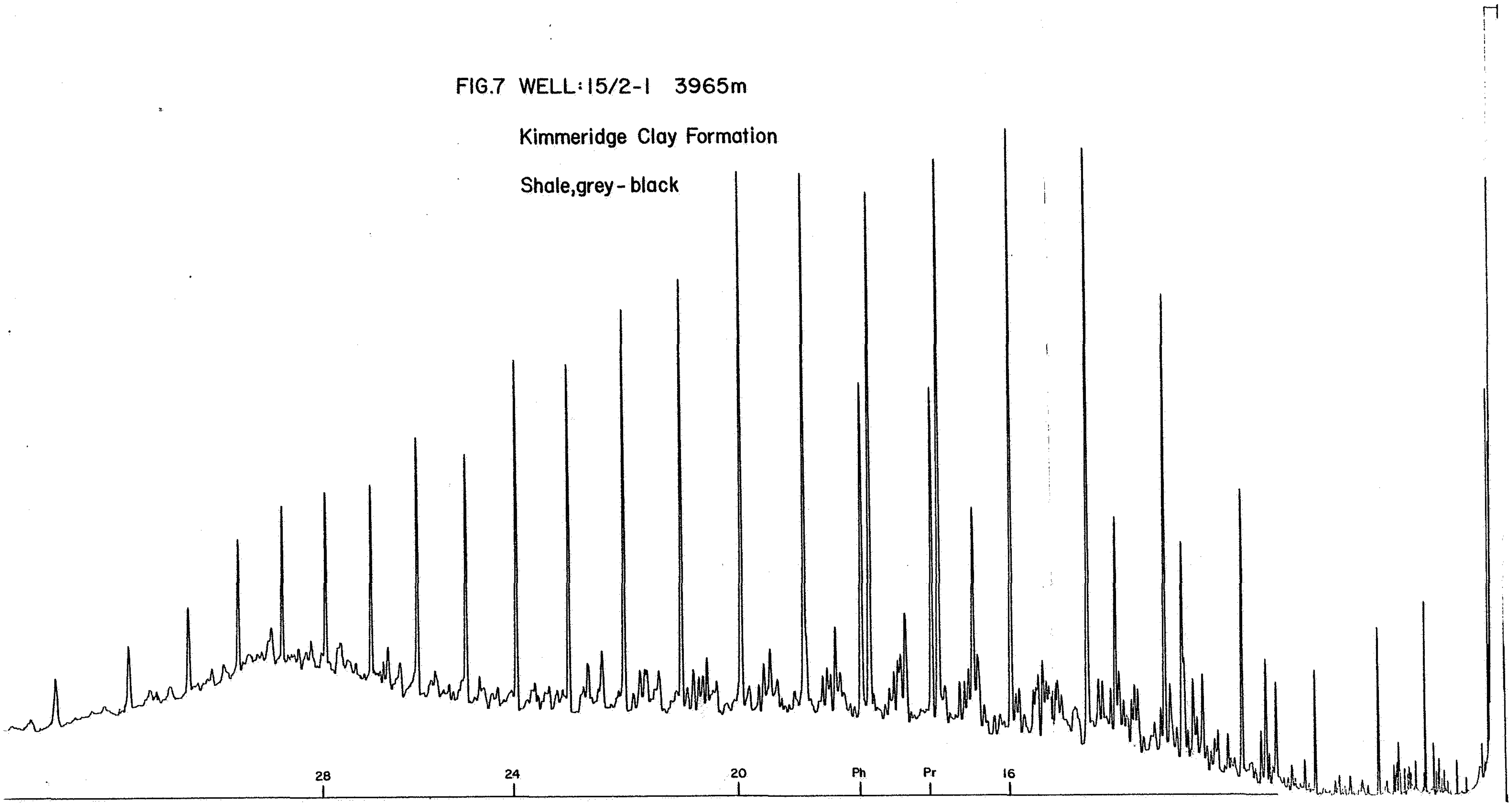


FIG.8 WELL: 15/2-1 4025m

Kimmeridge Clay Formation

Shale, grey - black

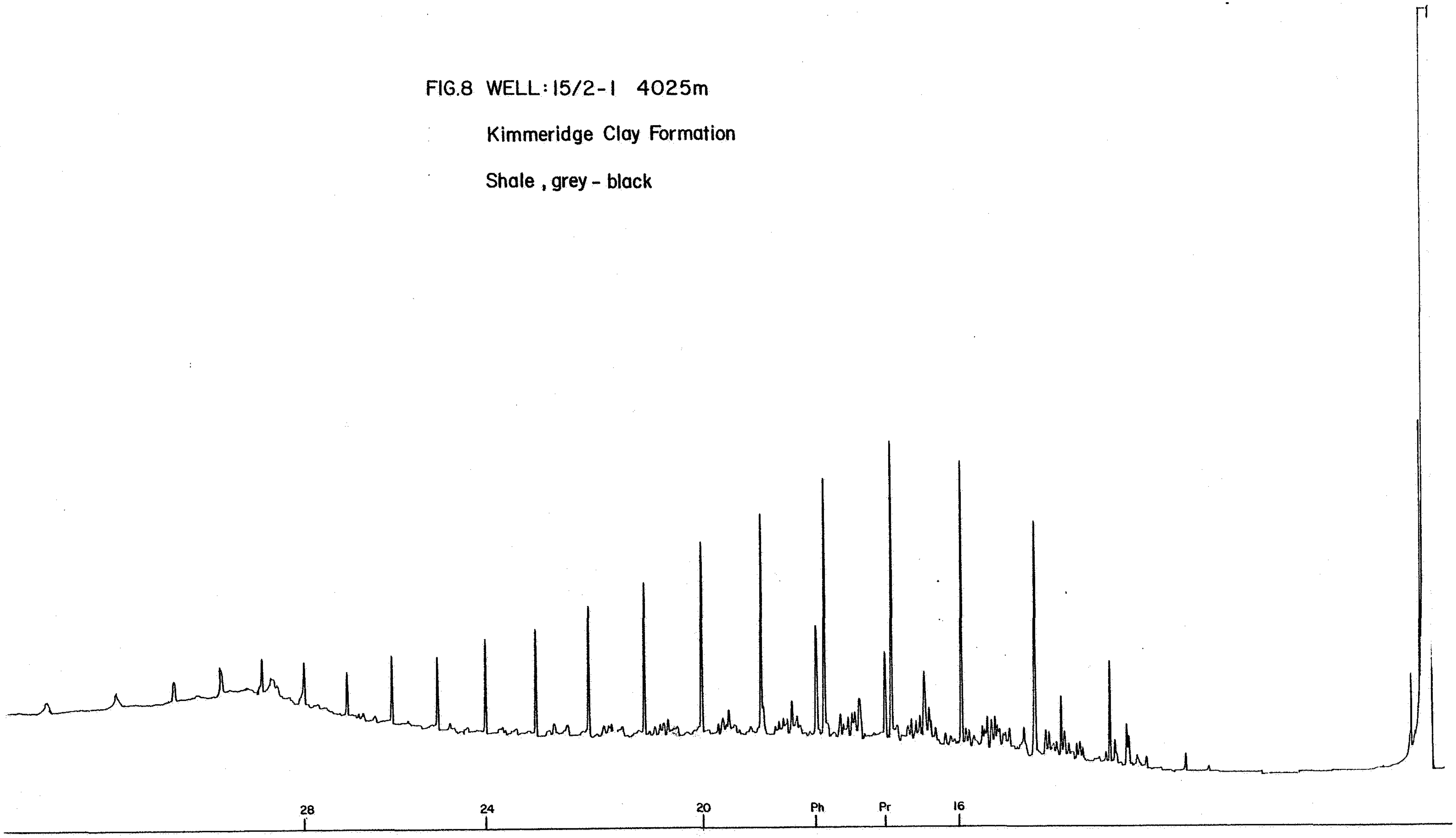


FIG.9 WELL: 15/2-1 4085m

Kimmeridge Clay Formation

Mudstone, brown - black, calcareous

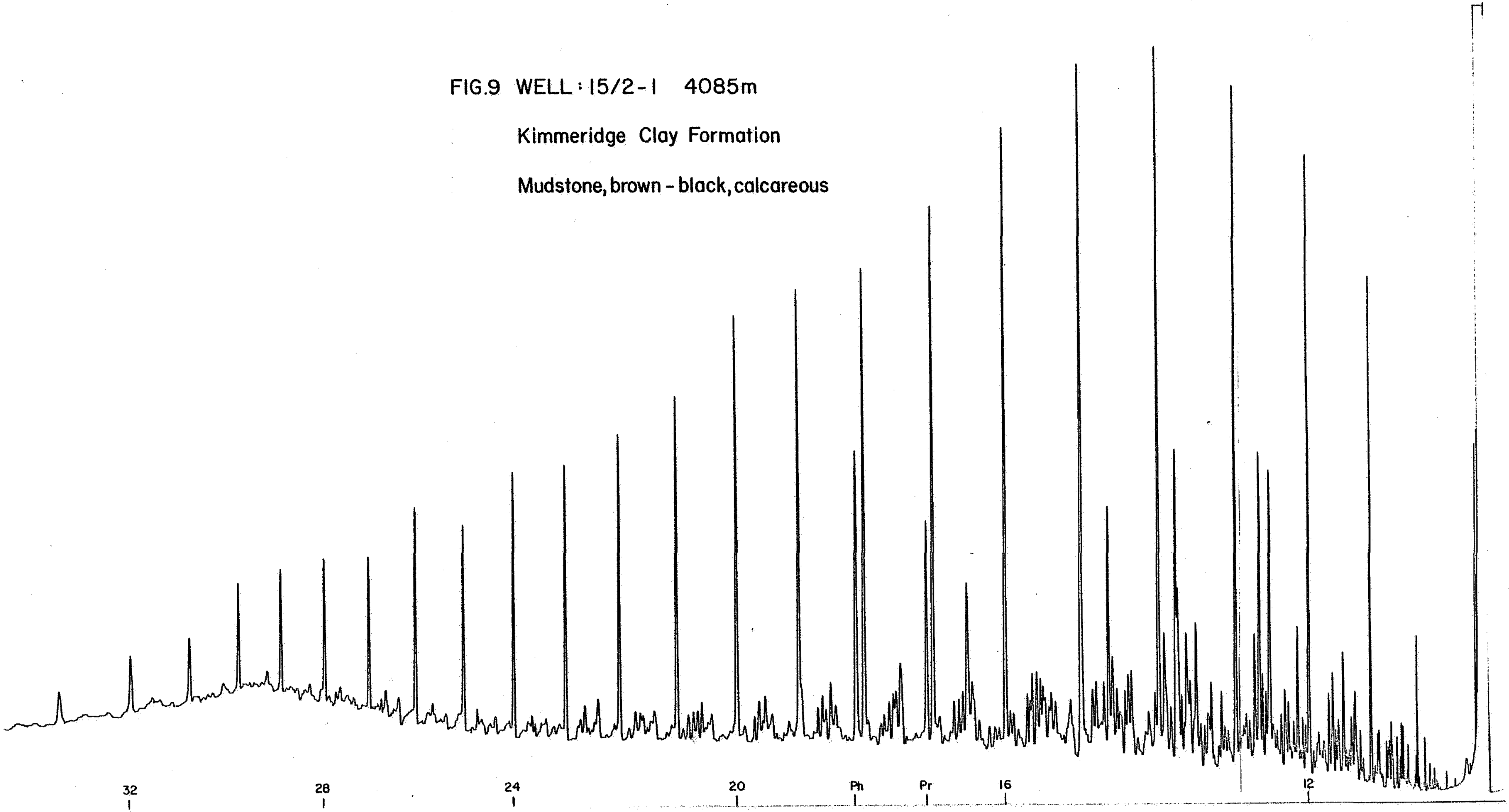


FIG.10 WELL: 15/2-1 4145m

Kimmeridge Clay Formation

Mudstone, brown - black, calcareous

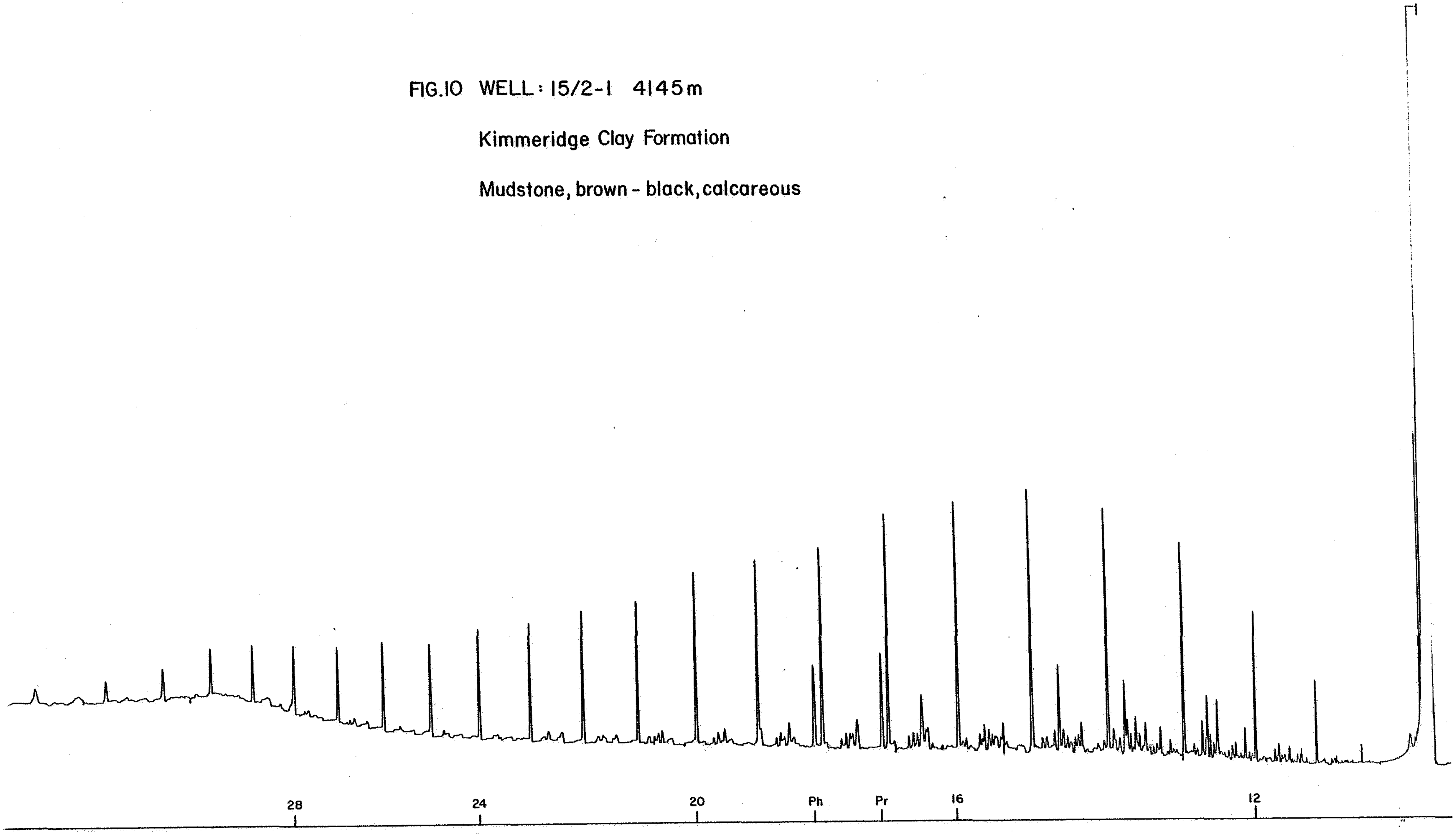


FIG.11 WELL: 15/2-1 4205m

Kimmeridge Clay Formation

Mudstone, brown - black, calcareous

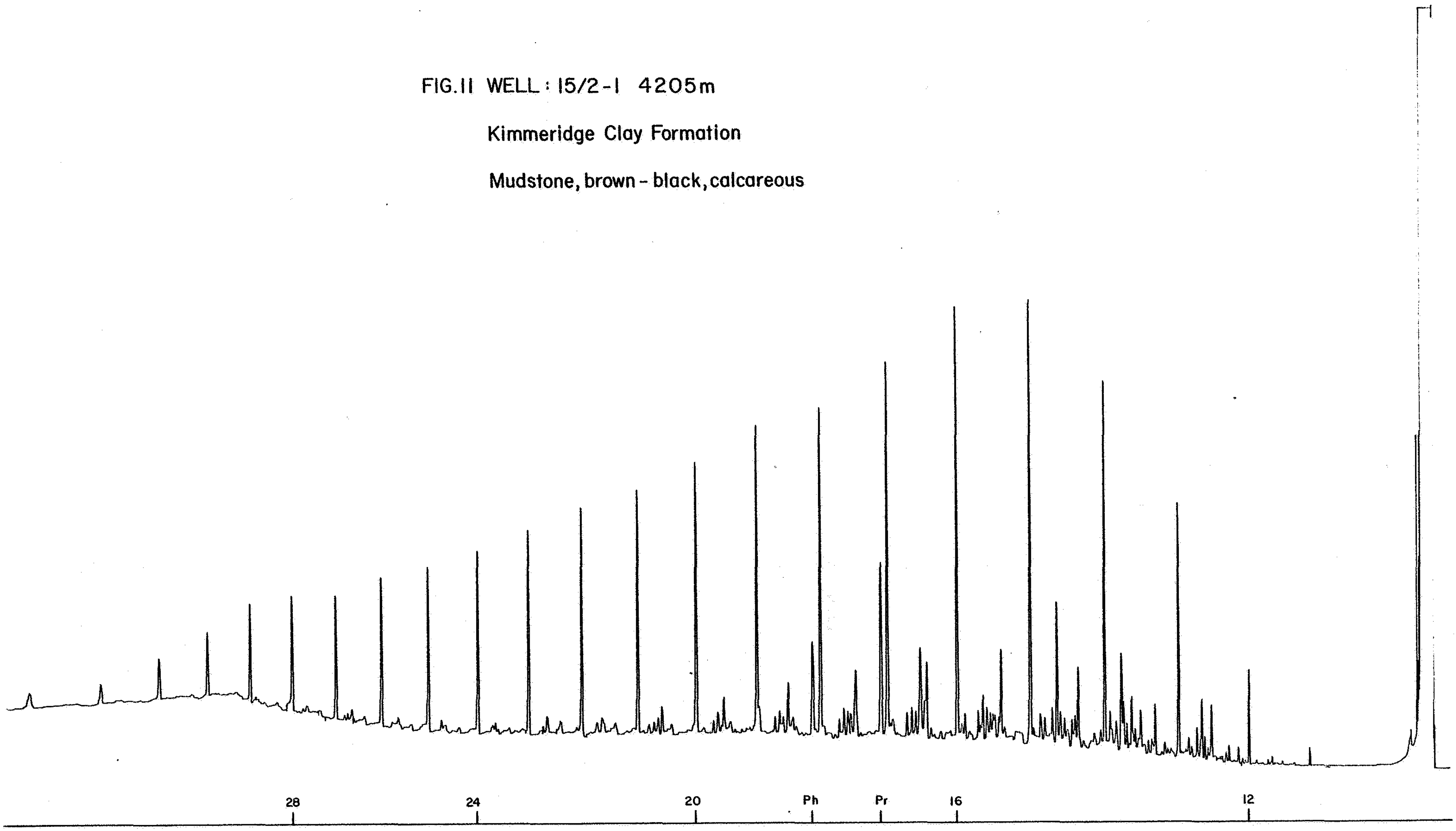


FIG.12 WELL: 15/2-1 4265m

Heather Formation

Mudstone, brown - black, calcareous

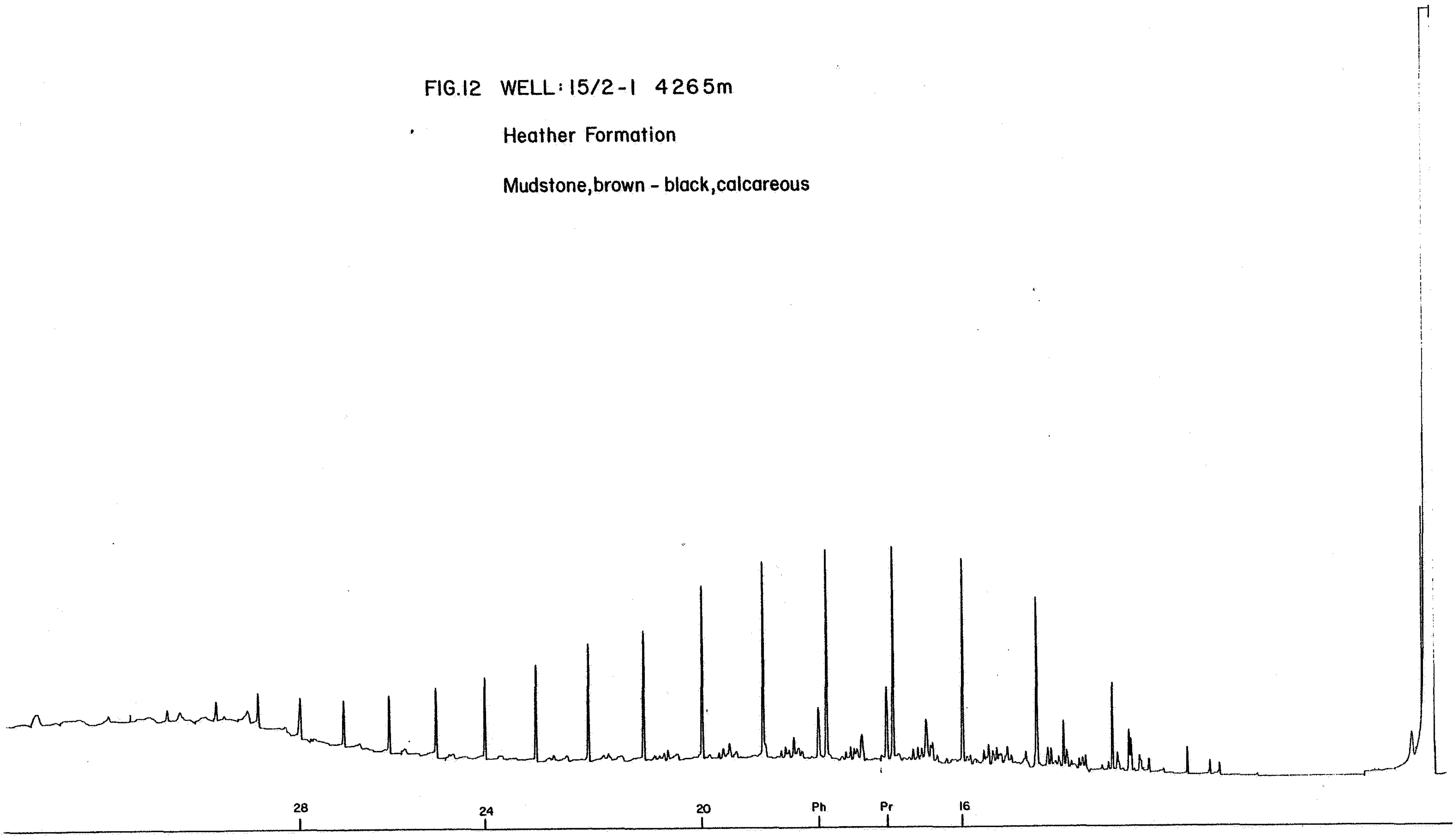


FIG.13 WELL: 15/2-1 4295m

Heather Formation

Mudstone / Shale, brown - grey/brown - black

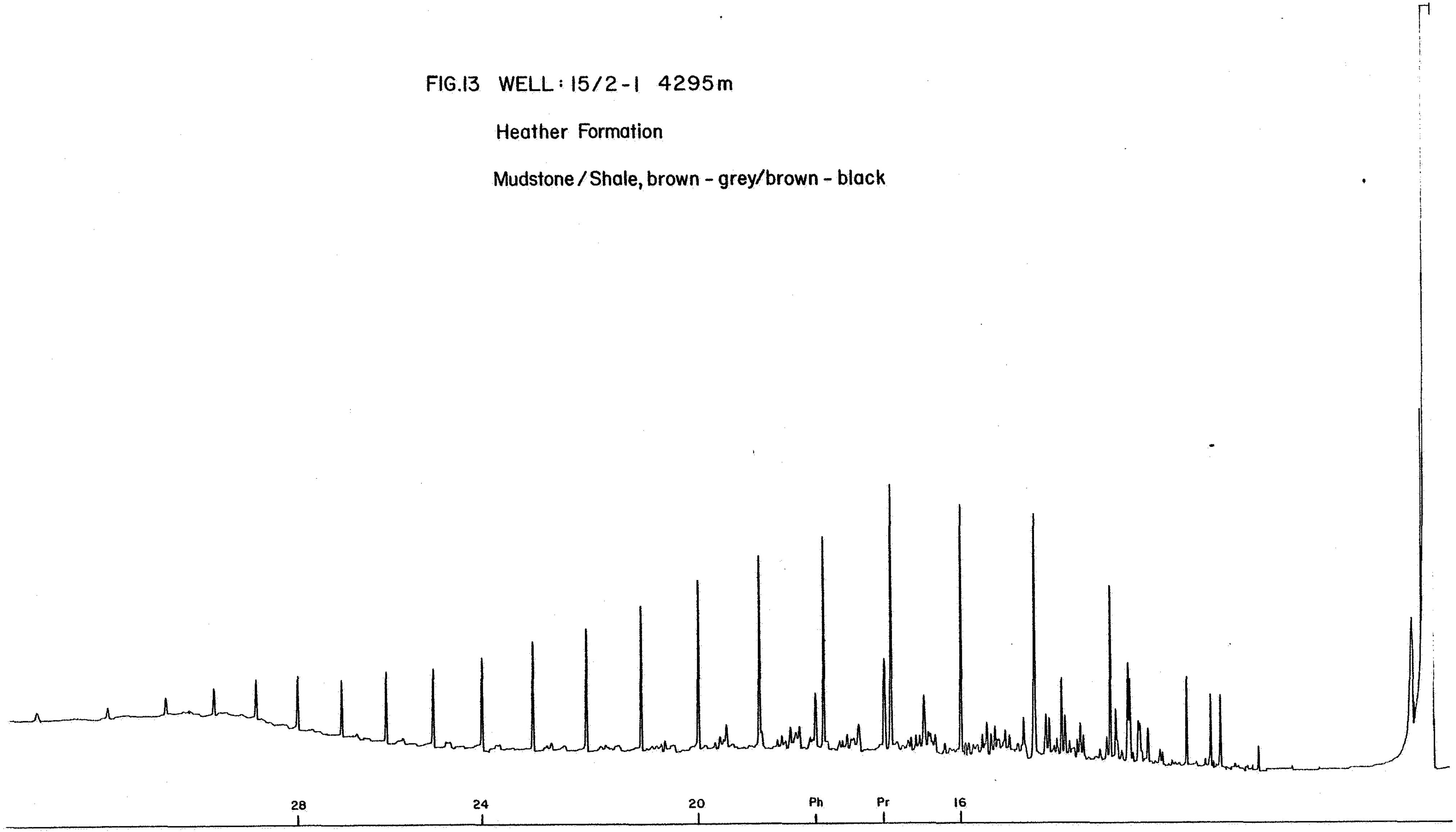


FIG.14 WELL: 15/2-1 4355m

Heather Formation

Mudstone/Shale, brown-grey/brown-black

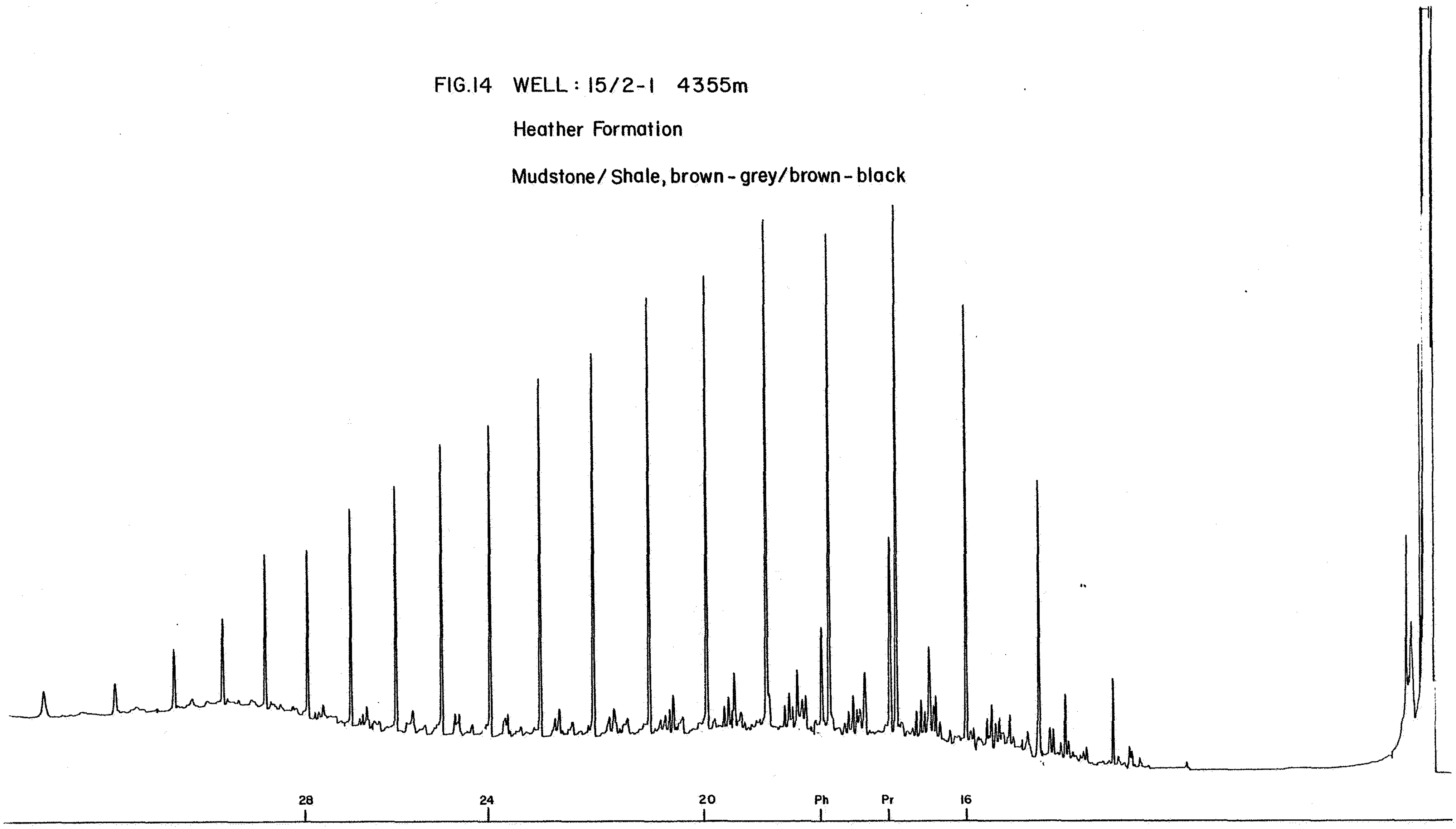


FIG.15 WELL: 15/2-1 4355m

Heather Formation

Shale, grey - black

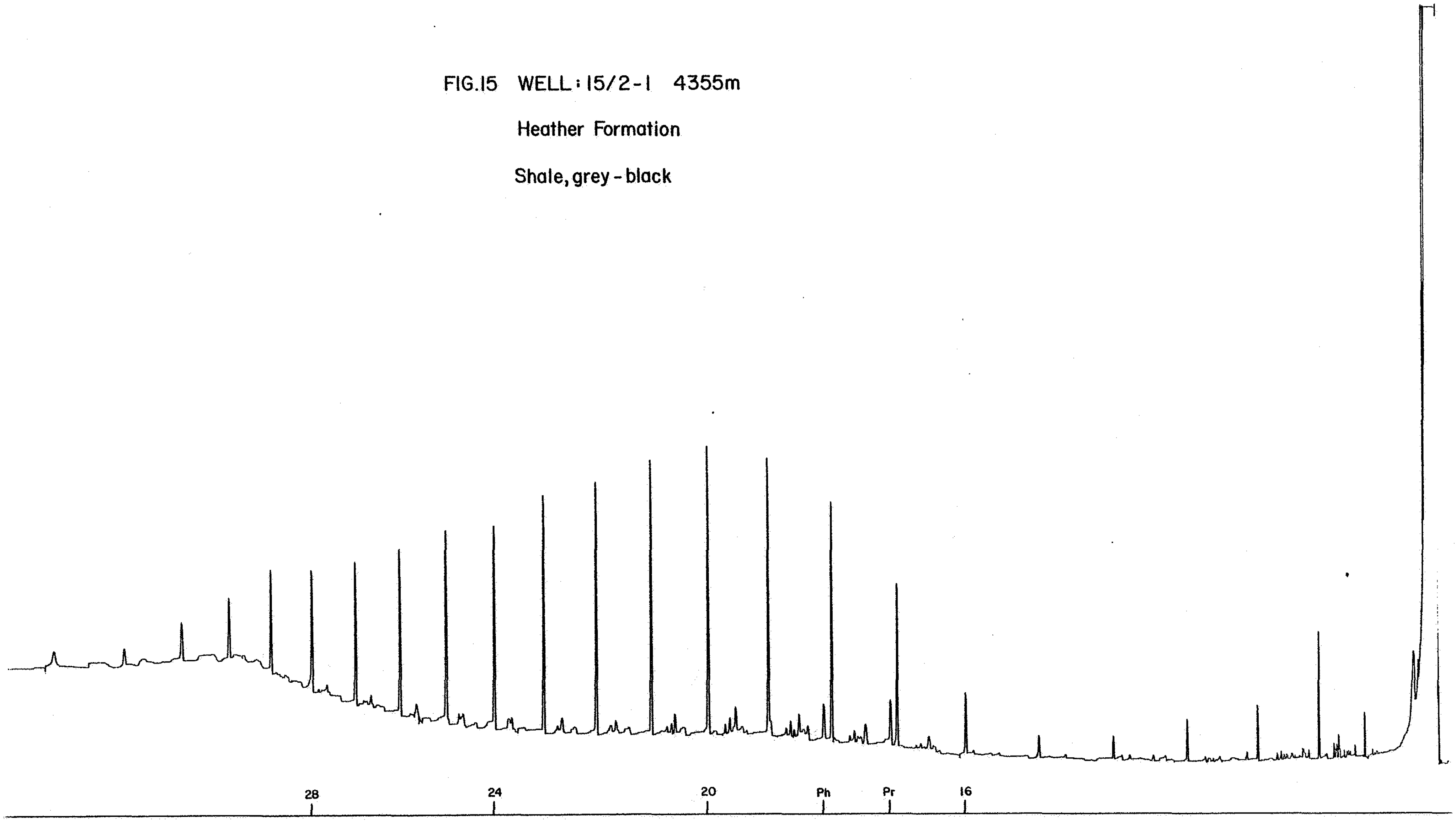


FIG.16 WELL: 15/2-1 4365m

Heather Formation

Mudstone, light/medium brown-grey

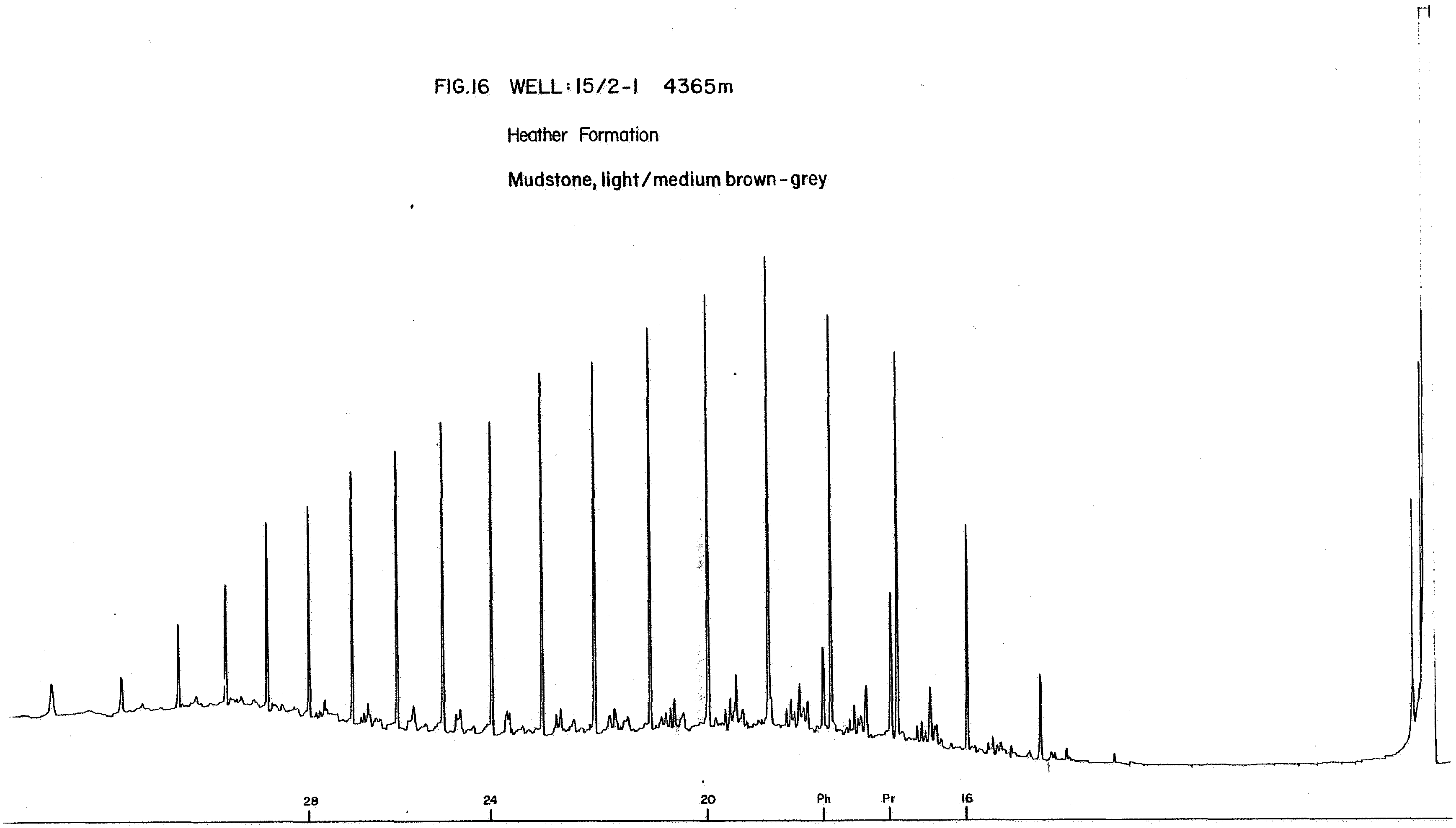


FIG.17 WELL: 15/2-1 4435m

Hugin Formation

Shale, olive - black

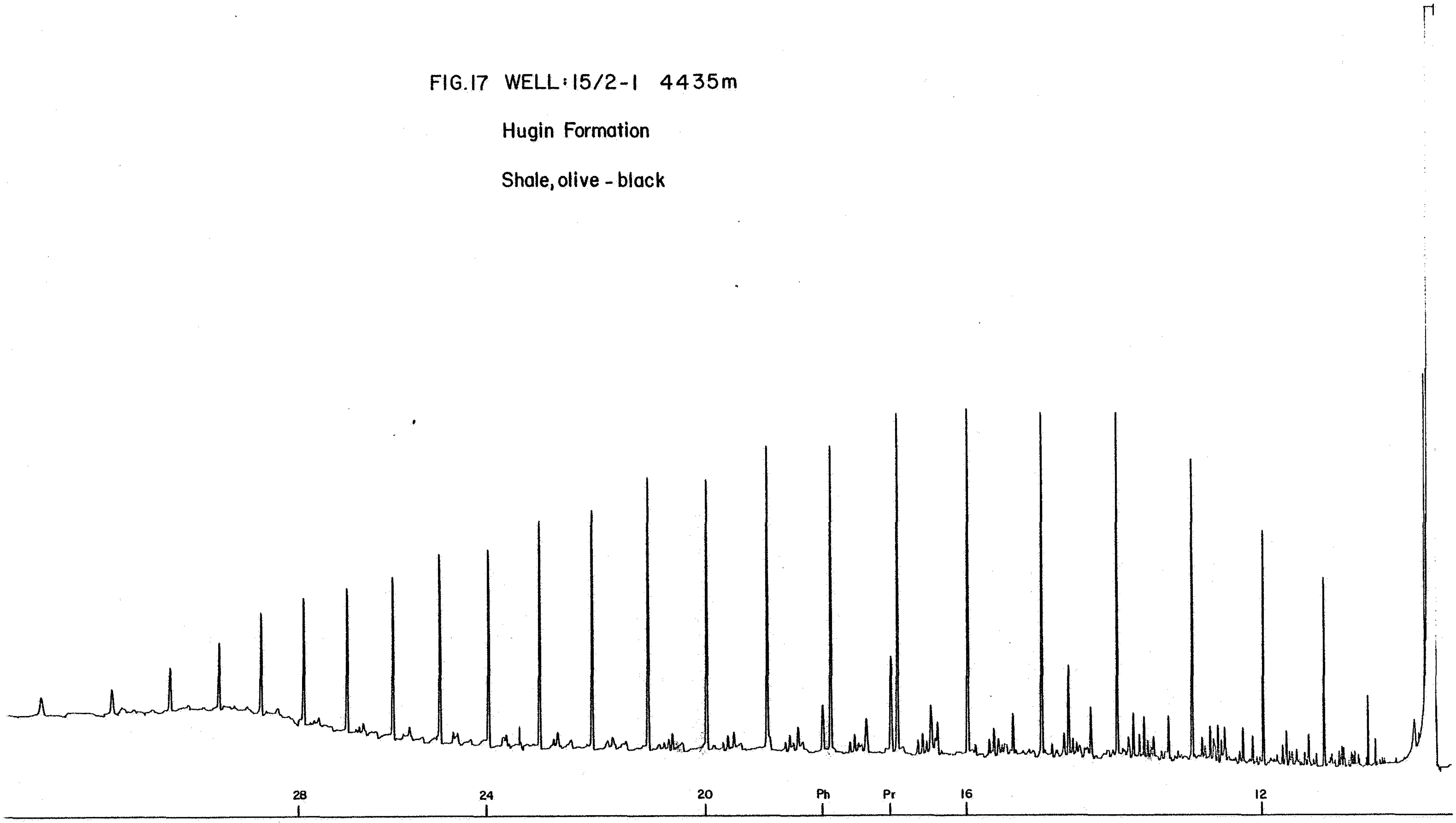
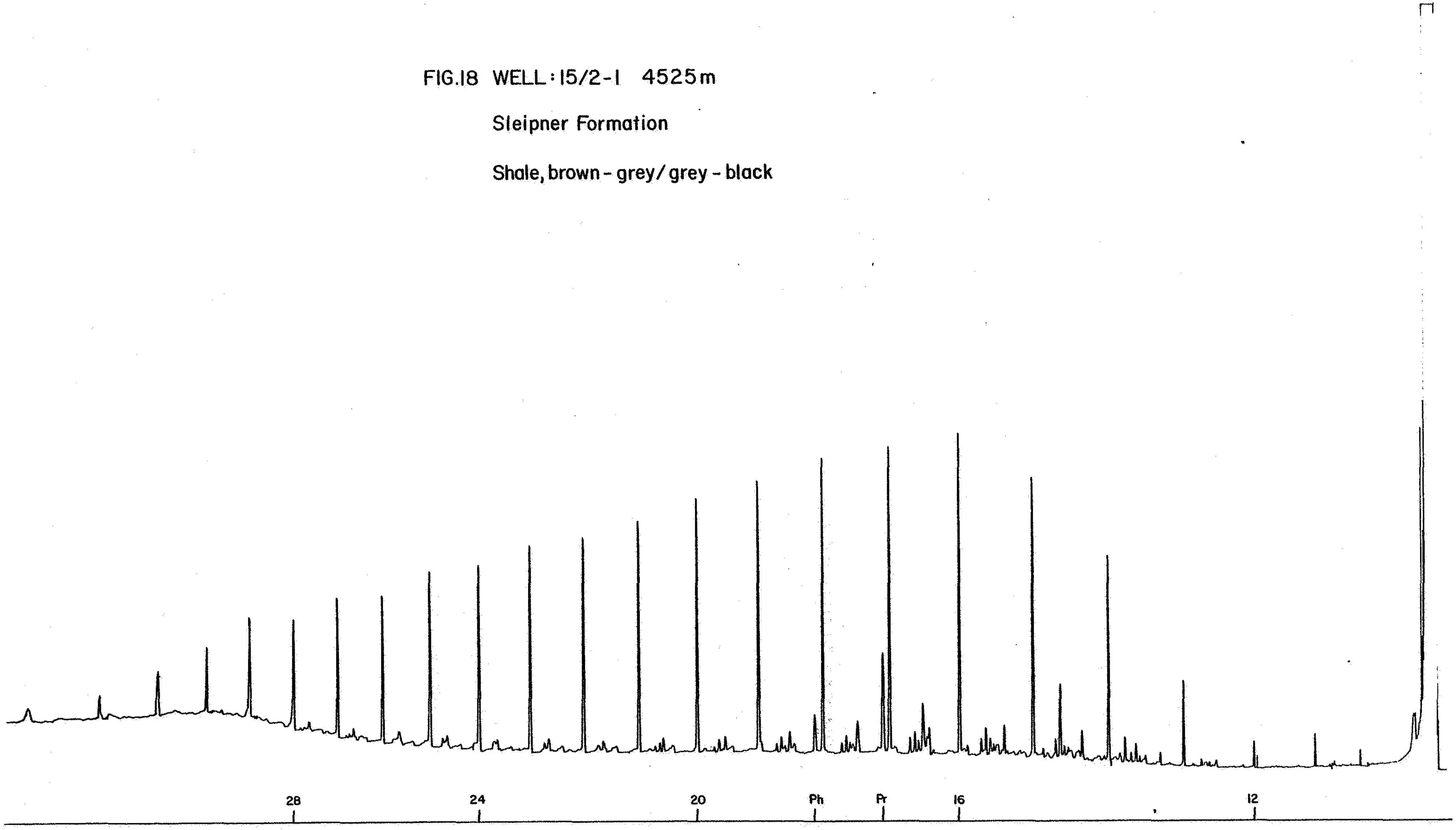


FIG.18 WELL: 15/2-1 4525m

Sleipner Formation

Shale, brown - grey/grey - black



APPENDIX I

ABBREVIATIONS USED IN ANALYTICAL DATA SHEETS

a/a	-	as above
Add	-	mud additive
Al	-	algae
Am	-	amorphous
ang	-	angular
ANH	-	anhydrite
aren	-	arenaceous
arg	-	argillaceous
bd	-	bedded/bedding
becm	-	becoming
Bit	-	bitumen/bituminous
bl	-	blue
blk	-	black
brn	-	brown
calc	-	calcareous
carb	-	carbonaceous
CHK	-	chalk
CHT	-	chert
CGL	-	conglomerate
CLYST	-	claystone
CMT	-	cement
Comp	-	composite
crs	-	coarse
CSG	-	casing point/shoe
Ctgs	-	ditch cuttings
Cu	-	cuticle
cvd	-	caved
Df	-	dinoflagellates
dk	-	dark
DOL	-	dolomite/dolomitic
dsky	-	dusky
Ex	-	exinite
Exs	-	exsudatinite
fer	-	ferruginous
flu	-	fluorescence
fm	-	formation
fn	-	fine
foss	-	fossils/fossiliferous
fr	-	friable
fract	-	fracture
frags	-	fragments
glauc	-	glauconite/glauconitic
gn	-	green
grd	-	graded/grading to
grns	-	grains
gy	-	grey
GYP	-	gypsum
hd	-	hard
hor	-	horizontal
P	-	picked lithology
i/b	-	inter-bedded
IGN	-	igneous rocks
incr	-	increasing
Inert	-	inertinite
lam	-	laminae/laminated
LCM	-	lost circulation material
LIG	-	lignite/lignitic
lns	-	lens(es)
LRV	-	low reflecting vitrinite
lse	-	loose
LST	-	limestone
lt	-	light
mass	-	massive
MDST	-	mudstone
med	-	medium
MET	-	metamorphic rock
mic	-	mica/micaceous
min	-	mineral
mnr	-	minor
mod	-	moderate
MRL	-	marl(y)
mtl	-	mottled
NA	-	not available
nod	-	nodule/nodular
NS	-	no sample
occ	-	occasional
ol	-	olive
ool	-	oolitic
orng	-	orange
OS	-	oil stain
pnk	-	pink
por	-	porous/porosity
pp	-	purple
predom	-	predominantly
pyr	-	pyrite/pyritic
QTZ(T)	-	quartz(ite)
Re	-	resin
rew	-	reworked
rnd	-	round(ed)
Sap	-	sapropel
SCI	-	Spore colour index
sft	-	soft
sh	-	shale
shly	-	shaly
sig	-	significant
sil	-	siliceous
sks	-	slickenside surface
sl	-	slight(ly)
SLT(ST)	-	silt(stone)
slty	-	silty
SND(Y)	-	sand(y)
Sp	-	spores
SST	-	sandstone
strks	-	streaks
subang	-	subangular
subrnd	-	subrounded
suc	-	sucrosic
surf	-	surface
SWC	-	side wall core
TD	-	total depth
tr	-	trace(s)
transp	-	transparent
v	-	very
vgt	-	variegated
Vit	-	vitrinite
vn	-	vein
VOLC	-	volcanic rocks
VR	-	vitrinite reflectivity
wht	-	white
xln	-	crystalline
yel	-	yellow
-	-	no analysis
*	-	analysed but no data obtained
gy-gn	-	greyish green
gy/gn	-	grey-green (gradation)
gn-gy	-	greenish grey

Note: (Maturity data tables only). Number in brackets refers to number of reflectivity values averaged to give quoted result.

APPENDIX II . ANALYTICAL PROCEDURES AND TECHNIQUES

This appendix summarises the main steps in the analyses carried out in the Robertson Research geochemistry laboratories. Conditions for chemical analyses are given and interpretation guidelines are defined. Techniques may in certain circumstances be adapted to suit particular samples or conditions.

1. Sample Preparation

Following airspace gas analysis of the canned samples, the cuttings are washed. After setting aside a wet sub-sample for gasoline analysis, the remainder is oven-dried at 50°C and described. Obvious cavings and particulate contaminants are removed and the significant lithologies hand-picked for organic carbon screening analysis. Coals if present are picked for vitrinite reflectivity measurement and splits of the total cuttings are made for the preparation of kerogen concentrates. Subsequently the bulk samples except those containing much loose sand or coal are crushed to pass through a 250 micron (60 - mesh) sieve and submitted for organic carbon screening analysis.

2. Maturity Evaluation

Maturation is assessed by measurement of spore colour and vitrinite reflectivity and the analysis of airspace gas and gasolines. Kerogen concentrates for microscopic analysis are prepared using standard palynological procedures (i.e. acid maceration) but without oxidation and acetolysis. Mineral residues, particularly pyrite, are separated from the kerogen by a combination of ultrasonic vibration and zinc bromide flotation. For spore colour measurement and kerogen typing, mounts are prepared of both the total kerogen and the coarser-than-20-micron size fraction. Sample blocks for measurement of vitrinite reflectivity are prepared by mounting the coarser-than-20-micron kerogen fraction in an epoxy resin, followed by polishing with carborundum and alumina.

Airspace Gas Analysis

If samples of wet cuttings are collected at the well-site and sealed in an airtight can, the headspace gases can be analysed in the laboratory to provide a rapid assessment of maturity. The gas is extracted from the sealed can using a can piercer fitted with a septum and analysed by gas liquid chromatography. The proportions of methane, ethane, propane and butane are calculated by comparison with a standard mixture of these gases. Methane is usually the dominant gas and comprises 90-100% from immature sediments and 30-70% from mature sediments. Abrupt departures from composition/depth trends may indicate faults with migrant gases or reservoir rocks.

Gasoline Analysis

Cuttings samples received wet, preferably in sealed containers, are suitable for gasoline analysis. A portion of the washed cuttings sample is retained wet, pulverised in a sealed shaker and warmed to expel the gasoline components into the shaker airspace. A sample of this airspace gas is then removed and analysed by gas chromatography. 28 hydrocarbon species are identified in the C_4 to C_7 range and their relative proportions calculated with reference to standard mixtures. Immature source rocks yield mixtures dominated by a small number of components but mature source rocks usually contain a full range of identified hydrocarbons in similar orders of concentration. The onset of maturity may also be indicated by an increase in total gasolines relative to the organic carbon content of the host rock (+200 ppm hydrocarbons per 1% organic carbon). Occasionally, oil stain will be recognised by the presence of anomalous amounts and it may be possible to identify its source rock by a similarity in distribution of components.

Spore Colouration

The maturity of oil-prone organic matter present in kerogen concentrates is assessed by visual examination of the indigenous sporomorphs. With increasing thermal maturity, spore colours change from pale yellow, through orange and brown, to black. Measurement is made using a standard reference set of sporomorphs. Spore colouration indices measured are on the Robertson Research scale of 1 to 10. Our experience shows that values of 3.0 to 3.5 are representative of the transition zone between immaturity and maturity. The range 3.5 to 8.0 is arbitrarily divided into zones of organic maturity: 3.5 to 5.0, early maturity; 5.0 to 7.0, middle maturity; 7.0 to 8.0 late maturity. Direct comparison with source rock data indicates that, given the presence of oil-prone organic matter, low gravity oils are likely to be generated in the zone of early maturity, medium gravity oils in the zone of middle maturity and high gravity oils in the zone of late maturity. The onset of generation of condensate, wet gas and, ultimately, dry gas is characterised by spore colour indices above 8.0.

Vitrinite Reflectivity

Vitrinite, a humic degradation product largely derived from the anaerobic decomposition of the lignin, cellulose and nitrogen-containing compounds of woody tissues, is the chief component of coals and is also common in fine-grained clastic rocks. The reflectivity of an optically flat surface is defined as the percentage of normally incident light reflected from the surface. Reflectivity can be used to define the level of thermal maturity of sedimentary organic matter since it increases from approximately 0.2% to 5.0% at a relatively uniform rate through the coal rank series. Zones of oil and gas generation can be related to the coal rank series and therefore defined in terms of vitrinite reflectivity, even though vitrinite is not an oil source but generates gas. The onset of oil generation has been placed at between 0.35% and 0.6% reflectivity, depending on the type of sedimentary basin; 0.5% is a widely accepted threshold value. The floor for oil generation is characterised by a vitrinite reflectivity of approximately 1.2%. Wet gas generation peaks at a reflectivity of about 1.0% and ceases at the 2.0% level. Dry gas generation peaks at a reflectivity of about 1.5% and ceases at the 3% level. However, to define the appropriate limits for a particular basin, vitrinite reflectivity must be correlated with other thermal maturation parameters.

3. Source Rock Evaluation

Organic Carbon Content

On average, between 1% and 2% of argillaceous sediments consist of organic carbon. Since major hydrocarbon accumulations are the exception rather than the rule it is likely that their sources are of above average organic carbon content. Sediments containing less than 0.3% organic carbon are regarded as having no source potential, and those containing between 0.3% and 1.0% are marginal sources. Obviously the kerogen type is also of fundamental importance in determining the source potential of a rock.

Organic carbon values are obtained as follows. A 0.1 or 0.5 g sample, depending on lithotype,of crushed rock is treated with concentrated hydrochloric acid to remove carbonates and the residue filtered onto a glass fibre paper prior to ignition in a 'Leco' carbon analyser.

Extract Analysis

The soluble organic materials present in rocks can be extracted with organic solvents, fractionated and analysed. The type and amount of material extracted depends largely upon the nature of the contained organic matter and its maturity.

A maximum of 40 g of crushed sample is extracted for a minimum of 12 hours in a 'Soxhlet' apparatus by a 2 : 1 mixture of laboratory redistilled dichloromethane and methanol. The weight of the 'total extract' after final evaporation is expressed as ppm of the total rock. The more volatile components (up to C-15) are lost during extraction. The total extract is dissolved in hexane and a known volume separated by high pressure liquid chromatography into saturate hydrocarbon (alkanes), aromatic hydrocarbon and resene-asphaltene fractions.

Extract analysis provides a measure of source-rock richness in the oil-generation maturity zone. In addition to organic carbon contents, five parameters are calculated; total extract, extract/organic carbon x 100 i.e. extractability or EPOC, hydrocarbons as ppm of rock, hydrocarbons as percent of extract and alkanes as percent of hydrocarbons.

The extractability of oil-prone sapropelic organic matter increases rapidly in the oil generation zone and diminishes to very low values in post-mature sediments. Overall the extractability of sapropelic organic matter is greater than that of gas-prone humic organic matter for similar levels of maturity. Samples with extractabilities of greater than 20% generally contain migrated oil or are contaminated with mud additives.

The hydrocarbon content of a rock is the sum of the alkane and aromatic fractions of the total extract. As maturation proceeds in the oil generation zone the proportion of hydrocarbons in the total extract increases from less than 20% to a maximum in the most productive horizons of around 60%. This trend is reversed as the oil-condensate zone is entered. The relative proportions of alkanes to aromatics can be used as a check for low levels of contamination.

Pyrolysis

Pyrolysis data are obtained using the IFP-Fina "ROCK-EVAL" apparatus. The method involves the heating of samples from 250^{o} to 550^{o}C at 25^{o}C/minute in a stream of inert gas. During this time, three pulses of gases are released and recorded as weights of gas. The first of these pulses relates to hydrocarbons present in the sediment which could normally be extracted by organic solvents; these are either the adsorbed hydrocarbons indicating present source potential, or reservoired hydrocarbons. The second gas pulse is of hydrocarbons released by the thermal breakdown of kerogen (optimum source potential), and simultaneously the temperature of maximum rate of evolution is measured. The third pulse comprises carbon dioxide.

The parameters used in interpretation are the hydrogen index (ratio of released hydrocarbons to organic carbon content), the oxygen index (ratio of released carbon dioxide to organic carbon content), the temperature of maximum rate of pyrolysis, and the production index (ratio of the amount of hydrocarbons released in the first stage of heating to the total amount of released hydrocarbons). Kerogens rich in sapropelic matter exhibit a high hydrogen index and a low oxygen index while those in which humic debris predominates will display a low hydrogen index and a high oxygen index. Hydrogen and oxygen indices for a particular type of kerogen are also susceptible to a reduction in their values during the course of thermal maturation.

The hydrogen index is a measure of the hydrocarbon generating potential of the kerogen. Immature, organically rich source rocks and oil shales give values above 500, mature oil source rocks give values between 200 and 550.

The temperature of maximum rate of pyrolysis depends on the nature of the organic matter, but the transition from immature to mature organic matter is marked by temperatures between 415^{o} and 435^{o}C. The maturity transition from oil and wet gas generation to dry gas generation is marked by temperatures between 455^{o} and 460^{o}C. In practice, greater variation than these ideal temperature ranges may be seen, but they are nevertheless useful as general guides to the level of maturity attained by the sediment.

The production index increases with maturity from values near zero for immature organic matter to maximum values of 0.15 during the late stages of oil generation. Anomalously high values indicate the presence of free oil. The hydrocarbon yield is an indication of the potential yield of hydrocarbons from the source rock at optimum maturity and is a measure of the quality of the source rock. A value of 0 to 2000 of hydrocarbon in ppm of rock characterises a poor source rock, 2000 to 6000 ppm fair, 6000 to 20,000 ppm good and above 20,000 ppm very good.

Visual Examination of Kerogen Concentrates

All palynological preparations are examined in transmitted white and ultraviolet light and the relative abundances of vitrinite, inertinite and sapropel (essentially a fine-grained, apparently amorphous mixture of liptinite and exinite) estimated. The coarser-than-20-micron fractions are also examined in reflected white and ultraviolet light.

Gas Chromatography of C-15+ Alkanes

A portion of the "total extract" obtained from Soxhlet extraction is eluted with pentane through a short silica column to yield the saturate hydrocarbon fraction. This fraction is evaporated to dryness in a stream of dry nitrogen at room temperature. A small portion of the fraction is then taken up in methylene dichloride and injected on to a 25 metre, wall-coated, open-tubular, glass capillary column coated with OV-1 mounted in a Perkin Elmer F-17 gas chromatograph and programmed from 80^{o}C to 260^{o}C at 4^{o}C/minute.

Distributions of n-alkanes and the relative abundances of steranes and triterpanes are noted and the ratios pristane/n-C_{17} and phytane/n-C_{18} are measured. The CPI may also be measured. Inspection of the chromatograms may reveal information about the kerogen type of the source rock, its maturity and conditions of deposition and, if migrant oil is present, whether this has been water-flushed or biodegraded. Drilling mud additives may be identified.