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GEOCHEMICAL ANALYSIS OF OUTCROP SAMPLES, NORTHWESTERN DE LONG MOUNTAINS, BROOKS RANGE, ALASKA

by

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DGSI, Inc.

August 1995

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GEOCHEMICAL ANALYSIS OF BROOKS RANGE OUTCROP SAMPLES ALASKA

For

State of Alaska
Department of Natural Resources
Division of Geology & Geophysical Surveys
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DGSI Project: 93/2826
February 21, 1994

DGSI
Total Quality Geochemistry

GEOCHEMICAL ANALYSIS OF OUTCROP SAMPLES,
NORTHWESTERN DE LONG MOUNTAINS,
BROOKS RANGE, ALASKA

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INTRODUCTION

Sixteen outcrop samples from the Brooks Range in Alaska (Table 1, Fig. 1) were analyzed for TOC content and with Rock-Eval pyrolysis. Twelve of the samples were designated for kerogen microscopy and seven for solvent extraction and whole extract gas chromatography. No other analyses were authorized but biomarker (gc/ms) data on a few samples would have provided useful information.

KEROGEN DATA

Total organic carbon is variable but most samples are rated as good (1.0 - 2.0 wt.% TOC) in source quality. A few are organic lean and are non source rocks (less than 0.5 wt.% TOC) and one (93-MU-80-1) is very organic rich (4.63 wt.% TOC). Organic carbon contents can be reduced by outcrop weathering but this does not appear to be a major problem here. Some reduction due to maturity, however, has taken place.

Pyrolysis response is very low in nearly all of the samples, apparently due primarily to fairly high maturity. T_{max} values are high for most samples (449 to 483°C), indicating maturities between about 1.0 and 1.5 R_o. Lower T_{max} values (444 & 445°C) for samples 93-MU-80-1 and 1a suggest maturities between 0.7 and 0.8 R_o. Very low T_{max} values (426 and 296°C) for samples 93-MU-104 and 104-6 are invalid due to poor pyrolysis response. Sample 93-MU-80-1 differs from the others by having a much higher hydrogen index (367), indicative of moderately mature, type II, (Fig. 2) oil generating kerogen. It is possible that pyrolysis response has been reduced by outcrop weathering but this does not appear to be the case in these samples. Low oxygen indices also attest to lack of kerogen oxidation.

Kerogen microscopy on twelve samples reveal mixed marine and terrigenous organic matter with the marine component being the most abundant in most samples. Solid bitumen is very common and indicates that oil generation has taken place. Structured lipids are primarily liptodentrinite or minor terrigenous sporinite and cutinite. Thermal maturity based on good vitrinite populations ranges from 1.17 to 1.47 R_o for most samples and is supported by pyrolysis T_{max} data, 2+ to 3- TAI values, weak orange structured lipids fluorescence, and moderate to intense background fluorescence intensity. These samples appear to be nearly spent oil source rocks in the late stages of oil generation. The presence of appreciable amounts of terrigenous organic matter including some high rank, recycled material, probably has reduced the oil generation capability of most samples.

1993 Mull, Crowder Geochem Samples

17-Dec-93

Sample #	Formation	Discription	Location	Collector	Comments
93-Mu-101	Torok Fm.	?	Eagle Creek	Mull	
93-Mu-104	Kingak Sh.	?	Kukpowruk R	Mull	
93-Mu-104-6	Kingak Sh.	?	Kukpowruk R.	Mull	
93-Mu-80	Kingak Sh.	?	Surprise Creek	Mull	
93-Mu-80-1	Shublik Fm.	?	Surprise Creek	Mull	
93-Mu-80-1a	Shublik Fm.	Paper	Surprise Creek	Mull	
93-Mu-84	Kingak Sh.	?	Tingmerkpuk Mnt.	Mull	
93-Mu-87	L. Brookian Sh.	?	Eagle Creek	Mull	
93-Mu-88-1	Torok Fm.		Tingmerkpuk R.	Mull	
93-Mu-93	L. Brookian Sh.	?	Tingmerkpuk Mnt. SE	Mull	
93-RKC-22-12-B	Kingak Sh.	Sh	Tingmerkpuk Mtn.	Crowder	
93-RKC-22-138-B	Tingmerkpuk Ss	SS	Tingmerkpuk Mtn.	Crowder	
93-RKC-22-153B.	Tingmerkpuk Ss	Org SS	Tingmerkpuk Mtn.	Crowder	
93-RKC-22-36-B	Top Kingak Sh.		Tingmerkpuk Mtn.	Crowder	
93-RKC-22-43-B	Tingmerkpuk Ss	?	Tingmerkpuk Mtn.	Crowder	
93-RKC-22-72-B	Tingmerkpuk Ss	SS	Tingmerkpuk Mtn.	Crowder	

Table 1. List of geochemical samples

ORGANIC CARBON AND ROCK-EVAL PYROLYSIS DATA

BROOKS RANGE OUTCROPS

Project: DGSI/93/2826

SAMPLE IDENTIFICATION DGSI ID		TOC Wt%	S1 mg/g	S2 mg/g	S3 mg/g	Tmax degC	S1/TOC	HI	OI	S2/S3	PI
1 :	93-MU-101 -	1.30	0.31	0.41	0.34	479	24	32	26	1.21	0.43
2 :	93-MU-104 -	0.36	0.03	0.05	0.06	426	8	14	17	0.83	0.38
3 :	93-MU-104-6 -	0.14	0.01	0.00	0.02	296	7	0	14	0.00	1.00
4 :	93-MU-80 -	1.87	0.14	0.57	0.23	461	7	30	12	2.48	0.20
5 :	93-MU-80-1	4.63	2.14	17.00	0.34	445	46	367	7	50.00	0.11
6 :	93-MU-80-1a	0.92	0.34	0.86	0.09	444	37	93	10	9.56	0.28
7 :	93-MU-84	0.41	0.01	0.00	0.11	449	2	0	27	0.00	1.00
8 :	93-MU-87	1.81	0.23	0.55	0.52	483	13	30	29	1.06	0.29
9 :	93-MU-88-1	1.06	0.15	0.36	0.06	475	14	34	6	6.00	0.29
10 :	93-MU-93	1.69	0.26	0.76	0.26	469	15	45	15	2.92	0.25
11 :	93-RKC-22-12-B	0.18	0.01	0.01	0.03	477	6	6	17	0.33	0.50
12 :	93-RKC-22-138-B	1.27	0.08	0.41	0.13	453	6	32	0	0.00	0.16
13 :	93-RKC-22-153-B	1.19	0.04	0.26	0.03	465	3	22	3	8.67	0.13
14 :	93-RKC-22-36-B	1.84	0.08	0.56	0.04	468	4	30	2	14.00	0.13
15 :	93-RKC-22-43-B	1.50	0.07	0.31	0.13	476	5	21	9	2.38	0.18
16 :	93-RKC-22-72-B	1.32	0.05	0.41	0.08	455	4	31	0	0.00	0.11

Table 2. Organic carbon and Rock-Eval pyrolysis data

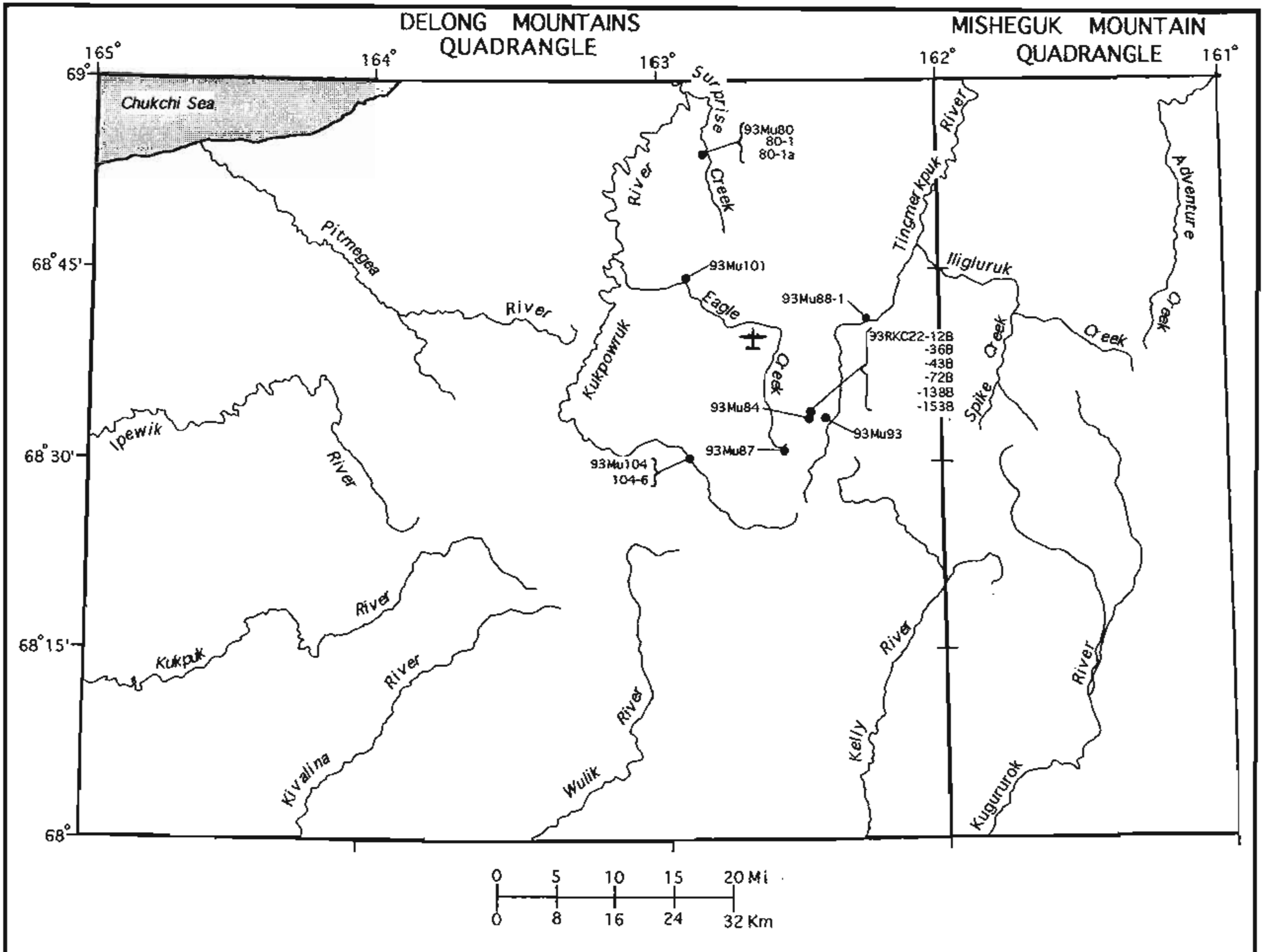


Fig. 1. Map showing location of geochemical samples, DeLong Mountains and western Misheguk Mountain quadrangles.

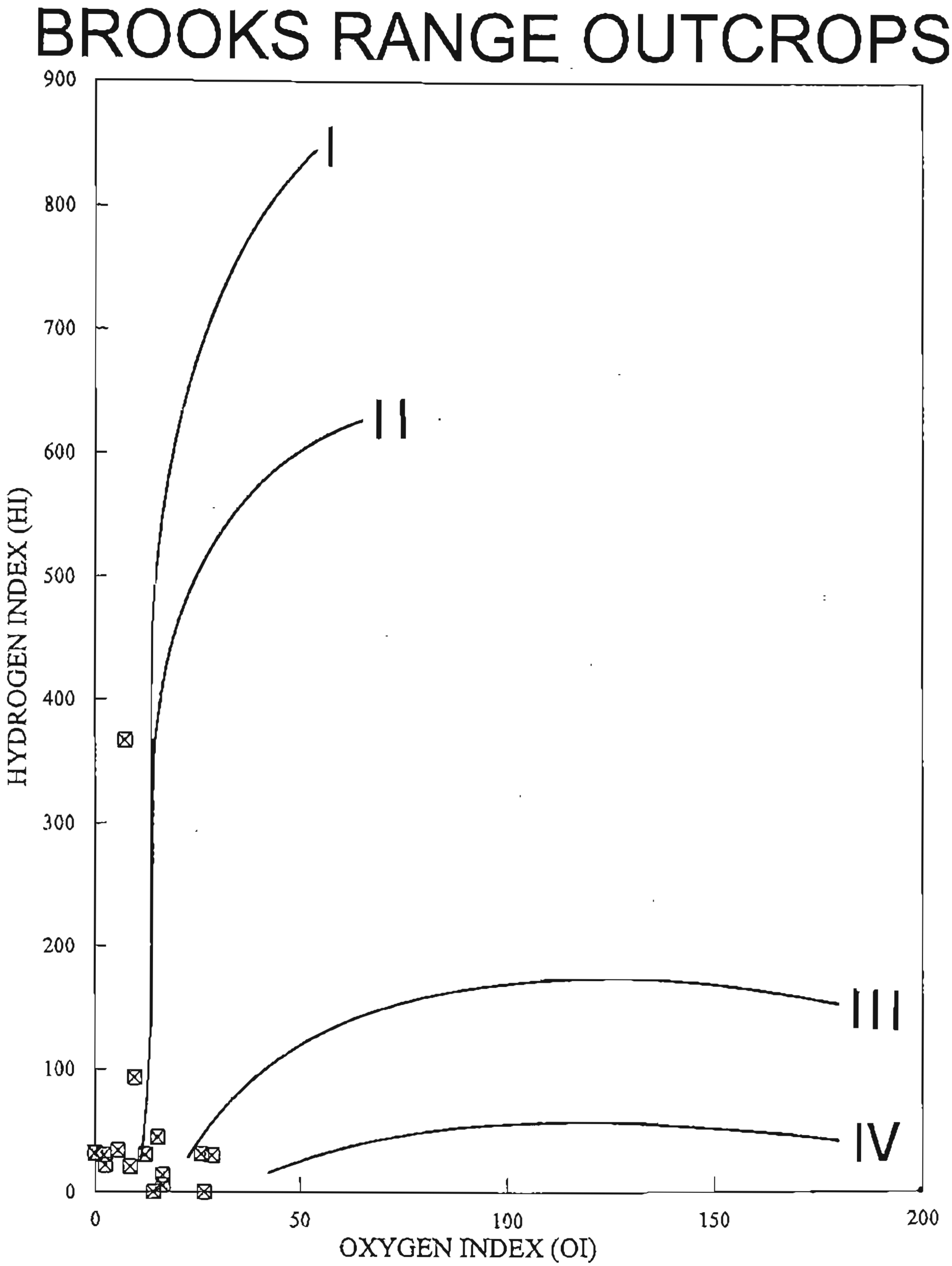


FIGURE 2 - Kerogen type determination from TOC and Rock-Eval pyrolysis data. Types I and II will generate oil, type III gas, and type IV little or no hydrocarbons.

Samples 93-MU-80, 80-1 and 80-1a contain similar type kerogen but appear to be lower in maturity than the others. Sample 93-MU-80 has a maturity of 0.92 R_o but the 0.74 & 0.77 R_o maturities of samples 93-MU-80-1 and 80-1a are questionable due to limited reflectance measurements. It is possible that the vitrinite in these two samples is weathered, lipid rich, or that some of the R_o values are on small fragments of solid bitumen. Other maturity indices such as pyrolysis T_{max}, kerogen fluorescence, and TAI support a maturity of about 0.9 to 1.0 R_o for these samples.

EXTRACT DATA

Seven outcrop samples were solvent extracted and analyzed with whole extract gas chromatography (gc). Six samples have low extract/TOC ratios (0.011 - 0.051) and probably contain indigenous bitumen. Sample 93-MU-80-1a has a high extract/TOC ratio (0.209), indicating that it contains migrated bitumen.

Samples 93-MU-80-1 and 93-MU-80-1a, from the Upper Triassic Sublik Formation at Surprise Creek, contain indigenous and migrated bitumen, respectively. Whole extract gas chromatograms are similar, indicating the same source and thermal maturity. Therefore, the migrated bitumen in sample 93-MU-80-1a was probably derived from adjacent, more organic-rich Sublik source rocks. The two extracts show quite similar C15+ n-alkane distributions (continuously decreasing with increasing carbon number) and isoprenoid distributions. The pristane/nC_{17} ratios (0.45 - 0.47) and phytane/nC_{18} ratios (0.19 - 0.21) (see Figure 3), high pristane/phytane ratios (2.6 - 2.7), CPI values > 1 (1.08 - 1.10) and minor C25+ n-alkanes indicate a mixed organic source with relatively minor terrigenous organic matter (probably deposited under oxic or suboxic conditions). A thermal maturity close to the peak oil generation stage is also indicated. Pristane/phytane ratios and pristane/nC_{17} ratios for these samples might have been increased due to surface weathering and, therefore may not reflect true depositional conditions. Kerogen microscopy data indicate a predominance of oil generating lipid kerogen and minor terrigenous organic matter in the mixed organic source facies. T_{max} data of 444 - 445°C are comparable with the maturity suggested from the pristane/nC_{17} versus phytane/nC_{18} plot. Measure R_o data (0.74 - 0.77%) are approximate and are somewhat lower.

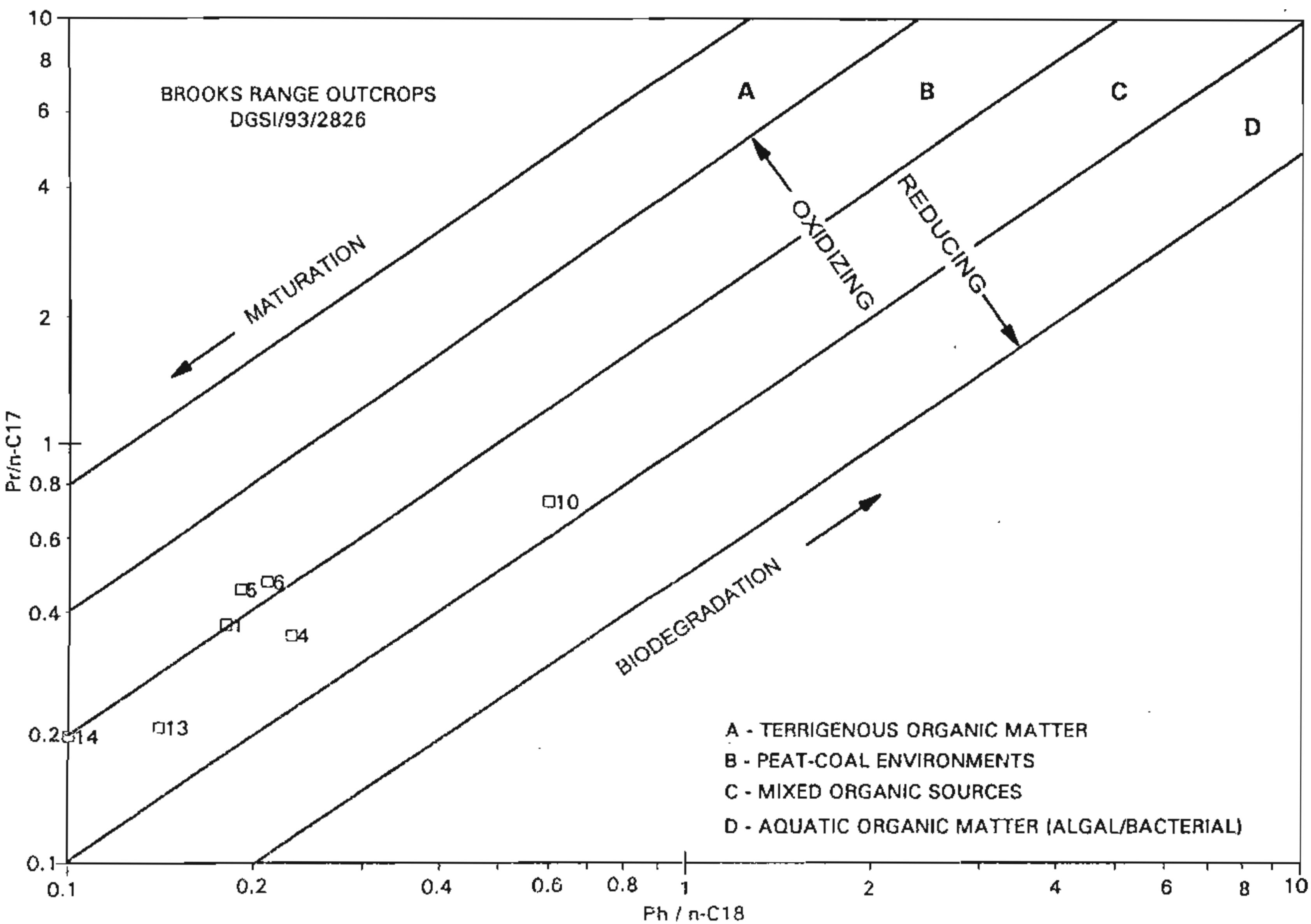


FIGURE 3 - Plot from chromatography data showing organic matter type, source rock depositional environment, and thermal maturity.

Sample 93-MU-80 from the Neocomian Kingkak shale at Surprise Creek contains indigenous bitumen. A whole extract gas chromatogram suggests a mixed organic source (type II/III) with significant terrigenous organic matter deposited under mild to moderately oxic conditions and a peak oil generation stage thermal maturity. This is evidenced by the high pristane/phytane ratio of 2.0, the cross plot of pristane/nC_{17} (0.35) versus phytane/nC_{18} (0.23) in Figure 3, very significant C_{25+} n-alkanes, an odd carbon number predominance in the nC_{25} - nC_{35} range, and the high CPI of 1.33. Kerogen microscopy data show 65% lipid kerogen (unstructured lipids 50%, structured lipids 5%, solid bitumen 10%) and 35% humic kerogen (vitrinite 25%, inertinite 10%) and agree with the gc data. The thermal maturity shown by the pristane/nC_{17} versus phytane/nC_{18} plot (Figure 3) also agrees with the measured R_o of 0.92%. The T_{max} value of 461°C is unreliable because of the low and undefined S_2 peak.

Sample 93-RKC-22-153-B probably, from Kingkak shale (top Ting sandstone), and sample 93-RKC-22-36-B from Kingkak shale (both from Tingmerkpuk Mountain) have extract gas chromatograms that are characterized by mixed organic facies (type II/III) with significant terrigenous organic matter and by high thermal maturities. This is evidenced by high pristane/phytane ratios (2.0 and 5.1, respectively), the pristane/nC_{17} versus phytane/nC_{18} plot (Figure 3), and the CPI values (1.21 and 1.01, respectively). Kerogen microscopy data support the gc data by showing abundant humic kerogen (25 - 40%) relative to lipid-rich kerogen (60 - 75%). A high thermal maturity is also indicated from the measured R_o values of 1.43 - 1.57%. T_{max} values are unreliable because of low and undefined S_2 peaks.

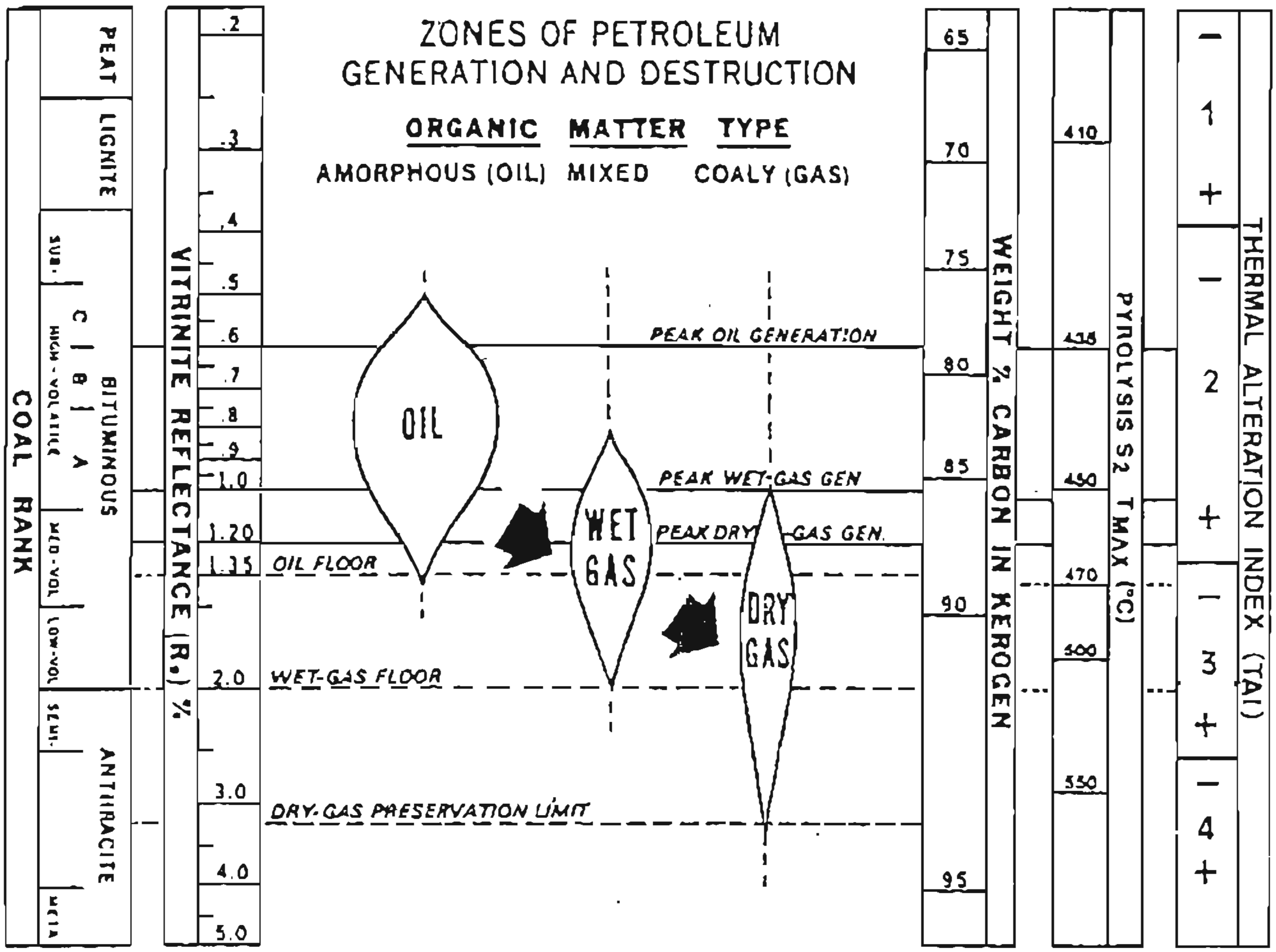
Sample 93-MU-101, representing the Albian Torok Formation from Eagle Creek, contains indigenous extract. A whole extract gas chromatogram shows a mixed organic source (type III?) with primarily terrigenous organic matter deposited under sub-oxic depositional conditions and a high thermal maturity. This is shown by a high pristane/phytane ratio of 2.4, the pristane/nC_{17} (0.37) versus phytane/nC_{18} (0.18) plot (Figure 3) and the CPI >1 (1.12). Kerogen microscopy data show a high proportion of humic kerogen (45%) relative to lipid-rich kerogen (55%; unstructured 50% and structured 5%) and support the gc data. The high measured R_o of 1.47% also supports the high maturity indicated from pristane/nC_{17} versus phytane/nC_{18} plot (Figure 2).

Sample 93-MU-93, from an unknown formation in Tingmerkpuk Mountain, contains indigenous extract derived from a mixed organic source containing significant terrigenous organic matter (type II/III) and probably deposited under mildly reducing conditions. This is indicated by the pristane/phytane ratio of 1.3, the pristane/nC_{17} (0.73) versus phytane/nC_{18} (0.60) plot in Figure 3, the CPI >1 (1.06) and abundant C25+ n-alkanes. The pristane/nC_{17} versus phytane/nC_{18} plot and the bimodal n-alkane distribution suggest a relatively low thermal maturity (0.70% R_o). Kerogen microscopy data agree with the organic source facies suggested from the gc data. The measured R_o of 1.17 is significantly higher than that suggested from the pristane/nC_{17} versus phytane/nC_{18} plot (Figure 3). The T_{max} value is unreliable because of a low and undefined S_2 peak.

Considering all of the gc data, we conclude that the Brooks Range samples contain some mature, oil-prone source rocks that have generated and expelled crude oil. The organic-rich Sublik source rocks (e.g. sample 93-MU-80-1) contain type II, oil-prone kerogen and are the best quality oil source rocks. The Kingkak shales are mature to highly mature and contain low yield type II/III kerogen which probably has generated some waxy oil and gas. The Torok Formation contains highly mature, type III source rocks that generated mostly gas.

APPENDICES

APPENDIX #1 —VITRINITE REFLECTANCE DATA

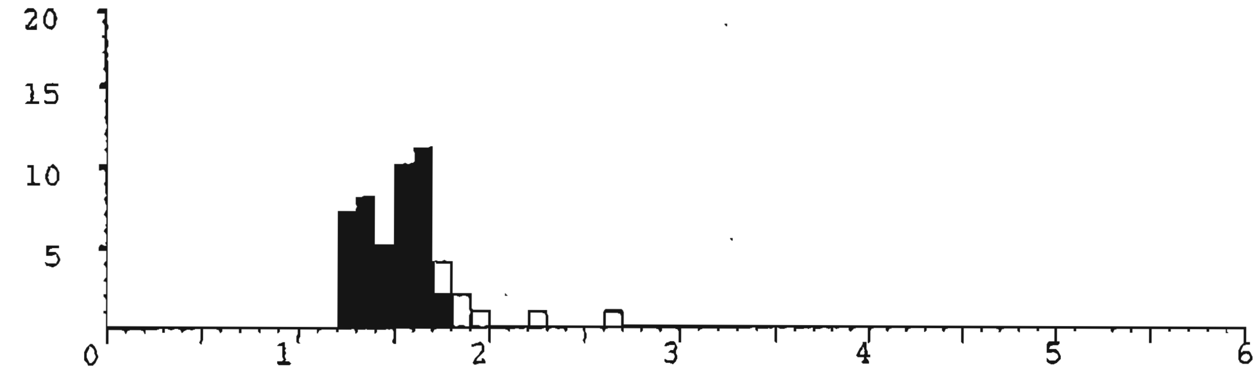


CORRELATION OF VARIOUS MATURATION INDICES AND ZONES OF PETROLEUM GENERATION AND DESTRUCTION.

BROOKS RANGE OUTCROPS

93-MU-101 OUTCROP KEROGEN

INTERPRETED MATURITY : 1.47 Ro Std. Dev. : 0.15 No. Readings : 43



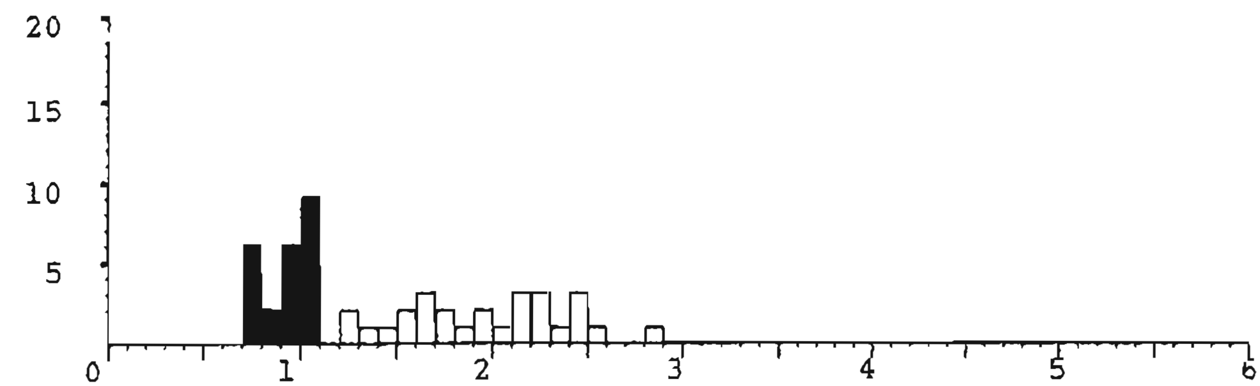
* = Maturity Values REFLECTANCE VALUES

*1.23	*1.35	*1.50	*1.60	*1.68
*1.23	*1.35	*1.51	*1.61	*1.71
*1.23	*1.35	*1.52	*1.61	*1.71
*1.26	*1.38	*1.53	*1.61	1.78
*1.27	*1.39	*1.54	*1.62	1.79
*1.27	*1.40	*1.54	*1.63	1.82
*1.28	*1.40	*1.55	*1.63	1.88
*1.31	*1.44	*1.55	*1.63	1.99
*1.32	*1.45	*1.56	*1.64	2.22
*1.33	*1.47	*1.56	*1.65	2.61

BROOKS RANGE OUTCROPS

93-MU-80 OUTCROP KEROGEN

INTERPRETED MATURITY : 0.92 Ro Std. Dev. : 0.13 No. Readings : 23



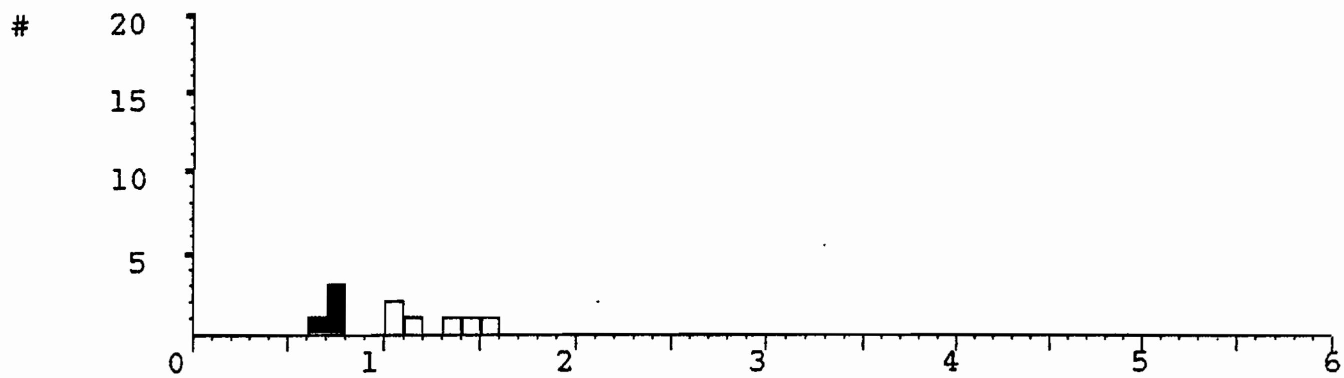
* = Maturity Values REFLECTANCE VALUES

*0.70	*0.92	*1.06	1.66	2.13
*0.74	*0.93	*1.09	1.66	2.20
*0.75	*0.94	*1.09	1.70	2.29
*0.75	*0.97	1.28	1.78	2.29
*0.76	*1.00	1.28	1.84	2.39
*0.77	*1.02	1.34	1.90	2.40
*0.83	*1.02	1.43	1.91	2.41
*0.87	*1.04	1.56	2.07	2.44
*0.90	*1.04	1.59	2.11	2.53
*0.90	*1.05	1.65	2.12	2.81

BROOKS RANGE OUTCROPS

93-MU-80-1 OUTCROP KEROGEN

INTERPRETED MATURITY : 0.74 Ro? Std. Dev. : 0.05 No. Readings : 4



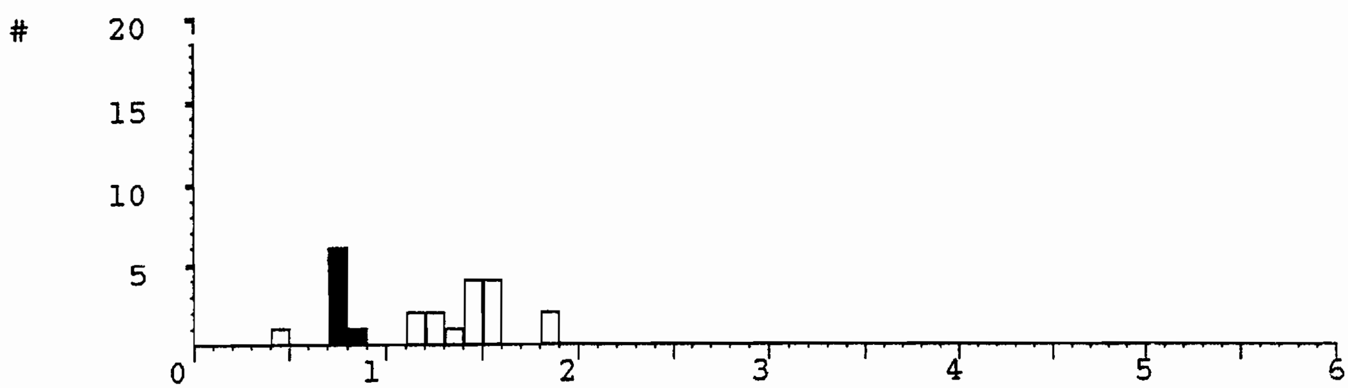
* = Maturity Values REFLECTANCE VALUES

*0.67
*0.74
*0.77
*0.77
1.01
1.09
1.11
1.39
1.49
1.58

BROOKS RANGE OUTCROPS

93-MU-80-1a OUTCROP KEROGEN

INTERPRETED MATURITY : 0.77 Ro? Std. Dev. : 0.05 No. Readings : 7



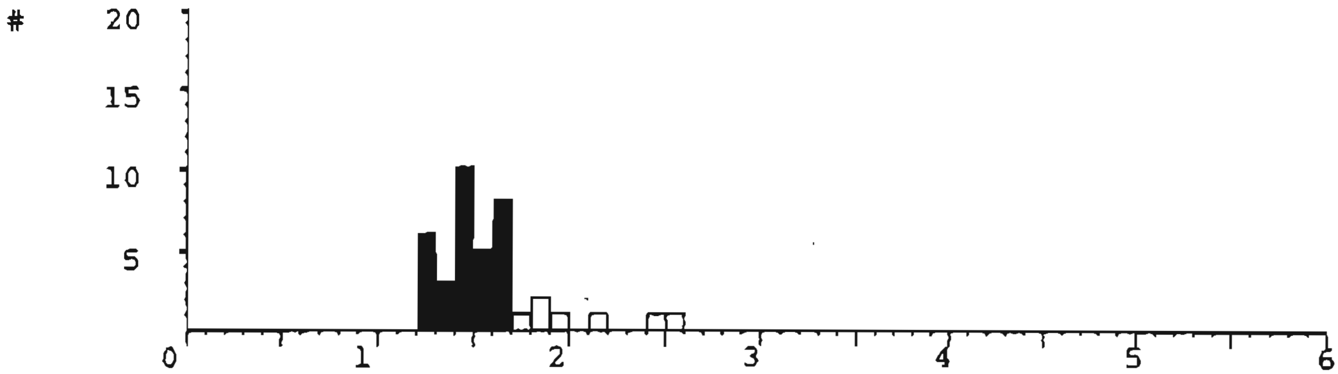
* = Maturity Values REFLECTANCE VALUES

0.46	1.21	1.55
*0.71	1.24	1.85
*0.73	1.32	1.89
*0.77	1.40	
*0.77	1.41	
*0.77	1.46	
*0.77	1.49	
*0.87	1.51	
1.11	1.52	
1.11	1.52	

BROOKS RANGE OUTCROPS

93-MU-87 OUTCROP KEROGEN

INTERPRETED MATURITY : 1.47 Ro Std. Dev. : 0.14 No. Readings : 32



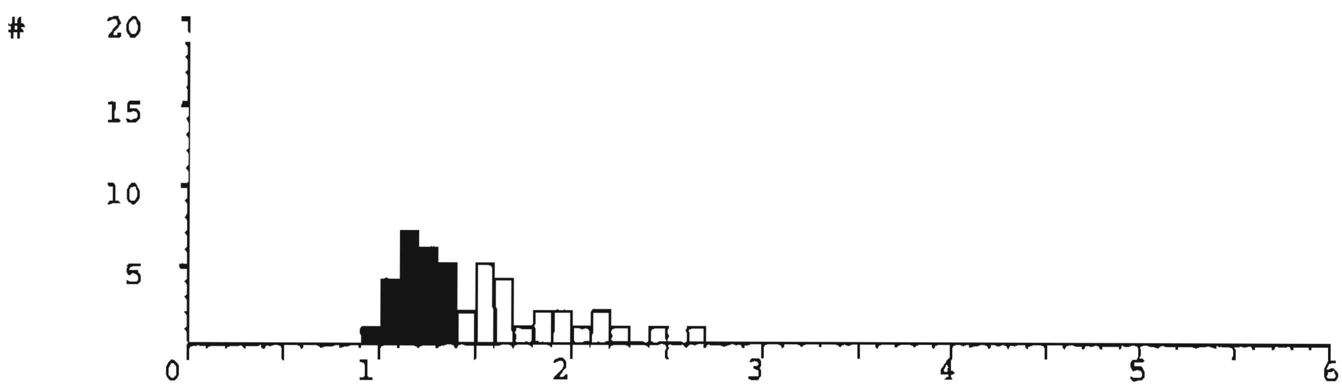
* = Maturity Values REFLECTANCE VALUES

*1.24	*1.42	*1.53	*1.68
*1.24	*1.42	*1.54	*1.68
*1.25	*1.43	*1.58	1.77
*1.25	*1.43	*1.59	1.82
*1.28	*1.43	*1.62	1.86
*1.28	*1.45	*1.63	1.99
*1.30	*1.46	*1.64	2.14
*1.35	*1.47	*1.64	2.41
*1.35	*1.47	*1.65	2.51
*1.41	*1.53	*1.65	

BROOKS RANGE OUTCROPS

93-MU-88-1 OUTCROP KEROGEN

INTERPRETED MATURITY : 1.19 Ro Std. Dev. : 0.12 No. Readings : 23



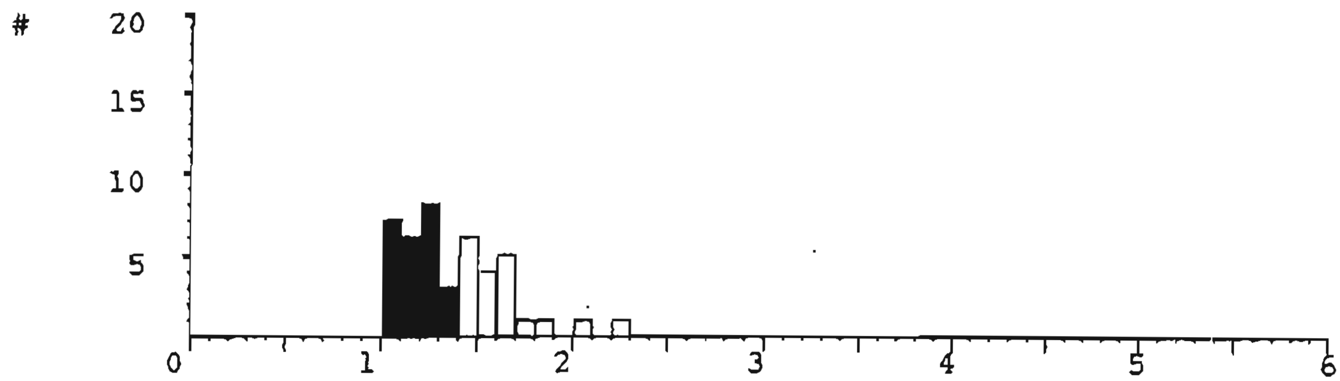
* = Maturity Values REFLECTANCE VALUES

*0.98	*1.17	*1.35	1.60	2.12
*1.01	*1.17	*1.36	1.62	2.19
*1.02	*1.22	*1.39	1.64	2.21
*1.04	*1.23	1.44	1.68	2.41
*1.08	*1.23	1.45	1.71	2.61
*1.11	*1.26	1.51	1.81	
*1.13	*1.27	1.51	1.87	
*1.14	*1.28	1.51	1.91	
*1.14	*1.30	1.55	1.94	
*1.15	*1.33	1.57	2.06	

BROOKS RANGE OUTCROPS

93-MU-93 OUTCROP KEROGEN

INTERPRETED MATURITY : 1.17 Ro Std. Dev. : 0.11 No. Readings : 24



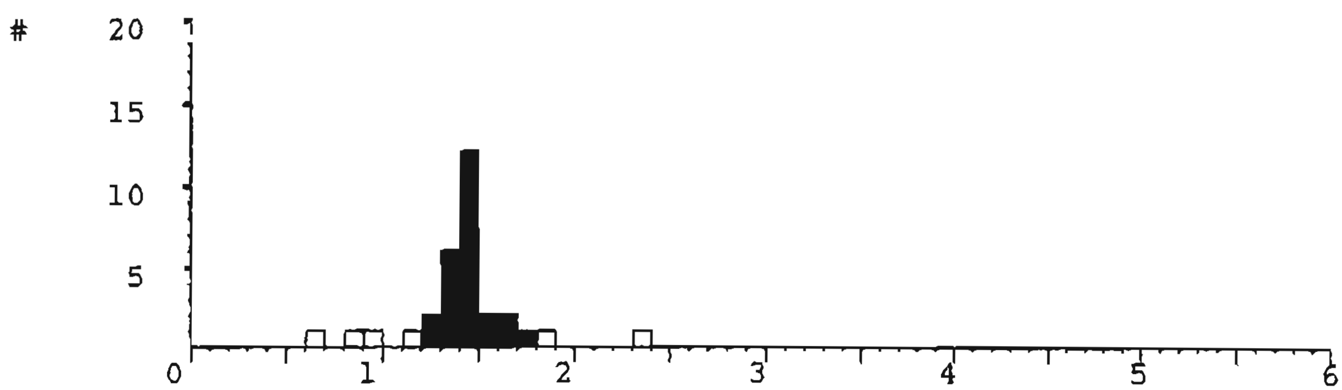
* = Maturity Values REFLECTANCE VALUES

*1.01	*1.11	*1.26	1.52	1.80
*1.02	*1.18	*1.34	1.52	2.09
*1.07	*1.19	*1.37	1.52	2.21
*1.08	*1.20	*1.38	1.57	
*1.08	*1.21	1.44	1.60	
*1.08	*1.23	1.44	1.62	
*1.08	*1.24	1.46	1.62	
*1.10	*1.24	1.46	1.65	
*1.11	*1.25	1.48	1.66	
*1.11	*1.26	1.49	1.74	

BROOKS RANGE OUTCROPS

93-RKC-22-138-B OUTCROP KEROGEN

INTERPRETED MATURITY : 1.44 Ro Std. Dev. : 0.12 No. Readings : 25



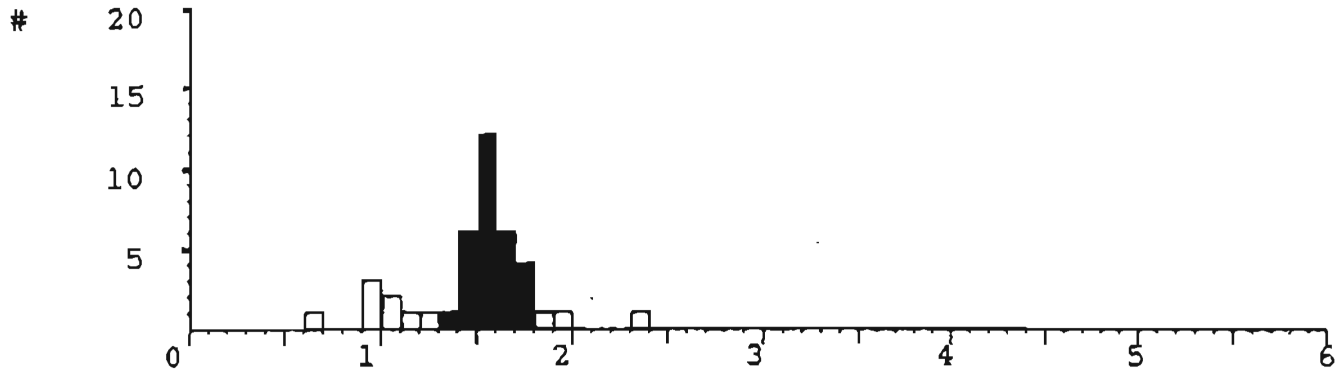
* = Maturity Values REFLECTANCE VALUES

0.64	*1.36	*1.46	2.38
0.87	*1.38	*1.46	
0.92	*1.41	*1.47	
1.12	*1.42	*1.48	
*1.21	*1.42	*1.55	
*1.23	*1.42	*1.57	
*1.32	*1.42	*1.60	
*1.33	*1.44	*1.66	
*1.33	*1.44	*1.70	
*1.36	*1.45	1.85	

BROOKS RANGE OUTCROPS

93-RKC-22-153-B OUTCROP KEROGEN

INTERPRETED MATURITY : 1.57 Ro Std. Dev. : 0.11 No. Readings : 29



REFLECTANCE VALUES

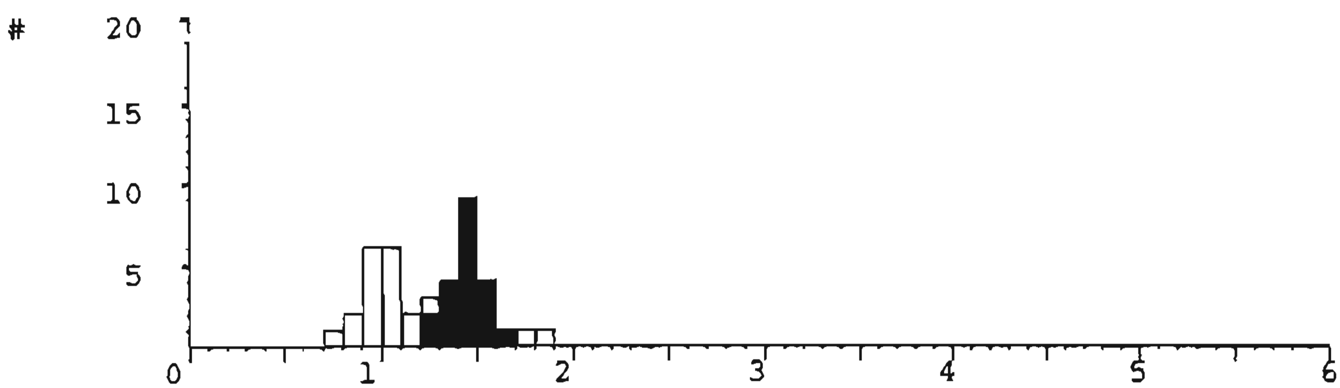
* = Maturity Values

0.63	*1.43	*1.54	*1.65
0.92	*1.44	*1.56	*1.65
0.96	*1.45	*1.56	*1.68
0.96	*1.47	*1.57	*1.72
1.04	*1.49	*1.58	*1.74
1.07	*1.50	*1.58	*1.76
1.16	*1.50	*1.59	*1.77
1.27	*1.51	*1.60	1.88
*1.37	*1.52	*1.61	1.99
*1.41	*1.52	*1.62	2.36

BROOKS RANGE OUTCROPS

93-RKC-22-36-B OUTCROP KEROGEN

INTERPRETED MATURITY : 1.43 Ro Std. Dev. : 0.09 No. Readings : 20



REFLECTANCE VALUES

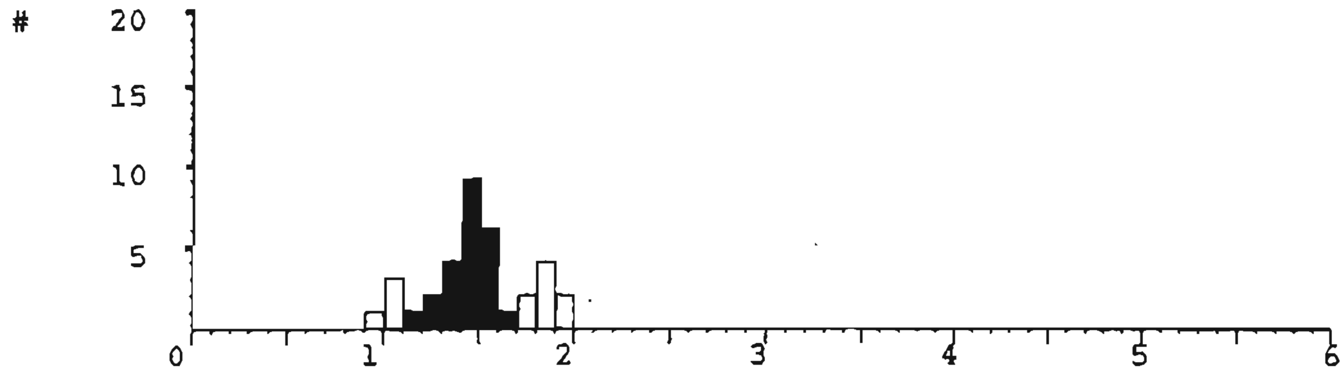
* = Maturity Values

0.78	1.01	*1.30	*1.44
0.80	1.03	*1.32	*1.45
0.88	1.04	*1.34	*1.48
0.93	1.06	*1.39	*1.50
0.93	1.07	*1.41	*1.52
0.95	1.16	*1.41	*1.52
0.96	1.17	*1.43	*1.52
0.96	1.21	*1.43	*1.62
0.99	*1.27	*1.43	1.74
1.01	*1.28	*1.44	1.88

BROOKS RANGE OUTCROPS

93-RKC-22-43-B OUTCROP KEROGEN

INTERPRETED MATURITY : 1.43 Ro Std. Dev. : 0.12 No. Readings : 23



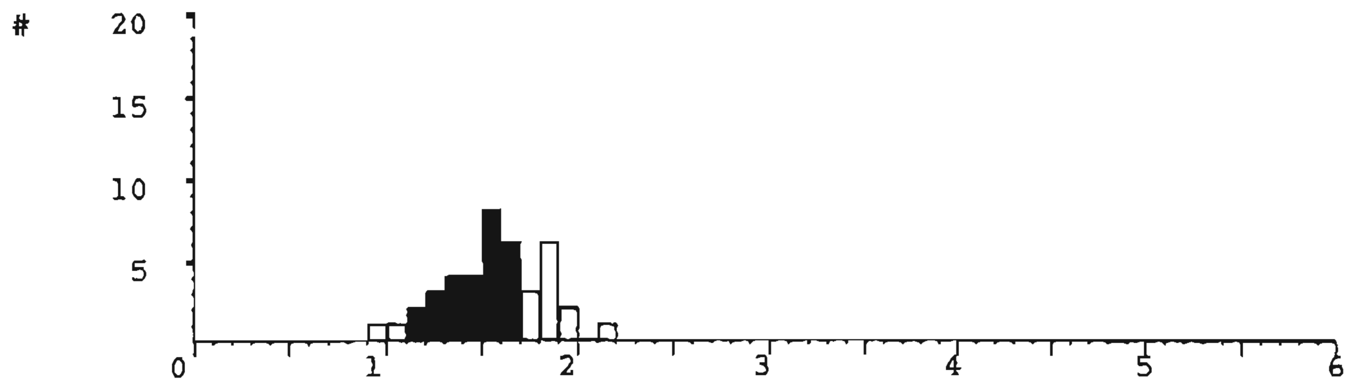
* = Maturity Values REFLECTANCE VALUES

0.93	*1.39	*1.51	1.85
1.02	*1.41	*1.51	1.85
1.05	*1.41	*1.53	1.88
1.07	*1.42	*1.54	1.92
*1.17	*1.43	*1.58	1.92
*1.24	*1.43	*1.59	
*1.25	*1.45	*1.66	
*1.31	*1.46	1.74	
*1.31	*1.47	1.78	
*1.37	*1.48	1.84	

BROOKS RANGE OUTCROPS

93-RKC-22-72-B OUTCROP KEROGEN

INTERPRETED MATURITY : 1.46 Ro Std. Dev. : 0.15 No. Readings : 27



* = Maturity Values REFLECTANCE VALUES

0.95	*1.39	*1.54	1.76	2.11
1.02	*1.43	*1.56	1.77	
*1.16	*1.45	*1.59	1.80	
*1.18	*1.47	*1.60	1.81	
*1.22	*1.49	*1.60	1.81	
*1.23	*1.50	*1.61	1.83	
*1.29	*1.51	*1.63	1.85	
*1.34	*1.52	*1.67	1.86	
*1.35	*1.52	*1.68	1.93	
*1.38	*1.53	1.72	1.97	

APPENDIX #2—VISUAL KEROGEN DATA

BROOKS RANGE OUTCROPS

DGSI

Project: DGSI/93/2826

DATE: 2/17/94

DGSI NUMBER	ID OR DEPTH	SAMPLE TYPE	ORGANIC MATTER – LIPIDS – UNSTRUCTURED: UNDIFFERENTIATED (%)	AMORPHOUS (%)	MASSIVE (%)	MICRINIZED (%)	LIPIDS – STRUCTURED: TYPE / (%)	TYPE / (%)	TYPE / (%)	TYPE / (%)	SOLID BITUMEN (%)	HUMIC: INERTINITE (%)	VITRINITE (%)	OTHER: TYPE / (%)	TYPE / (%)	RELATIVE ABUNDANCE: PYRITE TYPE	PYRITE	TOTAL ORGANIC MATTER	VITRINITE: NORMAL	ROUGH	LIPID-RICH	OXIDIZED	COKED	FLUORESCENCE / TAI – REFLECTED LIPIDS – UNSTR.: COLOR	INTENSITY	STRU.: COLOR	INTENSITY	BACKGROUND INTENSITY	TRANSMITTED LIPIDS – UNSTR.: TAI VALUE	FLUOR. COLOR	INTENSITY	STRU.: TAI VALUE	FLUOR. COLOR	INTENSITY	Ro: VITRINITE REFLECTANCE Maturity or Equivalent
1	93-MU-101	OC K	50				U 5	LD T			?	10	35			MA	-	+	M	M				BL	0	BL	0	2	3- 3	BL	0		BL O	0 1	1.47
Comments:	*Gray - brown, grainy unstructured material.*																																		
4	93-MU-80	OC K	50				U 5	LD T			10	10	25			MA	M	+	+			T	T	BL	0	BL	0	2 3	3 2+	BL O	0 1		BL O	0 1	0.92
Comments:	*Abundant VR ? Solid bitumen Ro 0.52, 0.55, 0.57, 0.78.*																																		
5	93-MU-80-1	OC K				65	T	LD 5			15	10	5			F	M	+	+			T		BL	0	O OB	1	2 3	3 3+	O BL	1 0		O Y	1	?0.74
Comments:	*Wide range of solid bitumen Ro - 0.57 - 0.72 probably indigenous, 0.07 contam. , 1.77 - 2.65 ?*																																		
6	93-MU-80-1a	OC K	15			40	LD 5				20	10	10			F MA	M	+	+					DB	1	O	2	3	3- 3+	BL	0		O	1	?0.77
Comments:	*Small, angular solid bitumen in micrinized unstructured material, Ro 0.51 - 0.55.*																																		
8	93-MU-87	OC K	60				U 5				5	10	20			MA F	-	+	+	-				BL	0			3	3-	BL	0				1.47
Comments:	*Grainy unstructured material. Difficult to identify some vitrinite from bitumen.*																																		

ANALYST

Castano
X O'Connor

MICROSCOPE

Jena
X Zeiss

SAMPLE TYPE/PREP
- CTG Cuttings
- CC Conv. Core
- SWC SideWallCore
- OC Outcrop
- NI No Inform.
- C Coal
- K Kerogen
- WR Whole Rock
- n.d. Not Determ.

STRUCTURED LIPIDS
- AL Alginite
- SB Suberinite
- C Cutinite
- LD Liptodetrinite
- U Undiffer.
- S Sporinite
- R Resinite
- O Other

OTHER ORGANIC MATTER
- E Exudatinite
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC VitriniteContamination
- VR Recycled Vitrinite

PYRITE
- E Euhedral
- F Framboid
- MA Massive
- RI Replace-infill

ABUND.
- N None
- T Trace
- \- Small Amt.
- M Mod. Amt.
- \+ Large Amt.
- ++ Abundant

FLUOR. INTENS.
- 0 None
- 1 Weak
- 2 Moderate
- 3 Strong
- 4 Intense

VIT. REFLECT. EQUIVALENCE
- B Bitumen
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC Vitrinite Contam.
- VR Recycled Vitrinite

FLUOR. COLOR
- W White
- G Green
- Y Yellow
- O Orange
- R Red
- B Brown
- BL Black
- L Light
- D Dark

TAI COLOR VALUES
- 1- Straw Yellow
- 1 Pale Yellow
- 1+ Yellow
- 2- Yellow-Orange
- 2 Golden
- 2+ Amber
- 3- Reddish Brown
- 3 Medium Brown
- 3+ Dark Brown
- 4- Brown-Black
- 4 Black
- 4+ Black-Opaque

VISUAL KEROGEN ANALYSIS
Total Quality Geochemistry

BROOKS RANGE OUTCROPS

DGSI

Project: DGSI/93/2826

DATE: 2/17/94

DGSI NUMBER	ID OR DEPTH	SAMPLE TYPE	ORGANIC MATTER – LIPIDS – UNSTRUCTURED: UNDIFFERENTIATED (%)	AMORPHOUS (%)	MASSIVE (%)	MICRINIZED (%)	LIPIDS – STRUCTURED: TYPE / (%)	TYPE / (%)	TYPE / (%)	TYPE / (%)	SOLID BITUMEN (%)	HUMIC: INERTINITE (%)	VITRINITE (%)	OTHER: TYPE / (%)	TYPE / (%)	RELATIVE ABUNDANCE: PYRITE TYPE	PYRITE	TOTAL ORGANIC MATTER	VITRINITE: NORMAL	ROUGH	LIPID-RICH	OXIDIZED	COKED	FLUORESCENCE / TAI – REFLECTED – LIPIDS – UNSTR.: COLOR	INTENSITY	STRU.: COLOR	INTENSITY	BACKGROUND INTENSITY	TRANSMITTED – LIPIDS – UNSTR.: TAI VALUE	FLUOR. COLOR	FLUOR. INTENSITY	STRU.: TAI VALUE	FLUOR. COLOR	FLUOR. INTENSITY	Ro: VITRINITE REFLECTANCE Maturity or Equivalent
9	93-MU-88-1	OC K	55				U T	LD T			?	10	35			MA	M	M	M	M		T	T	BL	0			2	3- 3	BL	0		O	1	1.19
Comments:	*Grainy unstructured material.*																																		
10	93-MU-93	OC K	70				LD T				5	10	15			MA	+	+	M	M		-	T	? DB	1			3	3-	BL	0		O	1	1.17
Comments:	*Same. Solid bitumen Ro 0.97 - 0.99.*																																		
12	93-RKC-22-138-B	OC K	69				LD 5				5	10	20			MA	M	+	+	-				DB	1			3	3-	BL	0		O	1	1.44
Comments:	*Grainy unstructured material.*																																		
13	93-RKC-22-153-B	OC K	50				LD 5	C T			5	20	20			MA	-	M	+					DB	1			3	3-	BL	0		O	1	1.57
Comments:	*Same. Solid bitumen Ro 0.73, 0.75, 0.78, 1.09.*																																		
14	93-RKC-22-36-B	OC K	60				LD T	S T	U 5		10	10	15	VL ?		MA	M	M	M	M	?	-		DB	1			4	2+ 3-	BL	0	2+	BL DO	0 1	1.43
Comments:	*Same. Solid bitumen Ro 0.81, 0.88, 0.99. Some VL ? Value at 0.78 looks like good vitrinite.*																																		

ANALYST

Castano
X O'Connor

MICROSCOPE

Jena
X Zeiss

SAMPLE TYPE/PREP
- CTG Cuttings
- CC Conv. Core
- SWC SideWallCore
- OC Outcrop
- NI No Inform.
- C Coal
- K Kerogen
- WR Whole Rock
- n.d. Not Determ.

STRUCTURED LIPIDS
- AL Alginite
- SB Suberinite
- C Cutinite
- LD Liptodetrinite
- U Undiffer.
- S Sporinite
- R Resinite
- O Other

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- E Exudatinite
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC VitriniteContamination
- VR Recycled Vitrinite

PYRITE
- E Euhedral
- F Framboid
- MA Massive
- RI Replace-infill

ABUND.
- N None
- T Trace
- \- Small Amt.
- M Mod. Amt.
- \+ Large Amt.
- ++ Abundant

FLUOR. INTENS.
- 0 None
- 1 Weak
- 2 Moderate
- 3 Strong
- 4 Intense

VIT. REFLECT. EQUIVALENCE
- B Bitumen
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC Vitrinite Contam.
- VR Recycled Vitrinite

FLUOR. COLOR
- W White
- G Green
- Y Yellow
- O Orange
- R Red
- B Brown
- BL Black
- L Light
- D Dark

TAI COLOR VALUES
- 1- Straw Yellow
- 1 Pale Yellow
- 1+ Yellow
- 2- Yellow-Orange
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- 2+ Amber
- 3- Reddish Brown
- 3 Medium Brown
- 3+ Dark Brown
- 4- Brown-Black
- 4 Black
- 4+ Black-Opaque

VISUAL KEROGEN ANALYSIS
Total Quality Geochemistry

DGSI

BROOKS RANGE OUTCROPS

Project: DGSI/93/2826

DATE: 2/17/94

DGSI NUMBER	ID OR DEPTH	SAMPLE TYPE	ORGANIC MATTER – LIPIDS – UNSTRUCTURED: UNDIFFERENTIATED (%)	AMORPHOUS (%)	MASSIVE (%)	MICRINIZED (%)	LIPIDS – STRUCTURED: TYPE / (%)	TYPE / (%)	TYPE / (%)	TYPE / (%)	SOLID BITUMEN (%)	HUMIC: INERTINITE (%)	VITRINITE (%)	OTHER: TYPE / (%)	TYPE / (%)	RELATIVE ABUNDANCE: PYRITE TYPE	PYRITE	TOTAL ORGANIC MATTER	VITRINITE: NORMAL	ROUGH	LIPID-RICH	OXIDIZED	COKED	FLUORESCENCE / TAI – REFLECTED – LIPIDS – UNSTR.: COLOR	INTENSITY	STRU.: COLOR	INTENSITY	BACKGROUND INTENSITY	TRANSMITTED – LIPIDS – UNSTR.: TAI VALUE	FLUOR. COLOR	INTENSITY	STRU.: TAI VALUE	FLUOR. COLOR	INTENSITY	Ro: VITRINITE REFLECTANCE Maturity or Equivalent
15	93-RKC-22-43-B	OC K	70				U 5				5	10	10			MA	M	M	M	M			T	DB	1			4	2+ 3-	BL	0				1.43
16	93-RKC-22-72-B	OC K	60				LD 5	S T			5	10	20			MA	M	M	M	M				DB	1			3 4	2+ 3-	BL	0	2+	O	1 2	1.46

Comments (15): *Grainy unstructured material. Solid bitumen Ro 0.88, 1.05, 1.1, 1.8, 1.24.*

Comments (16): *Same. Solid bitumen Ro 0.66, 0.69, 0.70, 0.74, 0.94, 1.05.*

Comments:

Comments:

Comments:

ANALYST

Castano
X O'Connor

MICROSCOPE

Jena
X Zeiss

SAMPLE TYPE/PREP
- CTG Cuttings
- CC Conv. Core
- SWC SideWallCore
- OC Outcrop
- NI No Inform.
- C Coal
- K Kerogen
- WR Whole Rock
- n.d. Not Determ.

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- C Cutinite
- LD Liptodetrinite
- U Undiffer.
- S Sporinite
- R Resinite
- O Other

OTHER ORGANIC MATTER
- E Exsudatinite
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC VitriniteContamination
- VR Recycled Vitrinite

PYRITE
- E Euhedral
- F Framboid
- MA Massive
- RI Replace-infill

ABUND.
- N None
- T- Trace
- - Small Amt.
- M Mod. Amt.
- + Large Amt.
- ++ Abundant

FLUOR. INTENS.
- 0 None
- 1 Weak
- 2 Moderate
- 3 Strong
- 4 Intense

VIT. REFLECT. EQUIVALENCE
- B Bitumen
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC Vitrinite Contam.
- VR Recycled Vitrinite

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- O Orange
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- B Brown
- BL Black
- L Light
- D Dark

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- 1+ Yellow
- 2- Yellow-Orange
- 2 Golden
- 2+ Amber
- 3- Reddish Brown
- 3 Medium Brown
- 3+ Dark Brown
- 4- Brown-Black
- 4 Black
- 4+ Black-Opaque

VISUAL KEROGEN ANALYSIS
Total Quality Geochemistry

APPENDIX #3—EXTRACT AND GAS CHROMATOGRAPHY DATA

EXTRACT AND GAS CHROMATOGRAPHY

BROOKS RANGE OUTCROPS

DGSI/93/2826

EXTRACT AND GAS CHROMATOGRAPHY RATIOS

DGSI No.	Sample Identification	PPM	Ext./TOC	Pr/Ph	Pr/C17	Ph/C18	CPI	TOC
1	93-MU-101	662	0.051	2.4	0.37	0.18	1.12	1.30
4	93-MU-80	321	0.017	2.0	0.35	0.23	1.33	1.87
5	93-MU-80-1	1888	0.041	2.7	0.45	0.19	1.08	4.63
6	93-MU-80-1a	1925	0.209	2.6	0.47	0.21	1.10	0.92
10	93-MU-93	859	0.051	1.3	0.73	0.60	1.06	1.69

EXTRACT AND AREA DATA

DGSI No.	SAMPLE wt.	EXTRACT wt.	C17	Pr	C18	Ph	C28	C29	C30
1	61.6215	0.0408	101336	37594	87486	15436	11245	9846	6302
4	58.5042	0.0188	279586	98953	215968	48894	79957	84246	47087
5	67.6555	0.1277	82856	36886	70497	13693	9212	8506	6533
6	58.1916	0.1120	88571	41905	77582	16280	11861	11087	8296
10	66.1321	0.0568	71386	52099	68185	39627	43424	36866	25868

NORMALIZED ISOPRENOID PERCENT

DGSI No.	iC13	iC14	iC15	iC16	iC18	iC19	iC20
1	9.2	14.1	31.8	35.4	3.8	4.0	1.6
4	9.1	8.5	11.5	18.0	17.9	23.5	11.6
5	6.0	8.1	11.0	21.2	24.1	21.6	8.0
6	10.7	13.7	13.4	19.2	17.8	18.1	7.0
10	8.8	10.2	16.5	22.8	13.2	16.2	12.4

AREA DATA

DGSI No.	iC13	iC14	iC15	iC16	iC18	iC19	iC20
1	87843	134295	302501	336684	36052	37594	15436
4	38416	35883	48356	76014	75425	98953	48894
5	10176	13876	18805	36126	41062	36886	13693
6	24805	31870	31036	44571	41333	41905	16280
10	28135	32614	52810	73105	42431	52099	39627

EXTRACT AND GAS CHROMATOGRAPHY

BROOKS RANGE OUTCROPS

DGSI/93/2826

EXTRACT AND GAS CHROMATOGRAPHY RATIOS

DGSI No.	Sample Identification	PPM	Ext./TOC	Pr/Ph	Pr/C17	Ph/C18	CPI	TOC
13	93-RKC-22-153-B	152	0.013	2.0	0.21	0.14	1.21	1.19
14	93-RKC-22-36-B	199	0.011	5.1	0.20	0.08	1.01	1.84

EXTRACT AND AREA DATA

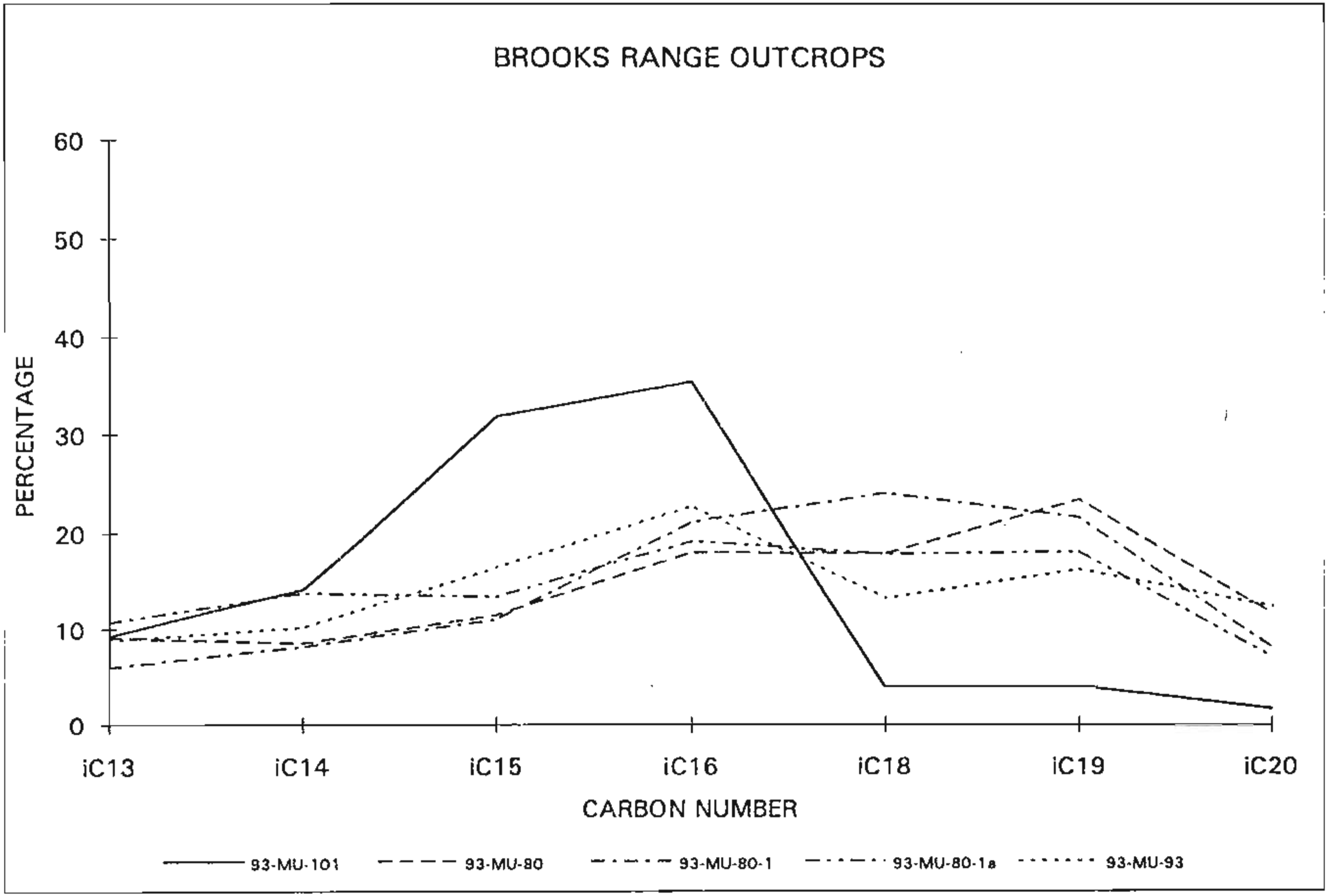
DGSI No.	SAMPLE wt.	EXTRACT wt.	C17	Pr	C18	Ph	C28	C29	C30
13	67.8166	0.0103	163494	33716	120061	16964	20140	20714	13972
14	72.4508	0.0144	294824	60312	144373	11878	26572	21177	15357

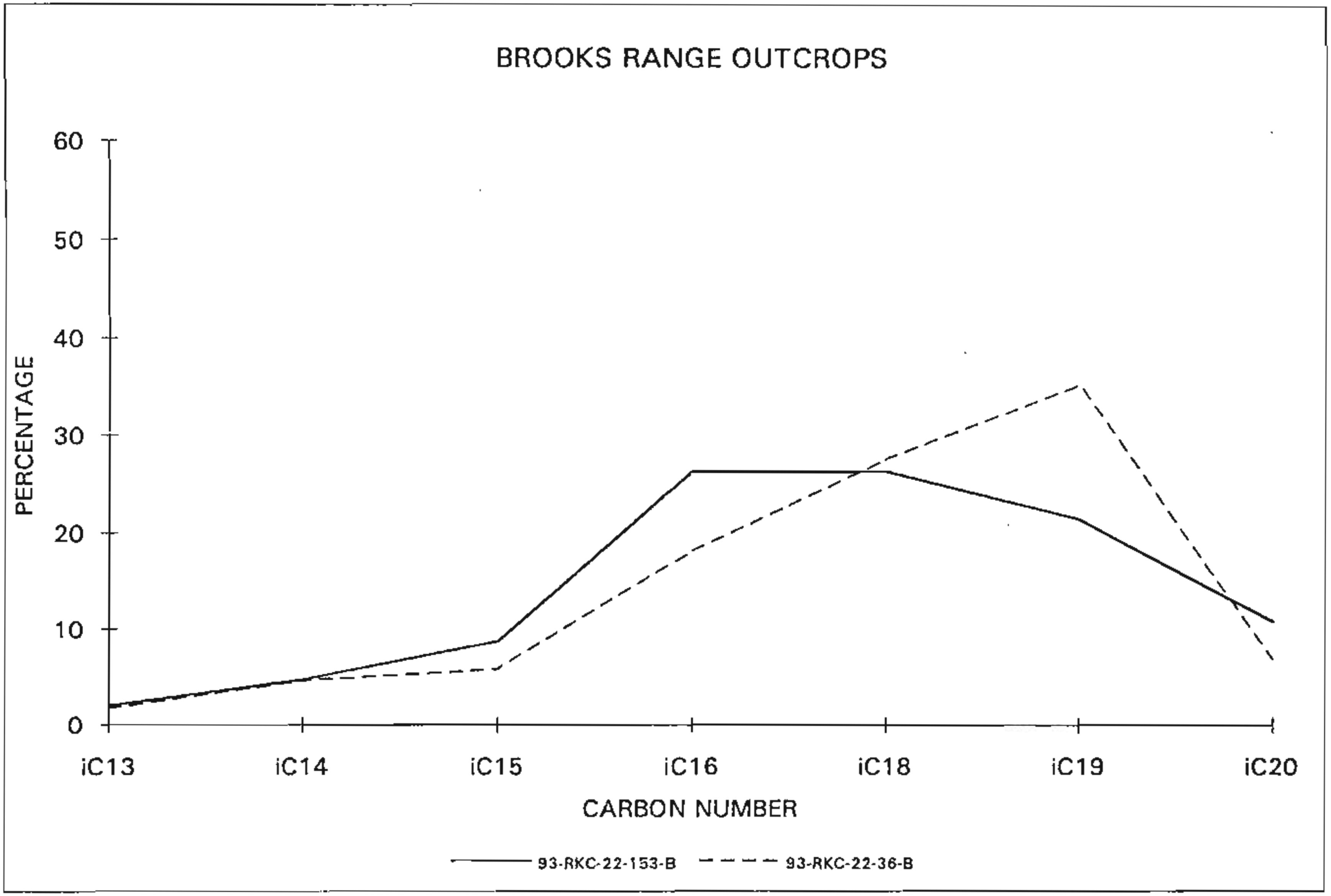
NORMALIZED ISOPRENOID PERCENT

DGSI No.	iC13	iC14	iC15	iC16	iC18	iC19	iC20
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1.8	4.6	5.8	18.2	27.5	35.2	6.9

AREA DATA

DGSI No.	iC13	iC14	iC15	iC16	iC18	iC19	iC20
13	3194	7468	13698	41410	41369	33716	16964
14	3001	7918	9975	31084	47048	60312	11878


BROOKS RANGE OUTCROPS
PERCENTAGE
60
50
40
30
20
10
0
iC13
iC14
iC15
iC16
iC18
iC19
iC20
CARBON NUMBER
93-MU-101
93-MU-80
93-MU-80-1
93-MU-80-1a
93-MU-93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PERCENTAGE
60
50
40
30
20
10
0
iC13
iC14
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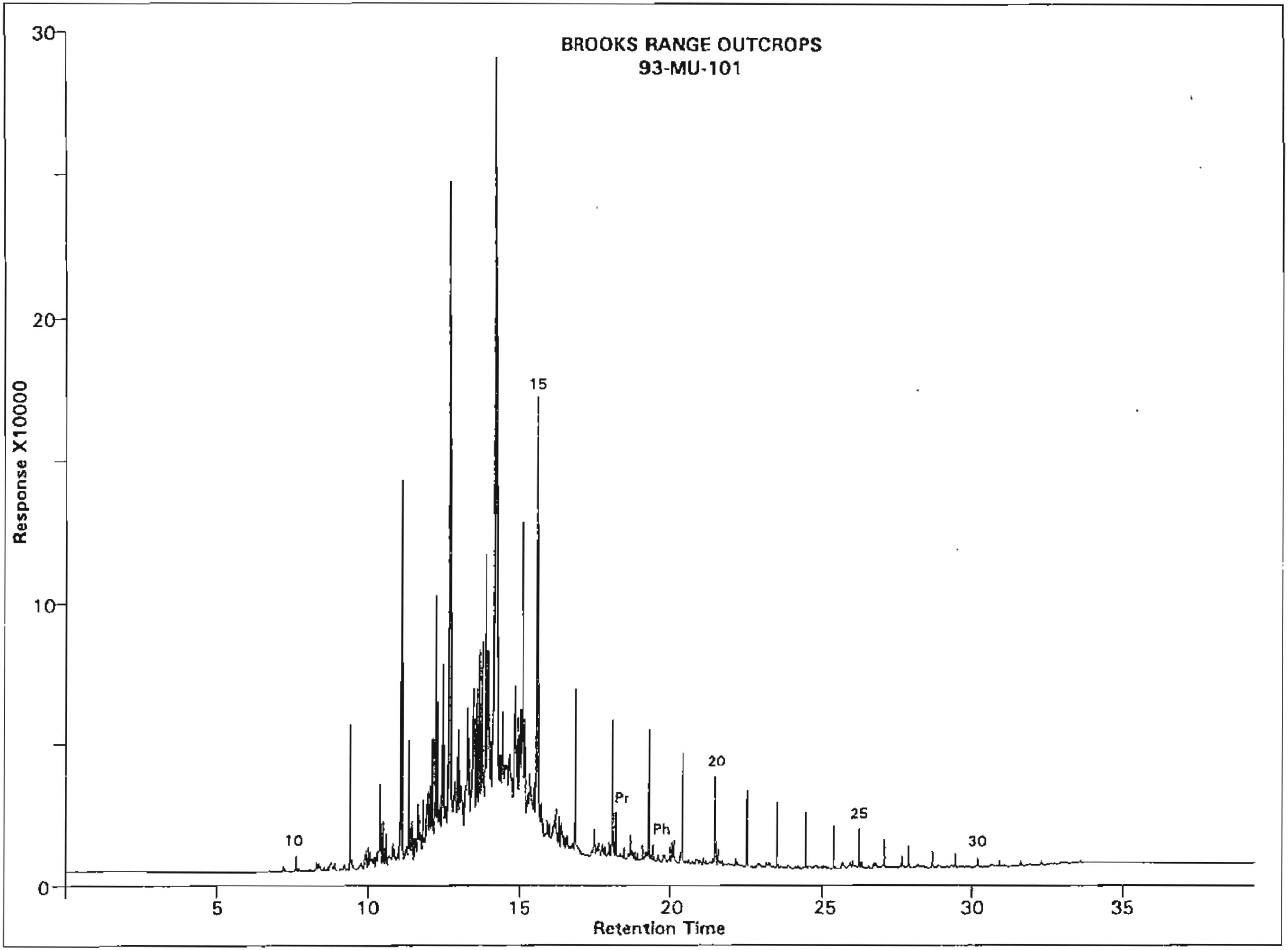
iC20
CARBON NUMBER
93-RKC-22-153-B
93-RKC-22-36-B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93-MU-101
Response X10000
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10
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Retention Time
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15
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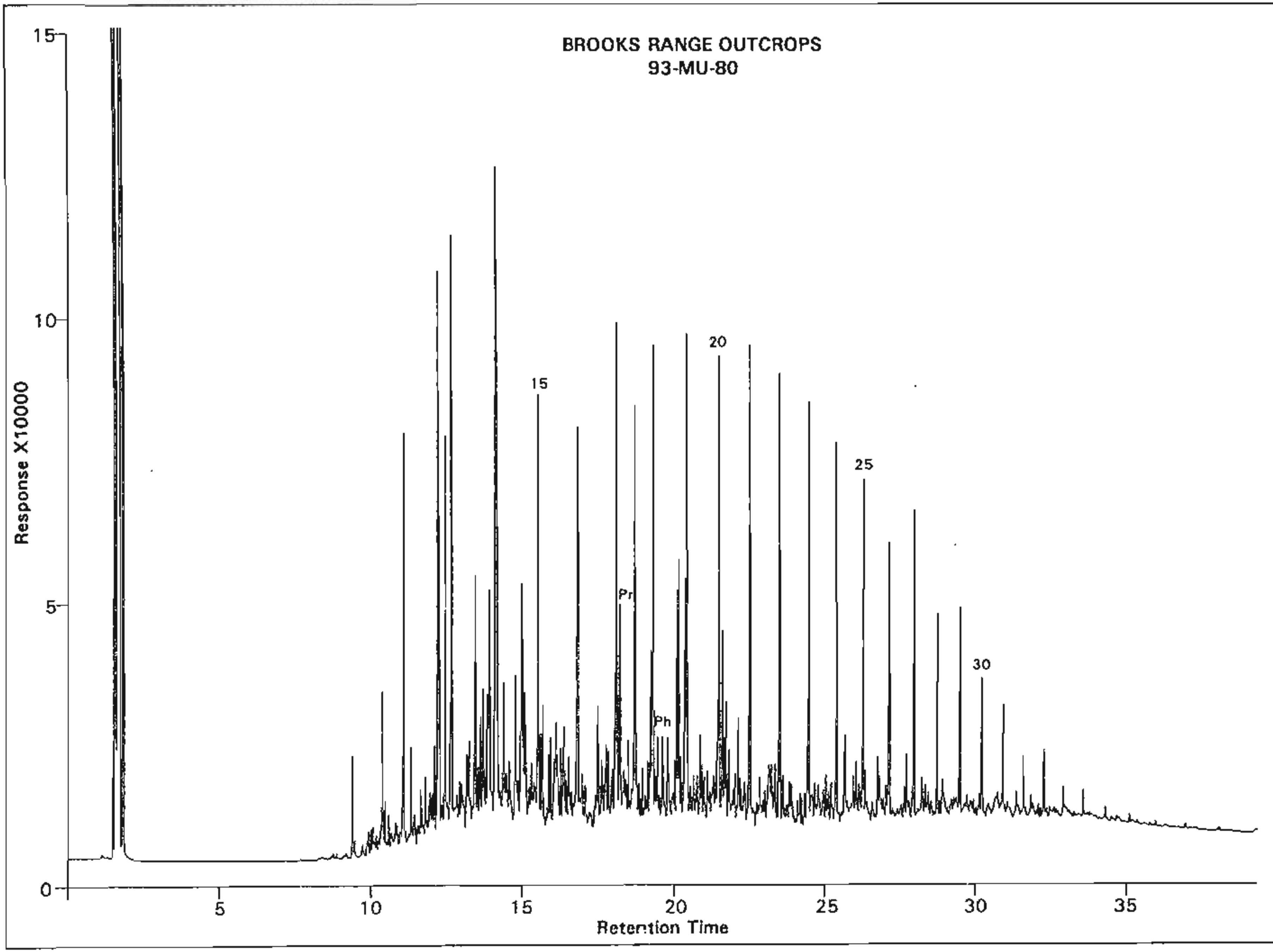
20
25
30
Pr
Ph



BROOKS RANGE OUTCROPS
93-MU-80
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Retention Time
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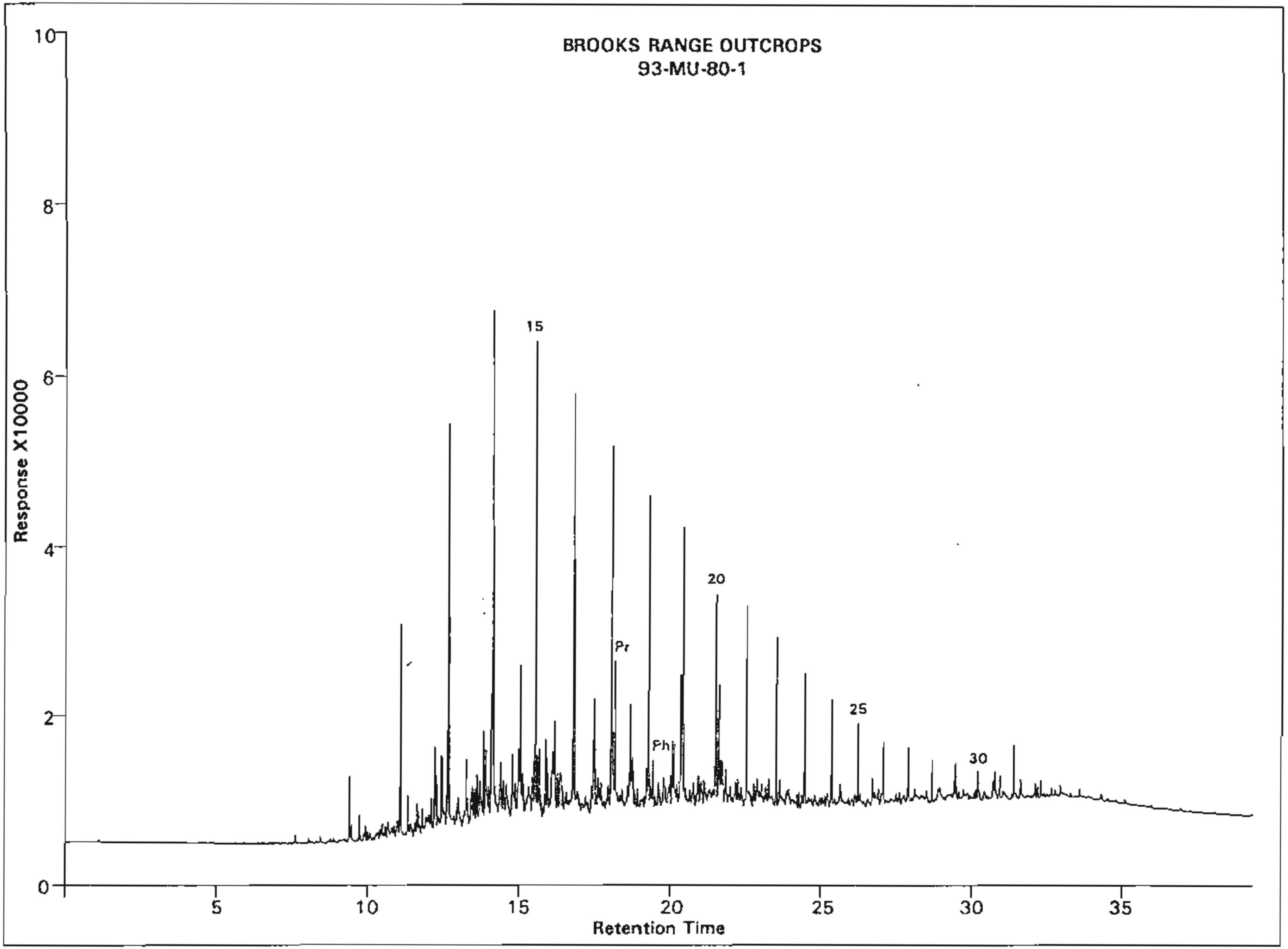
20
25
30
Pr
Ph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Response X10000
Retention Time
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4
6
8
10
5
10
15
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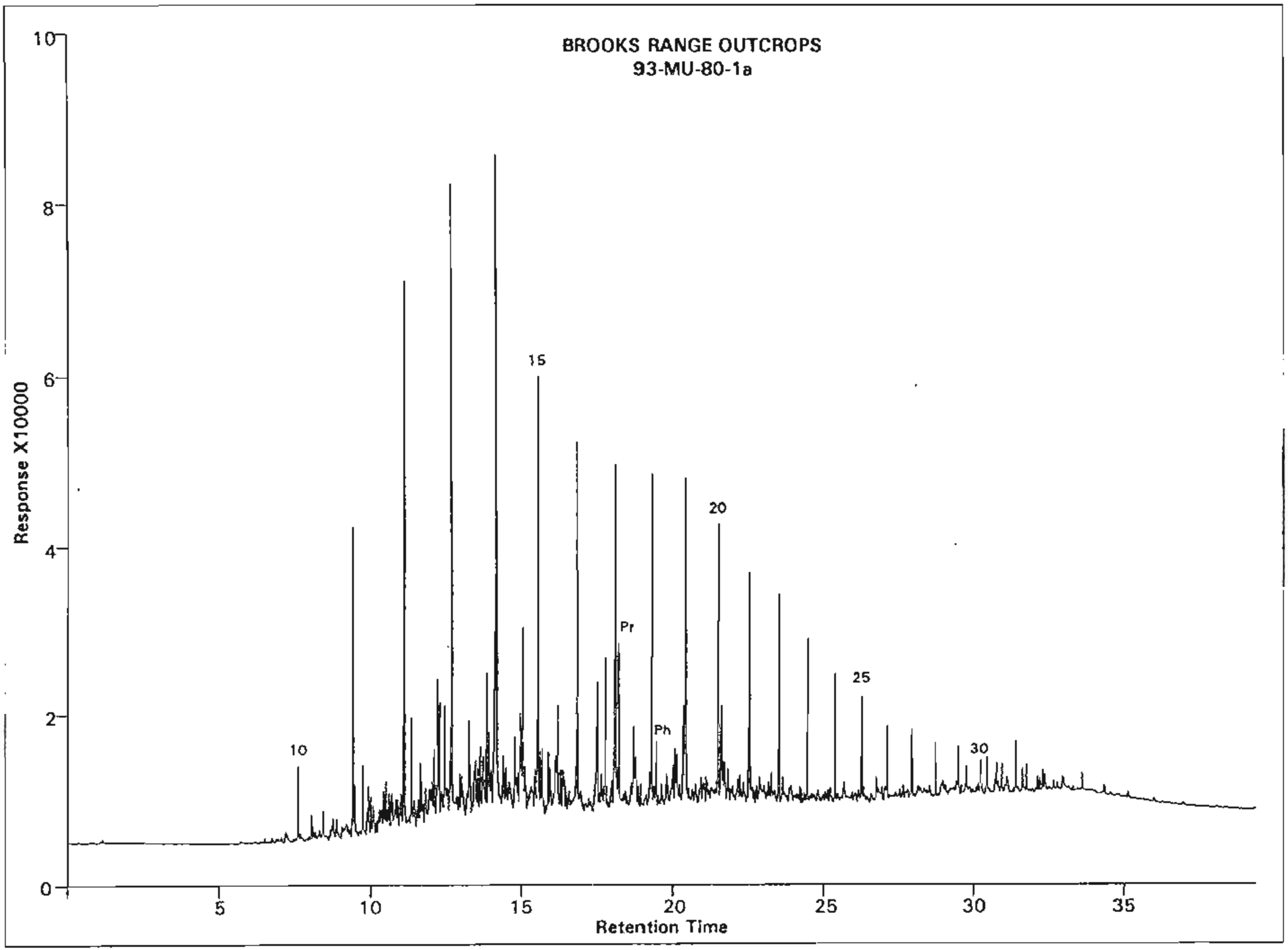
20
25
30
Pr
Ph


BROOKS RANGE OUTCROPS
93-MU-80-1a
Response X10000
Retention Time
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2
4
6
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10
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20
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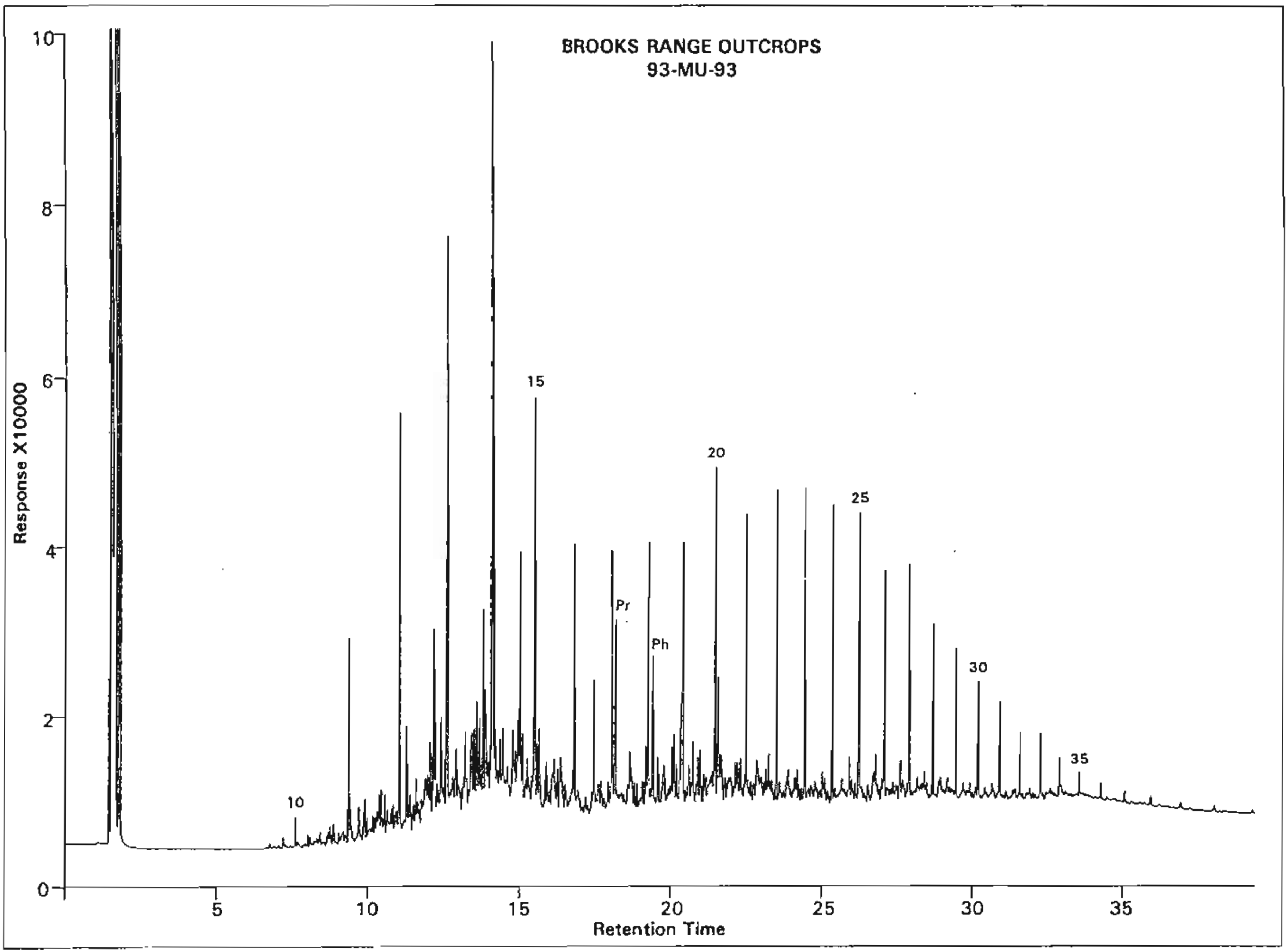
30
35
10
15
Pr
Ph
20
25
30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93-MU-93
Response X10000
Retention Time
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2
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6
8
10
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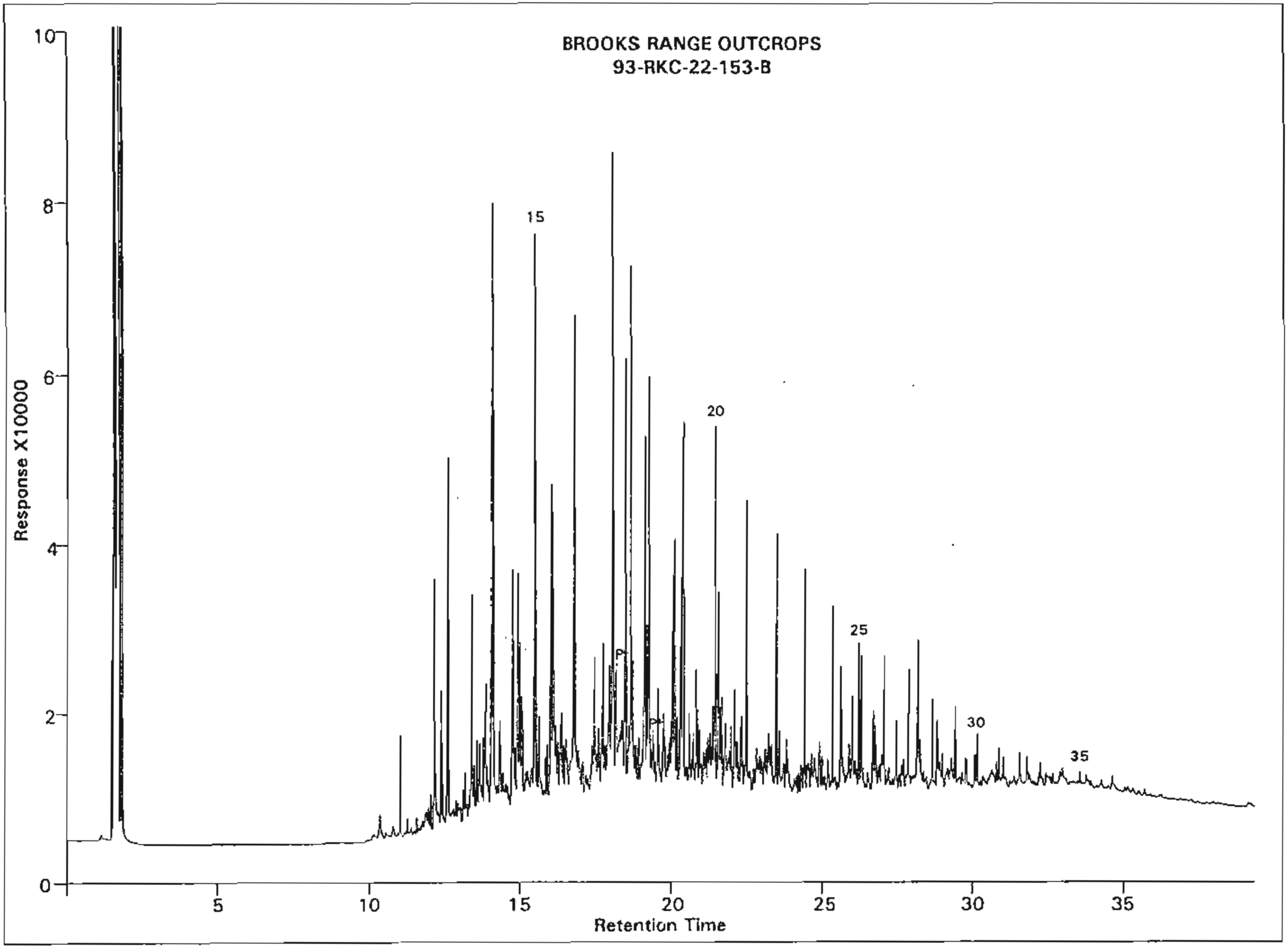
35
10
15
20
25
30
35
Pr
Ph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93-RKC-22-153-B
Response X10000
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4
6
8
10
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10
15
20
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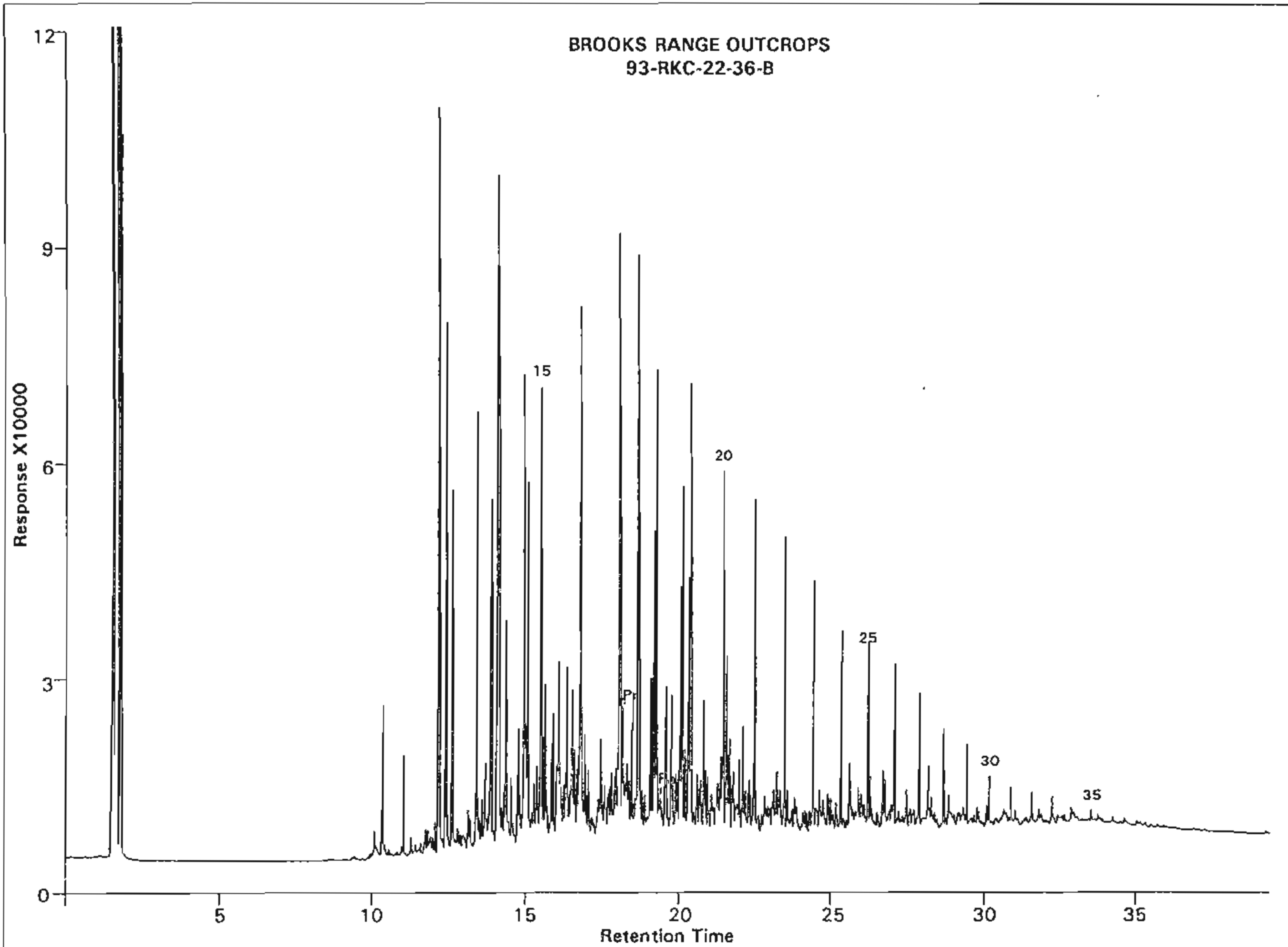
Retention Time
15
20
25
30
35


BROOKS RANGE OUTCROPS
93-RKC-22-36-B
Response X10000
0
3
6
9
12
Retention Time
5
10
15
20
25
30
35
15
20
25
30
35
Pr

APPENDIX #4—ANALYTICAL PROCEEDURES

ORGANIC CARBON AND PYROLYSIS DATA

Total Organic Carbon (TOC) and Rock-Eval pyrolysis data provide basic geochemical information and are frequently used to select samples for more detailed studies, particularly kerogen microscopy, extract chromatography and biomarker analyses. Well data can be plotted to make geochemical logs. Unless otherwise specified by a client, DGSI uses LECO TOC then Rock-Eval II pyrolysis as the standard analytical sequence and Rock-Eval is recommended for samples with greater than 0.4% TOC. Samples for LECO TOC and Rock-Eval pyrolysis are ground to pass through a 60 mesh sieve to assure homogeneity.

LECO ORGANIC CARBON AND TOTAL SULFUR

Total Organic Carbon is best determined by direct combustion. Approximately 0.15 grams of sample are carefully weighed, treated with concentrated HCl to remove carbonates, and vacuum filtered on glass fiber paper. The residue and paper are placed in a ceramic crucible, dried, and combusted with pure oxygen in a LECO EC-12 or LECO CS-444 carbon analyzer at about 1,000°C. A laboratory standard is run every five samples. Total, insoluble, mineral plus organic sulfur can be determined by the CS-444 analyzer during the carbon analysis. Total carbonate can be determined from sample and acid residue weight differences or by LECO combustion TOC differences before and after acid digestion.

ROCK-EVAL II PYROLYSIS

Rock-Eval II pyrolysis is used to determine kerogen type, kerogen maturity and the amount of free hydrocarbons. About 0.1 grams of the same ground sample used for LECO TOC are carefully weighed in a pyrolysis crucible and then heated to 300°C to determine the amount of free hydrocarbons, S1, that is thermally distilled. Next, the amount of pyrolyzable hydrocarbons, S_2, is measured when the sample is heated in an inert environment which rises from 300° to 550°C at a heating rate of 25°C/minute. S_1 and S_2 are reported in mg HC/g sample. T_{max}, a maturity indicator, is the temperature of maximum S_2 generation. When S_2 values are less than 0.2 mg HC/g sample, the S_2 maximum typically has poor definition and thus, T_{max} cannot be reliably determined (Peters, 1986). Carbon dioxide generated during the S_2 pyrolysis, an indicator of kerogen oxidation, is collected up to a temperature of 390°C and reported as S_3 in units of mg CO_2/g sample. A laboratory standard is run every 10 samples. Hydrogen Index ($HI = S_2 * 100/TOC$) and Oxygen Index ($OI = S_3 * 100/TOC$) are used as kerogen type indicators when plotted on a van Krevelen type diagram.

ROCK-EVAL II PYROLYSIS PLUS TOC

Rock-Eval II Plus TOC is used to determine both Rock-Eval data (S_1, S_2, S_3, T_{max}) and TOC of a 0.1 gram ground sample. With this instrument, the pyrolysis stage (S_2) ramps to 600°C at which point the sample is switched to an oxidation oven where the sample is oxidized at 600°C for 5 minutes in air to measure the residual organic matter (S_4). A laboratory standard is run every 10 samples. S_1, S_2, S_3, and S_4 are summed appropriately to calculate TOC. True TOC will be greater than this calculated sum for samples with maturity greater than about 1.0% R_o because the Rock-Eval final temperature is inadequate for complete combustion (Peters, 1986). This instrument is preferred when there is insufficient sample to run TOC and pyrolysis separately, or when all samples in a study are to be analyzed for both TOC and Rock-Eval data without prior TOC screening.

VISUAL KEROGEN ANALYSIS TECHNIQUES

Visual kerogen analysis employs a Zeiss Universal microscope system equipped with halogen, xenon, and tungsten light sources or a Jena Lumar microscope equipped with halogen and mercury light sources. Vitrinite reflectance and kerogen typing are performed on a polished epoxy plug of unfloated kerogen concentrate using reflected light from the halogen source. The digital indicator is calibrated using a glass standard with a reflectance of 1.02% in oil. This calibration is linearly accurate for reflectance values ranging from peat (R_o 0.20%) through anthracite (R_o 4.0%).

Reflectance values are recorded only on good quality vitrinite, including obvious contamination and recycled material. The relative abundance of normal, altered, lipid-rich, oxidized, and coked vitrinite is recorded. When good quality, normal vitrinite is absent, notations are made indicating how the maturity is affected by weathering, oxidation, bitumen saturation, or coking. When normal vitrinite is absent or sparse, other macerals may be substituted. Solid bitumen, for example is present in many samples. Although it often has a different reflectance than vitrinite, Jacob's calibration chart can be used to obtain an estimated vitrinite reflectance equivalent. Graptolites have about the same reflectance as vitrinite and can often be used to obtain maturity data in early Paleozoic rocks that have no vitrinite.

Unstructured lipid kerogen changes in texture and color during the maturation process. Typically, unstructured kerogen at low maturity is reddish brown and amorphous. Somewhere between R_o 0.50 to 0.65%, the kerogen takes on a massive texture and is gray in color. At higher maturity, generally above R_o 1.30%, unstructured kerogen is light gray and micrinized.

Kerogen typing and maturity assessments from the polished plug are enhanced by utilizing fluorescence from blue light excitation. The xenon or mercury lamp is used with an excitation filter at 495 nm coupled with a barrier filter of 520 nm. With the Jena microscope we also have the option of observing fluorescence under ultra violet excitation. The intensity of fluorescence in the epoxy mounting medium (background fluorescence) correlates well with the onset of oil generation and destruction. The identification of structured and unstructured liptinite is also enhanced with the use of fluorescence in those samples having a maturity less than R_o 1.3%. The relative abundance and type of pyrite is also recorded.

TAI is performed using tungsten or halogen light source that is transmitted through a glass slide made from the unfloated kerogen concentrate. Ideally, TAI color is based on sporinite of terrestrial origin. When sporinite is absent, TAI is estimated from the unstructured lipid material. Weathering, bitumen admixed with the unstructured material and micrinization can darken the kerogen and raise the TAI value. The character of the organic matter in transmitted light is correlated with observations made in reflected light for kerogen typing.

Kerogen typing and maturity assessments from the slide preparation are also reinforced by using different light sources. The slide is first observed in transmitted light to obtain TAI color and organic matter structure or type. The light is then switched to reflected halogen light to observe structure and amount of pyrite, and finally to reflected blue light excitation from the xenon or mercury source for fluorescence. The fluorescence of structured and unstructured liptinite is not masked by the epoxy fluorescence as it is in the reflected light mode because the mounting medium is non-fluorescent. Remnant lipid structures (e.g. sporinite and alginite) within the unstructured kerogen can often be identified in blue light.

Maturity calculations are made from the vitrinite reflectance histograms. Decisions as to which reflectance measurements indicate the maturity of the sample are based not only on the histogram but on all of the kerogen descriptive elements as well. Because it is not done at the time of measurement, alternate maturity calculations can be made if kerogen data and geological information dictate.

In summary, vitrinite reflectance measurements are performed on a polished plug in reflected light, TAI is performed on a slide in transmitted light, and kerogen typing is estimated from both preparations using a combination of reflected, transmitted, and fluorescent light techniques. Fluorescence in blue light is used to enhance the identification of structured and unstructured lipid material, solid bitumens, and drilling mud contaminants. Fluorescence also correlates with the maturity and state of preservation of the sample. Maturity calculations from measured reflectance data are made from the histograms and are influenced by all of the kerogen data.

VISUAL KEROGEN ANALYSIS GLOSSARY

Several key definitions are included in this glossary in order to make our reports more self-explanatory. In our reports, we refer to organic substances as *macerals*. Macerals are akin to minerals in rock, in that they are organic constituents that have microscopically recognizable characteristics. However, macerals vary widely in their chemical and physical properties, and they are not crystalline.

1. UNSTRUCTURED KEROGEN, or sometimes called structureless organic matter (SOM) and bituminite; it is widely held that unstructured kerogen represents the bacterial breakdown of lipid material. It also includes fecal pellets, minute particles of algae, organic gels, and may contain a humic component. As described on the first page of this section, unstructured lipid kerogen changes character during maturation. The three principal stages are amorphous, massive, and micrinized. Amorphous kerogen is simply without any structure. Massive kerogen has taken on a cohesive structure, as the result of polymerization during the process of oil generation. At high maturity, unstructured kerogen becomes micrinized. Micrinite is characterized optically by an aggregation of very small (less than one micron) round bodies that make up the kerogen.

2. STRUCTURED LIPID KEROGEN consists of a group of macerals which have a recognized structure, and can be related to the original living tissue from which they were derived. There are many different types, and the types can be grouped follows:
   a. Alginite, derived from algae. It is sometimes very useful to distinguish the different algal types, for botryococcus and pediastrum are associated with lacustrine and non-marine source rocks, while algae such as tasmanites, gloecapsomorpha, and nostocopsis are typically marine. Acritarchs and dinoflaggelates are marine organisms which are also included in the algal category.

b. Cutinite, derived from plant cuticles, the remains of leaves.
c. Resinite, (including fluorinite) derived from plant resins, balsams, latexes, and waxes.
d. Sporinite, derived from spores and pollen from a wide variety of land plants.
e. Suberinite is derived from the corky tissue of land plants.
f. Liptodetrinite is that structured lipid material that is too small to be specifically identified. Usually, it is derived from alginite or sporinite.
g. Undifferentiated. At times, one can readily distinguish structured lipid material from the unstructured without being able to make a specific determination of the structured material.

The algae are an important part of many oil source rocks, both marine and lacustrine. Alginite has a very high hydrogen index in Rock-Eval pyrolysis. Resins, cuticles, and suberinite contribute to the waxy, non-marine oils that are found in Africa and the Far East. At vitrinite reflectance levels above R_o 1.2 - 1.4%, structured lipid kerogen changes structure and it becomes very difficult to distinguish them from vitrinite.

3. SOLID BITUMEN, also called migrabitumen and solid hydrocarbon. In 1992, the International Committee for Coal and Organic Petrology (ICCP) has decided to include solid bitumen in the Exsudatinite group. Solid bitumens are expelled hydrocarbon products which have particular morphology, reflectance and fluorescence properties which make it possible to identify them. They represent two classes of substances: one which is present at or near the place where it was generated, and second as a substance which is present in a reservoir rock and may have migrated a great distance from its point of origin. The solid bitumens have been given names, such as gilsonite, impsonite, grahamite, etc., but they represent generated heavy hydrocarbons which remain in place in the source rock or have migrated into a reservoir and mature along with the rock. Consequently, it is possible to use the reflectance of solid bitumens for maturation determinations when vitrinite is not present.

4. HUMIC TISSUE, that is organic material derived from the woody tissue of land plants. The most important of this group is:

   a. Vitrinite is derived from woody tissue, which has been subjected to a minimum amount of oxidation. Normally, it is by far the most abundant maceral in humic coals, and because the rate of change of vitrinite reflectance is at a more even pace than it is for other macerals, it offers the best means of obtaining thermal maturity data in coals and other types of sedimentary rocks.

Because the measurement of vitrinite is so important, care is taken to distinguish normal (fresh, unaltered) vitrinite from other kinds of vitrinite. Rough vitrinite does not take a good polish and therefore may not yield good data. Oxidized vitrinite may have a reflectance higher or lower than fresh vitrinite; this is a problem often encountered in outcrop samples. Lipid-rich vitrinite, or saprovitrinite, has a lower reflectance than normal vitrinite, and will produce an abnormally low thermal maturity value. Coked vitrinite is vitrinite that has structures found in vitrinite heated in a coke oven. Naturally coked vitrinite is the product of very rapid heating, such as that found adjacent to intrusions. Where it is possible to do so, vitrinite derived from an uphole portion of a well will be identified as caved vitrinite. Recycled vitrinite is the vitrinite of higher maturity which clearly can be separated from the indigenous first-cycle vitrinite population. Often, the recycled vitrinite merges in with the inert group.

b. Inertinite is made up of woody tissue that has been matured by a different pathway. Early intense oxidation, usually involving charring, fungal attack, biochemical gelification, creates the much more highly reflecting fusinite and semi-fusinite. Sometimes the division between vitrinite and fusinite is transitional. Sclerotinite, fungal remains having a distinct morphology are considered to be inert. An important consideration is that the inerts, as the name implies, are largely non- reactive, "dead carbon", and they have an extremely low hydrogen index in Rock-Eval pyrolysis.

5. OTHER ORGANIC MATERIAL

a. In the table, we have put lipid-rich, caved and recycled vitrinite in this section so that we could show the percentages of these macerals; they are described above.
b. Exsudatinite. Oil and oily exudates fall in this group. Exsudatinite differs from the solid bitumens on the basis of mobility and solubility. We prefer to maintain this distinction although the ICCP has now included the solid bitumens in with the Exsudatinite group.
c. Graptolites are marine organisms that range from the Cambrian to the lower Mississippian; it has been found that they have a reflectance similar to that of vitrinite. Because vitrinite is lacking in early Paleozoic rocks, the proper identification and measurement of graptolites is important in these sediments.

6. PYRITE. Various forms of pyrite can be readily identified under the microscope. Euhedral is pyrite with a definite crystalline habit. Framboidal is pyrite in the form of grape-like clusters which are made up of euhedral to subhedral crystals. Framboidal pyrite is normally found in sediments with a marine influence; for example, coals with a marine shale roof rock usually contain framboidal pyrite. Massive pyrite is pyrite with no particular external form; often this is pyrite that forms rather late in the pore spaces of the sediment. Replacement/infilling is self-explanatory.

WHOLE EXTRACT GAS CHROMATOGRAPHY

About 50 grams of sample are crushed, passed through a 20 micron sieve, accurately weighed, and soxhlet extracted for 16 hours with dichloromethane. Other solvents can be substituted if desired. The solvent is evaporated and the residue weighed to obtain the weight percent of total organic extract. The advantage of whole extract chromatography over saturate chromatography is more of the lighter fraction (C_{10} - C_{15}) is preserved. A minor disadvantage is the nonsaturate compounds are retained and complicate the chromatograms in relatively immature extracts.

A sample of whole extract is injected directly into a Varian model 3400 gas chromatograph fitted with a Quadrex 50 meter fused silica capillary column. The GC is programmed from 40°C to 340°C at 10°C/minute with a 2 minute hold at 40°C and a 20 minute hold at 340°C. Analytical data are processed with a Nelson Analytical model 3000 chromatographic data system and IBM computer hardware. This software system facilitates data processing and graphic display as well as electronic data transmittal. All standard calculations are made including pristane/phytane ratio, carbon preference index, and other key parameters.

Whole extract gas chromatography provides information on organic facies and thermal maturity of source rocks and migrated petroleum. It serves as a basis for oil-rock correlations. It is recommended primarily to evaluate known or suspected source beds, oil shows, samples with anomalous pyrolysis S_1 values and to identify possible contamination products.