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ORGANIC GEOCHEMICAL DATA FOR MESOZOIC AND PALEOZOIC SHALES, CENTRAL AND EASTERN BROOKS RANGE, ALASKA

By

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Introduction

During geological investigations for the Alaskan Mineral Assessment Program in 1975 and 1976, fifty-two samples of black shale were collected in or near the Philip Smith Mountains quadrangle for analysis as possible source rocks for oil or gas. Most of these samples were of the Mesozoic rocks exposed immediately north of the Brooks Range. Since then, additional samples of Paleozoic black shale and a few samples of shaley limestone have been collected within the Brooks Range east and west of the Philip Smith Mountains in connection with regional geologic mapping and the study of Upper Devonian clastic rocks. Some of these samples were taken from bedrock outcrops, but in many cases they were taken from loose, frost-riven rubble derived from underlying bedrock.

Analytical Methods and Data

The U.S. Geological Survey laboratory in Denver under the supervision of George Claypool analyzed the samples collected in 1975-76, and Geochem Laboratories Inc. of Houston analyzed the 1978-79 samples in accordance with U.S. Geological Survey specifications. Table 1 lists the analytical data for 118 samples, subdivided by formation and by quadrangle. Figure 1 shows the location of sample sites on a quadrangle index map, Figure 2 the distribution of organic carbon by stratigraphic unit, Figure 3 the composition of kerogen by stratigraphic unit, and Figure 4 the map distribution of vitrinite reflectance measurements.

Total carbon was measured by combustion, and total organic carbon by combustion after removal of carbonate carbon with HCl. The total hydrocarbons and total volatile hydrocarbons were measured by the method of Thermal Evolution Analysis using a Flame Ionization Detector (TEA-FID) described by Claypool and Reed (1976). In this method the shale is heated in helium at a rate of 40°C per minute and the amount of gas evolved at each 40° increment of temperature is monitored. A large amount of gas is evolved at some temperature below 400°C (Peak I); this is listed as the volatile hydrocarbons. At some higher temperature (Peak II) an even larger amount of gas is evolved; this is the pyrolitic hydrocarbons. The total hydrocarbons listed is the sum of the volatile (Peak I) hydrocarbons and the pyrolitic (Peak II) hydrocarbons.

The other measurements shown on Table 1 were made on the kerogen separated from the shale. Atomic hydrogen and carbon were analyzed by combustion; the other measurements were optical. R_o is the percent reflectance in oil of any vitrinite found in the kerogen. The Thermal Alteration Index (TAI) is based on the color of the plant cuticle in the kerogen on a scale of 1 to 5 from yellow to black (Staplin, 1969). The visual types of kerogen are estimates of the relative abundance of each of four types: (a) Amorphous-sapropel, spores, pollen; (b) Herbaceous, cuticle, membranous debris; (c) Humic-woody structured plant debris; (d) Inertinite, black, opaque, charcoal.

Interpretation

Weathering effects

Total organic carbon and total hydrocarbon content are two measures of the richness of shales as hydrocarbon source rocks (Claypool and Reed, 1976). Both also depend in part on the degree of thermal metamorphism of the shale, and Leythaeuser (1973) found that they may also depend upon the effect of near-surface weathering. He therefore warned that data from surface samples should be interpreted with caution. However, Claypool, Love, and Maughan (1978) concluded from a study of outcrop samples of the Phosphoria Formation that the geochemistry of organic matter in those rocks did reflect primarily the rock temperatures at various maximum depths of sedimentary burial. They illustrated this by plotting the ratio of extractable hydrocarbon to organic carbon for each sample against the depth of burial inferred from isopach maps.

To see whether the Brooks Range outcrop data also show a systematic relationship between organic geochemistry and the degree of organic thermal metamorphism the data were plotted in Figure 5 on a coordinate system analagous, but not identical, to that used by Claypool, Love, and Maughan (1978). Where they plotted inferred depth of burial as a measure of thermal maturity, we have plotted the Vitrinite Reflectance (R_0) as a similar measure. Where they plotted the ratio of extractable hydrocarbons to total organic carbon we have plotted the ratio of volatile hydrocarbons (by TEA-FID) to total organic carbon. Within the range of thermal maturity common to both sets of data the curves drawn through our data for rocks containing 0.5% or more organic carbon are similar to that of Claypool, Love and Maughan. All three are L-shaped, with the bend at the boundary between the thermally mature rocks and the supra-mature rocks (4.5 km depth of burial, or R_0 1.3%). The Brooks Range outcrop data for R_0 and volatile hydrocarbons, therefore do not appear to be excessively affected by surficial weathering.

The ratio of hydrogen to carbon in kerogen depends on the type of kerogen and on the thermal history (Tissot and others, 1974), and may also be affected by weathering (Waples, 1977). In the thermal history of a kerogen the H/C ratio decreases rapidly through the zone of thermal maturity and then remains low through the supra-mature zone. On Figure 6 the H/C ratio in kerogen from the Brooks Range samples is plotted against the vitrinite reflectance (R_0) as a measure of maturity. Many of the samples plot along the path outlined for Type III kerogens as defined by Tissot and Welte (1978). However, most samples at various levels of maturity have H/C ratios that are less than those that limit the field of kerogen as shown by Tissot and Welte, suggesting that weathering may have reduced the hydrogen content of the kerogen.

Paleotemperatures

The Thermal Alteration Index and the Vitrinite Reflectance are correlative measures of the degree of thermal maturity of the sample and may also be correlated approximately with paleotemperature (Heroux, Chagnon, and Bertrand, 1979). According to Claypool and Reed (1976) the temperature of Peak II of the TEA-FID analysis is another measure of thermal maturity (although not a direct measure of paleotemperature). To see whether the three kinds of data are in agreement, the values for R_0, TAI, and Peak II

Temperature from Table 1 have been separately mapped and contoured. Figure 4 shows the contours for the R_o data. The other maps are not shown, but that for the TAI resembles the R_o map, while the map of Peak II temperatures generally shows gradients contrary to both of the others. For example, in the Killik River-Chandler Lake area, where there are samples in a band extending southward from the mountain front for about 40 km, the TAI and R_o maps indicate that paleotemperatures steadily decrease northward to a minimum at the mountain front, while the Peak II temperatures in these samples increase northward to a maximum at the mountain front. The reason for this discrepancy is not clear, and either of these opposite trends can be reconciled to the geology by different arguments.

On the one hand, geochemical studies usually conclude that the thermal metamorphism of organic material is a function of depth of burial. The rocks sampled in the Killik-Chandler area are in a stack of imbricate thrust sheets in which the lowest sheet is exposed at the mountain front and the highest sheet forms the divide in the central Survey Pass quadrangle. If these thrust sheets once extended over the whole area, the rocks sampled at the mountain front were much more deeply buried than those to the south, and the northward increase of Peak II temperatures is explained by depth of burial.

On the other hand, paleotemperatures indicated by R_o as shown on Figure 4 decrease northward in the Killik-Chandler area not only from higher thrust sheet to lower thrust sheet but also from the Mississippian rocks in the upper part of a sheet to the Devonian rocks farther north in the lower part of the same sheet. Thus the R_o data are completely contrary to inferred depth of burial. However, they are consistent with the metamorphic gradient of the southern Brooks Range, which also indicates a persistent northward decrease in paleotemperature. In addition, the actual temperatures inferred from the R_o data are in agreement with the temperatures inferred from the petrology of the metamorphic facies and from the color alteration of conodonts collected in the boundary area between greenschist facies metamorphic rocks and the unmetamorphosed black shales.

The northern boundary of the greenschist facies, representing a paleotemperature of 400°C, is in the northern part of the Survey Pass quadrangle (Mayfield, 1977). At this latitude conodonts are preserved (Nelson and Grybeck, 1980), and the numerous collections of conodonts in the area immediately south of the black shale sample localities indicate a progressive northwestward decrease of paleotemperature from the range of 300-400°C that corresponds to the limit of greenschist to the range of 200-250°C that corresponds to the temperatures inferred from the R_o data. The organic thermal metamorphism indicated by the R_o and TAI data for the central Brooks Range may thus result from the same Upper Cretaceous thermal event that reset the K/Ar ages of micas in Paleozoic granites in the southern Brooks Range at the localities shown on Figure 4 (Dillon and others, 1980). Thus these data indicate that in the central Brooks Range the maximum heating, and presumably the generation of oil or gas, occurred in Late Cretaceous time and that in this area the distance from the core of the range is more important than depth of burial in determining thermal maturity.

Source rock quality

Most of the samples are supra-mature when judged by the standard that maturity begins at a vitrinite reflectance (R_0) of 0.5% and a Thermal Alteration Index (TAI) of 2, and that supra-maturity begins at an R_0 of 1.3% and a TAI of 3 (Tissot and Welte, 1978; Heroux, Chagnon, and Bertrand, 1979). None of the samples is immature, and except for a few Paleozoic samples near the mountain front, all of the few samples that are mature are of Mesozoic rocks. Most of the Paleozoic rocks, therefore, are past the stage at which they might be regarded as potential source rocks. However, some estimate of their quality can be made, qualified by the fact that they have probably lost some organic material through organic metamorphism, and some additional material through weathering.

Shale rich enough to be a source of oil contains at least 0.5% organic carbon (Claypool and Reed, 1976; Tissot and Welte, 1978). Figure 2 shows that in the samples from the Brooks Range, the organic carbon (OC) content is least in the Hunt Fork Shale and the Permian shales, in which 75% of the samples contain less than 0.5% OC. It is greatest in the Mesozoic shales, in which 95% of the samples contain more than 0.5% OC. The Mississippian shales and the shale from the Kanayut Conglomerate are intermediate; 60-65% of the samples contain 0.5% or more OC.

The probability that the organic material will yield oil or gas depends on the type of kerogen of which it is composed (Tissot and others, 1974; Tissot and Welte, 1978). Kerogen of Type II, as described by Tissot and others, commonly yields oil and gas. It consists mostly of amorphous material and marine plant remains, and is characterized by H/C ratios greater than 1.0 in rocks that are immature or in early maturity (R_0 less than 1.0%). Kerogen of Type III has the lowest potential for oil, but may generate gas. It consists mostly of terrestrial plant material, and may contain much inertinite. It is characterized by H/C ratios less than 1.0.

Figure 3 shows that all the Paleozoic shales contain kerogen that is rich in the woody material and inertinite typical of Type III kerogen, and is very poor in amorphous material. The abundance of inertinite can not be attributed simply to the high degree of metamorphism, because the average composition of kerogen in the least metamorphosed Paleozoic samples is about the same as that for the other Paleozoic samples. The younger Paleozoic shales contain more amorphous and herbaceous material than the Hunt Fork Shale, but, based on the visible kerogen types, probably all of these shales contain Type III kerogen. On the other hand, almost half the kerogen in the Mesozoic shales is amorphous or herbaceous, so the Mesozoic shales probably contain Type II kerogen, based on visual types.

The ratios of Hydrogen to Carbon (H/C) in kerogens from all the shale units (Figure 6) indicate that most of the kerogen is Type III. None of the kerogen has a ratio H/C equal to 1.0, not even the least metamorphosed samples with R_0 between 0.5% and 1.0%. However, the H/C ratios may be unusually low because the samples are weathered. With a relatively small correction for weathering, some samples from Mesozoic, Mississippian and Upper Devonian units would lie on the Type II curve.

In conclusion, it appears that the Hunt Fork Shale and the Permian shales contain insufficient organic material and the wrong kind of organic material to have been good source rocks. The Cretaceous and Jurassic shales contain sufficient organic material, and probably the right kind of organic material to have been source rocks for oil and gas. The Mississippian shales and the shale in the Kanayut Conglomerate contain sufficient organic material to have been source rocks, but probably contain kerogen that would have yielded gas rather than oil; these rocks are now over-mature for petroleum generation.

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Table 1. Chemical analyses of shale, and descriptions of kerogen in outcrop samples from the Brooks Range and foothills.

Quadrangle names are abbreviated as follows: T.M. - Table Mountain; A - Arctic; P.S. - Philip Smith Mountains; Ch. - Chandalar; C.L. - Chandler Lake; W - Wiseman; K. - Killik River; S.P. - Survey Pass.

Mean R_o is the percent reflectance of vitrinite in oil. TAI is the Thermal Alteration Index. Kerogen types are: Am. - amorphous; Hb. - herbaceous; Hm. - humic; In. - inertinite. H/C is the ratio of the numbers of hydrogen to carbon atoms in the kerogen.

Quad	Field Sample Number	Total Carbon (Wt. %)	Organic Carbon (Wt. %)	Total Hydro-carbons (Wt %)	Volatile Hydro-carbons (p.p.m)	Temp. Peak II (°C)	Mean R_o	TAI	Kerogen: Visual types (%) Am.	Hb.	Hm.	In.	At. H/C
	Tuktu Fm. and Torok Fm. (Lower Cretaceous, Albian)												
P.S.	75A Dt 29A	0.80	0.76	0.07	137	433	0.73	2.5	19	31	25	25	0.55
	75A Dt 1	0.98	0.82	0.06	89	410	0.66	2.5	31	38	15	15	0.55
	75A Dt 45	-	0.82	0.01	21	641	-	-	-	-	-	-	-
	75ARR 53	-	0.94	0.01	-	663	-	-	-	-	-	-	-
	Mean	.89	.84	0.04	82	544	0.70	2.5	25	35	20	20	0.55
	Fortress Mountain Fm. (Lower Cretaceous, Albian)												
P.S.	75A Dt 28F	0.61	0.63	0.02	40	482	1.03	3.5	27	18	18	36	0.35
	75A Dt 17F	0.60	0.57	0.03	30	538	1.03	2.9	0	36	27	36	0.56
	Kongakut Fm. and Okpikruak Fm. (Lower Cretaceous, Neocomian)												
A.	75A Be 92A	0.86	0.86	0.06	135	402	0.83	3.4	0	30	30	40	0.40
	75A Be 92N	-	0.75	0.02	55	388	-	-	-	-	-	-	-
	78A Be 50A	0.64	0.63	0.03	97	412	3.75	3.2	0	27	36	36	-
P.S.	75A Dt 3	-	0.68	0.01	-	530	-	-	-	-	-	-	-
	75A Dt 38	1.40	1.44	0.01	35	450	1.11	4.0	0	11	44	44	0.37
	75A Dt 4	-	0.72	0.12	22	551	-	-	-	-	-	-	-
	75A Dt 9A	-	0.57	0.01	8	571	-	-	-	-	-	-	-
	75A Dt 9A1	-	0.56	0.01	-	536	-	-	-	-	-	-	-
	75A Dt 26B	0.57	0.60	0.02	28	530	1.11	2.8	50	25	13	13	0.48
	75A Dt 28	-	0.75	0.01	7	639	-	-	-	-	-	-	-
	75A Dt 41A	2.00	2.08	0.06	66	511	1.06	2.6	40	40	10	10	0.59
	75A Dt 42	-	0.67	0.22	8	518	-	-	-	-	-	-	-
	75A Dt 78	-	0.69	0.07	18	488	-	-	-	-	-	-	-
	75A Dt 110A	-	1.04	0.02	37	652	-	-	-	-	-	-	-
	75ARR 23	5.44	5.18	0.04	133	428	0.95	-	-	-	-	-	-
	75ARR158A	-	0.99	0.05	73	504	-	-	-	-	-	-	-
	75ARR199D	-	0.17	0.04	21	499	-	-	-	-	-	-	-
	75A Be 29C	-	0.56	0.02	8	599	-	-	-	-	-	-	-
	75A Be 31A	-	0.81	0.02	7	639	-	-	-	-	-	-	-
	75A Dt 20	-	0.81	0.02	16	585	-	-	-	-	-	-	-
C.L.	75A Dt 37	-	5.55	0.54	504	510	-	-	-	-	-	-	-
	Mean	1.82	1.24	0.08	67	522	1.47	3.2	18	27	27	29	0.46

Quad.	Field Sample Number	Total Carbon (Wt. %)	Organic Carbon (Wt. %)	Total Hydro-carbons (Wt %)	Volatile Hydro-carbons (p.p.m)	Temp. Peak II (°C)	Mean R_o	TAI	Kerogen Visual types (%) Am.	Hb.	Hm.	In.	At. $\frac{H}{C}$
	Kingak Shale (Jurassic)												
	75ADt 52	-	0.79	0.01	28	395	-	-	-	-	-	-	-
	75ADt 24	0.73	0.73	0.08	251	396	0.89	-	-	-	-	-	-
	75ARR 26	-	0.52	0.05	51	500	-	-	-	-	-	-	-
	75ARR 48B	7.58	8.07	0.04	118	420	4.26	4.0	0	0	50	50	0.09
P.S.	75ARR 56	-	1.01	0.03	27	429	-	-	-	-	-	-	-
	75ARR 160	-	0.97	0.04	50	508	-	-	-	-	-	-	-
	75ARR 199B	10.20	9.32	2.01	2278	435	0.83	3.2	0	80	0	20	0.82
	75ABe 4	-	0.68	0.02	17	609	-	-	-	-	-	-	-
	76ABe 430	-	3.61	0.44	253	480	-	-	-	-	-	-	-
C.L.	75ADt 37A	-	5.55	0.54	504	504	-	-	-	-	-	-	-
	Mean	6.17	3.13	0.33	358	468	1.99	3.6	0	40	25	35	0.46
	Shublik Formation (Middle and Upper Triassic)												
	75ADt 10	7.96	5.22	0.81	827	448	0.89	3.2	29	57	0	14	0.67
P.S.	75ADt 110B	-	0.85	0.02	31	659	-	-	-	-	-	-	-
	75ARR 66	0.45	0.35	0.02	53	420	0.54	4.0	80	0	0	20	0.80
	Mean	4.21	2.14	0.28	304	509	0.72	3.6	55	28	0	17	0.74
	Echooka Fm. and Siksikpuk Fm. (Permian)												
	78ARR 18G	0.14	0.29	0.06	227	418	-	4.0	0	33	0	67	-
	78ARR 27B	0.05	0.12	0.07	80	410	-	2.4	0	67	0	33	-
A.	78ARR 28B	1.46	0.43	0.02	87	418	-	4.0	0	20	40	40	-
	78ABe 52	0.92	0.90	0.02	54	410	2.34	3.8	17	17	33	33	0.30
	78ABe 60	0.32	0.28	0.02	80	413	-	4.0	17	17	33	33	-
	75ADt 7	0.53	0.60	0.02	50	420	0.93	3.9	0	0	50	50	0.32
P.S.	75ADt 22A	0.28	0.27	0.02	32	400	0.48	4.0	0	33	33	33	0.75
	75ABe 19A	-	0.45	0.01	13	532	-	-	-	-	-	-	-
	Mean	0.53	0.42	0.03	78	428	1.41	3.7	5	31	27	41	0.46
	Lisburne Group (Mississippian and Pennsylvanian)												
A.	78ABe 53B	9.04	0.82	0.02	66	417	3.38	4.0	44	11	11	33	-
C.L.	75ATR 1.2-115	14.80	5.27	0.64	1329	445	-	2.2	33	67	0	0	-
	78ABe 233BX	9.76	7.17	0.06	113	398	3.71	4.0	18	36	9	36	0.32
	Mean	11.20	4.42	0.24	503	420	3.55	3.4	32	38	7	23	-

Quad.	Field Sample Number	Total Carbon (wt %)	Organic Carbon (wt %)	Total Hydro-carbons (wt %)	Volatile Hydro-carbons (ppm)	Temp. Peak II (°C)	Mean R_o	TAI	Kerogen: Visual types (%)				Kerogen: At. $\frac{H}{C}$
									Am.	Hb.	Hm.	In.	
	Kayak Shale and Kekiktuk Conglomerate (Lower Mississippian)												
T.M.	78ABe 21	0.82	0.87	0.02	49	476	–	4.0	0	36	27	36	–
	78ABe 37C	0.49	0.42	0.04	139	410	–	4.0	17	33	17	33	–
A.	78ABe 4	0.40	0.43	0.02	37	426	1.88	4.0	0	29	14	57	–
	78ABe 22	0.38	0.39	0.01	45	475	–	4.0	0	20	40	40	–
	78ABe 32CX	0.74	0.70	0.03	97	471	–	4.0	17	17	33	33	–
	78ABe 47C	2.34	2.34	0.02	55	411	2.96	4.0	0	36	27	36	–
	78ABe 47P	2.19	2.49	0.04	61	412	–	4.0	29	14	29	29	0.64
	78ABe 48A	13.45	10.02	0.03	135	393	–	–	–	–	–	–	0.15
	78ABe 48F	4.86	4.85	0.02	69	464	5.00	–	–	–	–	–	0.15
	78ABe 54A	1.16	1.12	0.04	138	397	4.79	4.0	23	15	31	31	–
P.S.	75ARR 3.1A	1.50	1.53	0.02	45	443	1.65	3.9	0	0	50	50	0.35
	75ABe 68	2.47	2.48	0.02	47	402	1.20	4.0	0	0	50	50	0.32
W.	78ABe 239B	0.45	0.47	0.02	48	393	3.86	4.0	0	17	17	67	–
C.L.	78ABe 109B	0.45	0.45	0.01	57	413	1.25	3.2	15	23	31	31	–
	78ABe 116CX	0.45	0.41	0.02	68	419	2.27	3.2	0	27	36	36	–
	78ABe 126A	0.87	0.79	0.02	73	449	2.32	3.0	8	33	33	25	–
	78ABe 127	1.35	1.38	0.03	58	522	1.43	3.0	0	36	36	27	–
	78ABe 131	1.13	1.05	0.04	73	480	1.14	2.6	0	30	40	30	0.49
	78ABe 135	1.07	1.06	0.03	53	517	2.03	3.2	0	36	36	27	0.47
	79ABe 30BX	46.84		1.04	647	581							
	79ABe 30E	43.40		1.18	1345	551							
S.R	78ABe 180A	0.43	0.44	0.01	34	464	4.19	4.0	0	11	44	44	–
	78ABe 248	1.20	1.15	0.01	44	396	3.23	4.0	0	20	40	40	0.24
K.	79ABe 76B	48.98		0.92	788	595							
	Mean	7.39	1.66	0.15	175	458	2.61	3.7	6	23	33	38	0.35
	Mississippian? rocks												
A.	78ARR 12K	0.16	0.15	0.02	58	412	1.85	4.0	0	29	14	57	–
	78ARR 17	1.43	0.22	0.04	132	421	4.53	4.0	0	22	33	44	–
	Kanayut Conglomerate (upper Upper Devonian)												
T.M.	78ABe 20	0.40	0.42	0.05	205	402	5.13	4.0	0	30	30	40	-
	78ABe 40A	0.37	0.41	0.02	88	422	3.20	4.0	0	20	40	40	-
	78ABe 41D	1.42	1.30	0.03	119	415	3.44	4.0	0	20	40	40	-
A.	78ARR 15B	1.36	1.40	0.02	96	423	4.35	4.0	0	25	25	50	-
	78ABe 11E	0.08	0.12	0.04	122	401	–	4.0	40	0	0	60	-
	78ABe 31A	0.28	0.26	0.02	62	411	–	2.4	0	50	0	50	-
	78ABe 32B	0.97	1.02	0.03	87	412	4.85	4.0	0	20	40	40	-
	78ABe 36DG	0.01	0.11	0.08	140	420	–	4.0	0	50	0	50	-
	78ABe 46A	4.40	4.40	0.03	79	424	2.01	4.0	0	36	27	36	0.38
P.S.	75ABe 67F	1.27	1.27	0.02	67	415	0.92	3.9	0	0	50	50	0.39
C.L.	78ARR 46A	0.48	0.50	0.02	76	415	1.90	4.0	0	20	40	40	-
	78ABe 108A	3.32	3.25	0.07	105	576	1.49	3.2	0	36	27	36	0.52
	78ABe 108C	4.91	4.71	0.08	65	574	1.59	3.2	0	36	27	36	0.46
	78ABe 115A	2.81	2.82	0.02	37	450	2.74	4.0	0	20	40	40	0.33
	78ABe 184C	0.21	0.26	0.01	44	465	1.92	3.2	0	36	36	27	1.20
K.	78ARR 43	4.02	2.89	0.08	87	549	1.51	3.2	0	20	40	40	–
	79ABe 51	48.94		1.37	953	581							
	Mean	4.44	1.57	0.12	143	456	2.70	3.7	3	26	29	42	0.55

Quad.	Field Sample Number	Total Carbon (wt %)	Organic Carbon (wt %)	Total Hydro-carbons (wt %)	Volatile Hydro-carbons (p.p.m)	Temp. Peak II (°C)	Mean Ro	TAI	Kerogen Visual types (%) Am	Hb	Hm	In	At. H/C
	Hunt Fork Shale (lower Upper Devonian)												
A.	78ARR 3A	0.86	0.83	0.02	67	416	-	4.0	0	14	29	57	-
A.	78ABe 23	0.14	0.19	0.03	105	416	2.10	4.0	0	20	40	40	-
A.	78ABe 24	0.21	0.20	0.03	112	472	2.90	4.0	0	20	40	40	-
A.	78ABe 33C	0.19	0.17	0.04	96	415	2.97	4.0	0	20	40	40	-
Ch.	78ABe 7G	0.33	0.29	0.03	97	420	2.22	4.0	0	33	0	67	-
P.S.	76ABe 454B	0.73	0.81	0.02	55	408	4.66	4.0	0	0	50	50	0.25
P.S.	76ADu 2-350	0.28	0.27	0.03	75	427	0.63	3.9	0	20	40	40	0.30
P.S.	76ADu2-600	—	0.22	0.02	11	535	—	—	-	-	-	-	-
P.S.	76ADu2-950	0.18	0.22	0.02	60	468	5.00	4.0	0	0	50	50	0.32
P.S.	76ADu2-1600	-	0.23	0.01	16	469	—	-	-	-	-	-	—
P.S.	76ADu2-2200	0.27	0.22	0.05	147	471	1.09	4.0	0	0	50	50	0.45
W	78ABe 225C	0.07	0.15	0.01	48	468	4.48	4.0	0	20	40	40	-
C.L.	78ABe 76AX	0.29	0.30	0.03	91	412	-	4.0	0	20	40	40	-
C.L.	78ABe 83B	0.29	0.29	0.02	73	474	-	3.3	0	20	40	40	-
C.L.	78ABe 219	0.26	0.27	0.01	47	462	2.94	4.0	0	20	40	40	0.41
K.	78ABe 163A	0.20	0.27	0.02	59	464	2.73	4.0	17	17	33	33	-
K.	78ABe 169A	0.25	0.26	0.01	41	470	4.61	4.0	9	18	36	36	-
K.	78ABe 173A	0.36	0.34	0.02	88	402	3.93	4.0	0	27	36	36	-
	Mean	0.31	0.31	0.02	72	448	3.10	4.0	1	17	38	44	0.35
	Beaucoup Formation (lower Upper Devonian)												
P.S.	76ADu 1K	-	0.42	0.02	25	402	-	-	-	-	-	-	-
	upper Paleozoic? rocks												
A.	78ARR29C	1.88	1.05	0.03	95	410	3.24	3.9	0	20	40	40	-
A.	78ARR29E	0.72	0.70	0.02	80	416	1.87	4.0	0	20	40	40	-
A.	78ARR34	0.28	0.29	0.10	47	365	4.49	4.0	0	20	40	40	-
A.	78ARR34K	1.14	0.78	0.01	47	408	—	4.0	18	18	27	36	-
A.	79ABe 234	2.03		0.07	151	430							
	Mean	1.21	0.71	0.05	84	406	3.20	4.0	5	20	37	39	—

Figure Captions

Figure 1. Index map of the central and eastern Brooks Range showing the location of shale sample sites and of the 1:250,000 scale quadrangles. Field sample numbers are abbreviated; for instance, the site of 75ADt37 and 75ADt37A is shown on the map as D37.

Figure 2. Histograms showing the distribution of organic carbon in samples of shale from the Hunt Fork Shale (Dhf); Echooka and Siksikpuk Formations (Pe-Ps); Kanayut Conglomerate (Dk); Kayak Shale and Kekiktuk Conglomerate (Mk-Mkt); Kingak Shale (Jk); Kongakut and Okpikruak Formations (Kk-Ko). Arrows indicate average organic carbon content for each histogram.

Figure 3. Histograms showing the average composition of kerogen in samples of shale from the Hunt Fork Shale (Dhf, 13 samples), Kanayut Conglomerate (Dk, 16 samples); Kayak Shale and Kekiktuk Conglomerate (Mk-Mkt, 19 samples), Echooka and Siksikpuk Formations (Pe-Ps, 7 samples); undivided Cretaceous formations and Kingak Shale (K-J, 11 samples). The kerogen types shown are: Am - amorphous; Hb - herbaceous; Hm - humic; In - inertinite.

Figure 4. Reflectance of vitrinite (R_0) in shales from the central and southeastern Brooks Range, and paleotemperatures inferred from the vitrinite reflectances and from the metamorphism of conodonts in Paleozoic limestones. The measured reflectance index is shown at the circled sample localities, and is contoured in unit intervals, with the 1.3 unit contour added. Inferred paleotemperatures in degrees Celsius as correlated with R_0 by Heroux and others (1979) are shown in parentheses on contours 1.3 and 3. Paleotemperatures inferred from the color of conodonts (Anita G. Harris, written communication, 1978; Nelson and Grybeck, 1980) are shown in degrees Celsius at sample localities marked by crosses. Triangles show the location of biotite samples from Paleozoic granites and their contact zones (Dillon and others, 1980) that have yielded reset Cretaceous K/Ar ages (Grybeck and others, 1977). Diamonds show the location of biotite samples from Paleozoic granite that do not have reset K/Ar ages. Dotted line is northern boundary of greenschist facies (Mayfield, 1977). Hachured line is northern margin of the Brooks Range. Dots are at sample localities where R_0 is not available.

Figure 5. Vitrinite reflectance (R_0) and ratio of volatile hydrocarbon by TEA-FID (VHC) to total organic carbon (OC) in black shales from the central and southeastern Brooks Range. Symbols: circles, Mesozoic rocks; squares, upper Upper Devonian to Permian rocks; triangles, lower Upper Devonian rocks. Large solid symbols indicate samples with 1.5% or more organic carbon; large diagonally ruled symbols, 0.5% to 1.49% organic carbon; small open symbols, less than 0.5% organic carbon. Solid curve is drawn through points for samples with 1.5% or more organic carbon. Dashed curve separates fields of samples with more and less than 0.5% organic carbon.

Figure 6. Vitrinite reflectance (R_o) and ratio of atomic hydrogen to atomic carbon (H/C) in kerogen in black shales from the central and eastern Brooks Range. Symbols: circles, Mesozoic rocks; squares, upper Upper Devonian to Permian rocks; triangles, lower Upper Devonian rocks. Large solid symbols indicate samples with 1.5% or more organic carbon; large diagonally ruled symbols, 0.5% to 1.49% organic carbon; small open symbols, less than 0.5% organic carbon. Dot-dashed lines are the evolution paths of Type II (oil prone) and Type III (gas prone) kerogen shown by Tissot and Welte (1978). Dotted line is the boundary of the field of kerogen shown by Tissot and Welte. Dashed line is drawn through our data points.

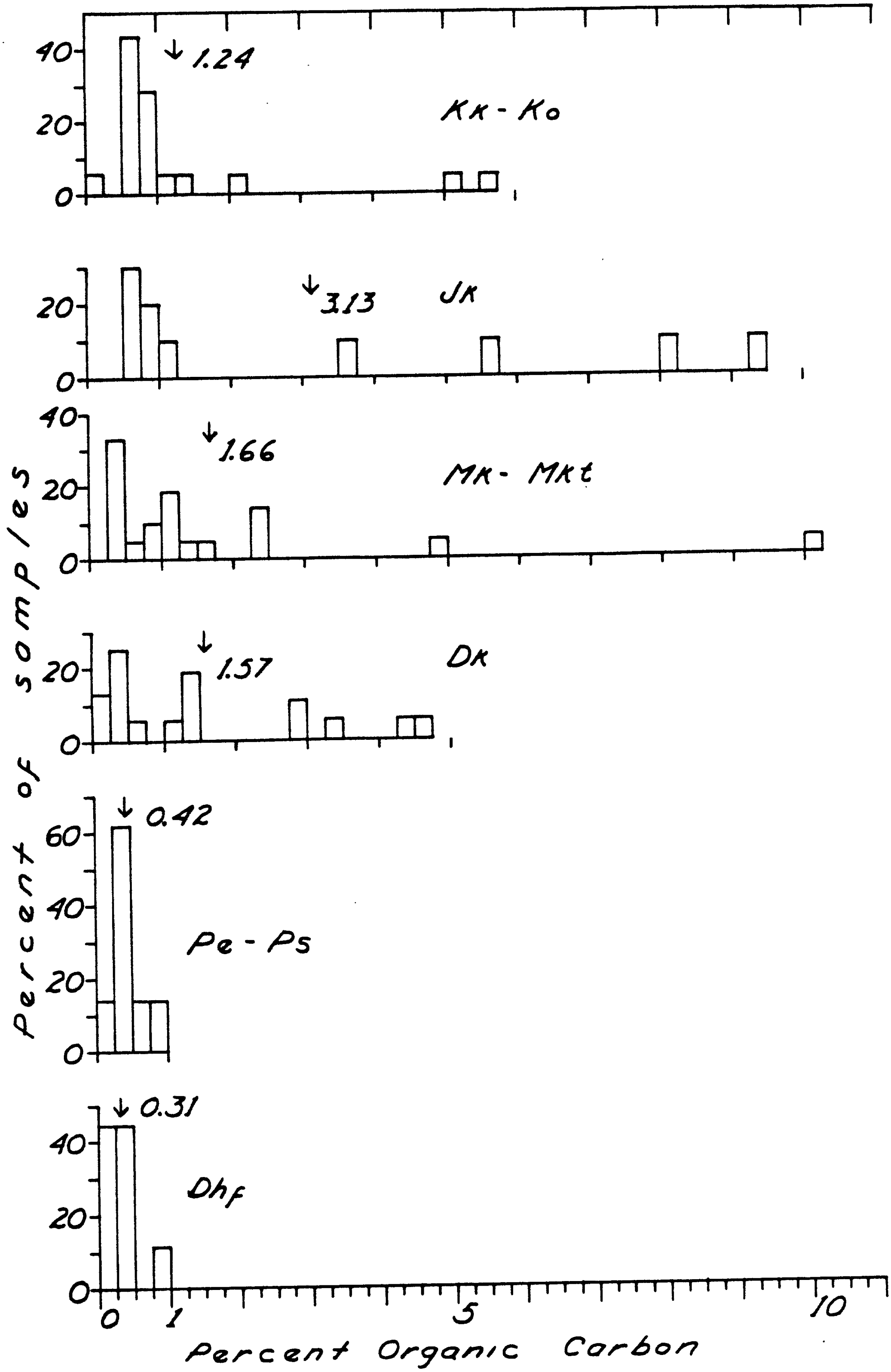

Figure 2. Histograms showing distribution of organic carbon.

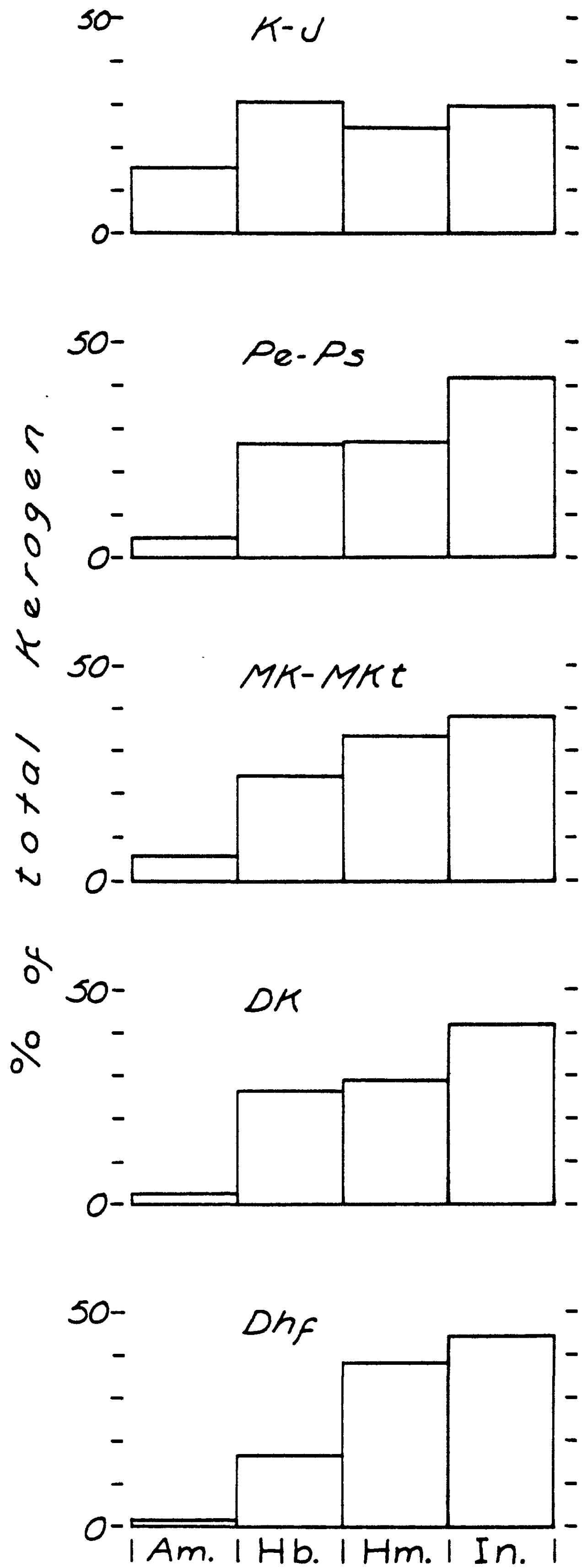

Figure 3. Histograms showing the average composition of Kerogen.

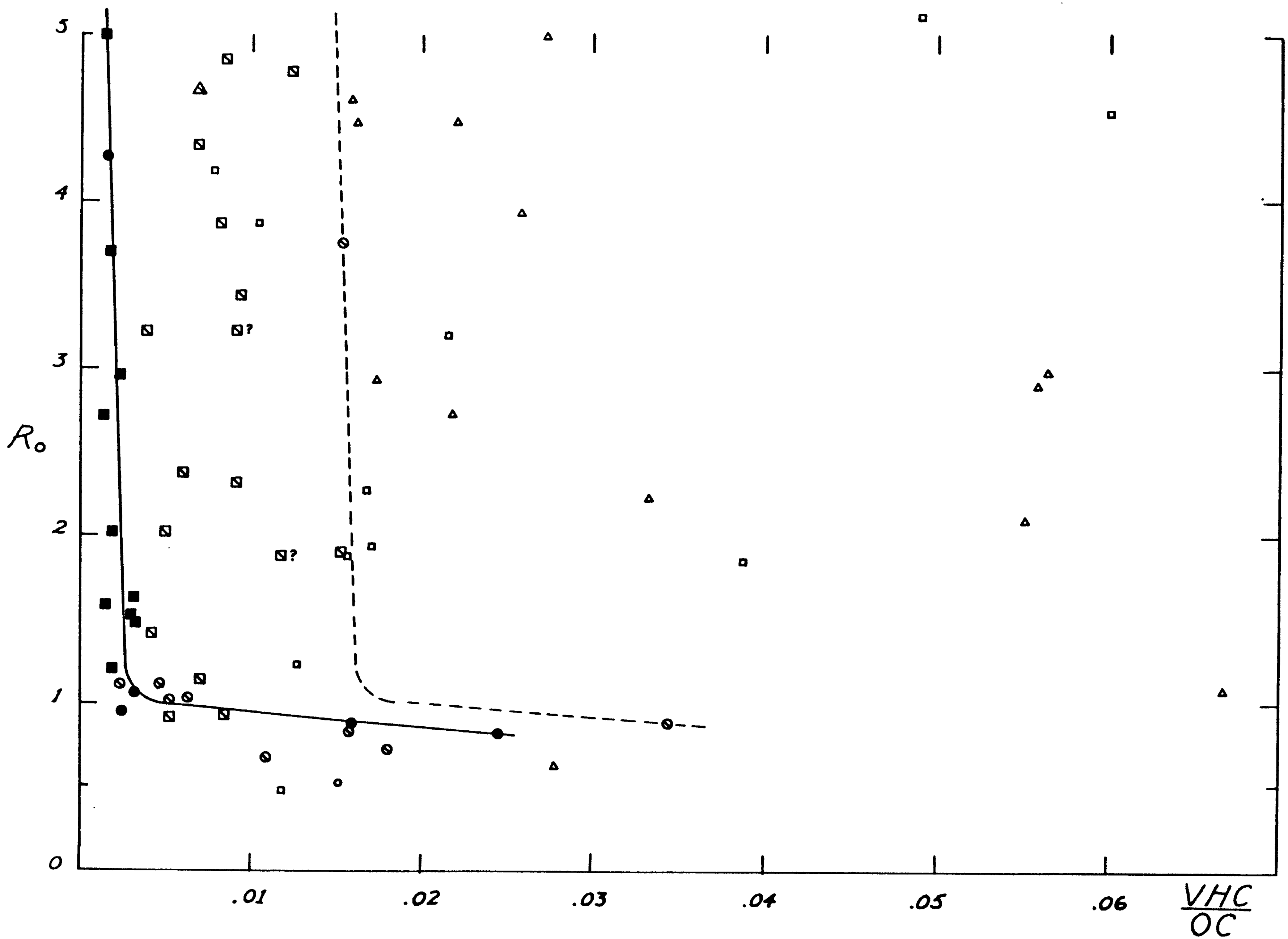

Figure 5. Vitrinite reflectance and ratio of volatile hydrocarbon to organic carbon.

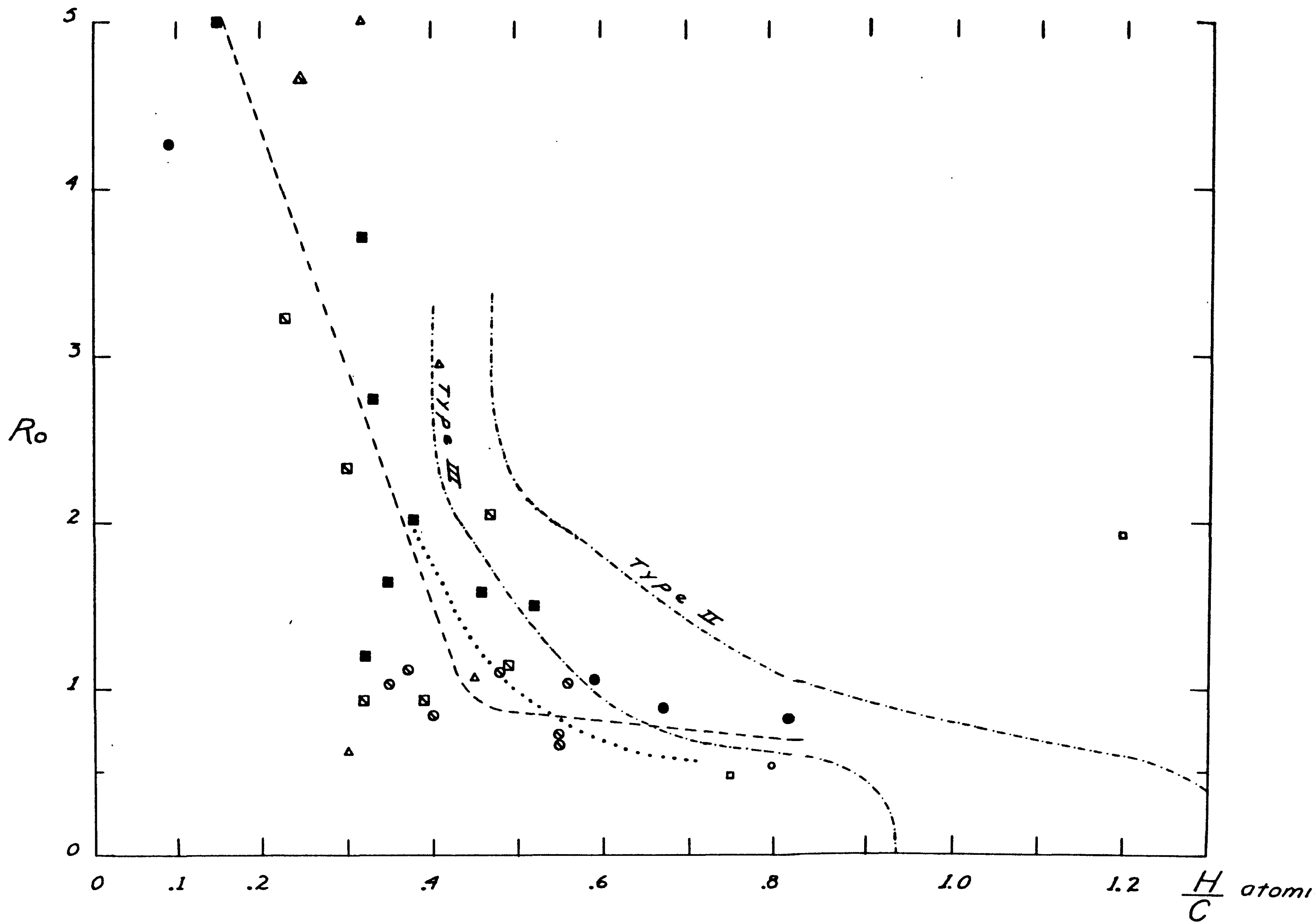

Figure 6. Vitrinite reflectance and hydrogen to carbon ratios of Kerogen.