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Organic Geochemistry of Crude Oil from Potwar-Kohat Region

Wasim Ahmed[1] and Shahnaz Alam[1]

ABSTRACT

Geochemical studies of 29 samples of crude oil from various oil fields and seepages from Potwar-Kohat region have been carried out to characterise and correlate oils. The results indicate that oil belongs to one family in Potwar region and two families in Kohat region. The study further shows an increase in maturity from southeast to northwest.

INTRODUCTION

The Potwar-Kohat region is located in Northern Pakistan and forms the northernmost division of the Indus basin. The region is a productive oil province, with reservoired oil present at a number of stratigraphic levels from Cambrian to Miocene.

The present geochemical study was carried out under Hydrocarbon Development Institute of Pakistan (HDIP) and West German Federal Institute of Geosciences and Natural Resources (BGR) collaborative project to characterise and correlate the oils produced from Potwar region. Twenty nine oil samples from producing fields and seepages were collected and analysed. These included oil produced from Meyal, Dhulian, Adhi, Balkassar, Dhurnal, Dakhni, Toot, Khaur and Joya Mair fields and seepage samples from Jaba, Kundal, Jatta, Sahidan Kulikhel, etc. Well names, depths, formations and localities of the samples are listed in Table 1.

ANALYTICAL METHODS

All samples were analysed for bulk fractional composition (percent) of saturates, aromatics and NSO's and C_{15+} saturated hydrocarbon distributions, selected samples for light hydrocarbon and biomarker analyses. Carbon isotopic ratios were also determined for correlations.

The oil samples were stabilized at 50 °C for 24 hours and then fractionated by column chromatography (adsorbents used were silica gel and aluminium oxide) using n-hexane and dichloromethane as solvents. The seepage samples were extracted with dichloromethane and then fractionated as above.

[1] Hydrocarbon Development Institute of Pakistan, Islamabad.

Saturated C_{15+} fractions were analysed with Perkin Elmer Sigma 115 gas chromatograph using fused silica capillary column operated from 100 to 300 °C with hydrogen as a carrier gas and flame ionization detector.

Biomarker and isotope analyses were carried out at BGR while light hydrocarbon analysis was carried out at the Nuclear Research Centre, Jülich, West Germany.

RESULTS AND DISCUSSION

C_{15+} Saturated Hydrocarbons

Oil from Producing Fields of Potwar Region.— The close chemical similarities of oils from producing fields of Potwar are clearly demonstrated by the C_{15+} saturated hydrocarbon distribution (Tables 1,2). The chromatograms display a relatively continuous envelope of C_{15}-C_{35} normal paraffins which is a characteristic either of thermally mature, land derived or aquatic derived, nonbiodegraded oil. Some of the typical chromatograms of C_{15+} saturated hydrocarbons (SHC) are shown in Figure 1. The chromatograms show a well developed pattern with a decreasing content of n-alkanes towards increasing carbon number. The iso and anti-isoalkane peaks(small peaks between n-alkanes) are also similar between different oil samples. The pristane/phytane ratio is invariably above 1, which is known to result from deposition of organic matter under not strictly anoxic conditions. Though isoprenoid/n-alkane ratios of samples are comparable there are certain variations which may be due to difference in maturities (or degree of biodegradation). A transitional change in organic facies within the source rock formation also cannot be ruled out. The pr/n-C_{17} ratios are plotted vs ph/n-C_{18} and are shown in Figure 2. The relative concentration of these isoprenoids is said to be dependent on source, maturity and secondary biodegradation of samples. (Dembicki et al, 1976; Baily et al, 1973; Mackenzie, 1984). In view of this it is probable that oils from Meyal, Dhurnal, Toot, Kot Sarang, Dhulian, Dakhni and Khaur are coming from more mature source rocks than Joya Mair, Balkassar and Adhi.

Sterane and Triterpane biomarkers are not dominant and the odd-even preference for the C_{29} n-alkanes is near unity which may be attributed either to oil generated from aquatic derived organic matter and/or to optimal maturity.

Table 1. Samples locality and formation depths.

Sample No.	Locality	Formation	Depth (metres)
PP 263	Adhi 5	Khewra	2679-2706
PP 264	Adhi 7	Sakesar	718-721
PP 265	Adhi 9	Tobra	822-823
PP 266	Adhi 9	Khewra	855-857
PP 255	Joya Mair	Bhadrar	2090-2123
PP 251	Balkassar A5	Bhadrar	2528-2555
PP 252	Balkassar A7	Sakesar	2530-2546
PP 253	Balkassar P2	Sakesar	2497-2527
PP 576	Dakhni 4	Up Lockhart	Surface
PP 577	Dakhni 4	Up Lockhart	Surface
PP 578	Dakhni 4	Up Lockhart	Surface
PP 579	Dakhni 4	Up Lockhart	Surface
PP 221	Toot 10A	Jurassic	4450-4422
PP 222	Toot 15	Jurassic	4530-4490
PP 223	Toot 16	Jurassic	4466-4383
PP 224	Toot 18	Jurassic	4578-4565
PP 243	Meyal 6	Ranikot	3902-3954
			4036-4242
PP 244	Meyal 7	Sakesar	3877-3934
PP 245	Meyal 9	Sakesar	3770-3861
PP 246	Meyal 12	Varigated beds	4117-4150
PP 247	Meyal 13	Varigated beds	4183-4208
			4231-4249
PP 267	Dhulian 25	Sakesar	2400-2462
PP 268	Dhulian 34	Sakesar	2400-2462
PP 269	Dhulian 43	Ranikot	2400-2462
PP 248	Khaur 1	Murree	1292
PP 249	Khaur 5	Murree	1292
PP 250	Khaur 8	Murree	1292
PP 232	Dhurnal 1	Chorgali/Sakesar	3791-4038
PP 233	Dhurnal 2	Chorgali/Sakesar	3866-4019
PP 107	Jaba (Salt R)	Chorgali/Sakesar	Surface
PP 507	Panoba Anticline	Sembar	Surface
PP 132	Dom Nala	Chorgali	Surface
PP 131	Kundal	Siwaliks	Surface
Pr 1004	Bannu Meran Shah	Kirthar	2170
Pr 1086	Kallar Kahar 1	Salt Range	2232
Pr 967	Karampur 1	Salt Range	2232
Pr 968	Karampur 1	Salt Range	3827
Pr 761	Kot Sarang 1	Chorgali(?)	Surface
Pr 167	Salgi Nala	Siwaliks	Surface
Pr 166	Salgi Nala	Siwaliks	Surface
Pr 64	Khanzaman Nala	Datta	Surface
Pr 65	Khanzaman Nala	Datta	Surface
Pr 506	Dharangi	Eocene Ls	Surface
Pr 122	Shahidan Khel	Khuldana	Surface
Pr 123	Shahidan Khel	Kuldana	Surface
Pr 124	Shahidan Khel	Kuldana	Surface
Pr 125	Sahidan Khel	Jatta Gypsum	

Table 1. (continued).

Sample No.	Locality	Formation	Depth (metres)
Pr 126	Jatta Salt Quarry	Bahadur Khel Salt	Surface
Pr 127	Jatta Salt Quarry	Bahadur Khel Salt	Surface
Pr 128	Jatta Salt Quarry	Bahadur Khel Salt	Surface
Pr 129	Jatta Salt Quarry	Bahadur Khel Salt	Surface
Pr 130	Shakhi Sanda	Bahadur Khel Salt	Surface
Pr 308	Jatta (Mirkalan)	Bahadur Khel Salt	Surface
Pr 309	Jatta (Mirkalan)	Bahadur Khel Salt	Surface
Pr 311	Jatta (Mirkalan)	Bahadur Khel Salt	Surface
Pr 312	Jatta (Mirkalan)	Bahadur Khel Salt	Surface
Pr 942	Chharat	Eocene Ls	Surface
Pr 943	Chharat	Eocene Ls	Surface
Pr 505	Camp (E NE)	Siwaliks	Surface
Pr 563	Golra	Siwaliks	Surface
Pr 564	Golra	Siwaliks	Surface
Pr 564	Golra	Siwaliks	Surface

The chemical similarities of oil samples from producing fields are further illustrated by the abundance of saturated, aromatic and NSO compounds. Most oil samples contain more than 80% hydrocarbons and are nearly homogeneous group. The results are plotted on the ternary diagrams (Figure 3). Samples from Kot Sarang, Joya Mair and Balkassar fall outside the main cluster by their lower content in SHC. A lower maturity for the latter samples seems to be the best explanation for the lower SHC contents.

Seepages and Oil Shows.— Contrary to oil samples from producing fields, seepage samples are heavily biodegraded, water washed and as a result thereof depleted in n-alkanes. These samples show larger variations in saturated, aromatic and NSO compounds (Figure 4). Samples from Jaba, Panoba and Camp are more similar to oil samples from Potwar region while samples from Chharat and Golra are enriched in aromatic fraction, which is most resistant to biodegradation. The remaining samples are more enriched in the non hydrocarbon fraction, which probably may be either due to immaturity or biodegradation.

Seepage samples from Shahidan Kulikhel and Jatta are different, as is demonstrated by different ratios of isoprenoids pristane and phytane. These samples exhibit low pr/n-C_{17} and high ph/n-C_{18} ratios, indicating that these source sediments were deposited under strongly reducing conditions and restricted environments.

The gas chromatograms of core samples from Kallar Kahar and Karampur wells are different as these contain some additional peaks which are not present in other samples. These peaks constitute another series of saturated hydrocarbons usually not found in crude oils. In both wells pr/ph ratio is also low.

Biomarker.— Apart from n-alkanes and branched alkanes, more complicated biomarkers like steranes and pentacyclic triterpanes have been extensively studied. The steranes are tetracyclic compounds with a characteristic structure derived from inherited biological precursors. The distribution of steranes in oil is dependent upon source type, maturation, migration and biodegradation. Mass fragmentograms of samples from oil fields are essentially similar and support the hypothesis that Potwar oils belong to one genetically related family (Figure 5). On the other hand, seepage samples are more variable which is understandable as these were heavily biodegraded.

Light Hydrocarbons.— Thirty three oil samples from producing fields and seepages were analysed at the Nuclear Research Centre (KFA), Jülich, for the relative content of light hydrocarbons in the range of C_2 to C_8 (Table 3). The samples from producing fields show similar normalised hydrocarbon distribution patterns and there appears to be no significant difference between the samples. The ratios of neighbouring peaks are similar for all samples. The difference is only in concentration which is more pronounced at the lighter end as compared to heavier end. For further correlations, isomers with 6 and 7 carbon atoms are also plotted (Figures 6, 7). The sample points show a close elongated grouping with small variations only. Thompson (1979 & 1983) introduced indices of heptane and isoheptane values which were also calculated. Most samples have value between 18 and 22 and can be classified as normal mature (Figure 8). Samples

Table 2. Geochemical data for oil samples.

Sample No.	API	C_{15}- of oil	sat.hc	aro.hc	pr/ph	ph/n-C_{18}	OEP(C_{29})
pp263	48.00	67.00	69.00	17.00	1.70	0.52	0.97
pp264	39.00	48.00	58.00	31.00	1.60	0.53	0.89
pp265	41.00	59.00	79.00	18.00	1.30	0.62	1.04
pp266	48.00	65.00	65.00	20.00	1.30	0.53	1.06
pp255	13.00	20.00	21.00	42.00	1.10	0.82	0.95
pp251	24.00	28.00	40.00	39.00	1.40	0.54	0.88
pp252	22.00	27.00	38.00	38.00	1.10	0.75	1.05
pp253	24.00	27.00	40.00	37.00	1.20	0.71	1.10
pr1084	n.d.	n.d.	11.00	30.00	1.30	0.45	1.10
pr1086	n.d.	n.d.	28.00	18.00	0.72	1.93	n.d.
pr967	n.d.	n.d.	16.00	35.00	0.43	1.10	1
pr968	n.d.	n.d.	15.00	33.00	0.45	1.12	1
pr761	n.d.	n.d.	50.00	32.00	1.22	0.35	1.02
pp507	n.d.	n.d.	39.00	35.00	n.d.	n.d.	n.d.
pp132	17.00	1.00	47.00	26.00	n.d.	n.d.	n.d.
pr166	n.d.	n.d.	45.00	21.00	n.d.	n.d.	n.d.
pr167	n.d.	n.d.	48.00	23.00	n.d.	n.d.	n.d.
pr64	n.d.	n.d.	40.00	27.00	n.d.	n.d.	n.d.
pr65	n.d.	n.d.	41.00	21.00	n.d.	n.d.	n.d.
pp7	26.00	16.00	58.00	27.00	n.d.	n.d.	n.d.
pp131	n.d.	3.00	45.00	24.00	n.d.	n.d.	n.d.
pr506	n.d.	n.d.	65.00	15.00	n.d.	n.d.	n.d.
pr122	n.d.	n.d.	38.00	35.00	0.52	1.50	n.d.
pr123	n.d.	n.d.	12.00	23.00	0.19	4.40	n.d.
pr124	n.d.	n.d.	14.00	36.00	0.24	1.20	n.d.
pr125	n.d.	n.d.	12.00	11.00	0.31	0.90	n.d.
pr126	n.d.	n.d.	34.00	24.00	0.49	0.95	n.d.
pr127	n.d.	n.d.	37.00	29.00	0.58	n.d.	n.d.
pr128	n.d.	n.d.	62.00	20.00	0.67	n.d.	n.d.
pr129	n.d.	n.d.	68.00	21.00	0.71	n.d.	n.d.
pr130	n.d.	n.d.	34.00	33.00	0.42	1.90	n.d.
pr308	n.d.	n.d.	55.00	22.00	0.73	0.86	1.10
pr309	n.d.	n.d.	50.00	20.00	0.50	1.40	n.d.
pr311	n.d.	n.d.	60.00	23.00	0.50	1.06	1.08
pr942	n.d.	n.d.	55.00	27.00	n.d.	n.d.	n.d.
pr943	n.d.	n.d.	49.00	47.00	n.d.	n.d.	n.d.
pp107	24.00	5.00	60.00	19.00	n.d.	n.d.	n.d.
pr505	n.d.	n.d.	53.00	16.00	n.d.	n.d.	n.d.
pr563	n.d.	n.d.	51.00	40.00	n.d.	n.d.	n.d.
pr564	n.d.	n.d.	39.00	42.00	n.d.	n.d.	n.d.
pr565	n.d.	n.d.	32.00	45.00	n.d.	n.d.	n.d.
pp576	50.00	n.d.	77.00	17.00	1.90	0.30	1.01
pp577	48.00	n.d.	77.00	16.00	1.80	0.37	0.97
pp578	48.00	n.d.	71.00	14.00	2.00	0.36	1.00
pp579	48.00	n.d.	79.00	10.00	1.80	0.31	0.94
pp221	41.00	52.00	65.00	25.00	1.90	0.42	0.93
pp222	37.00	42.00	56.00	25.00	1.90	0.37	1.20
pp223	41.00	48.00	64.00	19.00	2.00	0.33	1.01
pp224	39.00	47.00	64.00	21.00	2.00	0.33	1.10

Table 2. (continued).

Sample No.	API	C_{15}- of oil	sat.hc	aro.hc	pr/ph	ph/n-C_{18}	OEP(C_{29})
pp243	45.00	60.00	71.00	16.00	2.00	0.32	0.89
pp244	41.00	51.00	65.00	23.00	1.80	0.33	0.93
pp245	45.00	65.00	66.00	21.00	1.80	0.33	1.14
pp246	48.00	63.00	77.00	16.00	2.00	0.33	1.03
pp247	45.00	61.00	75.00	16.00	2.10	0.29	0.94
pp267	22.00	32.00	64.00	25.00	1.50	0.44	0.95
pp268	29.00	34.00	65.00	25.00	1.60	0.38	0.85
pp269	41.00	50.00	60.00	28.00	2.00	0.32	0.95
pp248	21.00	7.00	69.00	22.00	1.60	0.41	0.99
pp249	27.00	11.00	67.00	23.00	1.60	0.47	1.22
pp250	26.00	4.00	67.00	21.00	1.50	0.41	0.88
pp232	35.00	37.00	63.00	22.00	1.70	0.37	0.97
pp233	37.00	n.d.	66.00	21.00	1.60	0.38	1.19

from Toot and some samples from Meyal are more mature, whereas two samples from Joya Mair are less mature. Based on light hydrocarbon analysis, it can be concluded that: (1) most oil fields contain normal mature light hydrocarbons generated from source rocks at temperature above 130 °C; and (2) light hydrocarbon data do not prove different source rocks.

Carbon Isotopes.— Selected oil samples from producing fields and seepage samples were analysed at BGR for the stable carbon isotope ratios. The $\delta^{13}C$ values were determined for the C_{15+} saturated and aromatic hydrocarbon fractions of oils (Table 4) and shown on the cross plot (Figure 9). As is evident from cross plot, most of the oil samples from Meyal, Toot, Balkassar, Dhurnal, Dakhni and Khaur are close together and constitute one group. Samples from Adhi, Joya Mair and probably Dhulian are falling apart from the main group but the variation of all oil samples from producing fields is small compared to seepage samples. In addition, it was found that the variation among different samples from the same field is small as compared to samples from other fields. Nevertheless, based on the relative homogeneity of the isotopic ratios, it is reasonable to assume similar or identical source rocks for all oil samples from producing fields of Potwar region. The isotopically heaviest oils are Joya Mair and Adhi compared to the main group of oils. This change is significant and more pronounced in the fraction. There can be four possible reasons (apart from the assumption of different source rocks) for this shift towards heavier isotopes, which are: (1) Gradual change of isotope composition within the source rock formations. Recently it has been shown that within Patala Formation $\delta^{13}C$ of kerogen increased drastically for samples from the basin centre (Seemann et al, 1987); (2) Biodegradation of hydrocarbons, especially of saturated fraction, but the n-alkane distribution pattern of the samples negate any possibility of biodegradation; (3) Thermal maturity of source rock can also cause this shift, but this is also not supported by other geochemical parameters, which on the contrary indicate that these samples are less mature as compared to other oils of Potwar region; and (4) The thermal maturation of already existing oils. Association of isotopically very light gas with oils supports this hypothesis. Sackett (1978) and Schoell (1984) had demonstrated that due to secondary thermal maturation of oils, initially a very light gas is formed and the resultant oil becomes enriched in heavier isotope especially in saturated fraction. For Joya Mair and Balkassar light natural gas has been found, the gas is depleted both in $\delta^{13}C$ isotopes and deuterium.

Isotope values of seepage samples show much larger variations compared to samples from producing fields. Seepage samples from Camp, Panoba, Jaba and Dharangi are more near to oil samples from producing fields of Potwar, while seepage samples from Dom Nala, Kundal and Khanzaman Nala are isotopically much lighter than other oil samples and might be early products of less mature Phanerozoic rocks or even products of Precambrian oil shales found in the area. From foregoing results and discussion, it can be concluded that: (1) oil samples from producing fields of Potwar region are isotopically homogeneous and are probably formed from the same source rocks; (2) in the southern part, the observed variations might have resulted either by secondary thermal heating of crude oil or change in source rock facies; and (3) regarding the seepage samples from Salt Range and Kundal, nothing could be said with

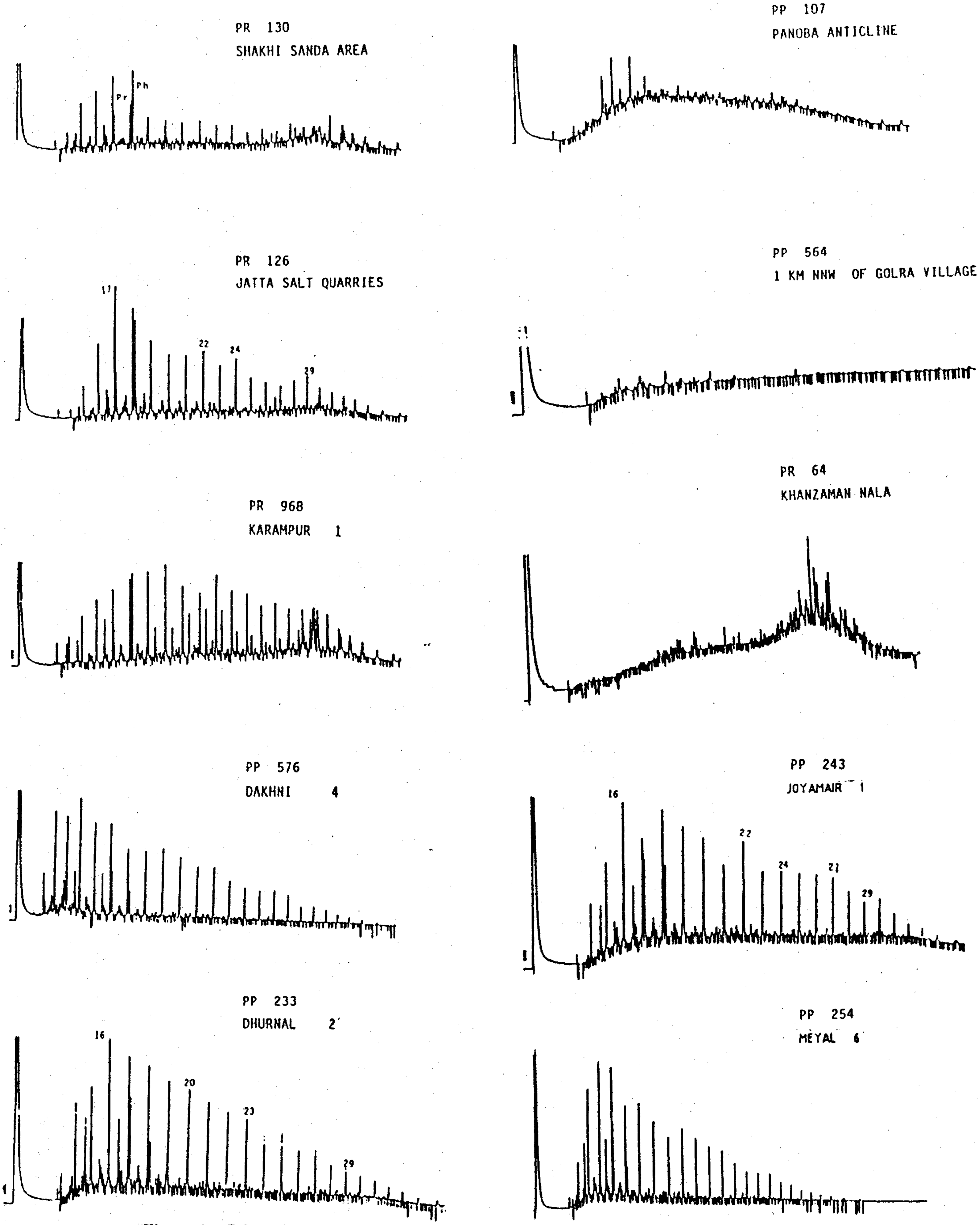


Figure 1—Selected gas chromatograms of the saturated hydrocarbon fraction of oil samples.

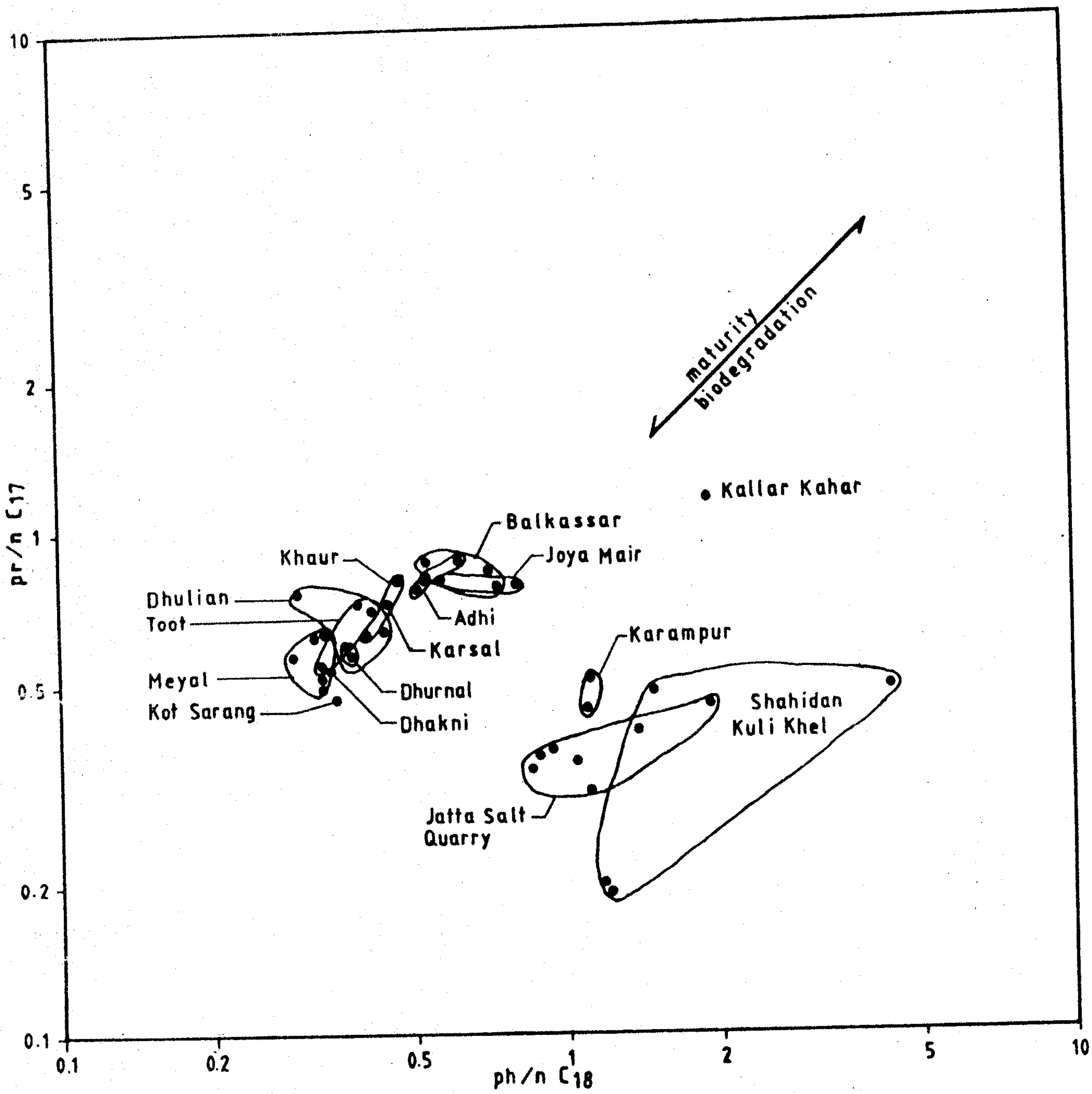


Figure 2—N-alkane normalized pristane ratios versus phytane ratios of oil samples.

certainty except that these oils were probably altered or were early products of the Potwar oil source rocks.

CONCLUSIONS

1. The geochemical studies illustrated that oil from producing fields of Potwar constitute one family which can be divided into two sub-families. The source rocks probably have been deposited in a marine environment under not strictly reducing conditions. At least two different oil families are present in Kohat region. One of them is from a source rock deposited under strong euxinic conditions in a restricted environment.

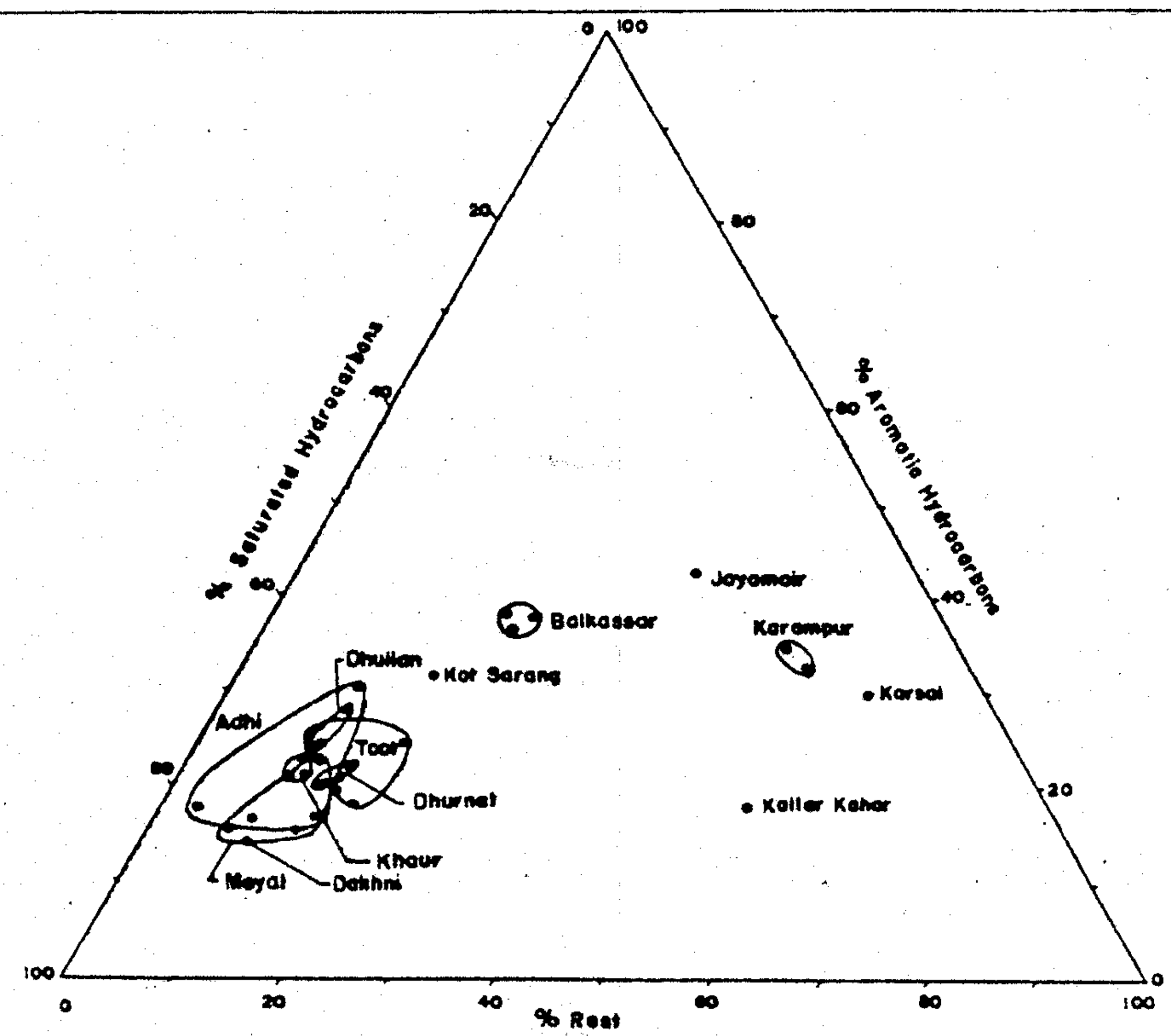
2. The sub-families of oils from Joya Mair, Balkassar and Kot Sarang are different from other oils of Potwar in

Table 3. Light hydrocarbon data

Sample No.	Locality	n - alkanes in %							hexane isomers(%)			hexane iso/cyc
		ethane	propane	butane	pentane	hexane	heptane	octane	iso	n	cyclo	
7	Jaba	14	9	14	16	21	24	3	22	25	53	0.42
107	Panoba	2	2	10	7	33	43	5	12	43	46	0.26
131	Kundal	5	9	6	4	28	48	1	8	37	56	0.14
132	Salgi Nala	5	6	6	16	25	42	1	9	34	58	0.16
221	Toot 10A	1	1	12	16	20	27	24	22	29	49	0.45
222	" 15	2	2	2	1	3	23	67	11	21	68	0.16
223	" 16	1	1	1	1	5	28	62	12	24	64	0.19
224	" 18	1	1	1	1	4	24	67	12	23	65	0.18
228	evap.T oot 10A	1	1	1	1	1	1	98	6	36	58	0.10
229	" " 18	1	1	1	1	2	1	97	5	69	27	0.11
230	w.t. Toot 16	1	1	1	9	22	35	33	21	29	50	0.42
231	" " 18	1	1	6	18	24	27	25	22	30	48	0.46
232	Dhurnal 1	1	1	3	5	12	36	43	18	25	57	0.32
233	" 2	1	3	7	12	20	27	29	24	27	48	0.50
243	Meyal 6	1	1	1	1	3	22	74	12	24	64	0.19
244	" 7	3	7	9	11	18	27	26	22	31	47	0.47
245	" 9	1	4	12	22	29	22	9	28	33	40	0.70
246	" 12	1	3	4	4	15	53	21	16	27	57	0.28
247	" 13	1	1	1	5	33	62	1	19	29	53	0.36
248	Khaur 1	2	6	11	17	25	40	1	23	29	48	0.48
249	" 5	1	1	1	2	5	17	74	20	26	54	0.37
250	" 8	1	1	1	2	5	20	72	17	19	64	0.27
251	Balkassar A5	1	1	2	5	8	24	60	22	23	55	0.40
252	" A7	1	1	1	1	1	13	83	14	16	70	0.20
253	" P2	3	7	17	22	16	17	18	30	27	43	0.70
254	Joyamair 1	1	1	8	21	19	23	28	30	24	46	0.65
263	Adhi 5 (k)	1	1	2	5	8	24	60	32	32	37	0.86
264	" 7 (s)	1	2	5	14	25	33	20	28	28	44	0.64
265	" 9 (t)	1	2	4	12	23	35	23	28	31	41	0.68
266	" 9 (k)	1	2	5	16	28	31	19	31	32	38	0.82
267	Dhulian 25	1	2	6	15	24	32	21	21	29	50	0.42
268	" 34	1	3	9	18	24	27	19	23	29	48	0.48
269	" 43	1	5	13	18	21	26	18	20	25	55	0.36

Table 3. (continued)

Sample no.	locality	heptane isomeres in % iso	n	cyclo	heptane iso/cyc	paraffin indices I	II	(i/cC6)/(i/cC7)	cC6/M-cC5	trans/cis 2-DMcC5	cC6/benz
7	Jaba	11	10	79	.14	.65	8.8	3	.9	n.d.	1
107	Panoba	60	20	20	3	6.9	20.7	.09	.36	n.d.	2.3
131	Kundal	62	19	19	3.3	6.5	19.7	.04	.32	n.d.	2.5
132	Salgi Nala	70	20	10	7	15.5	20.3	.02	.32	n.d.	1.6
221	Toot 10A	20	23	57	.35	1.1	20.7	1.29	1.1	4.6	1
222	" 15	13	24	63	.21	.9	24.1	.76	2	2.8	1.6
223	" 16	18	25	57	.32	1.2	24.1	.59	1.8	2.9	1.1
224	" 18	15	25	60	.25	1	24.3	.72	1.8	3	1.3
228	evap.T oot 10A	37	28	35	1.06	6.1	31.4	.09	.34	9.9	2.9
229	" " 18	52	19	29	1.79	15	18.7	.06	.31	n.d.	2.4
230	w.t. Toot 16	23	24	53	.43	1.3	22	.98	1.2	3.9	1.1
231	" " 18	21	23	56	.38	1.1	20.6	1.21	1	4.8	1.2
232	Dhurnal 1	21	22	57	.37	1.5	20.9	.86	1.6	2.9	1.3
233	" 2	25	21	53	.47	1.7	18.9	1.06	1.3	3.7	1.1
243	Meyal 6	17	24	59	.29	1.5	23	.66	1.9	2	1.5
244	" 7	22	24	54	.41	1.4	21.9	1.15	1.2	3.6	1.3
245	" 9	30	22	49	.61	1.5	19	1.15	1	4.9	1.1
246	" 12	22	24	55	.4	1.6	22.6	.7	1.7	2.4	1.3
247	" 13	25	22	53	.47	1.7	20.6	.77	1.4	3.1	1.1
248	Khaur 1	39	22	39	1	3.7	21	.48	.9	n.d.	.8
249	" 5	37	22	41	.9	4.1	22.6	.41	.8	n.d.	1.5
250	" 8	23	17	60	.38	1.6	16.9	.71	1.6	(2.2)	2
251	Balkassar A5	21	21	58	.36	1.3	21.1	1.11	1.2	3.8	1.1
252	" A7	14	19	66	.21	1.1	20	.95	1.8	2.6	1.5
253	" P2	27	21	52	.52	1.5	19.1	1.35	.9	4.8	.9
254	Joya Mair 1	28	19	53	.53	1.5	17.9	1.23	.8	5.2	.7
263	Adhi 5 (k)	34	22	44	.77	2.4	20.4	1.12	1.1	4.5	.5
264	" 7 (s)	30	20	50	.6	1.9	18.9	1.07	1	3.9	.7
265	" 9 (t)	30	23	47	.64	2.3	21.5	1.06	1.2	4	.5
266	" 9 (k)	33	22	45	.73	2.4	20.8	1.12	1.1	4.4	.5
267	Dhulian 25	23	23	54	.43	1.1	20.5	.98	1.1	4.8	1.4
268	" 34	24	22	54	.44	1.1	20	1.09	1	5.1	1.4
269	" 43	21	19	60	.35	1.3	16.5	1.03	1.4	4.1	1.8



Fifure 3—Saturated and aromatic hydrocarbon fractions in oil samples from oil fields of northern Pakistan.

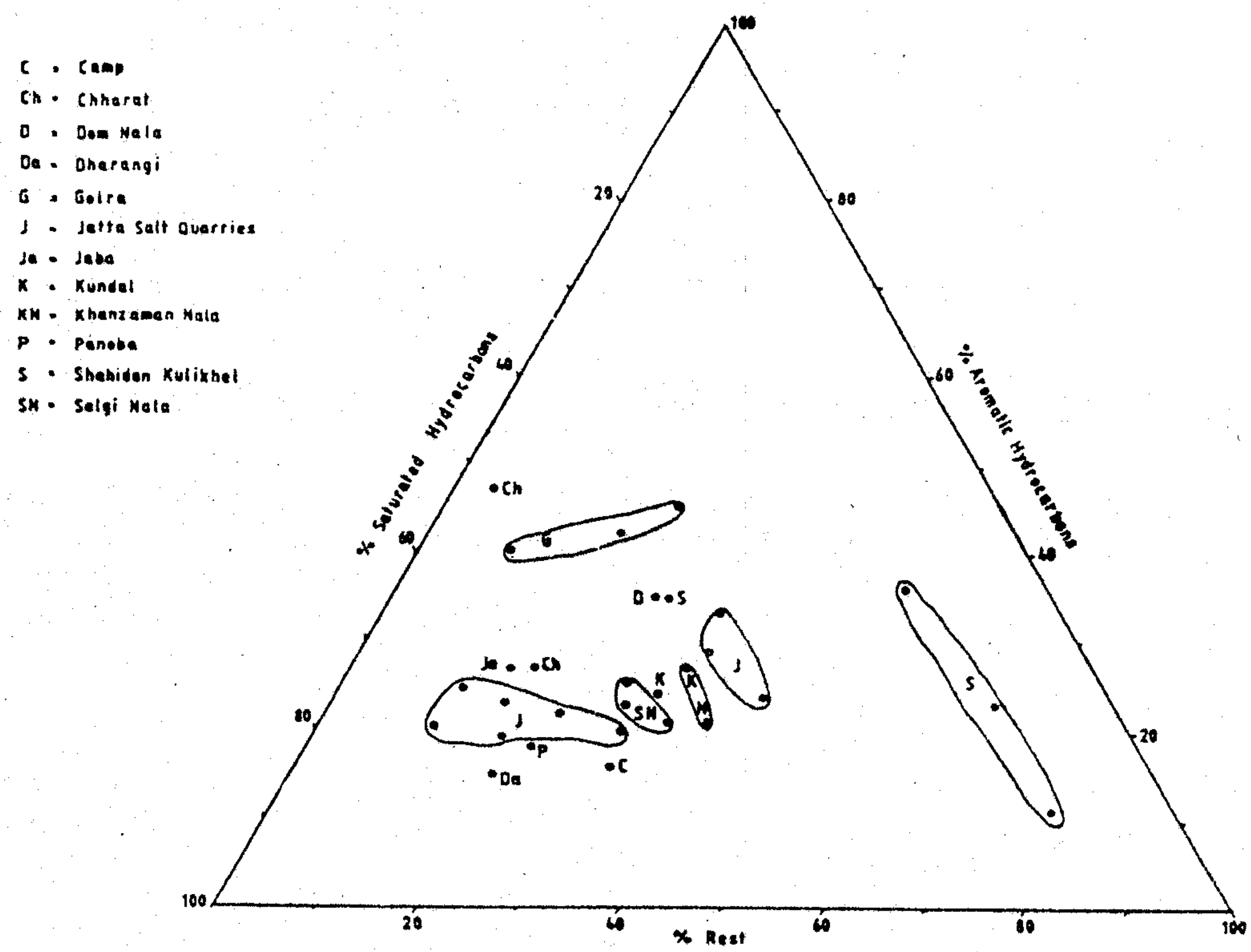
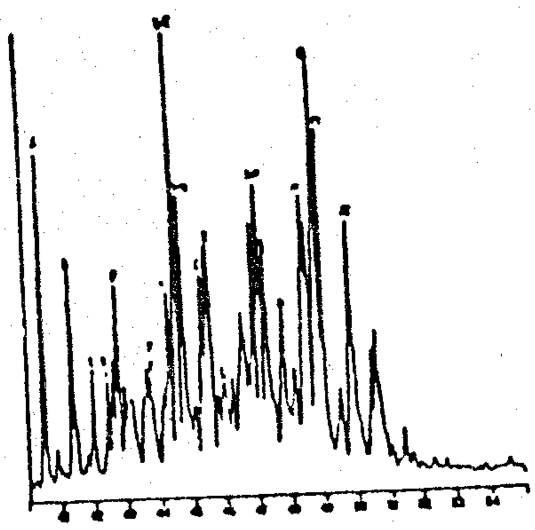
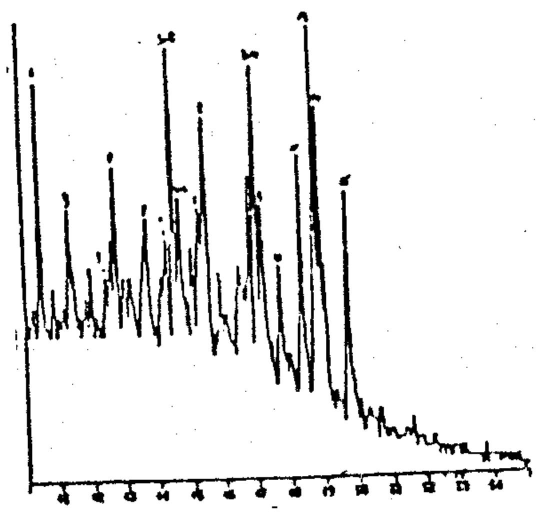
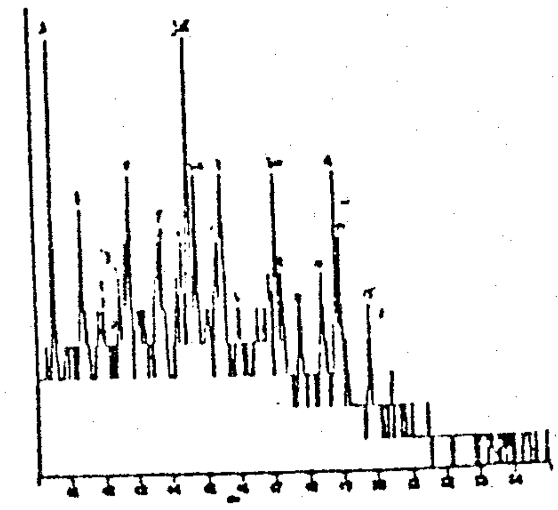
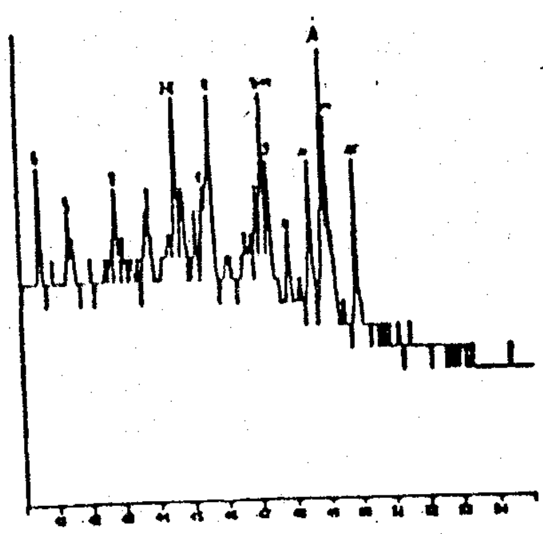


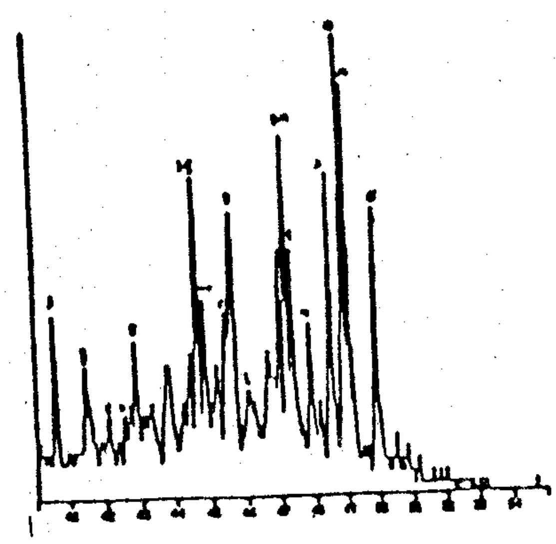
Figure 4—Saturated and aromatic hydrocarbon fractions in oil samples from oil seepages.

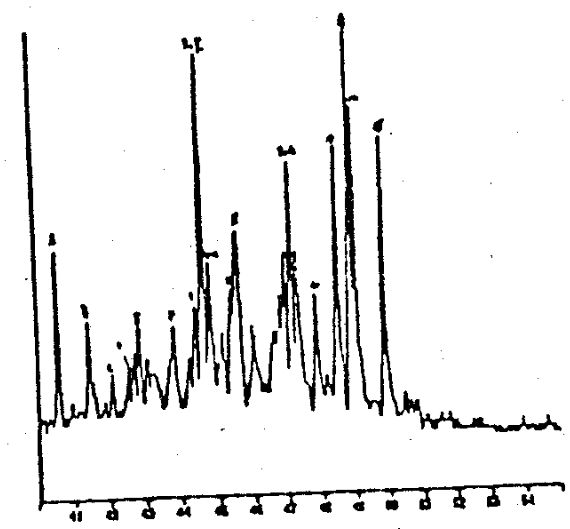

PR 311
Jatta Salt Quarries

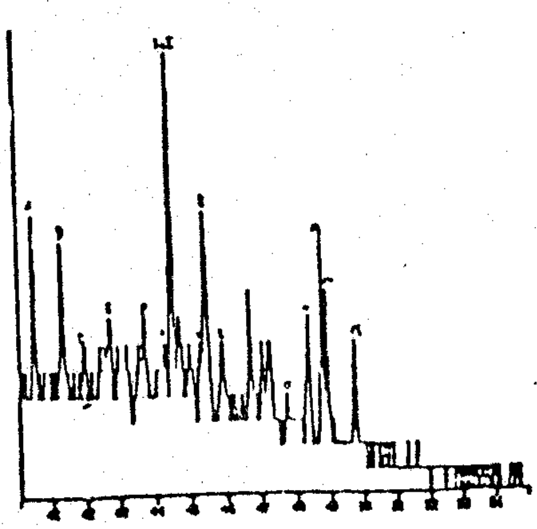

PR 505
Camp

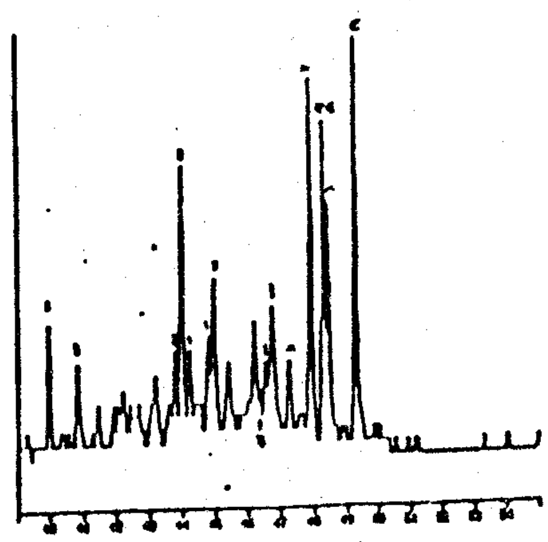

PP 578
Dakhni 4


PP 243
Meyal 6


PP 233
Dhurnal 2


PP 252
Balkassar A1


PP 263
Adhi


PR 1084
Karsal 1

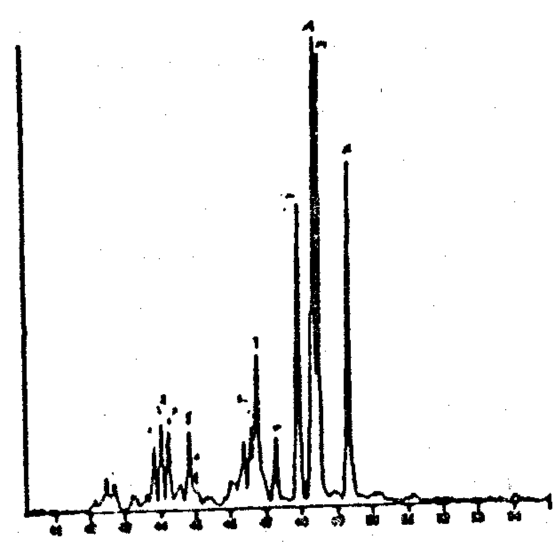

PR 968
Karampur 1

Figure 5—Steranograms (m/z 217) of selected oil samples.

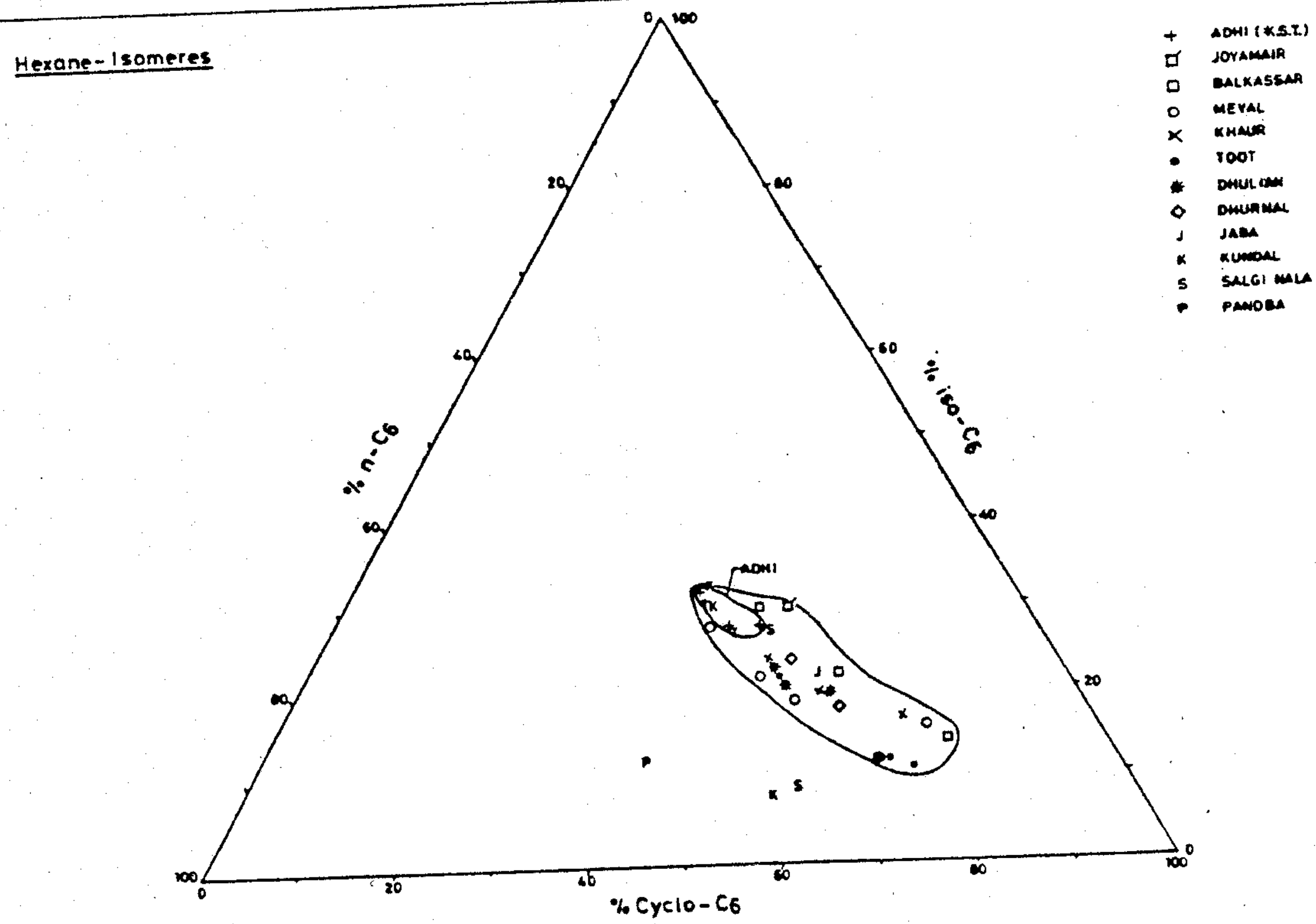


Figure 6—Distribution of straight chain(n-), iso and cyclohexane.

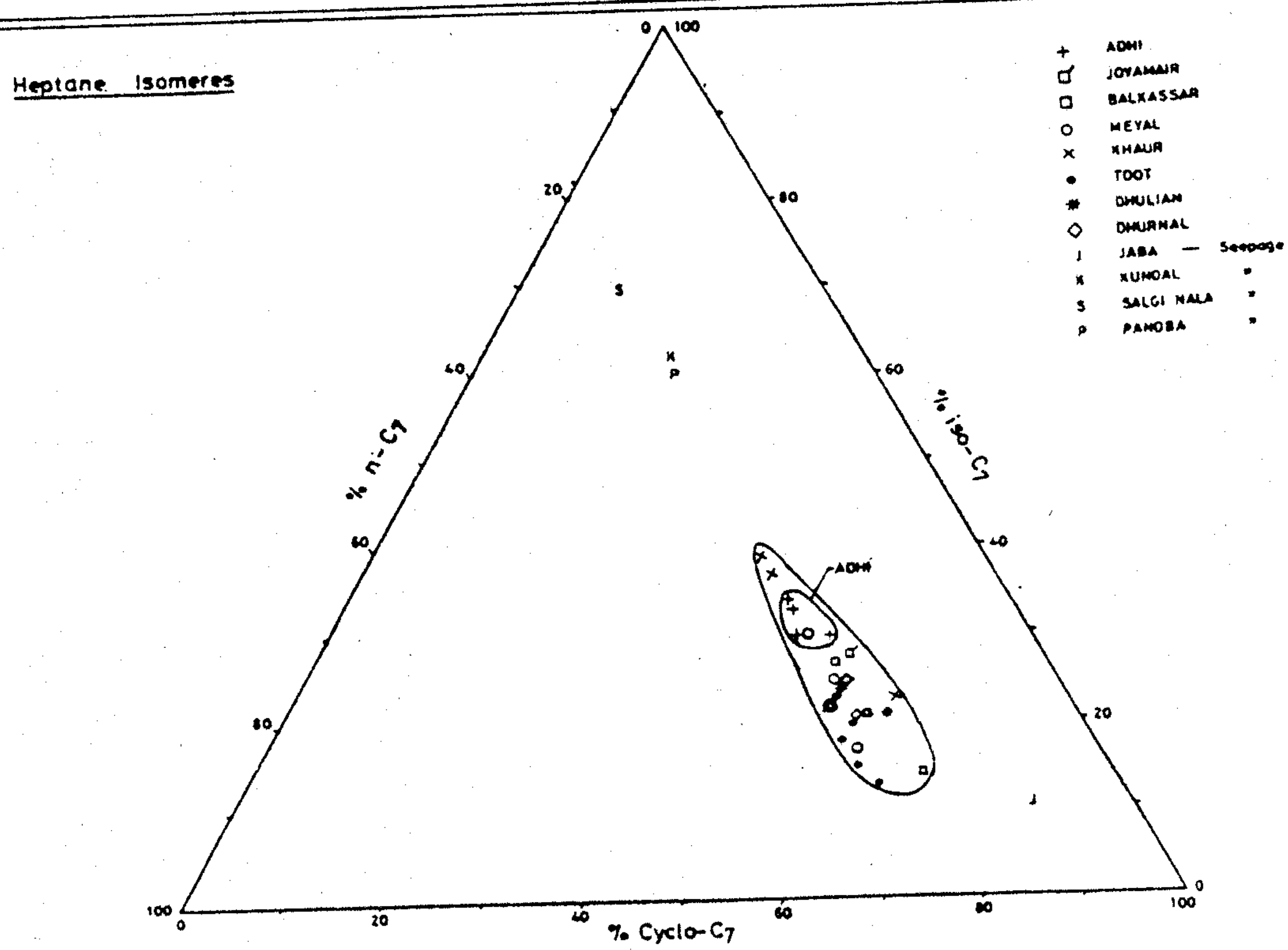


Figure 7—Distribution of straight chain(n-), iso and cycloheptane.

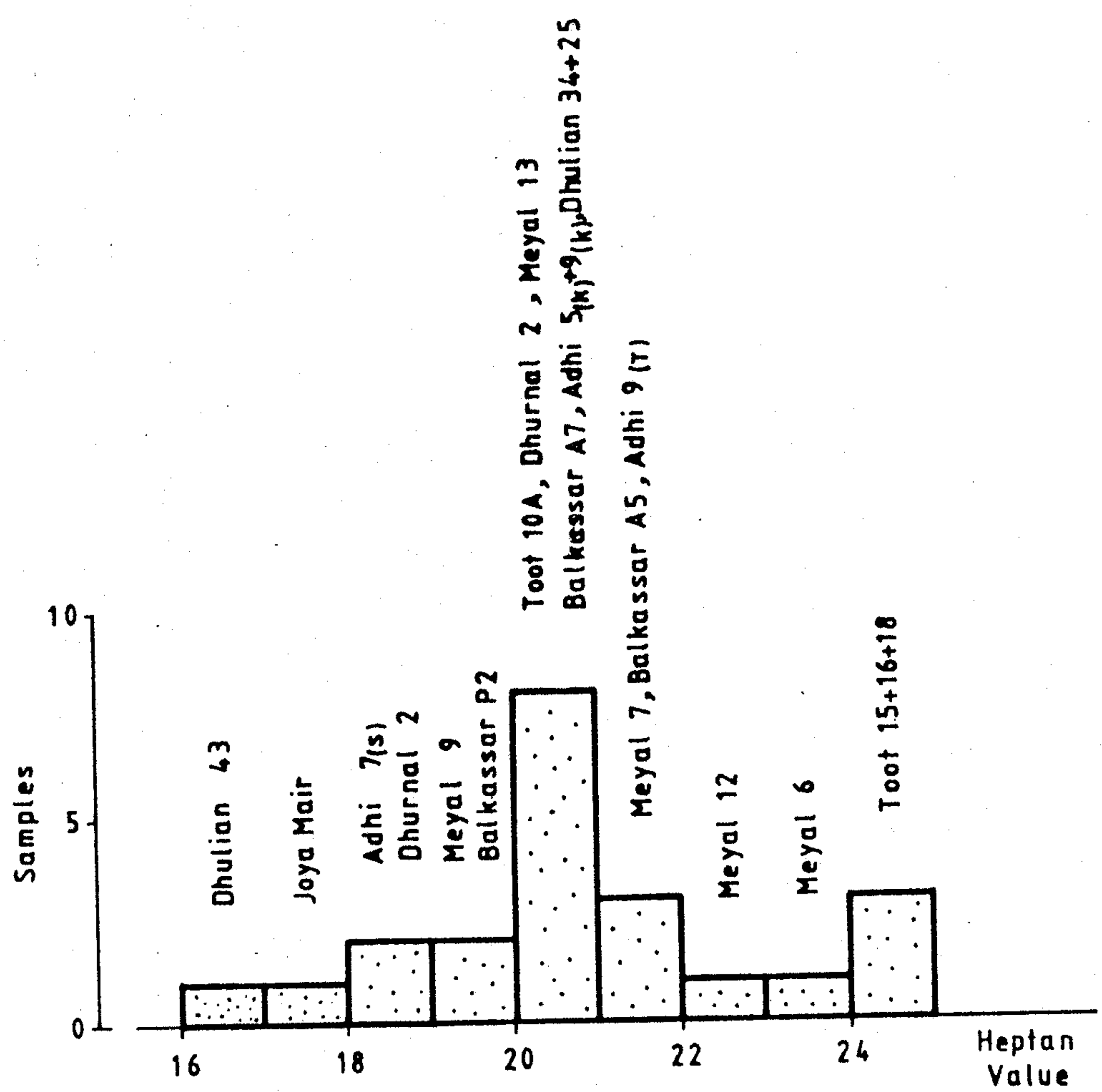


Figure 8—Classification of the heptane values.

physical appearance and also in bulk chemical composition. These are black, highly viscous oils with low API. Genetically, these are similar to the main oil family of Potwar but can be sub-divided from other oils on the basis of $C_{15}+$ hydrocarbon distribution, heavier isotope and biomarkers. These oils, as all oils from producing fields of Potwar are non-biodegraded.

3. A continuous shift in certain geochemical parameters in a northwest to southeast direction of Potwar region could best be explained by an increase in maturity towards a northwest direction and by a shift in the organic facies of the source rock formation.

4. The seepage samples usually are heavily biodegraded, resulting in the alteration of biomarkers to some extent. Partly they could be correlated with crude oils from producing fields of Potwar. A contribution from other source rocks as well as immaturity of the facies of some samples is probable. A different oil family sourced from the Precambrian Salt Range Formation could be positively detected for an oil show in the Karampur well farther south of Salt Range.

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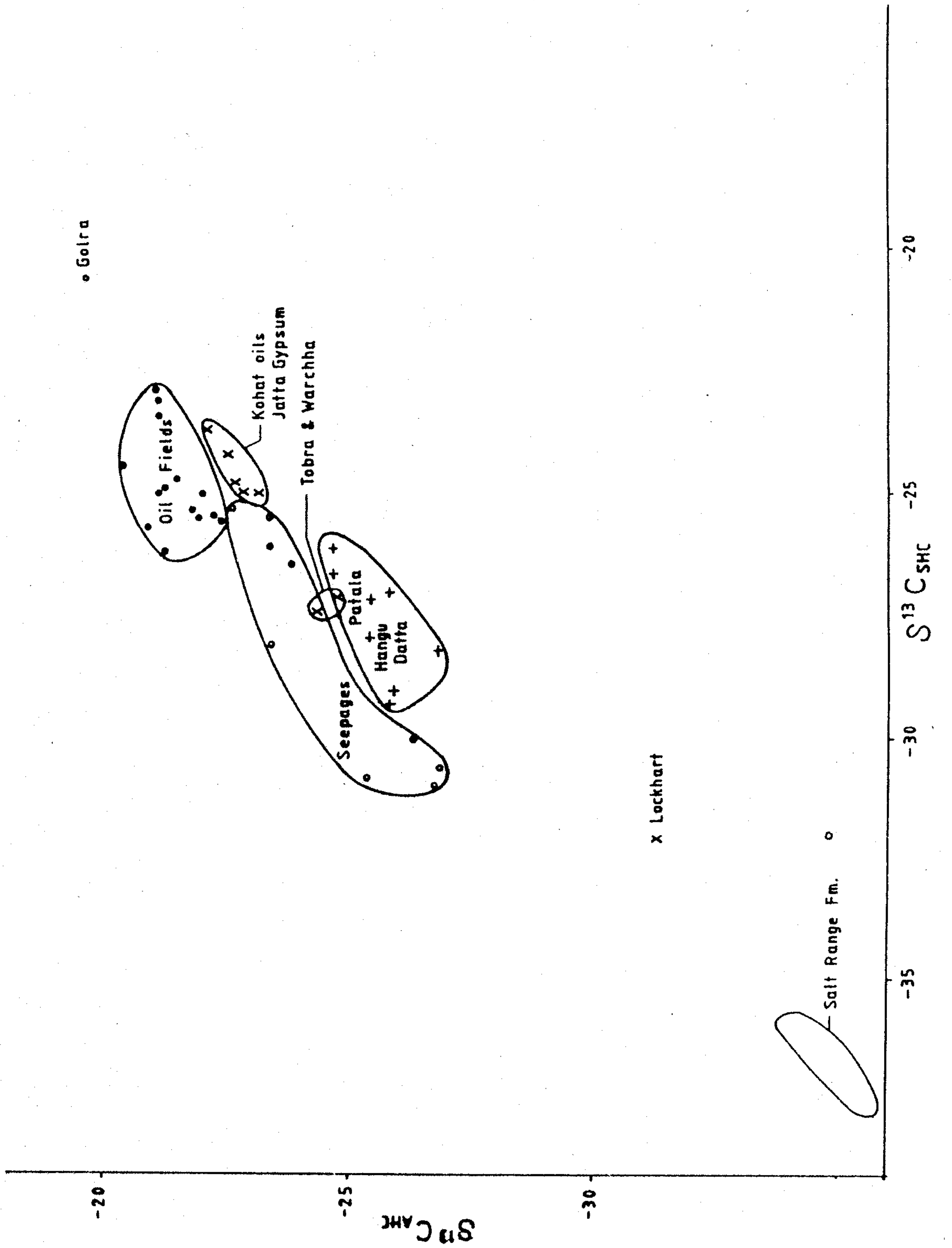

Figure 9—Carbon isotope ratios of the saturated vs aromatic hydrocarbons.

Table 4. Carbon isotope data[1].

Sample No.	Locality	Whole oil	sat.hc	aro.hc	CV
pp 263	Adhi 5		-23.0	-21.1	-0.30
pp 264	Adhi 7	-21.9	-22.8	-21.1	-0.81
pp 266	Adhi 9	-22.6			
pp 254	Joya Mair 1		-23.1	-21.1	-0.05
pp 255	Joya Mair 1	-21.7			
pp 252	Balkassar A7		-24.6	-21.5	2.86
pp 253	Balkassar P2	-22.6			
pp 576	Dakhni 4	-24.6			
pp 578	Dakhni 4		-25.5	-22.4	3.14
pp 222	Toot 15		-25.6	-20.9	6.72
pp 223	Toot 16	-24.9			
pp 224	Toot 18		-26.1	-21.2	7.32
pp 243	Meyal 6		-25.4	-21.9	3.99
pp 244	Meyal 7	-23.5	-24.9	-21.1	4.51
pp 245	Meyal 9		-24.8	-21.2	4.28
pp 268	Dhulian 34	-24.2			
pp 269	Dhulian 43		-24.3	-20.3	4.76
pp 249	Khaur 5	-24.1			
pp 250	Khaur 8		-25.4	-22.2	3.33
pp 232	Dhurnal 1	-23.8			
pp 233	Dhurnal 2		-25.3	-21.8	3.96
pp 7	Joba(Salt R)		-25.4	-23.4	0.66
pp 107	Panoba Anticline		-26.0	-23.4	2.18
pp 507	Dom Nala		-28.0	-23.3	7.46
pp 132	Salgi Nala		-30.6	-26.8	6.27
pp 131	Kundal		-30.0	-26.3	5.86
pr 166	Salgi Nala		-30.8	-25.3	10.11
pr 64	Khanzaman Nala		-31.0	-26.8	7.28
pr 506	Dharangi		-26.4	-23.8	2.31
pr 124	Shahidan Kuli Khel		-24.7	-22.6	0.67
pr 127	Jatta Salt Quarry		-24.1	-22.5	0.63
pr 311	Jatta Salt Quarry		-23.6	-22.1	-1.00
pr 505	Camp(E NE)		-25.2	-22.5	2.16
PR 564	Golra		-20.6	-19.6	-3.04

[1]dC13 in ppt relative to the PDB standard. CV = cononical value (Sofer, 1984). BGR measurements only.

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