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Organic Geochemistry and Source Rock Characteristics of Salt Range Formation, Potwar Basin, Pakistan.

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ABSTRACT

The hydrocarbon source potential of Precambrian Salt Range Formation was assessed by analysis of 91 outcrop and core samples using Leco (total organic carbon contents), pyrolysis, liquid column chromatography, gas chromatography, gas chromatography mass spectrometry, vitrinite reflectance spectroscopy and low carbonisation analysis (Fisher Assay). The formation is exposed along the outer periphery of the Salt Range from Kalabagh in the west to the eastern Salt Range. The oil shales found near the top of the Precambrian Salt Range Formation of eastern Salt Range are extremely rich in organic carbon, with TOC of upto 30 % and have excellent geochemical source rock parameters (HI upto 879 mg/kg and Extractable Organic Matter (EOM)/TOC upto 255 mg/kg). Also the low grade oil shales found in the central and western salt range are excellent potential source rocks having TOC 2.5-8%, HI upto 746 mg/kg and EOM/TOC mg/kg upto 204. The EOM of most of the surface samples from Salt Range Formation contains less than 20% saturated hydrocarbons (SHC), which suggests their low maturity. However, the oil shale extracts have SHC portion slightly more than 40%. The organic matter consists predominantly of prebitumen and solid bitumen, and partly contains major proportions of liptinite. The oil yield of high-grade oil shales varies from 15 to 20% of rock weight.

INTRODUCTION

The Potwar Basin has been the scene of intensive studies concerning its economic importance as a Petroliferous province. Several papers have discussed various aspects of Potwar Basin (Porth, et al., 1987; Seeman, et al., 1988; Ahmad, et al., 1990 and Ahmed, et al., 1994).

The major source rocks in the Potwar Basin have been the subject of debate for more than a decade. The studies conducted in the past favored the shales of Patala as the major source rock in the area. Consequently, the generated hydrocarbons are thought to have migrated into older stratigraphic levels at some time in the past. The oil is found at different stratigraphic levels, which exhibit close similarities, potentially leading to the impression that these are generated from a single source.

The region is a productive oil province, with oil present at a number of stratigraphic levels from Cambrian to Miocene. These oils exhibit close similarities, implying that these are generated from a single source.

The Salt Range Formation represents typical evaporites sequence deposited in restricted marine environments. Oil shale horizons developed within the formation exhibit good source rock potential containing high percentage of organic matter. The best quality occurs within the top most part of the formation in the eastern Salt Range with TOC values of more than 30% and oil yield of more than 20%. The maximum thickness is 1-2m only, but nevertheless this oil shale will have a tremendous oil-sourcing potential if present in the sub-surface of Potwar basin. Oil shale also occurs in western salt range in the middle part of formation where they likewise constitute good oil source rocks though somewhat of lower quality (TOC 6-8%).

Geochemical studies conducted so far indicate that organic rich, Calcareous black shales of Pre-Cambrian rocks are one of the principal source rocks of the area. These oil shales are equivalent to India and Oman, infra Cambrian source rocks which have been reported to generate heavy oil (Ahmed, et al., 1994; Al- Marjeby, and Nash, 1986). In addition, commercial accumulations of indigenous Proterozoic petroleum in Siberia (Meyerhosff, 1980) were also reported. Australia has also a number of un-metamorphosed Proterozoic basins (Murray, et al., 1980; Muir, 1974; Jackson, et al., 1987).

The objective of present study was to assess Salt Range source rock potential, its significance and possible contribution in the basin.

MATERIALS AND METHODS

Samples

Precambrian oil shales of Salt Range Formation occur in two different stratigraphic levels (Figure 1):

1. High Grade Oil shales in the upper most part of the Salt Range Formation are associated with gypsum and altered extrusive volcanic rocks in the Eastern Salt Range. In the Khewra Gorge, the exposed oil shale layers vary in thickness from a few millimeters to 20cm. In Makrach Nala, the thickness observed was 0.5 m. In Sohal Nala, several outcrops of oil shales were found. The thickness ranges from few centimeters to two meters. In Nila Wahan, the "Khewra Trap" is overlain by a gypsum and dolomite sequence, which contains several thin oil shale layers, each of about 5cm thickness.
2. Low grade oil shale layers alternating with sandstone, siltstone and dolomite in the middle part of the Salt Range Formation in Western Salt Range (Rukhala Area, Dhodha Wahan). In the Rukala Area (Jan Sukh Nala) and in Dhodha Wahan, the middle part of the Salt Range Formation contains an alternation of gypsum, dolomite, shale, siltstone and sandstone with several oil shale layers of up to 0.6m thickness. The oil shale is brownish black or black, silty and finally laminated. Between Kalabagh and the mouth of Chilas Algad (Kalabagh), a gypsum anhydrite dolomite sequence is exposed which contains some dark-grey to black, partly laminated shales of up to 15cm thickness, some portions of which

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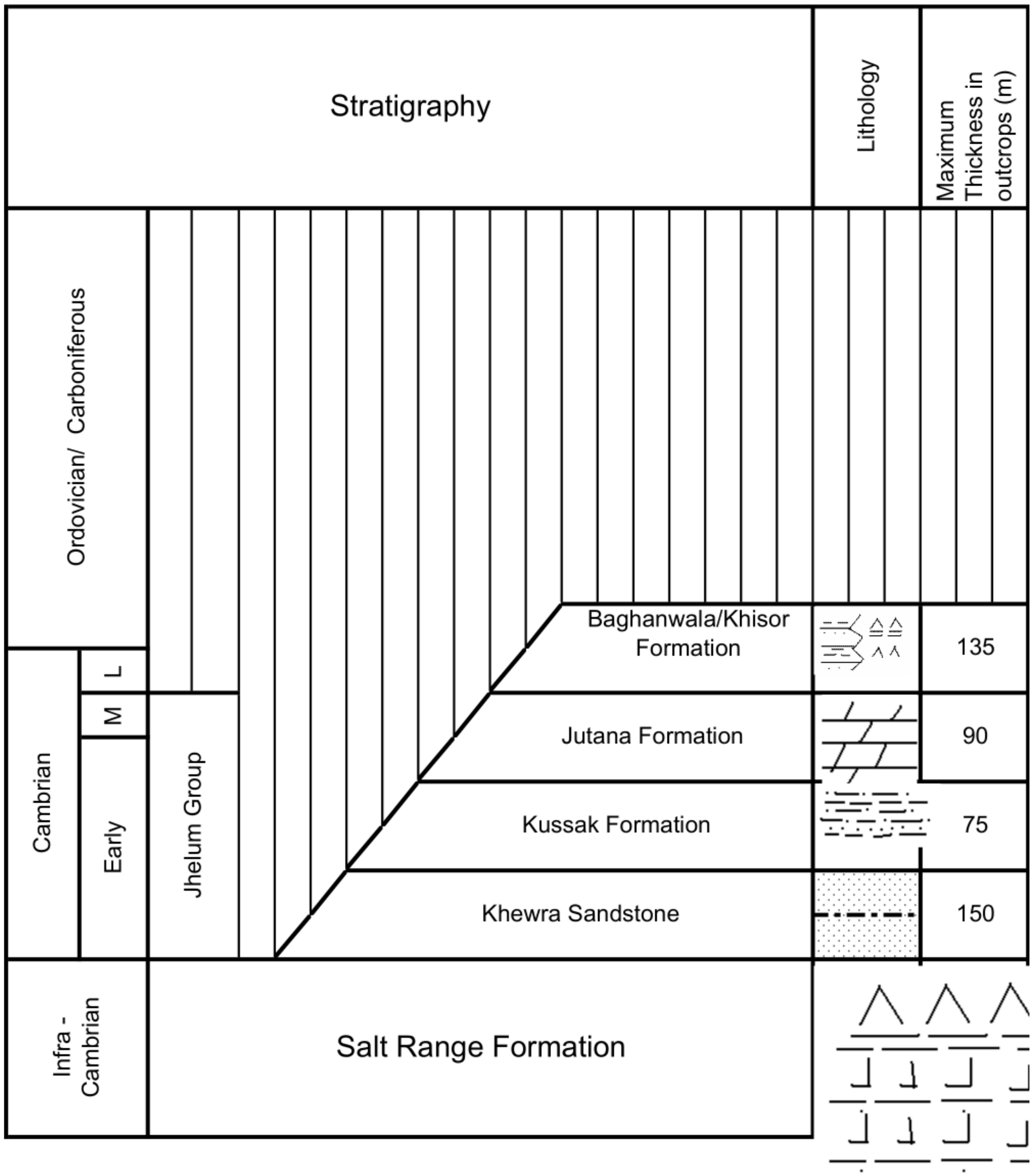


Figure 1 - The Precambrian/Paleozoic Sedimentary Formation of Potwar Basin

giving off a strong hydrocarbon smell.

Twenty eight outcrop samples (Table 1) of the Salt Range Formation from the Eastern Salt Range and 55 samples from Western Salt Range were collected for the study (Figure 2).

Eight core samples from 4 wells i.e. Dulmial-1, Dhariala-1, Kallar Kahar-1 and Karam Pur-1, were also selected for source rock evaluation (Table 2).

Analytical Procedures

Total organic carbon (TOC) was determined for 83 outcrop samples by combustion in a Leco Carbon Analyzer CS-300 after removal of carbonate carbon using HCl. TOC was also determined for the 8 selected core samples for the test wells; Dulmial-1, Dhariala-1, Kallar Kahar-1 and Karam Pur-1.

Pyrolysis was carried out isothermally at 600°C using a Shimadzu GC 9A Pyrolyser and also a Rock-Eval II instrument. The maturity status of the formation was assessed by vitrinite reflectance and Tmax data from Rock-Eval. EOM C_{15}+ was determined by extracting the sample for 15 hours with dichloromethane, followed by evaporation of the solvent at 60°C. The EOM (C_{15}+) was fractionated into saturated hydrocarbons (C_{15}+), aromatic hydrocarbons and non-hydrocarbons by liquid column chromatography using silica gel, alumina (as adsorbents) and eluting successively with n-hexane and dichloromethane. The amount of each fraction was determined gravimetrically.

Gas chromatographic analysis of the saturated hydrocarbons (C_{15}+) was performed on a Perkin Elmer Gas-Chromatograph Sigma-115 equipped, with fused silica capillary column SE-54 and flame ionization detector. Column temperature programming was from:

100°C (1 min) with a 10°C/min gradient, followed by
150°C - 50°C/min - 300°C (9min) held isothermally

Biological marker analysis was carried out in selected ion monitoring mode on a Finnigan Mat Incos-50 mass - spectrometer using a fused silica capillary column SE 54 and electron multiplier detector. Relative intensities of the peaks in m/z 191 and 217 fragmentograms were used to quantify the compounds.

Stable carbon isotope analysis was done at the Federal Institute of Geosciences (BGR), Germany.

RESULTS

Organic Richness

Most of the samples are organically rich. Twenty eight outcrop samples selected for study from the Eastern Salt Range showed TOC ranging from 1.58 - 36% in the Khewra Gorge samples, 31% in Nawabi Kas; 24 - 33.7% in Makrach Nala and 0.58 - 41.7% in the Nila Wahan samples (Table 1).

Fifty five outcrop samples collected from the Western Salt Range showed TOC ranging from 0.1 - 0.3% in Mari Salt Hills; 0.7 - 8.1% in Jan Sukh Nala (Rukhala Area); 0.3 - 2.2 in Chilas Algad (Kalabagh); 0.2 - 7.2% in Dhodha Wahan and 5.3% in the Khanzaman Nala samples (Table 1, Figures 3 and 4).

The cores from the Dulmial-1 well have TOC contents ranging from 20.5 to 47.8%; 5.2 to 9.8% in Dhariala-1 and from 1.3 to 1.6% in the Karam Pur-1 (Table 2).

The results indicate that oil shales and shales samples of eastern salt range are extremely rich in organic carbon Siltstones in Western Salt Range also show marginal organic richness. The samples taken from Dulmial-1 and Dhariala-1 are also found rich in organic carbon. Oil impregnated dolomite in Karam Pur-1 also showed moderate organic richness.

Pyrolysis Data

Pyrolysis data also exhibited high source potential ranging in value from 6.6 - 278 kg/ton. On the basis of these high values SRF may be classified as potential source rock capable of generating oil, both in outcrop and well samples (Figures 5, 6,7 and 8).

EXTRACTABLE ORGANIC MATTER

C_{15} + Extractable Organic Matter (EOM) and Hydrocarbon Fractions

Nineteen outcrop samples of Salt Range Formation were selected for bitumen extraction. The extraction yielded high proportion of extractable organic matter. The relative high proportion of soluble substances is demonstrated, when related to total organic carbon. EOM/TOC ratio ranges from 292mg/g to 1196mg/g, the highest EOM/TOC ratio of 1196mg/g is observed in Karampur well (Table 3 and 4, Figure 9 and 10).

Compositionally, the extracts on a gross level are characterized by greater proportions of hydrocarbons than non-hydrocarbons. Saturated and aromatic contents varied from 43%-23% and from 38%-16% respectively. The wide variation of these ratios is probably due to large part of maturity difference and variation in source facies.

C_{15}+ Saturated Hydrocarbon Distribution

The distribution of C_{15}+ alkanes are illustrated by gas chromatograms in Figure 11, 12, 13 and data is given in Table 3, 4. The gas chromatography data reveals:

- Wide range of n-alkanes with carbon number of C_{25} or higher.
- Abundant Pristane, Phytane and extended acyclic Isoprenoids.
- A distinct hump of unresolved branched or cyclic compounds.
- Presence of steranes and triterpanes.
- Showed no apparent evidence of biologic biodegradation in outcrop/core samples but it was apparent in seepage samples from Kundal , Salgi Nala and Klanzaman Nala.
- The presence of X- compounds (Klomp, 1986).
- A strong predominance of C_{29} Steranes.
- The absence or very low relative contents of re-arrange Steranes.
- Presence of extended acyclic Isoprenoid, which are characteristics of many lacustrine or hypersaline strata.
- One of the distinguishing features of these extract is low Pristane/Phytane, Pristane/ nC_{17} and Phytane/nC_{18} ratios, indicative of strongly reducing restricted depositional environments. The presence of Isoprenoids

Table 1- Organic carbon and pyrolysis data of outcrop samples from Salt Range Formation.

	Field No.	Lab. No.	Location	Lithology	TOC (%)	GP [kg/t]	HI
Eastern Salt Range	SaR-70	Pr- 67	Khewra Gorge	Oil Shale	36	278.0	772
	SaR-205	Pr- 361	Khewra Gorge	Oil Shale	27.2	174.0	640
	SaR-206	Pr- 362	Khewra Gorge	Oil Shale	29.5	179.0	607
	SaR-207	Pr- 363	Khewra Gorge	Oil Shale	28.4	224.0	789
	96.11.13-1	Pr- 7592	Khewra Gorge	-	15.3	-	-
	96.11.13-10	Pr- 7593	Khewra Gorge	-	1.6	6.69	398
	96.11.13-11	Pr- 7594	Khewra Gorge	-	24.8	-	-
	96.11.13-12	Pr- 7595	Khewra Gorge	-	5.6	36.44	614
	96.11.13-13	Pr- 7596	Khewra Gorge	-	23.4	-	-
	SaR-202	Pr- 358	Makrach Nala	Oil Shale	31.2	219.0	702
	96.11.15-1	Pr- 7597	Makrach Nala	-	0.2	-	-
	96.11.15-2	Pr- 7598	Makrach Nala	-	33.8	-	-
	96.11.15-3	Pr- 7599	Makrach Nala	-	32.2	-	-
	96.11.15-3	Pr- 7600	Makrach Nala	-	24.1	-	-
	SaR-142	Pr- 90	Nawabi Kas	Oil Shale	31	250.0	787
	SaR-210	Pr- 366	Sohal Nala	Oil Shale	18.7	113.0	604
	SaR-21 1	Pr- 367	Sohal Nala	Oil Shale	22.8	138.0	605
	SaR-213	Pr- 369	Sohal Nala	Oil Shale	20.2	131.0	649
	SaR-214	Pr- 370	Sohal Nala	Oil Shale	23.4	130.0	556
	SaR-215	Pr- 371	Sohal Nala	Oil Shale	24.8	131.0	528
	96.11.16-3	Pr- 7602	Sohal Nala	-	19.6	-	-
	96.11.16-4	Pr- 7603	Sohal Nala	-	15.2	-	-
	SaR-223	Pr- 379	Nila Wahan	Oil Shale	22	85.0	386
	96.11.16-5	Pr- 7604	Nila Wahan	-	1.3	4.87	360
	96.11.16-6	Pr- 7605	Nila Wahan	-	1.1	4.53	329
	96.11.16-8	Pr- 7606	Nila Wahan	-	0.2	-	-
	96.11.16-9	Pr- 7607	Nila Wahan	-	41.7	-	-
	96.11.17-8	Pr- 7608	Nila Wahan	-	0.6	-	-
Western Salt Range	SaR-226	Pr- 382	Jan Sukh Nala (Rukhala Area)	Shale	0.7	0.5	65
	SaR-227	Pr- 383	Jan Sukh Nala (Rukhala Area)	Shale	0.2	-	-
	SaR-228	Pr- 384	Jan Sukh Nala (Rukhala Area)	Shale	3.9	24.0	611
	SaR-229	Pr- 385	Jan Sukh Nala (Rukhala Area)	Siltstone	8.2	61.0	746
	SaR-230	Pr- 386	Jan Sukh Nala (Rukhala Area)	Shale	1.4	5.9	424
	SaR-231	Pr- 387	Jan Sukh Nala (Rukhala Area)	Shale	1.1	3.9	368
	SaR-232	Pr- 388	Jan Sukh Nala (Rukhala Area)	Siltstone	0.8	1.9	244
	SaR-233	Pr- 389	Jan Sukh Nala (Rukhala Area)	Oil shlale	6.4	7.3	115
	SaR-235	Pr- 391	Jan Sukh Nala (Rukhala Area)	Siltstone	0.8	3.0	370
	SaR-237	Pr- 393	Jan Sukh Nala (Rukhala Area)	Siltstone	3.0	20.4	687
	SaR-238	Pr- 394	Jan Sukh Nala (Rukhala Area)	Shale	0.2	<0.1	<50
	SaR-239	Pr- 395	Jan Sukh Nala (Rukhala Area)	Shale	0.2	<0.1	<60
	SaR-240	Pr- 396	Jan Sukh Nala (Rukhala Area)	Siltstone	2.5	13.1	520
	SaR-241	Pr- 397	Jan Sukh Nala (Rukhala Area)	Shale	2.2	13.2	611
	96.11.20-1	Pr- 7611	Jan Sukh Nala (Rukhala Area)	-	0.1	-	-
	96.11.20-2	Pr- 7612	Jan Sukh Nala (Rukhala Area)	-	0.2	-	-
	96.11.20-3	Pr- 7613	Jan Sukh Nala (Rukhala Area)	-	0.1	-	-
	96.11.20-4	Pr- 7614	Jan Sukh Nala (Rukhala Area)	-	0.2	-	-
	96.11.20-6	Pr- 7615	Jan Sukh Nala (Rukhala Area)	-	0.3	-	-
	96.11.20-7	Pr- 7616	Jan Sukh Nala (Rukhala Area)	-	0.3	-	-
	96.11.20-8	Pr- 7617	Jan Sukh Nala (Rukhala Area)	-	7.3	40.43	497
Western Salt Range	96.11.20-9	Pr- 7618	Jan Sukh Nala (Rukhala Area)	-	1.6	12.06	615
	96.11.20-10	Pr- 7619	Jan Sukh Nala (Rukhala Area)	-	0.1	-	-
	96.11.20-11	Pr- 7620	Jan Sukh Nala (Rukhala Area)	-	1.4	5.19	333
	96.11.20-12	Pr- 7621	Jan Sukh Nala (Rukhala Area)	-	2.3	10.15	395
	96.11.20-13	Pr- 7622	Jan Sukh Nala (Rukhala Area)	-	0.7	-	-
	96.11.20-14	Pr- 7623	Jan Sukh Nala (Rukhala Area)	-	2.5	14.88	447
	96.11.20-15	Pr- 7624	Jan Sukh Nala (Rukhala Area)	-	0.4	-	-
	96.11.20-16	Pr- 7625	Jan Sukh Nala (Rukhala Area)	-	3.2	14.32	385
	96.11.20-17	Pr- 7626	Jan Sukh Nala (Rukhala Area)	-	0.3	-	-
	96.11.20-18	Pr- 7627	Jan Sukh Nala (Rukhala Area)	-	6.4	36.38	513
	SaR-260	Pr- 420	Dhodha Wahan	Shale	1.4	2.3	164
	SaR-261	Pr- 421	Dhodha Wahan	Shale	0.2	<0.1	<50
	SaR-262	Pr- 422	Dhodha Wahan	Oil Shale	6.6	45.7	692
	SaR-263	Pr- 423	Dhodha Wahan	Siltstone	0.3	0.3	(90)
	SaR-264	Pr- 424	Dhodha Wahan	Oil Shale	7.2	43.0	601
	96.11.20-22	Pr- 7628	Dhodha Wahan	-	1.1	2.97	238
	96.11.20-23	Pr- 7629	Dhodha Wahan	-	0.2	-	-
	96.11.20-24	Pr- 7630	Dhodha Wahan	-	1.5	4.92	292
	96.11.20-25	Pr- 7631	Dhodha Wahan	-	2.4	7.79	296
	96.11.20-25	Pr- 7632	Dhodha Wahan	-	1.0	-	-
	96.11.20-26	Pr- 7633	Dhodha Wahan	-	0.2	-	-
	96.11.20-27	Pr- 7634	Dhodha Wahan	-	0.2	-	-
	96.11.20-28	Pr- 7635	Dhodha Wahan	-	0.4	-	-
	SaR-308	Pr- 994	Khanzaman Nala	Shale	5.3	35.0	662
	SaR-1	Pr- 25	Mari Salt Hill	Shale	0.1	-	-
	SaR-2	Pr- 12	Mari Salt Hill	Shale	0.2	-	-
	SaR-245	Pr- 402	Mari Salt Hill	Shale	0.3	0.3	100
	SaR-247	Pr- 404	Chilas Algad (Kalabagh)	Siltstone	0.4	<0.1	<50
	SaR-248	Pr- 405	Chilas Algad (Kalabagh)	Shale	0.4	<0.1	<50
	SaR-250a	Pr- 407	Chilas Algad Junction / Indus river (Kalabagh)	Shale	2.2	13.2	454
	SaR-250b	Pr- 408	Chilas Algad Junction / Indus river (Kalabagh)	Shale	1.7	7.1	430
	SaR-251	Pr- 409	Northern bank of Indus river, East of Kalabagh	Shale	1.7	5.6	324
	SaR-252	Pr- 410	Northern bank of Indus river, East of Kalabagh	Shale	0.3	<0.1	<50
	SaR-253	Pr- 411	Northern bank of Indus river, East of Kalabagh	Shale	2.3	13.3	583

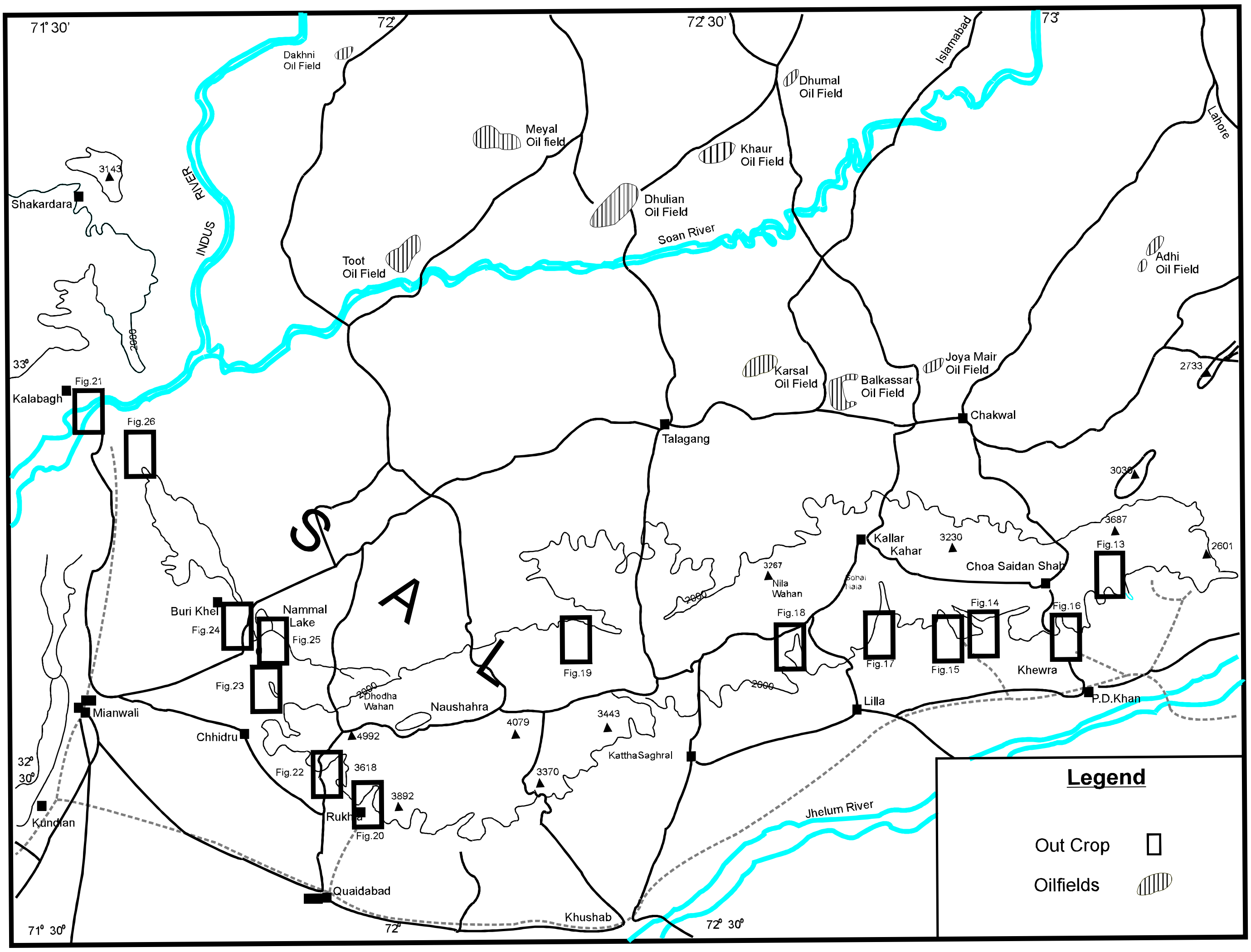


Figure 2 - Location Map of Outcrop Samples and oil fields

Table 2 - Organic Carbon and pyrolysis data of well core Samples from Salt Range Formation.

Field No.	Lab. No.	Location	Depth [feet]	Lithology	TOC [%]	GP [kg/t]	HI
8.10.85	Pr- 281	Dulmial -1	1918-1919	Oil Shale	23.6	163.00	775
8.10.85	Pr- 282	Dulmial -1	1952-1953	Oil Shale	20.5	189.00	922
8.10.85	Pr- 283	Dulmial -1	1954	Oil Shale	47.8	146.00	305
POL/Mud 87	Pr- 1097	Dhariala -1	606m	Gypsum Grey	5.2	-	-
POL/Mud 87	Pr- 1098	Dhariala -1	596m	Brown Limestone	9.8	8.42	85
POL/Mud 87	Pr- 1086	Kallar Khar -1	2170	Carbonaceous Oil Impregnated	-	5.40	-
-	Pr- 967	Karam Pur -1	7253	Dolomite Oil Impregnated	1.3	10.60	835
-	Pr- 968	Karam Pur -1	7254	Dolomite Oil Impregnated	1.6	13.30	842

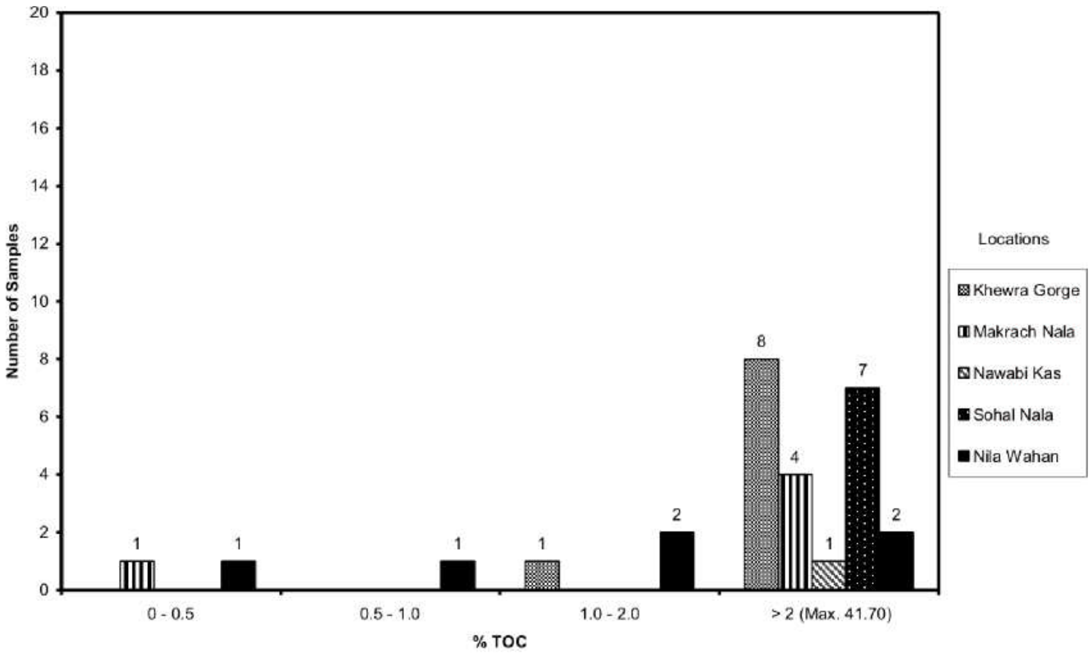


Figure 3 - Distribution of organic richness (% TOC) of outcrop samples of Eastern salt Range from Salt Range Formation.

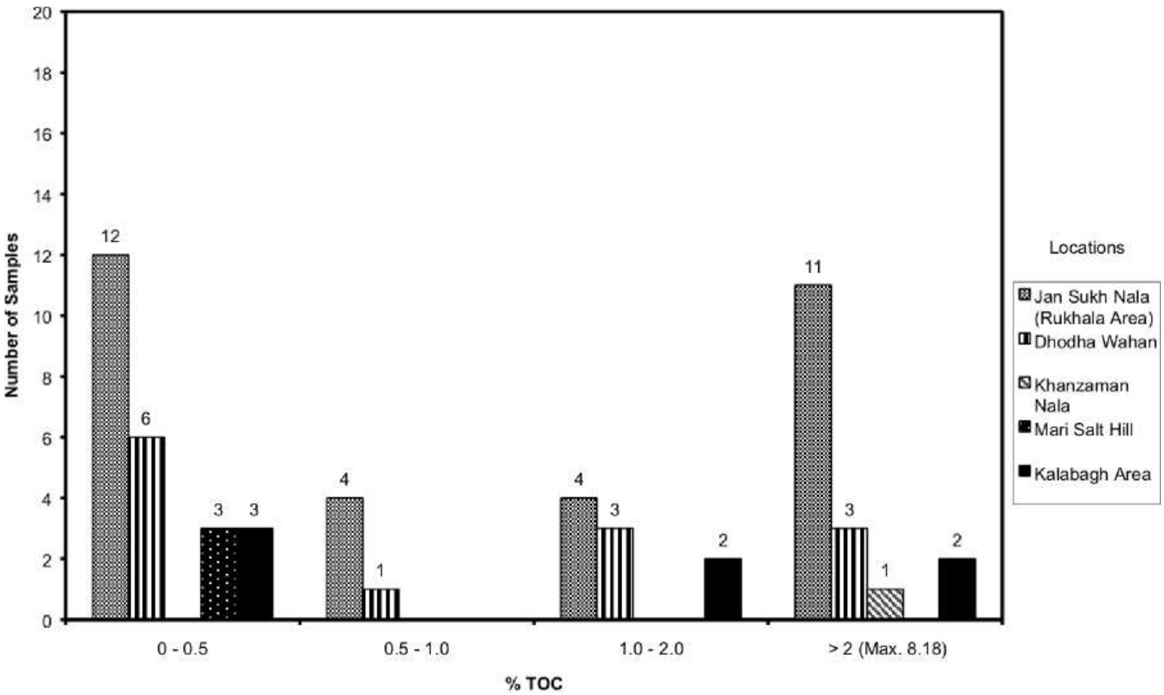


Figure 4 - Distribution of organic richness (% TOC) of outcrop samples of Western salt Range from Salt Range Formation.

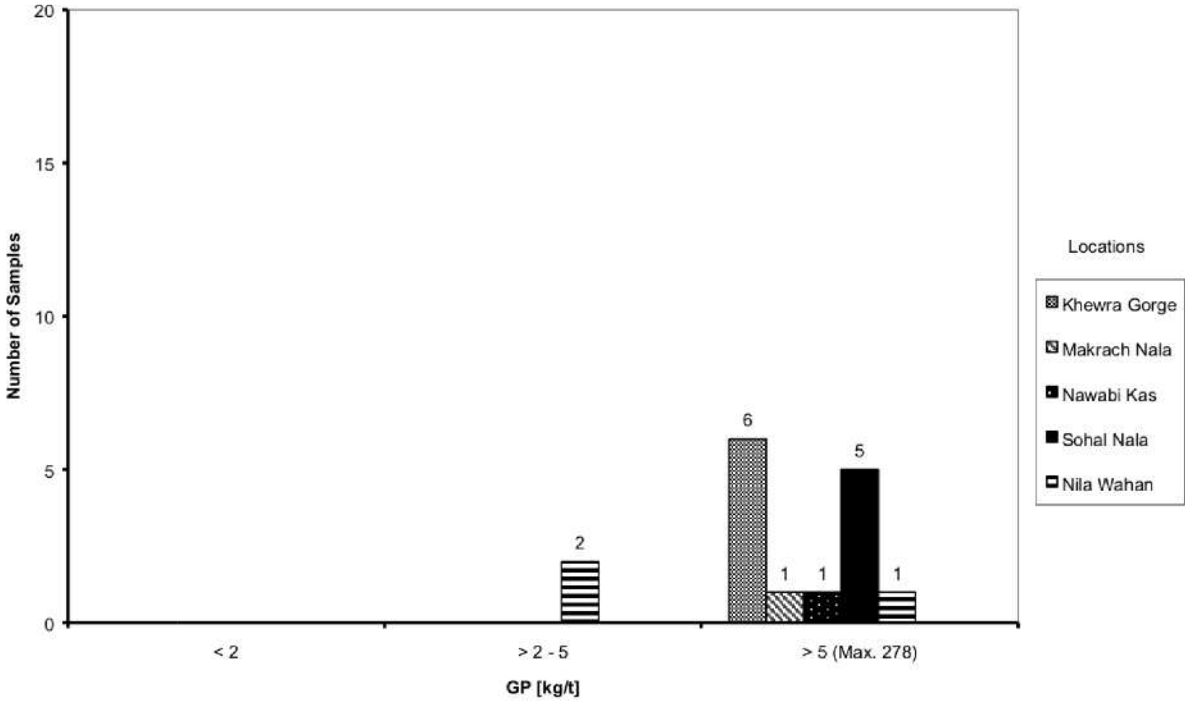


Figure 5 - Distribution of genetic potential (GP) of outcrop samples of Eastern salt Range from Salt Range Formation.

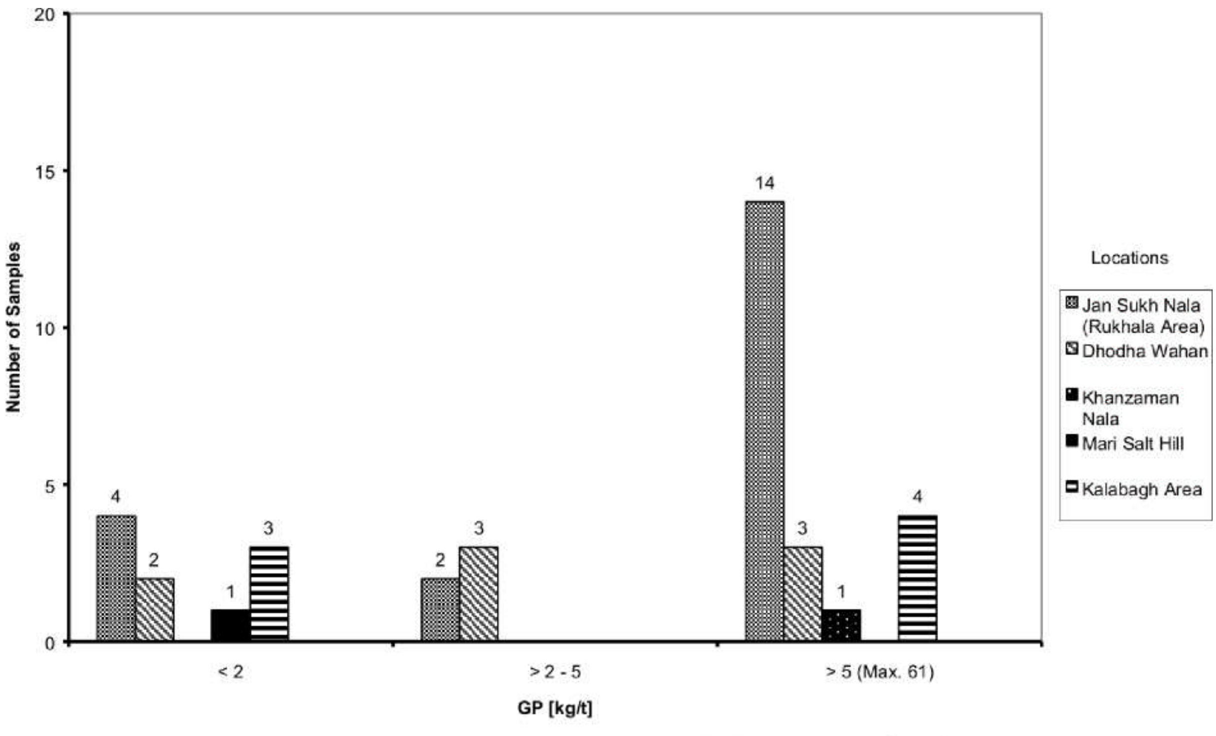


Figure 6 - Distribution of genetic potential (GP) of outcrop samples of Western salt Range from Salt Range Formation.

Table 3- Organic matter in outcrop samples from Salt Range Formation.

Field No.	Lab. No.	Location	EOM [ppm]	EOM/TOC [mg/g]	SHC [%]	AHC [%]	Pr/Ph	Pr/nC$_{17}$	Phy/nC$_{18}$	OEP$_{29}$
SaR-70	Pr- 67	Khewra Gorge	45763	127.11	27	27	1.06	1.50	2.20	n.d
96.11.13-10	Pr- 7593	Khewra Gorge	464	29.30	14	6	0.8	0.96	1.29	-
96.11.13-12	Pr- 7595	Khewra Gorge	4789	85.20	38	24	-	-	-	-
SaR-202	Pr- 358	Makrach Nala	39565	126.81	24	21	0.95	3.60	4.50	n.d
SaR-142	Pr- 90	Nawabi Kas	78922	254.58	14	34	n.d	n.d	n.d	n.d
SaR-211	Pr- 367	Sohal Nala	43389	190.30	11	13	0.53	1.04	1.40	n.d
SaR-228	Pr- 384	Jan Sukh Nala (Rukhala Area)	2955	75.19	34	25	1.50	0.69	0.54	1.10
SaR-229	Pr- 385	Jan Sukh Nala (Rukhala Area)	11613	141.96	44	38	1.00	1.10	1.40	n.d
SaR-230	Pr- 386	Jan Sukh Nala (Rukhala Area)	1491	107.26	40	35	0.93	0.88	1.30	n.d
SaR-231	Pr- 387	Jan Sukh Nala (Rukhala Area)	1157	109.15	43	38	1.20	0.83	0.89	1.00
SaR-237	Pr- 393	Jan Sukh Nala (Rukhala Area)	6051	203.73	42	33	1.10	0.66	0.88	1.00
96.11.20-8	Pr- 7617	Jan Sukh Nala (Rukhala Area)	10499	143.40	34	20	-	-	-	-
96.11.20-9	Pr- 7618	Jan Sukh Nala (Rukhala Area)	10641	677.70	31	18	-	-	-	-
96.11.20-12	Pr- 7621	Jan Sukh Nala (Rukhala Area)	3474	151.70	43	16	0.8	0.70	0.97	-
96.11.20-14	Pr- 7623	Jan Sukh Nala (Rukhala Area)	7793	274.40	42	21	0.8	0.90	1.18	-
96.11.20-18	Pr- 7627	Jan Sukh Nala (Rukhala Area)	13368	213.80	42	20	0.99	1.04	2.17	-
SaR-264	Pr- 424	Dhodha Wahan	10280	143.77	32	26	0.80	0.89	1.80	n.d
SaR-250a	Pr- 407	Chilas Algad Junction / Indus river (Kalabagh)	3051	104.81	34	32	1.60	0.37	0.34	1.10
SaR-253	Pr- 411	Northern bank of Indus river, East of Kalabagh	4180	183.33	41	29	0.81	0.37	0.83	1.10

Table 4- Organic matter in well core samples and oil seepages from Salt Range Formation.

Field No.	Lab. No.	Location	Depth	EOM [ppm]	EOM/TOC [mg/g]	SHC [%]	AHC [%]	NSO [%]	Pr/Ph	Pr/nC$_{17}$	Ph/nC$_{18}$	OEP$_{29}$
8/10/1985	Pr- 283	Dulmial -1	1954'	51730	292.0	23	33	44	0.60	0.72	1.90	n.d
-	Pr- 1086	Kallar Kahar -1	2170m	4082	-	28	19	53	0.72	-	1.93	
-	Pr- 967	Karam Pur -1	7253'	15007	1181.0	35	16	49	0.43	-	0.43	<1
POL/Mud 87	Pr- 968	Karam Pur -1	7254'	18893	1196.0	33	15	52	0.45	-	0.45	<1
-	Pp- 131	Kundal Oil Seep	Surface	-	-	45	24	31	-	-	-	-
-	Pp- 132	Salgi Nala Oil Seep	Surface	-	-	47	26	27	-	-	-	-
-	Pp- 507	Dom Nala Oil Seep	Surface	-	-	38	31	31	-	-	-	-

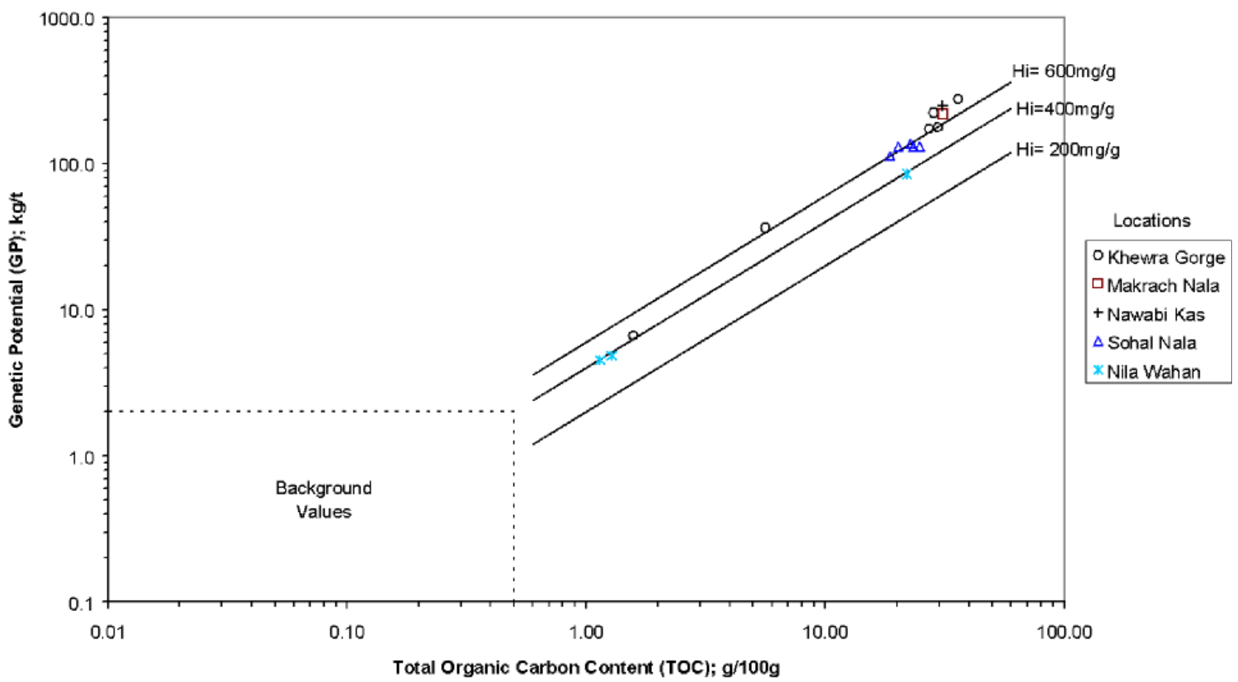


Figure 7- Cross plot of organic richness vs genetic potential of outcrop samples of Eastern Salt Range from Salt Range Formation.

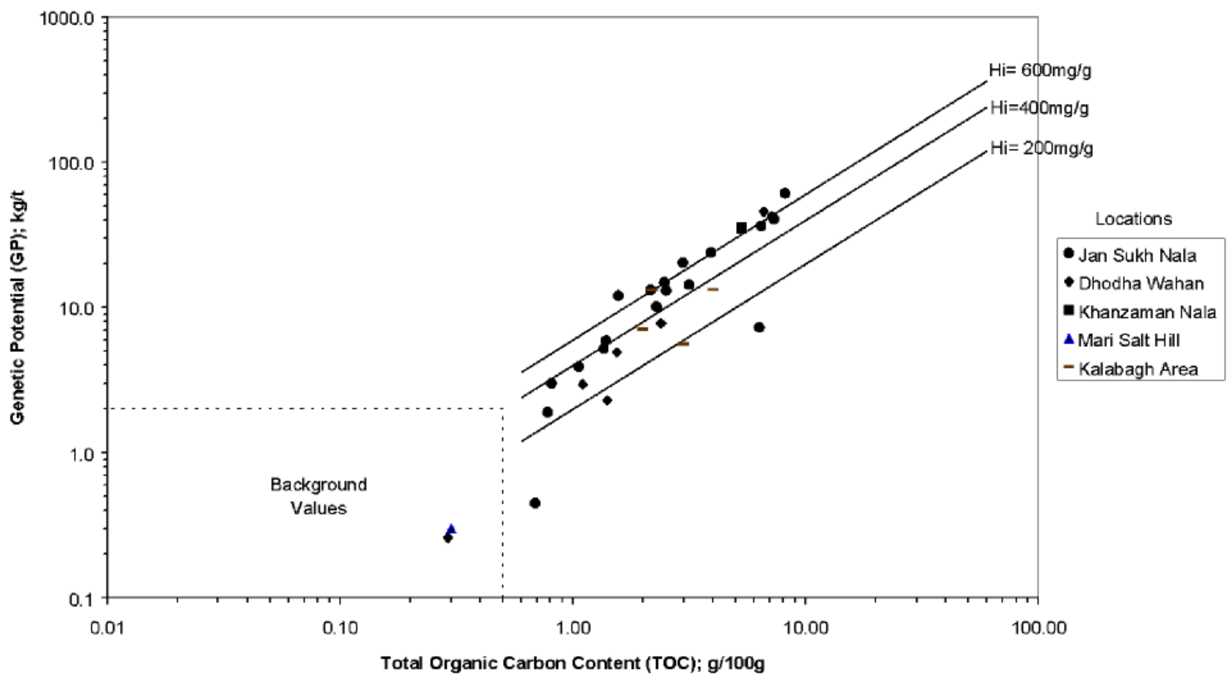


Figure 8- Cross plot of organic richness vs genetic potential of outcrop samples of Western Salt Range from Salt Range Formation.

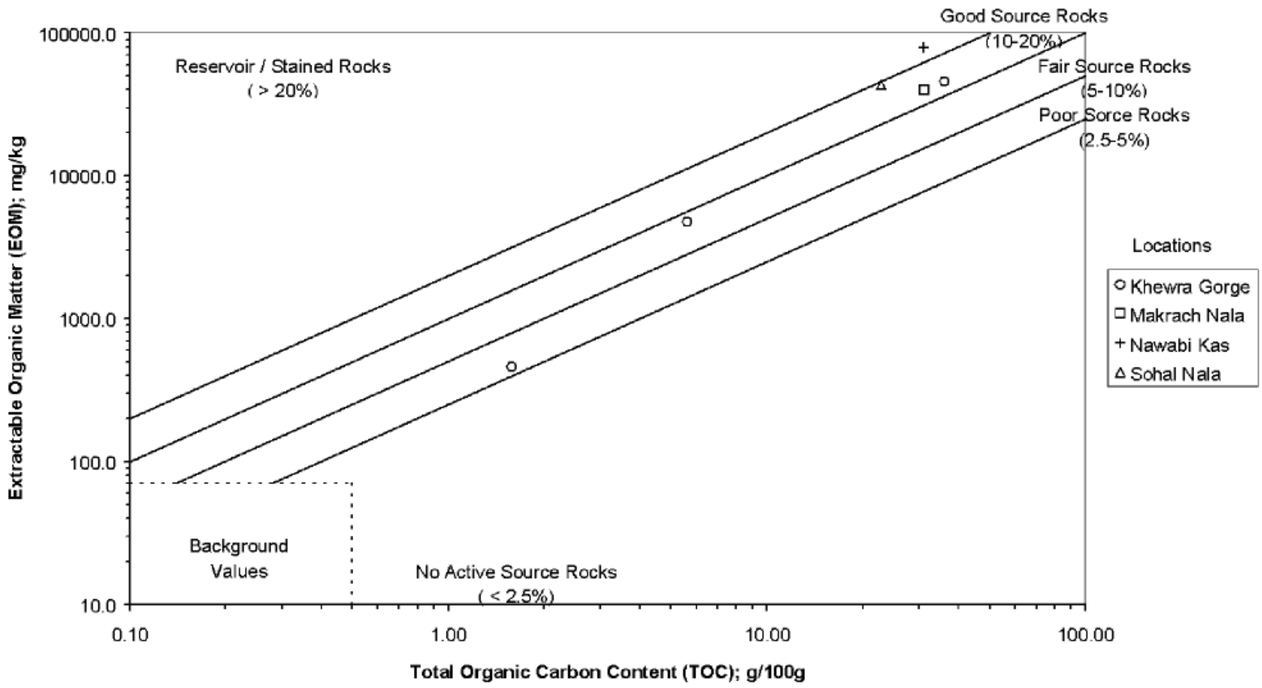


Figure 9- Organic richness (% TOC) vs amount of bitumen of outcrop samples of Eastern Salt Range from Salt Range Formation.

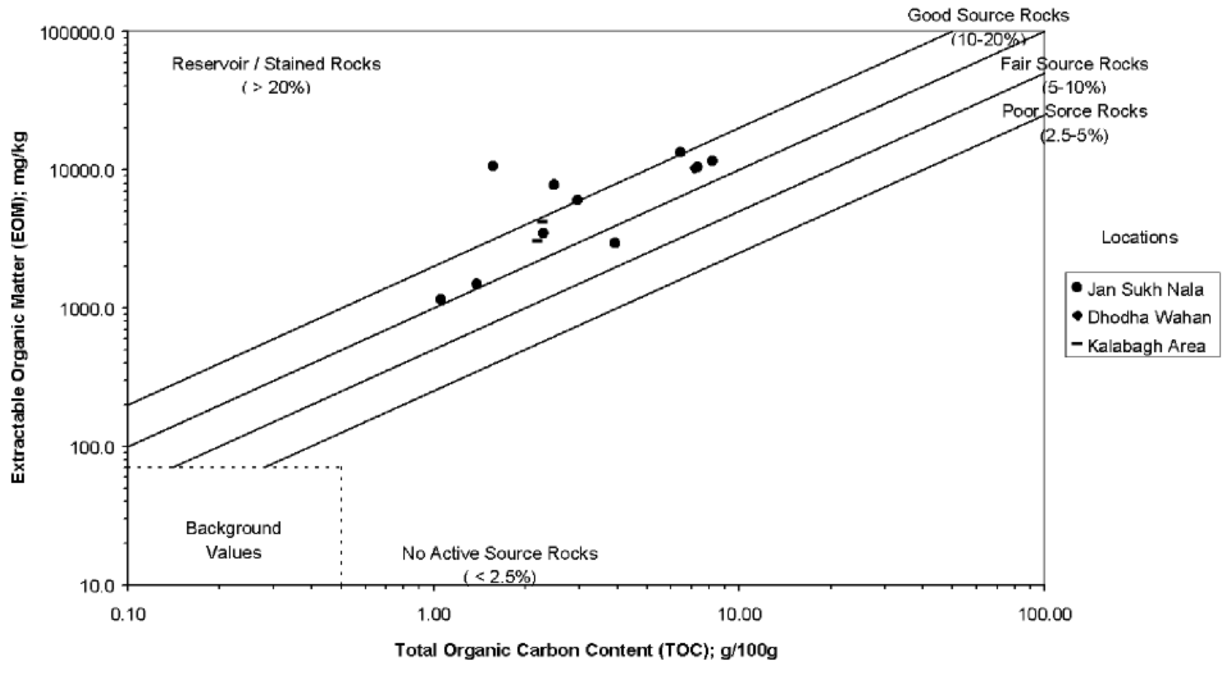


Figure 10- Organic richness (% TOC) vs amount of bitumen of outcrop samples of Western Salt Range from Salt Range Formation.

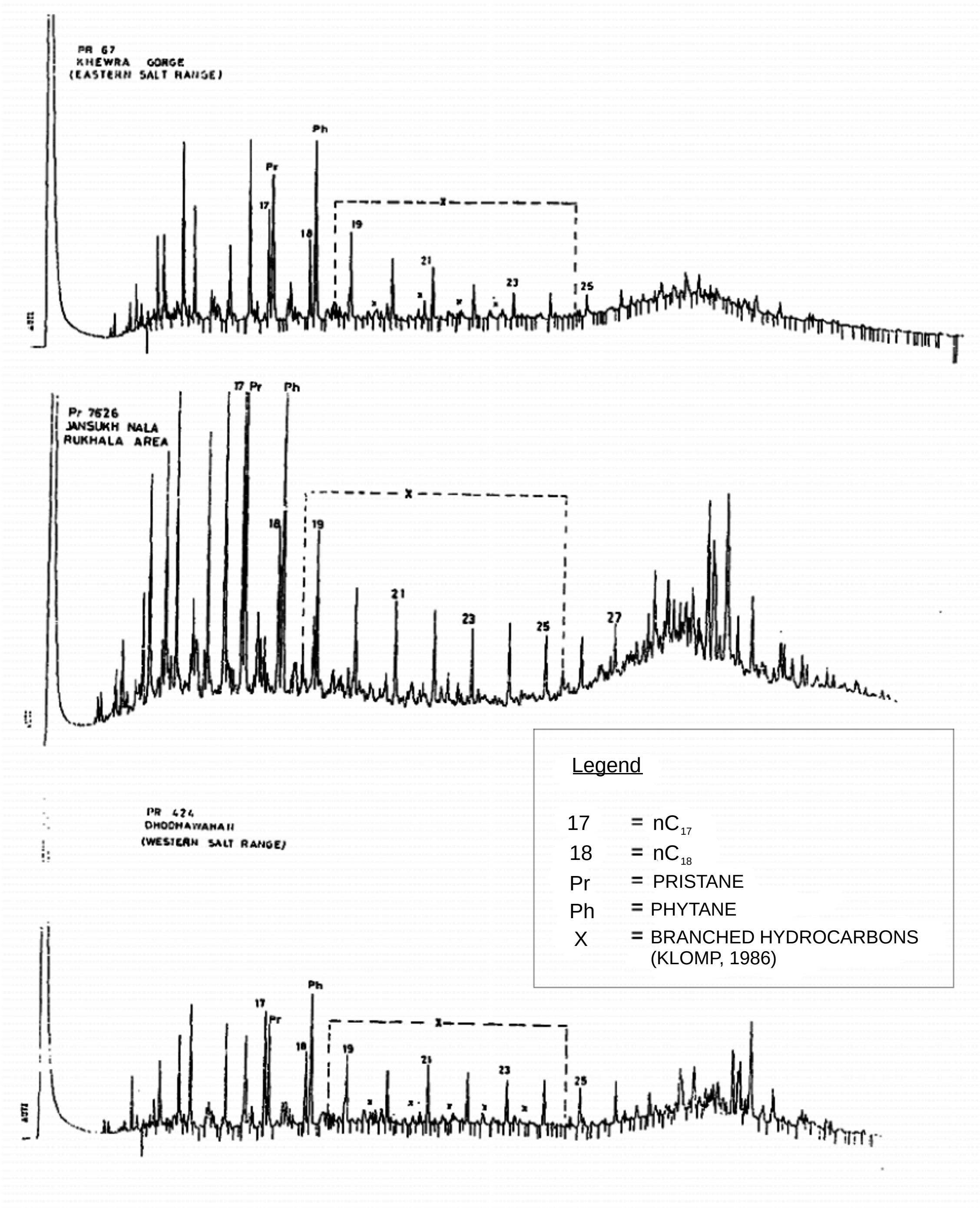


Figure 11 - Typical gas chromatograms for the saturated hydrocarbons of the outcrop samples from Salt Range Formation.

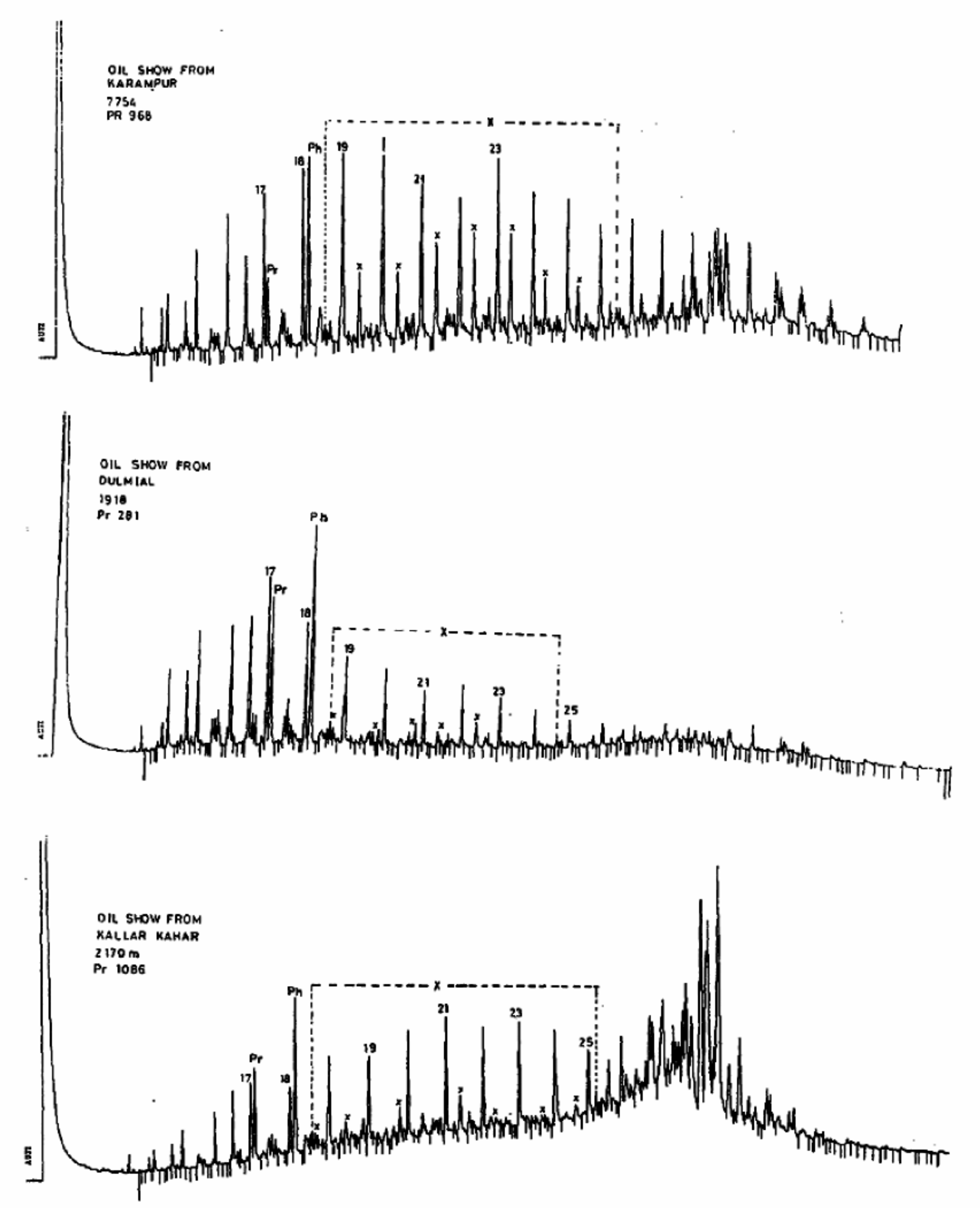


Figure 12 - Typical gas chromatograms for the saturated hydrocarbons of the core samples from Karam Pur-1, Dulmail-1 and Kallar Kahar-1.

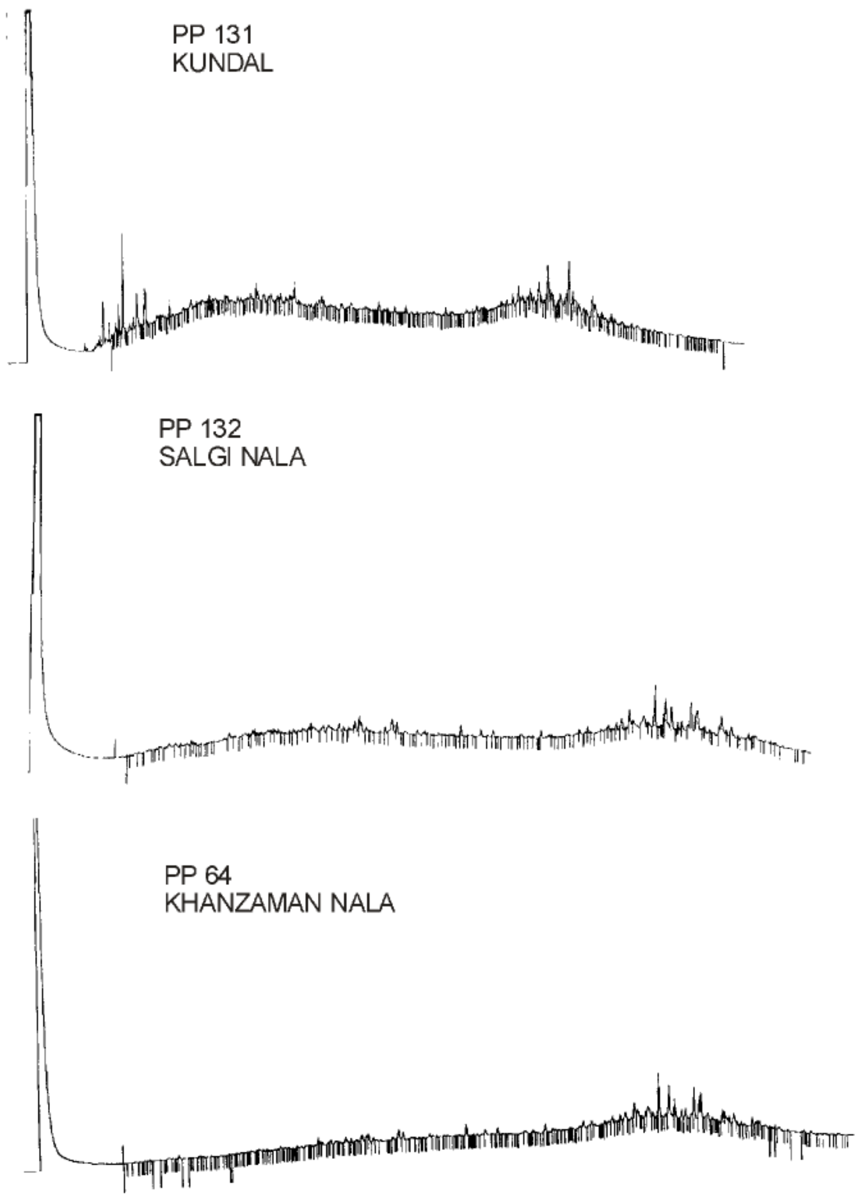


Figure 13 - Typical gas chromatograms for the saturated hydrocarbons of seepage oil samples from Kundal, Salgi Nala and Khanzaman Nala..

is characteristic of many lacustrine or hypersaline starta (Powell, 1978).

Biomarker Distribution

All the samples of Salt Range Formation (Table 5 and 6 Figure 14a, 14b, 15, 16 and 17) shows

- Predominance of C_{29} steranes
- Low concentrations of re- arranged steranes
- Predomionance of pentacyclic terpanes in core and outcrop samples
- Dominance of tricyclic triterpanes over pentacyclic triterpanes in seepage samples.
- The nearly identical biological markers compositions strongly suggest that these were derived from the same organic facies.

The abundance of C_{29} over C_{27} steranes would suggest normally a terrestrial source. However, in an evaporative environment conditions such as intense microbiological activity and highly preservative saline conditions could lead to a greater production of C_{29} steranes.

The same geochemical features are observed in Oman crudes generated from Precambrian source rocks (Grantham, 1986). C_{29} steranes predominance has also been reported for Siberian crude oils of Precambrian origin (Arefev, et al., 1980; Moldowan, et al., 1983; Fowler and Douglas, 1987). The absence or very low relative concentration of rearranged steranes was reported for Oman crudes (Grantham, 1986). The Pakistan and South Oman Salt Range basins were in close proximity, and were possibly continous during the Intra Cambrian (Gorin, et al., 1982).

Stable Carbon Isotope Distribution

The carbon isotopic composition of C_{15}+ saturate and aromatic fractions were determined and evaluated. The C_{15}+ saturate and aromatic hydrocarbon fractions of rock extracts indicated extraordinarily negative values ranging between -36.0 to -37.9‰ and -33.9 to -37.6‰ respectively (Table 5). The extracts of core samples from Dulmial-1 and Karampur-1 followed the same pattern and yielded values for saturated hydrocarbons -35.5 to -37.0‰ and aromatic hydrocarbon between -37.5‰ to -39.0‰ respectively. Such values are not unusual for late Precambrian organic matter (Schidhowski et al., 1983).

The carbon isotope values of the seepage oils from Kundal, Salgi Nala and Dom Nala show that these are isotonically lighter than the Dulamial-1 and Karam Pur-1 extracts. The $\delta^{13}C$ saturated hydrocarbons values range from -30.0 to -28.0 ‰.

The carbon isotopic values of the Karam Pur-1 and Dulmial-1 samples indicate that these oils are isotopically similar to the autochthonous bitumen of the Salt Range Formation outcropping in the Salt Range (Table 7).

The isotope ratios of the oil samples from producing fields of Potwar Basin and the rock bitumen of most of the potential source rocks from the same area are completely different from the Precambrian oil shales. Thus, there is no doubt that Salt Range Formation is not the source for Potwar Oils. A comparison of isotopic data of Potwar oils with Salt Range Formation extracts (Table 7).

Thermal Maturity

On the basis of many properties that are used to assess thermal maturity Salt Range Formation is considered to be immature.

Some of these properties are

- Low Vitrinite Reflectance value (0.29-0.46%)
- Low Tmax value (422 - 432˚C)
- Moderate proportion of C15+hydrocarbon (46%-26%)
- Low production Index (0.02-0.17)

The low value of Vitrinite Reflectance is observed in the core and outcrops sample. The maturation parameters derived from Rock-Eval (Espitalie et al., 1977), such as Tmax and Production index are especially low in samples collected from Khewra Gorge and Nila Wahan. The same pattern is repeated in Eastern salt range sections where Tmax value range varies from 422- 432˚C implying low maturation. The production index is fairly independent of organic matter type (Tissot and Welte, 1984). The production Index varies from 0.02-0.17 within the formation. The maturity is increasing from east to west (Table 8).

DISCUSSION

During our study, though we did not find any geochemical evidence regarding correlation of Potwar oils with Pre-Cambrian Salt Range Formation, still there exist evidences to suggest that the Salt Range Formation has generated oil. The extracts of Salt Range Formation differ from the Potwar oils in regular steranes and disteranes. Similarly there is a vast difference in their carbon isotope composition ($\delta^{13}C$ -27 and -36 ‰ respectively). The biomarkers data suggest that the Potwar oils are far more mature than the extracts of the Salt Range Formation, making oil/source rock correlation completely out of question. The oils from Joya Mair and Balkassar are different from other oils of the Potwar, not only in physical appearance, but also in bulk chemical composition. These are black, highly viscous oils with low API gravities. The results indicate that the oil shales of the Salt Range Formation are not source rocks for these oils. These oils bear some resemblance in geochemical characteristics with Potwar oils and can be considered as sub-group of Potwar oils.

The positive evidence, which indicates that the Salt Range Formation might have generated oil, comes from the seepage samples from Khanzaman Nala, Salgi Nala and Kundal. The isotope results indicate that these seep samples are not only lighter than Potwar and Kohat oils, but also lighter than other extracts of source rocks. In fact, these are intermediate between the Precambrian bitumens and the Potwar and Kohat oils. These seepages also reveal C_{29} steranes predominance over C_{27} and C_{28} which is characteristics of Precambrian oils (Peter et al., 2005). The petrographic results (Table 10) indicate that these shales have been deposited under strong reducing conditions in a restricted environment. The organic matter consists predominantly of pre-bitumen and contains major portion of liptinite. The vitrinite reflectance varies from 0.29-0.46%. These are immature and exhibit excellent source potential.

Table 5- Biological marker and isotopic distribution in outcrop, well cores and seepage from Salt Range Formation.

Field No.	Lab No.	Location	Sterane Type			Steranes Stereo Chemical Composition			Pentacyclic triterpanes	δ C SHC	δ C ARO
			ISO	Normal	Rearranged	C27	C28	C29	C29/C30	[ppt]	[ppt]
.	Pr- 283	Dulmial -1	43	26	31	30	29	41	0.60	-	-
-	Pr- 968	Karam Pur -1	63	37	0	13	15	72	1.02	-	-
SaR-70	Pr- 67	Khawra Gorge (Eastern Salt Range)	39	19	42	21	39	40	0.59	-36.0	-33.9
SaR-237	Pr- 393	Jan Sukh Nala (Rukhala Area, Western Salt Range)	41	15	44	19	19	62	0.60	-37.9	-37.9
SaR-264	Pr- 424	Dhodha Wahan (Western Salt Range)	51	49	0	14	17	69	0.65	-36.9	-37.6
-	Pp- 131	Kundal Oil Seep	48	25	27	22	18	60	0.70	-30.0	-26.0
-	Pp- 132	Salgi Nala Oil Seep	46	18	36	21	17	62	0.96	-30.6	-26.3
-	Pp- 507	Dom Nala Oil Seep	50	26	24	18	21	61	-	-28.0	-23.3

Table 6- Main geochemical characteristics of extract from Salt Range Formation.

Location	Isoprernoids	X Compounds	Sterane Carbon Number	Rearranged Sterane Contents
Dulmial -1	Phytane dominant over Pristane	Present	Strong C_{29} Predominance	Low
Karam Pur -1	Phytane dominant over Pristane	Present	Strong C_{29} Predominance	Absent
Khewra Gorge (Eastern Salt Range)	Pristane dominant over Phytane	Present	C_{29}, C_{28} equivalent	High
Jan Sukh Nala (Rukhala Area, Western Salt Range)	Pristane dominant over Phytane	Present	Strong C_{29} Predominance	High
Dhodha Wahan (Western Salt Range)	Phytane dominant over Pristane	Present	Strong C_{29} Predominance	Absent

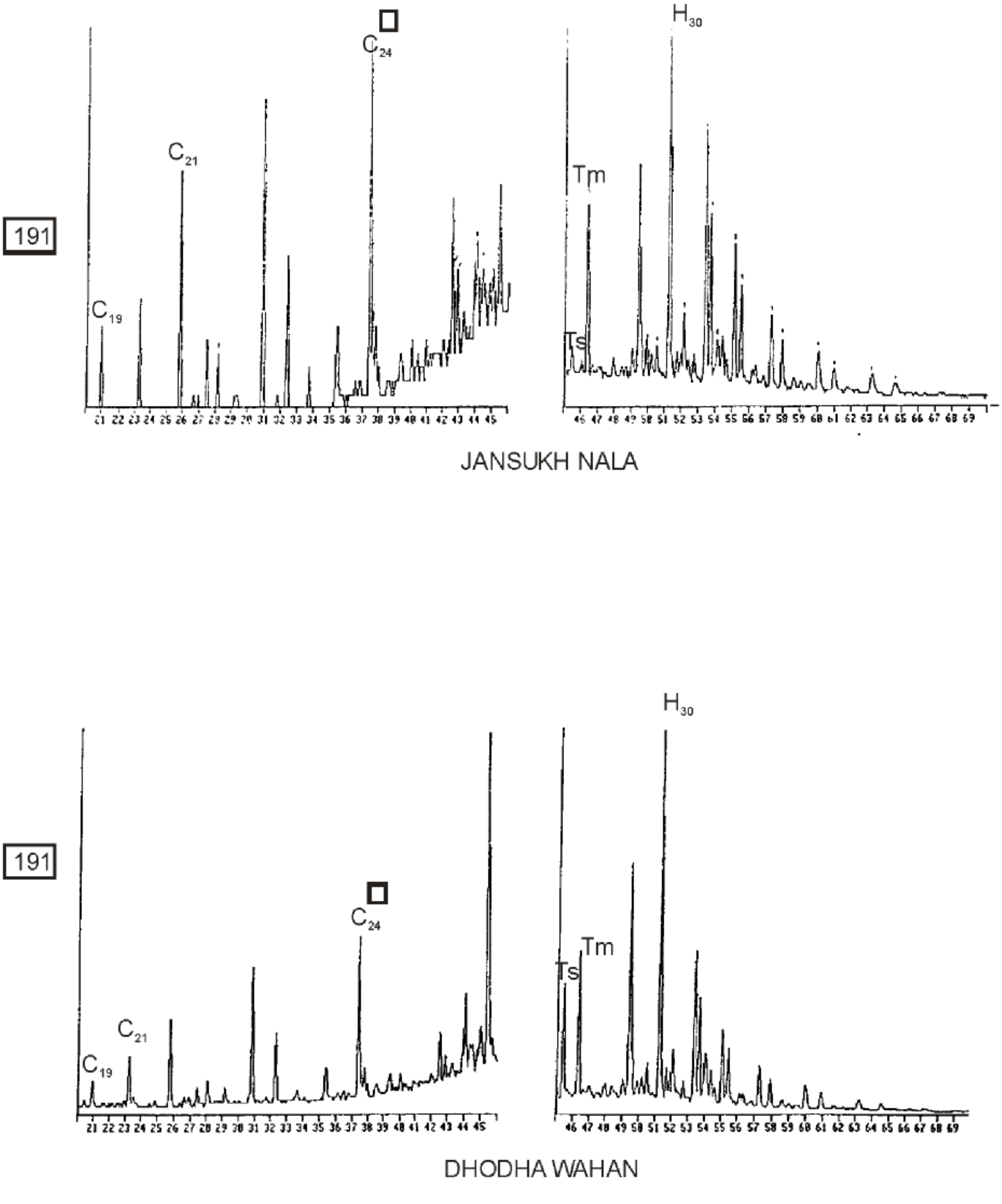


Figure 14a - Terpanograms (m/z 191) of well core and outcrop samples from Salt Range Formation.

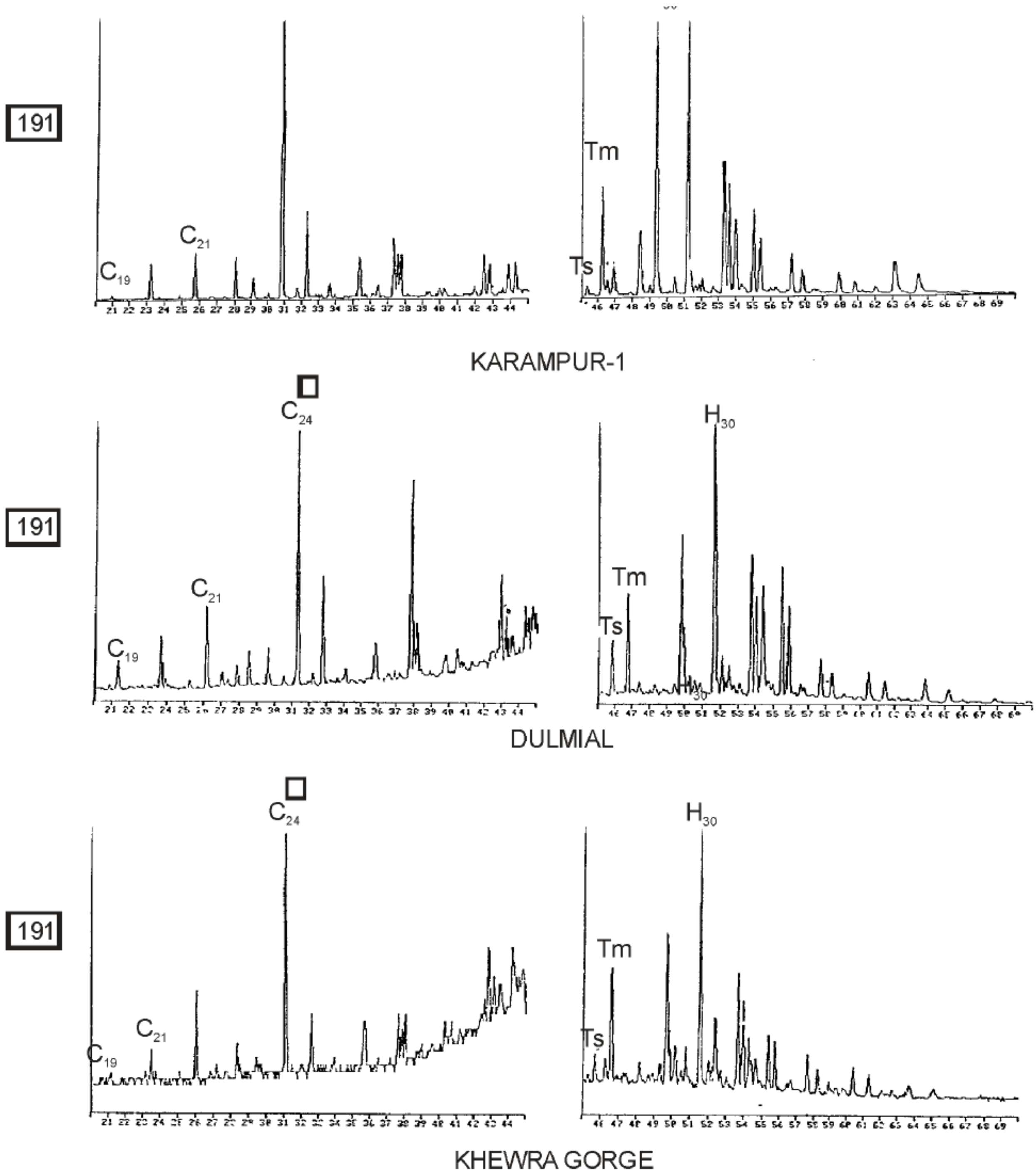
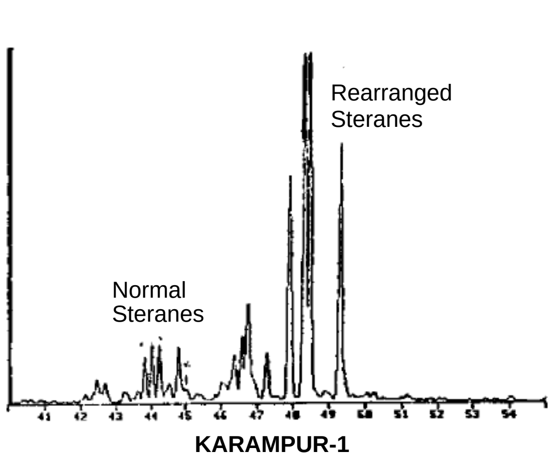
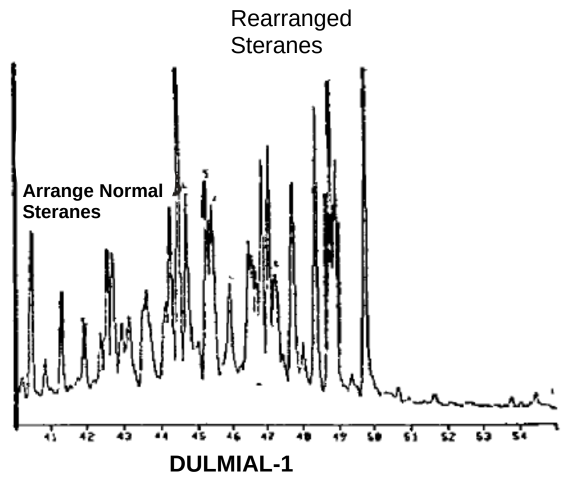
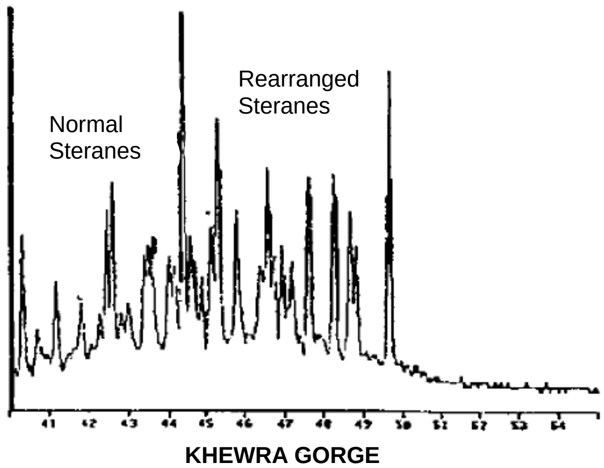
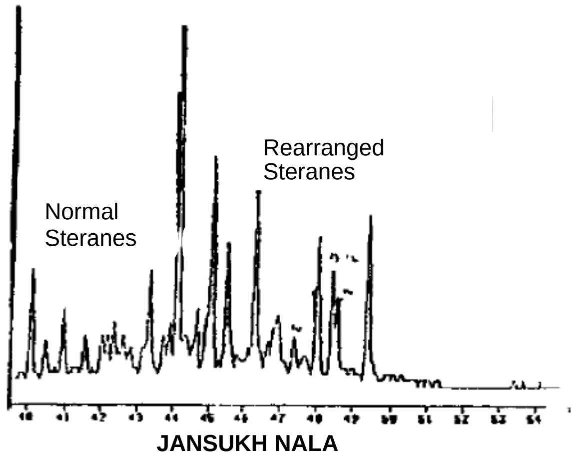


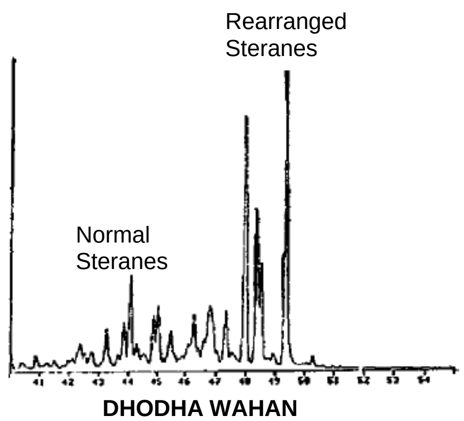
Figure 14b - Terpanograms (m/z 191) of well core and outcrop samples from Salt Range Formation.











Peak Designation	Compound Type		
a	13β, 17α - dicholestane	(20S)	Re-arranged [illegible]
b	13β, 17α - dicholestane	(20R)	
c	13α, 17β - dicholestane	(20S)	
d	13α, 17β - dicholestane	(20R)	
e	24-methyl - 13β, 17α - dicholestane	(20S)	Re-arranged [illegible]
f	24-methyl - 13β, 17α - dicholestane	(20R)	
g	24-methyl - 13α, 17β - dicholestane	(20S)	
h	24-methyl - 13α, 17β - dicholestane	(20R)	
i	24-ethyl - 13β, 17α - dicholestane	(20S)	Re-arranged [illegible]
k	24-ethyl - 13β, 17α - dicholestane	(20R)	
l	24-ethyl - 13α, 17β - dicholestane	(20S)	
m	24-ethyl - 13α, 17β - dicholestane	(20R)	
1	5α, 14α, 17α - Cholestane	(20S)	Normal [illegible]
2	5β, 14α, 17α - Cholestane	(20S/R)	
3	5α, 14β, 17β - Cholestane	(20R)	
4	5α, 14β, 17β - Cholestane	(20S)	
5	5α, 14α, 17α - Cholestane	(20R)	
6	5α, 14α, 17α - Methyl Cholestane	(20S)	Normal [illegible]
7	5β, 14α, 17α - Methyl Cholestane	(20S/R)	
8	5α, 14β, 17β - Methyl Cholestane	(20R)	
9	5α, 14β, 17β - Methyl Cholestane	(20S)	
10	5α, 14α, 17α - Methyl Cholestane	(20R)	
11	5α, 14α, 17α - Ethyl Cholestane	(20S)	Normal [illegible]
12	5β, 14α, 17α - Ethyl Cholestane	(20S/R)	
13	5α, 14β, 17β - Ethyl Cholestane	(20R)	
14	5α, 14β, 17β - Ethyl Cholestane	(20S)	
15	5α, 14α, 17α - Ethyl Cholestane	(20R)	

Figure 15 - Steranes (m/z 217)distribution of well core and outcrop samples from Salt Range Formation.

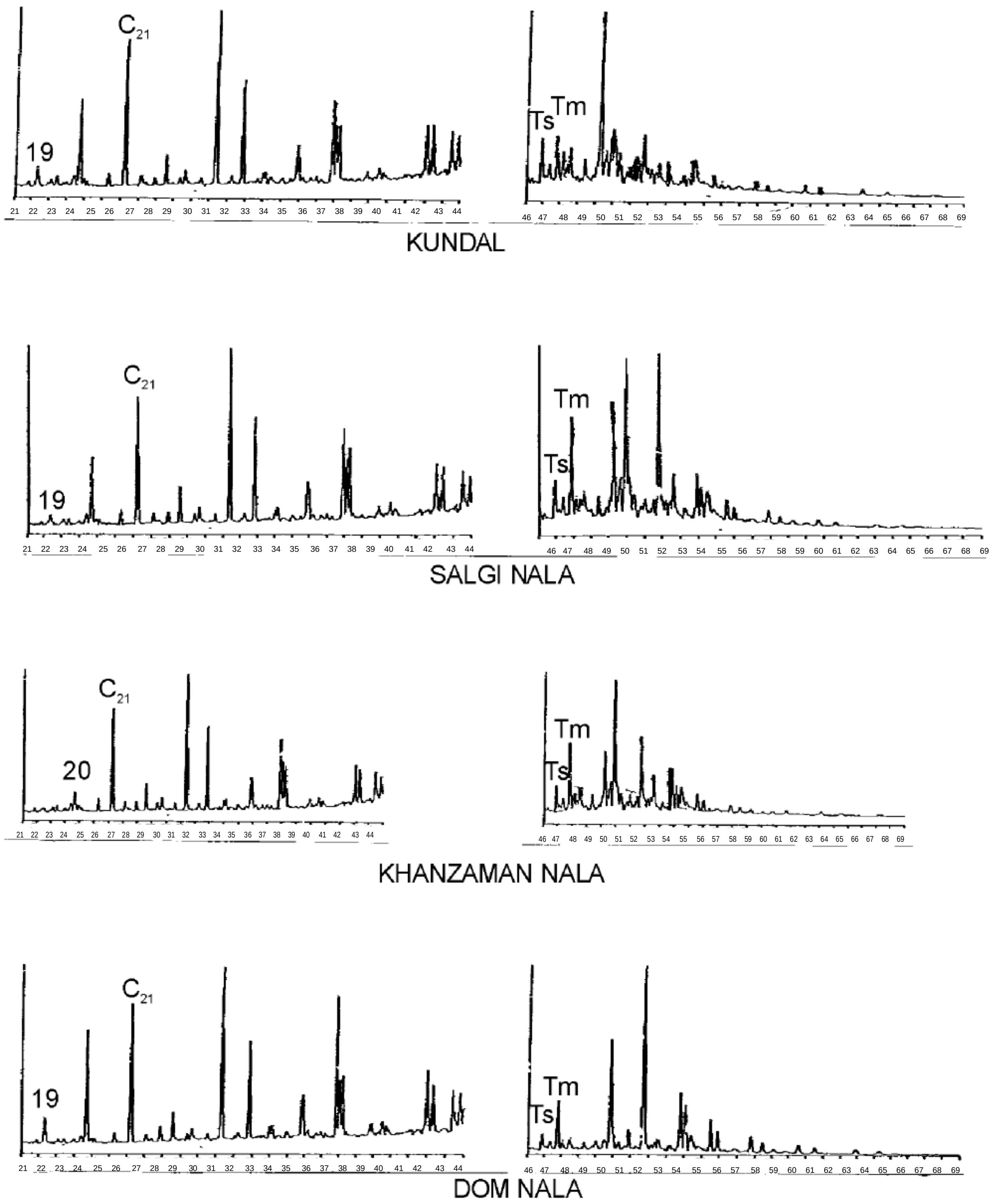


Figure 16 - Terpanograms (m/z 1991) of seepage oil samples from Salt Range Formation.

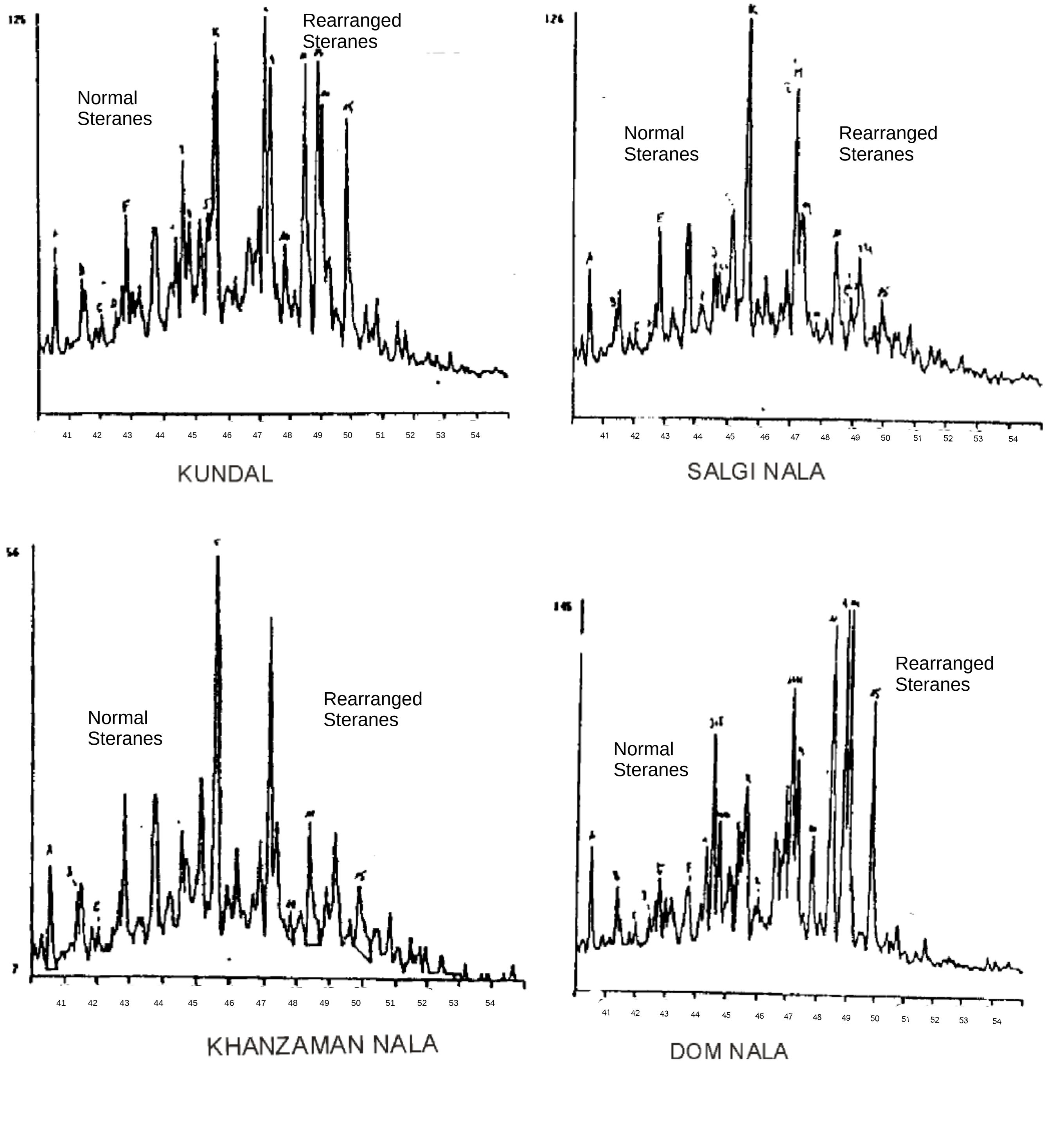


Figure 17 - Steranes (m/z 217) distribution in seepage oil samples from Salt Range Formation.

Table 7- Comparision of isotopic data from Salt Range Formation, oils from Potwar Basin and their probable source i.e. Patala Formation.

	Salt Range Formation								Patala Formation			-	
Lab. No.	Pr-60	Pr-358	Pr-398	Pr-424	Pr- 645	Pp-132	Pr-283	Pr-968	Pr-63	Pr-95	Pr-1074/75	Pp-263	Pp-222
Location	-	-	-	-	Khan Zaman Nala (Seep)	Salgi Nala (Seep)	Dulmial -1	Karampur -1	-	-	Dhurnal -3	Adhi -5	Toot -15
δ^{13}C SHC [ppt]	-33.9	-35.0	-37.2	-37.6	-31.0	-30.6	-35.5	-37.0	-28.4	-26.1	-21.9	-23.0	-25.6
δ^{13}C AHC [ppt]	-36.0	-36.4	-37.9	-37.5	-26.8	-26.3	-37.5	-39.0	-28.8	-24.7	-18.2	-21.1	-20.9

Table 8 - Vitrinite reflectance (Rr) and Tmax of surface samples and cores of Dulmial-1 from Salt Range Formation

Field No.	Lab. No.	Location	Rr [%]	T_{max} [°C]
SaR-70	Pr- 67	Khewra Gorge	0.32	423
SaR-205	Pr- 361	Khewra Gorge	0.30	432
SaR-202	Pr- 358	Makrach Nala	0.29	-
SaR-142	Pr- 90	Nawabi Kas	0.36	-
SaR-21 1	Pr- 367	Sohal Nala	0.46	-
-	Pr- 7604	Nila Wahan	-	423
-	Pr- 7605	Nila Wahan	-	422
96-11-20-11	Pr- 7670	Jan Sukh Nala (Rukhala Area)	-	427
96-11-20-24	Pr- 7630	Dhodha Wahan	-	426
-	Pr- 281	Dulmial -1	0.34-0.37	-

The oil yield is partly more than 20% of the rock weight.

The other positive evidence regarding the generation of oil from the Salt Range Formation comes from the Karam Pur-1 well, which is situated south of Salt Range. The gas chromatogram of the Karam Pur-1 oil was different from others and contained same additional peaks which are typical of Pre-Cambrian oils as these compounds are also reported from Precambrian oils of Oman and Siberia. A comparison of crude oil characteristics of Oman with Karam Pur-1 oil is presented (Table 9).

The main geochemical features which characterise our Precambrian crude are:

1. The presence of iso-alkanes between n-alkanes.
2. Pristane/ Phytane ratio less than 1.
3. Strong predominance of C_{29} steranes.
4. Isotope values in the range -36.0 ‰ to -37.0 ‰.

The above geochemical signatures are present in Oman and Siberian oils and are also exhibited by the extracts of Salt Range Formation and oil shows of Karam Pur-1 well.

The heavy oil has also been reported to be generated from Pre-Cambrian source rocks in Bikaner basin of India. The geochemical data from India was not available to make any comparison, but the information tentatively is suggestive of a possibility of finding oil source from the Salt Range Formation in the Punjab Monocline.

CONCLUSIONS

Examination of geochemical data reveals that:

1. The Salt Range Formation is organic rich and exhibits excellent source rock characteristics.
2. The biomarker and isotope data of seepage samples of Salgi Nala, Khanzaman Nala and Kundal indicate that part of these seepages might have been sourced from the Salt Range Formation.
3. The high grade oil shales developed near the top of the formation are mostly lenticular. But the low grade oil shales developed in the middle part of the formation are laterally more persistent and can be a prolific oil source if attaining an appropriate maturity level.

REFERENCES

Ahmad, R., S.M. Ali, and J. Ahmad, 1994, Review of petroleum occurrence prospects of Pakistan with special reference to adjoining basins of India, Afghanistan and Iran. Pakistan Journal of Hydrocarbon Research, v. 6, no. 1 and 2, p. 7-18.

Ahmad, W.,S. Alam, 1990, Organic Geochemistry of Crude Oil from Potwar- Kohat Region, HDIP-BGR internal

Table 9- Comparison of Oman crude with Karam Pur-1 oil show and seepage oil from Salgi Nala of Pakistan.

Location	API Gravity	Isoprenoids	X Compounds	Sterane Carbon Number	Rearranged Sterane Contents	Carbon Isotope Ratio [ppt]
Oman	25-30	Phytane dominant over Pristane	Present	Strong C_{29} Predominance	Absent	-36.0
Karam Pur -1	-	Phytane dominant over Pristane	Present	Strong C_{29} Predominance	Absent	-36.0
Salgi Nala Oil Seep	17	-	-	Strong C_{29} Predominance	Low	-30.6

Table 10- Composition of the Organic Matter of Surface rock samples from Potwar Basin.

Formation	Well No	Depth	Lithology	TOC %	Inertinite	Vitrinite	Liptinite	Prebitumen	Solid Bitumen
Salt Range	Dulmial-1	585 m	Oil shale	23.4	-	/	-	-	X
Salt Range	Dulmial-1	595 m	Oil shale	20.2	-	/	-	-	X
Salt Range	Dulmial-1	596 m	Oil shale	17.7	-	-	-	-	X

project report.
Al-Marjeby, A. And D. Nash, 1986, a summary of the geology and oil habitat of the eastern park hydrocarbon province of South Oman, Marine and Petroleum Geology, v. 3, p. 306-315.
Arefev, O.A., M.N. Zabrodina, V.M. Makushina, and A.A. Petrov, 1980, Relic tetra and pentacyclic hydrocarbons in the old oils of the Siberian Platform. Izv. Akad. Nauk. SSR, Ser. Geol, v. 3, p. 135-140.
Espitalie, J.,J. L. LaPorte, M. Madec, F. Marquis,P. Leplat, J. Paulet ,and A. Boutefeu. 1977, Methode rapide de caracterisation des roches meres de leur potentiel petrolier et de leur degre d' evolution. Rev. de l' Inst. Francias Petrol., v. 32 (1), p. 23-42.
Fowler, M.G., And A.G. Douglas, 1987, Saturated hydrocarbon biomarkers in oils of Late PreCambrian age from eastern Siberia. Org. Geochem., V. 11, p. 201-213.
Gorin, G.E., L.G. Racz, and M.R. Walter, 1982, Late PreCambrian-Cambrian sediments of Huqf group. Sultanate of Oman. AAPG Bull., v. 66 (12), p. 2609-2627.
Grantham, P.J., 1986, The occurrence of unusual C27 and C29 sterane predominances in two types of Oman crude oil. Org. Geochem., V. 9, p. 1-10.
Jackson, J.M., M.D. Muir and K.A. Plumb, 1987, Geology of the Southern Mc Arthur basin, Northern Territory, Geology and Geophysics Bulletin, p. 220, 173.
Klomp, U.C., 1986, the chemical structure of a pronounced series of iso-alkanes in south Oman crude oils, in D. Leythaeuser and J. Rullkotter, eds., Advances in organic geochemistry (1985): Oxford, Pergamon, p. 807-814.
Meyerhoff, A.A., 1980, Geology and Petroleum field in Proterozoic and Lower Cambrian strata, Lena - Tunguska Petroleum Province, eastern Siberia, USSR, in M.T. Halbouty, ed., Giant oil and gas fields of the decade, 1968-78: AAPG, Memoir 30, p. 225-252.
Moldowan, J.M., W.K. Seifert, and E.J. Gallegos, 1983, Identification of extended series of tricyclic terpanes in petroleum. Geochim. Cosmochim. Acta, 47: p. 1531-1534.
Muir, M.D., 1974, Microfossils of the middle Precambrian Mc Arthur Group, Northern Territory, Australia: Origin of life, v.5, p. 143-173.
Murray, G.E.,M.J. Kaczor, and R.E. Mc Arthur, 1980, Indigenous Precambrian Petroleum Revisited: AAPG Bulletin, v.64, p.1681-1700.
Peter, K.E., B.G. Rohrback, and I.R. Kaplan, 1980, Laboratory-simulated thermal maturation of recent sediments. In: A. G, Dougles and Maxwell (Editors), Advances in Organic geochemistry, 1979. Physics and chemistry of the earth, 12. Pergamon, Oxford, p. 547-557.
Porth, H., W. Seeman, Results of Organic geochemical analyses on surface rock samples Int. Report HDIP/GAG, November 1987, 26p.
Powell, T.G., 1978, An assessment of the hydrocarbon source rock potential of the Canadian Arctic Islands: Geological Survey of Canada Paper 78-12, 82p.
Schidhowski, M., J.M. Hayes, and I.R. Kaplan, 1983, Isotopic inferences of ancient biochemistries: carbon, sulpur, hydrogen and nitrogen. In: J.W.Schopf (Editor), Earths Earliest Biosphere: Its Origin and Evolution. Princeton university press, Princeton, N.J., P. 149-186.
Seeman, W., W. Ahmad, and S. Alam, 1988, Petroleum geochemistry of potential source rock samples and their correlation with oil families of upper and middle Indus basin, HDIP-BGR internal project report.
Tissot, B.P.; D.H. Welte, 1984, Petroleum formation and occurrence Spring Verlag. Heidelberg, 699p.

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