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Source Rock Potential of Oil Shale Deposits in Kohat Basin, Pakistan

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ABSTRACT

Jatta Gypsum in Kohat basin (Kohat and Karak districts, North Western Frontier Province) contains oil shale horizon at six widely scattered localities. Generally, the oil shale horizon occurs at about 27 to 30m below the top of Jatta Gypsum. The thickness of the oil shale is 0.5 to 1.5m with total organic carbon (TOC) upto 25% and oil-yield 20%.

Another oil shale horizon with average TOC upto 13% has been located in Nikki Pail area, west of the main oil shale occurrences, in a transitional zone at the top of Kuldana Formation.

The average composition of most of these shale occurrences is much above the critical limit of TOC for classifying them as oil shale. However their limited lateral extent and thickness are constraints in their economic exploitation as oil shale. They may act as excellent potential source rocks if present at depth with lateral continuity.

Besides oil shale, oil impregnated rocks and oil seeps have also been reported from the area.

INTRODUCTION

The oil shale outcrops mainly occur in Kohat-Karak area covered by Survey of Pakistan topographic sheets 38/O and 38/K. The occurrence of oil shale deposits in the region was reported by Rashid et al. (1965), Meissner et al. (1974) and Porth and Raza (1990). The preliminary investigations by Porth and Raza (1990) indicated high quality oil shale horizon in Jatta Gypsum in Kohat basin. The present study was undertaken to assess the thickness and lateral extent of these deposits. A geological party comprising geologists of Hydrocarbon Development Institute of Pakistan (HDIP) and Geological Survey of Pakistan (GSP) surveyed 1700 square kilometre area for checking 31 sections and located six oil shale outcrops in the lower middle part of the Jatta Gypsum and one of the transitional zone between Kuldana Formation and Kohat Limestone (Figure 1). Forty surface channel and composite samples were collected from these occurrences for determination of total organic content and other geochemical parameters. The results rate these shales as an excellent source rock. However, the commercial extraction of oil from the oil shales is not economical due to their limited thickness and lateral extent.

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REGIONAL GEOLOGICAL SETTING

The Kohat basin is filled with Eocene to Recent sediments of more than 6km thickness (Meissner et al., 1974). The Eocene sequence is the youngest marine deposition on the northern edge of the Indus basin. Its lower part in Kohat-Karak region is distinctly divided into two prominent facies. The northern facies is mainly composed of carbonate and clastic sequences, while the evaporites comprise the southern facies exposed in southern Kohat area. Bahadur Khel Salt (southern facies) and Panoba Shale (northern facies) are considered to be the oldest Eocene rock units, which are overlain by Jatta Gypsum and Shekhan Limestone, respectively. The Kuldana and Kohat Formations make up the upper part of the Eocene sequence in the entire basin (Shah, 1977). The evaporite sequence represents deposits of a hypersaline, remnant land locked sea comparable to the present Persian Gulf. The Eocene succession is unconformably overlain by Miocene-Pliocene clastics of continental origin. The generalized stratigraphic succession of the region is illustrated in Table 1.

The Kohat basin is characterised by complex structures exhibiting one principal direction of deformation. Generally all the structures show E-W orientation and southward vergence. The deformation is manifested in fan folds, isoclinal folds, thrust faults alongwith small scale features, viz., drag folds, diapiric movement of salt, flowage of clay and contortion of gypsum beds. The structural complexities become more severe by salt diapirism. Additionally, the high plasticity and dehydration of anhydrite beds gave rise to complex folding and thrusting spread over large areas.

The Eocene strata generally occur in the core of tight, narrow and thrust bounded anticlines. The features related to salt diapirism, and tight anticlines separated by broad valleys representing synclines are common.

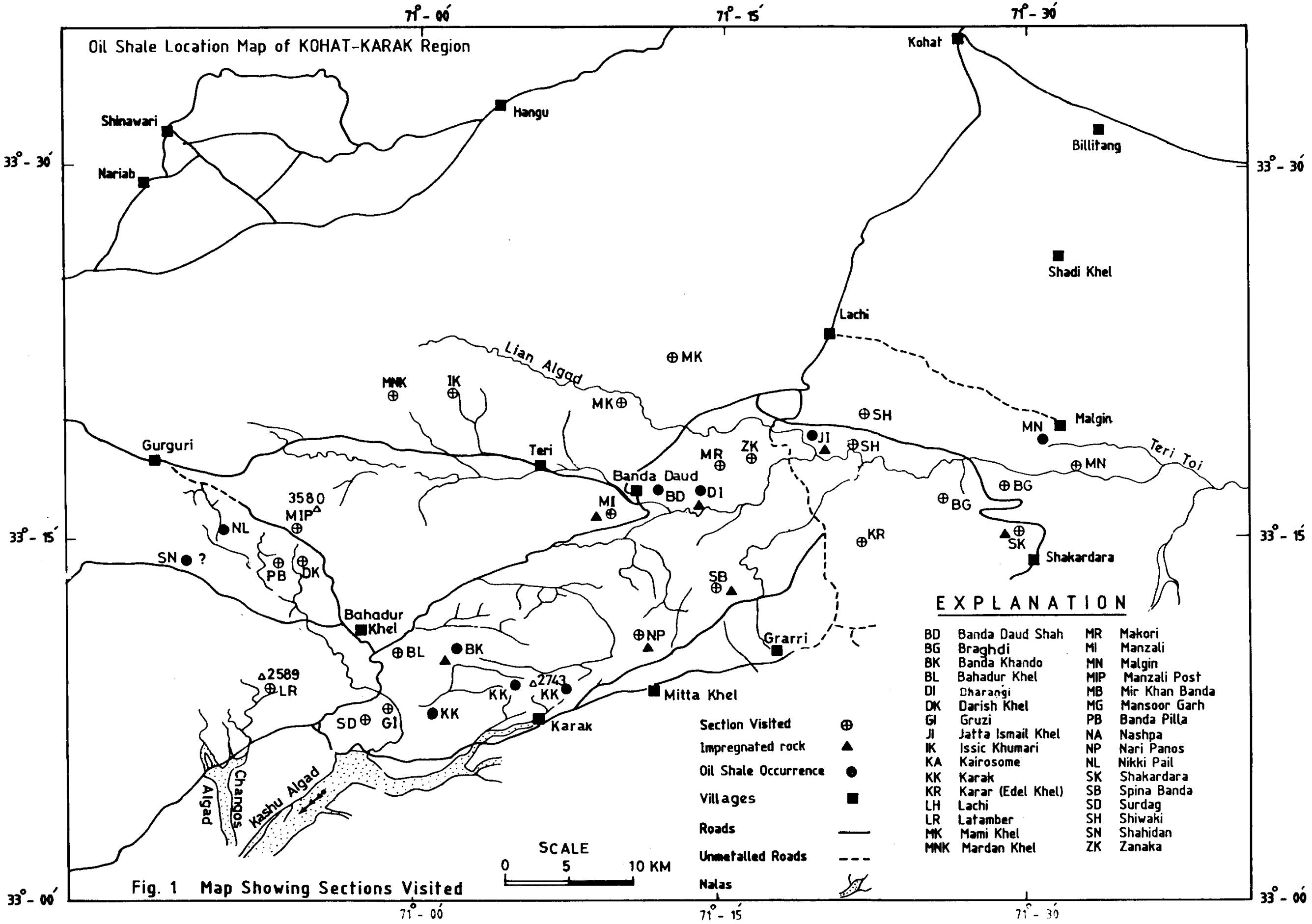

Fig. 1 Map Showing Sections Visited

Figure 1– Oil shale location map of Kohat-Karak study area.

Table 1. Generalized sequence of the strata found in Kohat region (after Meissner et al., 1974)

Age	Group	Formation	Average Thickness (metres)	Description
Pliocene	Siwalik Group	Dhok Pathan	1700	Sandstone, light-grey, conglomerate common near top.
		Nagri	2650	Sandstone, greenish and brownish grey pebbles throughout formation.
		Chinji	944	Sandstone, yellowish and brownish grey.
Miocene	Rawalpindi Group	Kamlial	568	Sandstone, greenish grey to greyish green, fine to coarse grained, conglomerate beds, ridge forming.
		Murree	102	Sandstone, purple, dark greyish brown, greenish grey, medium to coarse grained, conglomeratic, shale, purple and reddish brown.
----------		Unconformity	----------	
Eocene		Kohat	60	Habib Rahi Limestone Member: limestone, tan to light-grey, pink, fine to medium crystalline, thick bedded.
			6	Sadkal Member: shale, green, greenish grey, foraminifera common, missing at places.
			106	Kaladhand Member: limestone, grey, fine to medium crystalline, thin bedded and inter bedded with shale.
		Kuldana	70	Clay, brownish red, silty, some beds of sandstone and conglomerate, dolomitic at places.
		Shekhan Formation/ Jatta Gypsum	62/ 42	Shekhan Formation (northern facies): limestone yellowish grey to grey, dense, thin bedded to massive, gypsiferous, shale and gypsum beds at top.
				Jatta Gypsum (southern facies): gypsum, yellowish green to grey, at places white or dark brownish grey, bedded to massive (in basal part), banded, oil shale associated in middle parts at places.
		Panoba Shale/ Bahadur Khel Salt	102/ 106	Panoba Shale (northern facies): greyish green to light olive to brownish green, silty, soft, forming core of anticlines at places.
				Bahadur Khel Salt (southern facies): salt, white to blackish white, bedded to massive, some clear crystals, bituminous coating at places, base not exposed.

The synclines are open, having wide areal extent and are generally unaccompanied by major faulting. They are covered by Miocene and Plio-Pliestocene sediments.

PREVIOUS WORK

The occurrence of wide spread Eocene Salt deposits in Kohat-Karak region has fascinated the earth scientists since long time. Earliest work on salt deposits of the region (Burnes, 1832) was followed by investigations by several workers of the Geological Survey of India (Karsten, 1864; Fleming, 1853; Oldham, 1868; Wynne, 1875; Pinfold, 1918; and Davies, 1962). Gee (1944) published a comprehensive regional geological overview of the area, which provided a base for establishing the stratigraphy of the salt deposits of Salt Range and the Kohat region. Rashid et al. (1965) and Meissner et al. (1974) carried out regional geological investigations and appraisal of mineral deposits of the area under USAID-GSP collaborative project. Rahman et al. (1981-82) published a regional geological report on the area.

Several oil exploration companies also remained actively engaged in Kohat-Karak region. So far only 10 wells have been drilled in the area of which 8 could penetrate below Siwalik Group. Hydrocarbon Development Institute of Pakistan (HDIP) and the Federal German Institute of Geosciences and Natural Resources (BGR) have carried out detailed study for source rock evaluation of the area (Porth and Raza, 1990).

OIL SHALE PARAMETERS

The term oil shale is generally used for dark coloured, fine grained, laminated, compact and organic rich rock of sedimentary origin which can yield oil in commercial quantities upon pyrolysis (Kinghorn, 1983). Gavin (1924) defined the oil shale as follows: "Oil shale is a compact, laminated rock of sedimentary origin, yielding over 33% of ash and containing organic matter that yields oil when distilled, but not appreciably when extracted with the ordinary solvents for petroleum. In distinguishing between the coal and oil shale, it seems that the material which yields less than 33% ash should be considered as coal". Some workers consider that 4% oil yield of rock weight which corresponds approximately to an oil yield of 25 litres per tonne of rock is the critical lower limit for commercial oil-shale mining. However due to low oil price and high cost of pyrolysis, such low values are now considered uneconomical and generally 42 litres per tonne of rock is taken as a lower limit for economic exploitation (Tissot and Welte, 1984).

Generally, oil shale contains marine organic matter which is oil prone and can generate oil in suitable temperature regimes. In laboratory, isothermal programme pyrolysis at high temperature also yield hydrocarbons. As such oil shale can also be considered as potential source rock which can produce hydrocarbons on deep burial at high temperature during geological times.

OIL SHALE OCCURRENCES

The oil shales in Kohat-Karak region occur in Jatta Gypsum at 27 to 30m below its top at the following localities (Figures 2 and 3).

1. Malgin
2. Banda Daud Shah
3. Dharangi
4. Banda Khando
5. Karak
6. Jatta Salt Quarry

Another oil shale horizon has been located in Nikki Pail area in a transitional zone between Kuldana Formation and Kohat Limestone.

The oil shale occurrences are widely scattered and scarcely exposed due to complex structural deformation of the area and salt diapirism of varying intensity. As such lateral extent of most of the oil shale outcrops is limited. Generally the deposits occur as thin sheets embedded in greenish blue shale horizons between the gypsum beds. However, sometimes the shale horizons are very thin or absent and a sharp and distinct contact of oil shale with the gypsum beds can be observed. Due to limited exposures and structural complications, it has not been possible to ascertain from the surface studies whether the deposition of oil shale is laterally continuous, in the entire Kohat-Karak area or these are isolated lenticular accumulations. The thickness of oil shale horizon has been obliterated due to tectonism often resulting in wrong estimation of thickness.

MINERALOGY OF OIL SHALE

The mineral constituents of oil shale are mainly clay minerals with subordinate amounts of quartz, gypsum and feldspar (Figure 4). The organic matter contained in the oil shale is mainly kerogen and soluble bitumen fraction (Figures 5 and 6). Kerogen usually makes up less than 50% of the rock by weight and is composed of carbon, hydrogen and oxygen with a small amount of nitrogen and sulphur.

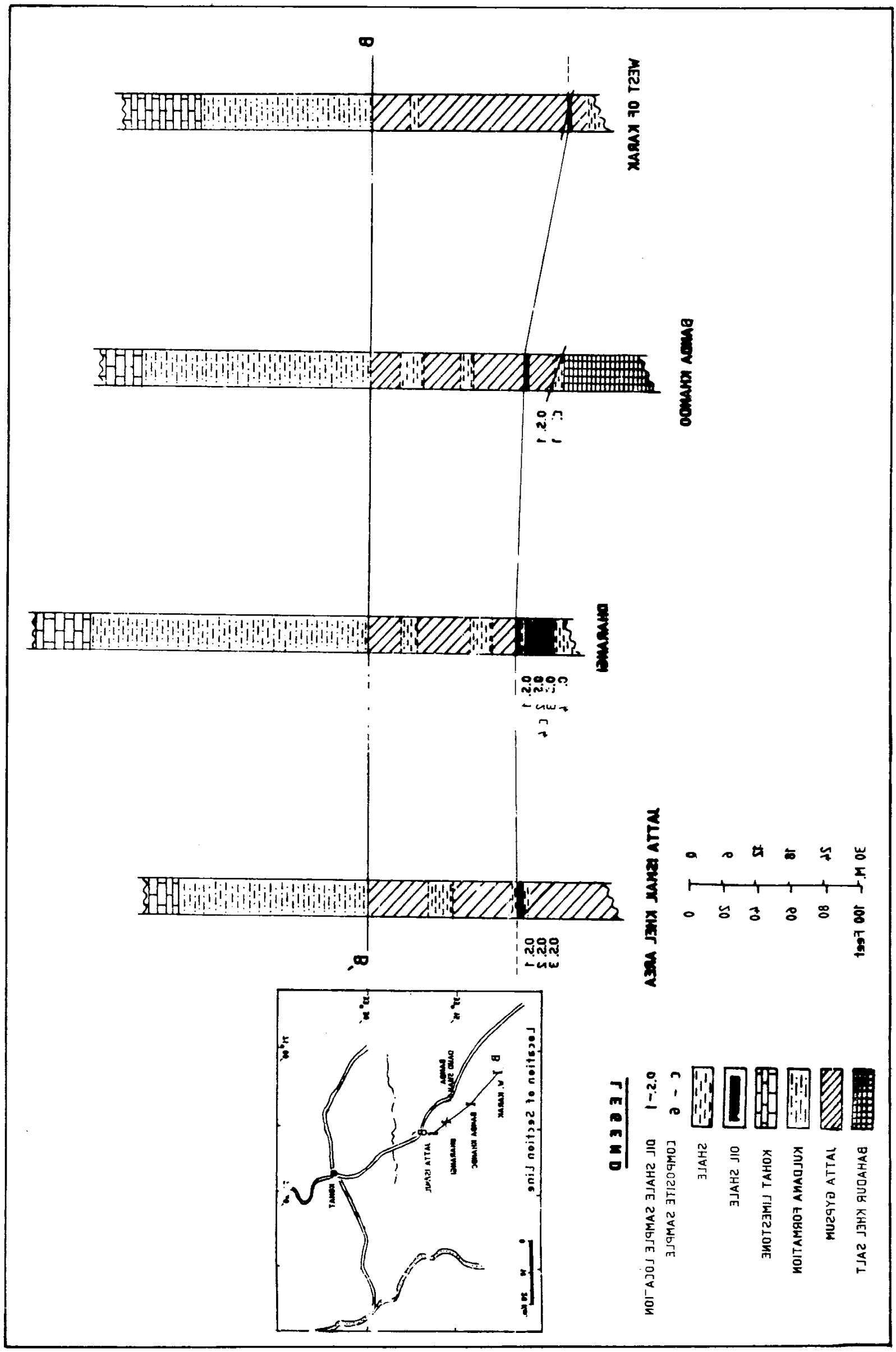

Figure 2– N-S correlation of oil shale deposits.

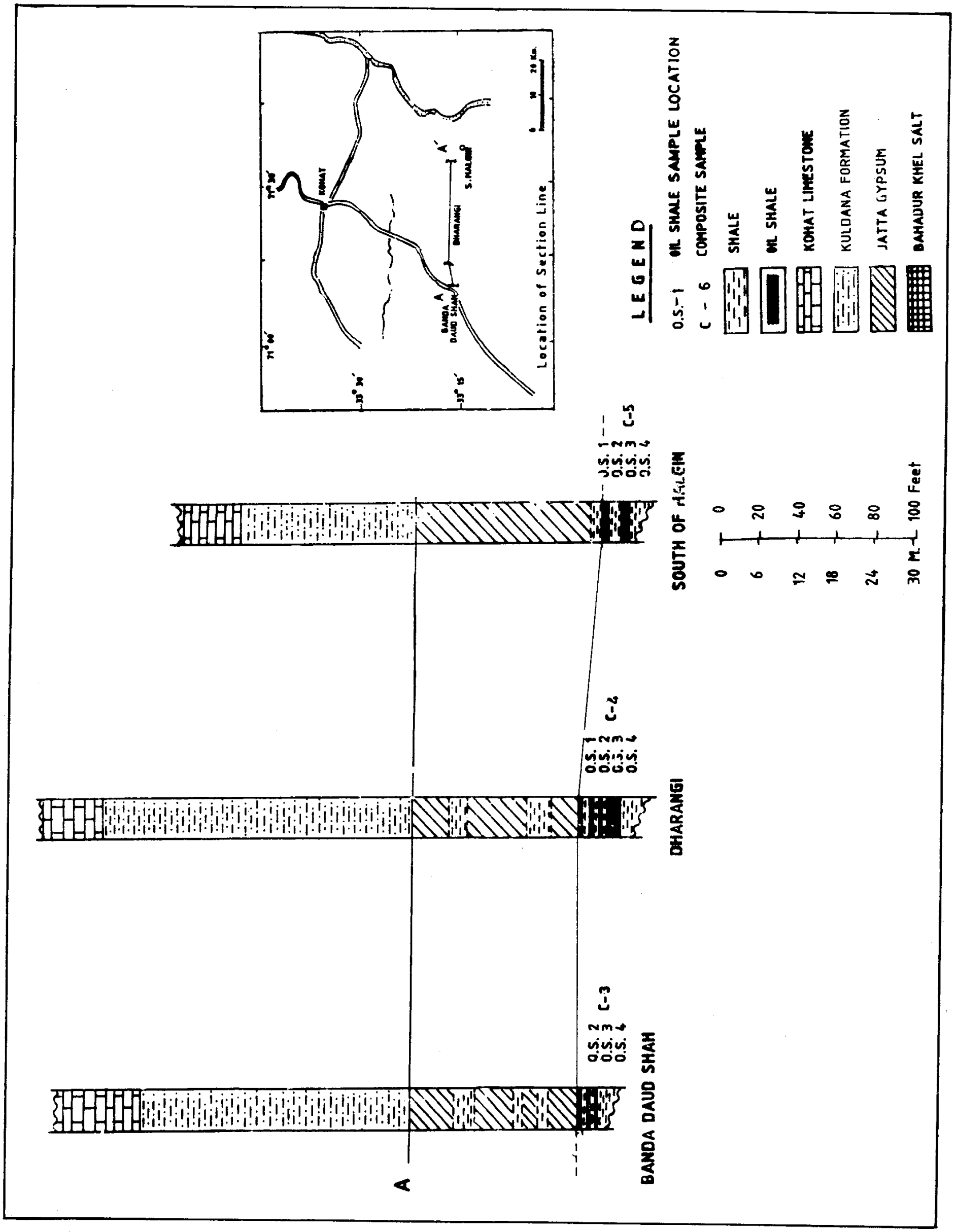

Figure 3– E-W correlation of oil shale deposits.

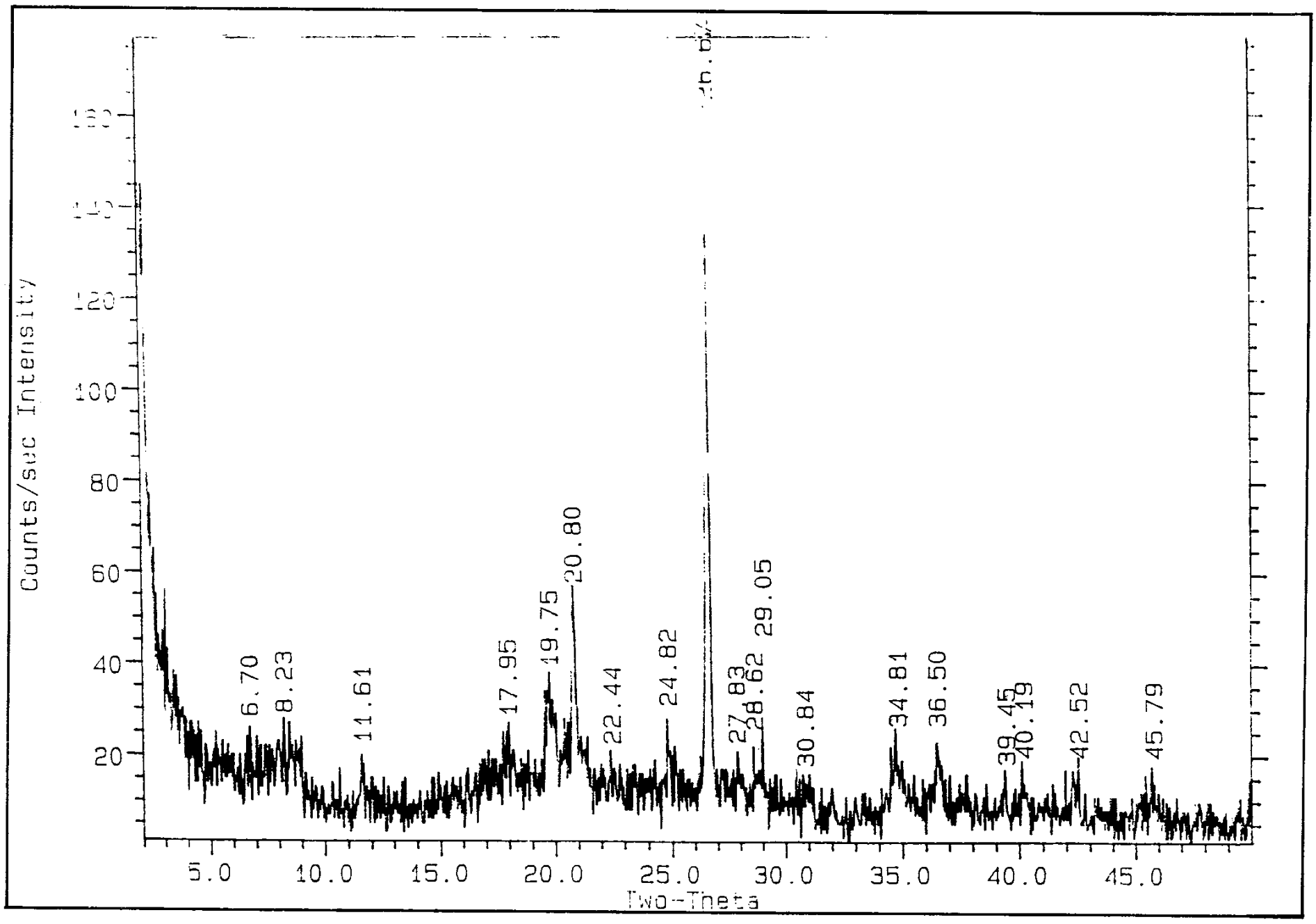

Figure 4— X-ray difractogram showing typical mineral composition of oil shale (Sample no. K/1, Locality: Karak); the dominant minerals are illite, smectite, gypsum, feldspar and quartz.

GEOLOGY AND GEOCHEMISTRY OF OIL SHALE

Malgin Oil Shale
(Figures 1 and 3)

The village Malgin (33°17' 52"N, 71°31' 22"E on Survey of Pakistan topographic sheet no. 38 O/11) is approximately 20km southeast of Lachi and is linked with it through an unmetalled road.

Oil shale occurrence is located at about 2km southwest of Malgin village in an east-west trending gypsum outcrop. The stratigraphic succession in this section is truncated by a regional thrust fault due to which lower part of Jatta Gypsum overrides the Siwalik Group.

A 7m thick shale horizon occurring at about 27m below the top of Jatta Gypsum contains four bands of dark grey, gypsiferous and sulphurous organic shales. The uppermost 70 cm thick organic shale horizon (Sample M/1 containing 6.11% TOC) can be classified as oil shale while the lower three horizons ranging in thickness from 30cm to 80cm (sample no. M/2, M/3 and M/4) are relatively lean in organic matter and contain TOC less than 4% (Table 2).

The oil shale is light to dark grey, laminated, calcareous, silty, compact and brittle, sulphurous and riddled with very thin gypsum veins. Clay partings, brown to buff and gypsum flakes along bedding planes are common.

The oil shale could not be laterally traced due to the heavy debris cover of overlying formations and due to truncation of the lower part of Jatta Gypsum in strike direction by a regional thrust fault.

Banda Daud Shah Oil Shale
(Figures 1 and 3)

The Banda Daud Shah Section (33°15' 30"N, 70°11' 10"E on Survey of Pakistan toposheet no. 38 O/3) is located at about 0.6 km on unmetalled road west

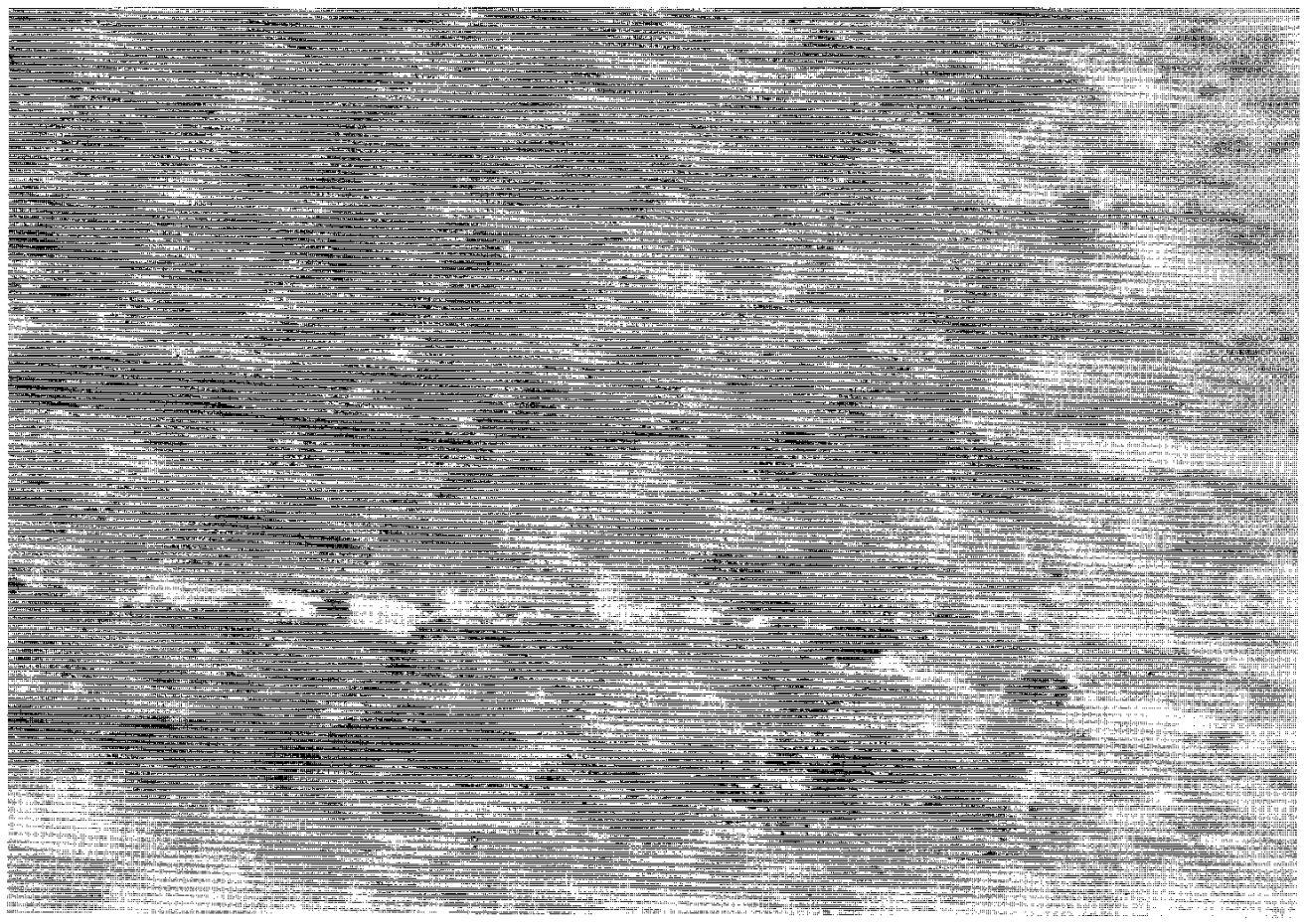

Figure 5– Photomicrograph (x63) of oil shale in thin section (Sample no. K/1, Locality: Karak); note thin layers of organic matter intercalated within clay matrix.

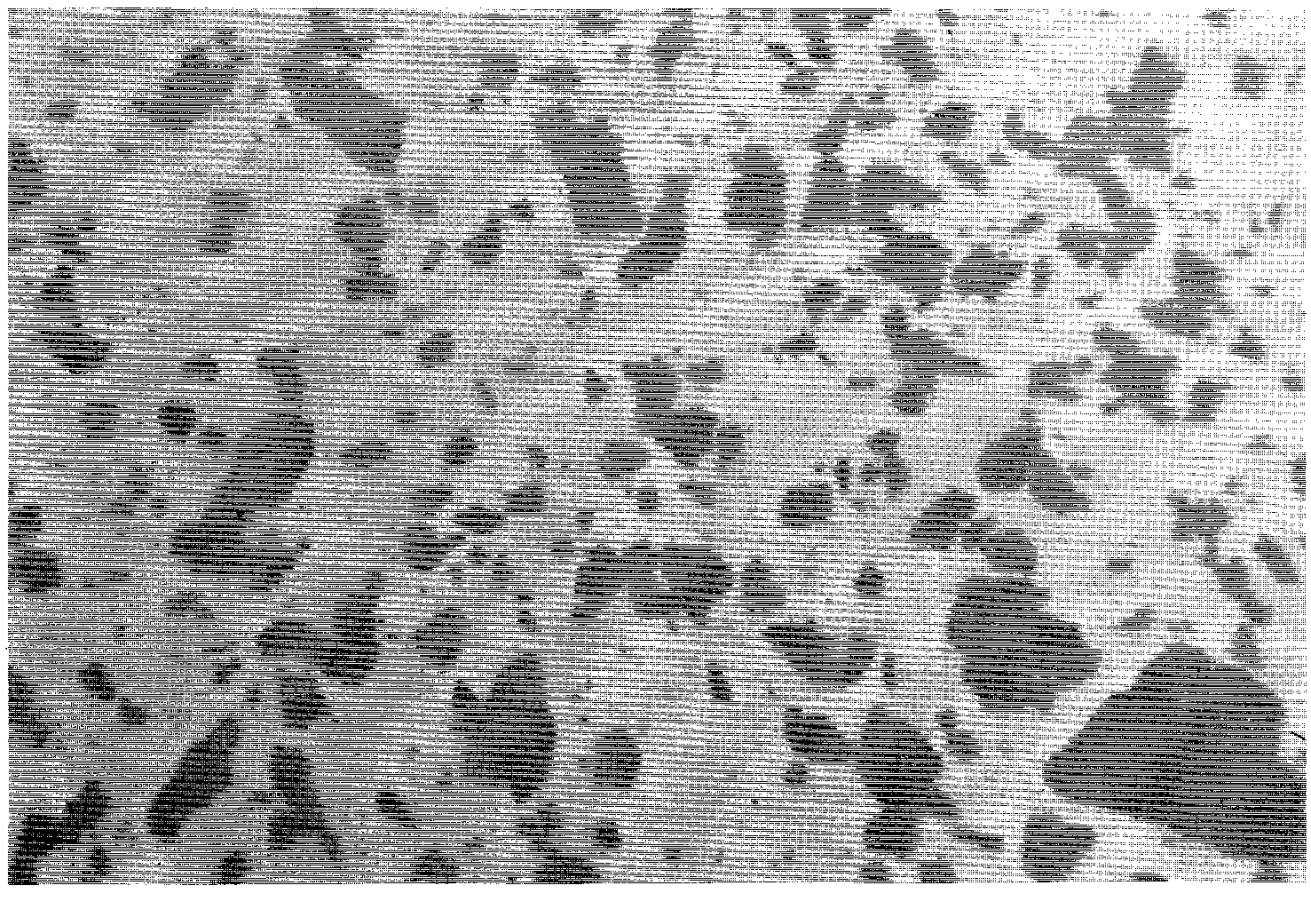

Figure 6– Photomicrograph (x25) of oil shale in thin section (Sample no. BK/1, Locality: Banda Khando); note amorphous and structureless kerogen.

Figure 7– An abandoned mining site of oil shale at Dharangi.

of Banda Daud Shah village, which is 51km southwest of Kohat on the Kohat-Bannu road.

The exposures of Jatta Gypsum occur in steeply dipping northern flank of a breached anticline. The oil shale of about 70cm thickness is exposed in patchy form in a small nala and is mostly covered by the fallen blocks of gypsum; however it can be traced for 100m confirming the development of oil shale horizon in the westward strike extension of Dharangi occurrence.

The Banda Daud Shah oil shale is black to light grey on weathered surface, thinly laminated, generally appear crumbly loose and friable due to weathering effect, light in weight, and burns with hydrocarbon odour.

Three grab samples show TOC ranging from 17.94% to 24.4% while the average composition of a composite sample is 13.38%. The oil yield is 12% or 146 litres per tonne from the richest sample (Tables 2 and 3).

Dharangi Oil Shale
(Figures 1, 2 and 3)

The village Dharangi (30°16' 24"N, 71°13' 20"E on Survey of Pakistan toposheet no. 38 O/3) is about 4km east of Banda Daud Shah. The oil shale occurrence is located in a nala at about 1 km north of Dharangi village (Figure 7). The Jatta Gypsum forms the core of a doubly plunging anticline. The structure is further complicated by faults and isoclinal folding in the northern limb of the anticline.

The eastern most outcrop of oil shale horizon at this locality is poorly exposed in a small stream cutting the terrace of Jatta Gypsum. There are three small pits at this locality, where oil shale was previously mined as "coal". Due to complex structural setting of the area and poor exposure of intensely weathered oil shale horizon, it is very difficult to measure its exact thickness. However in a mining pit it appears approximately 1.2m thick, whereas its westward extension shows lenticular behaviour with thickness ranging from 30 to 60cm. In strike extension, the oil shale horizon can be traced for about 500 to 600m.

The oil shale horizon along with the enclosing dark grey shale is mostly weathered and traversed by several small lenticular veins of limonite and goethite. The oil shale is black, hard and compact, laminated and sulphurous. It gives hydrocarbon odour on burning.

The average TOC content varies from 16.6% to 24.7%, whereas the composite sample shows TOC reduced to 13.18%. The oil yield is 13% per weight of rock or 148 litre per tonne (Tables 2 and 3).

Banda Khando Oil Shale
(Figures 1 and 2)

The Banda Khando village (33°10' 19"N, 71°02' 30"E on Survey of Pakistan toposheet no. 38 O/4) is located 6km northeast of Bahadur Khel. It is connected with Kohat-Bannu road through an unmetalled jeepable track.

Table 2. Results of gechemical analysis of surface samples from Kohat–Karak region.

Field No.	Lab No.	Locality	Lithology	TOC %	qp kg/t	HI mg/g	EOM ppm	EOM/ TOC mg/g	SAT. HC %	ARO. HC %
BK/1	3211	Banda Khando	Oil shale	12.97	94	724	7470	58	45	14
BK/2	3212	Banda Khando	Composite–1	10.90	83	761				
K/1	3223	Karak	Oil shale	11.53	81	702				
K/2	3222	Karak	Oil shale	6.95	55	791				
K/3	3221	Karak	Oil shale	20.70	174	840	18881	91	29	21
K/4	3220	Karak	Oil shale	12.13	82	666				
K/5	3219	Karak	Oil shale	13.15	90	684	7326	56	16	14
ko–155*	pr347	Karak	Oil shale	26.90			23900		20	30
ko–157b*	pr350	Karak	Oil shale	22.90			25446		33	38
ko–159*	pr352	Karak	Oil shale	26.90			19645		34	20
K/6	3224	Karak	Composite–2	12.43	30	124				
BD/2	3203	Banda Daud Shah	Oil shale	17.94	100	557				
BD/3	3204	Banda Daud Shah	Oil shale	18.04	116	630	14136	77	31	15
ko–137a*	pr325	Banda Daud Shah	Oil shale	24.40			19619	77	31	15
BD/4	3205	Banda Daud Shah	Composite–3	13.38	83	620				
D/1	3206	Dharangi	Oil shale	16.61	101	608				
D/2	3207	Dharangi	Oil shale	17.41	96	551	33370	191	58	9
D/3	3208	Dharangi	Oil shale	7.43	42	565				
D/4	3209	Dharangi	Oil shale	6.79	40	589				
ko–76*	pr121	Dharangi	Oil shale	24.70			39888		49	19
ko–130*	pr318	Dharangi	Oil shale	21.90			41512		52	25
ko–133*	pr321	Dharangi	Oil shale	17.80			26982		39	32
D/5	3210	Dharangi	Composite–4	13.18	79	599				
J/1	3230	Southeast of Jatta Salt Quarry	Shale	3.11	9	289	2968	95	11	52
J/2	3231	North of Jatta Rest House	Shale	1.71	6	351				
J/3	5001	North of Jatta Rest House	Shale	7.05			4520			
M/1	3213	South of Malgin	Oil Shale	6.11	38	621				
M/2	3214	South of Malgin	Shale	2.37	13	476				
M/4	3216	South of Malgin	Shale	3.73	19	509				
M/5	3217	South of Malgin	Composite–5	4.19	11	123				
NP/1	3225	Nikki Pail	Oil Shale	3.73	19	509				
NP/2	3226	Nikki Pail	Oil Shale	24.90	103	413	17781	71	18	34
NP/3	3227	Nikki Pail	Oil Shale	24.65	37	150				
NP/4	3228	Nikki Pail	Shale	4.29	12	280				
NP/5	3229	Nikki Pail	Shale	12.21	22	180	6129	50	10	18
ko–138a*	pr328	Nikki Pail	Shale	6.20			3657		15	32
ko–138c*	pr330	Nikki Pail	Shale	3.90			2820		27	24
ko–139*	pr331	Nikki Pail	Shale	25.10			12943		6	19

* Dressed samples collected earlier by Dr. Porth.

A 50 to 60cm thick oil shale horizon is found at about 1km south of Banda Khando village in the core of an anticline at about 30m below the top of Jatta Gypsum. This oil shale horizon is exposed in both the flanks of the east-west oriented anticline. In the southern flank, it laterally extends for a short distance of about 100m due to truncation of Jatta Gypsum by Bahadur Khel Salt. In the northern flank it is traceable for about 2km length along the nala bed where it is seen progressively pinching out in westward direction, while it disappears eastward due to structural deformation.

The oil shale, embedded in reddish brown to green shale, is dark brown to black with light grey coating on

Table 3. Summarized results of low-temperature carbonization analysis (Fischer Assay) of oil-shale samples from Kohat area (after Porth and Raza, 1990).

Sample No.	Oil yield (%)	Oil yield (l/t)	Oil density (g/ml)
Ko - 76	13	148	0.867
Ko - 137	12	146	0.880
Ko - 155	18	204	0.906
Ko - 157b	20	226	0.893
Ko - 159	19	214	0.885

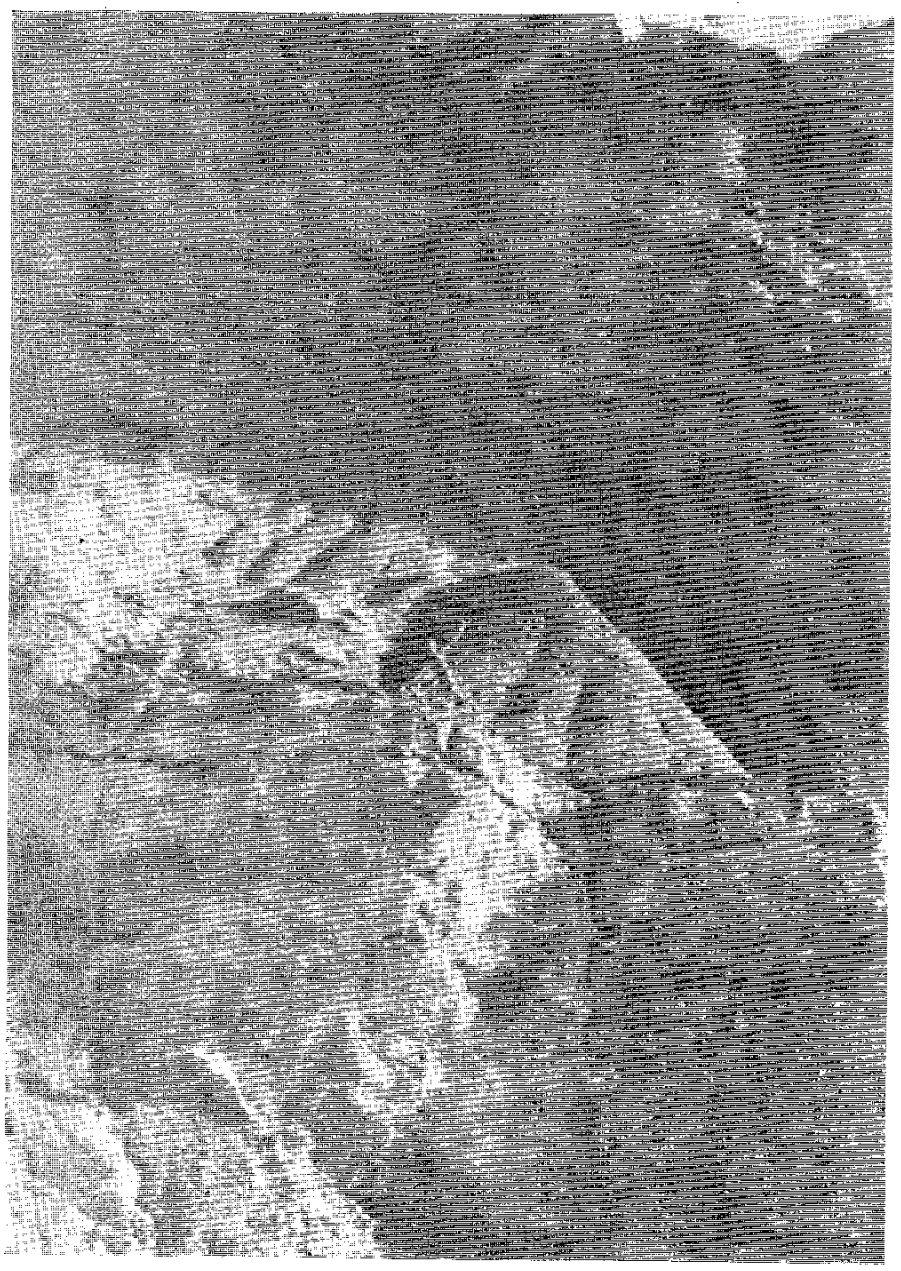

Figure 8– Oil shale occurrence at about 27m below the top of Jatta Gypsum near west of Karak.

the weathered surface, thinly laminated, compact and brittle, light in weight, and burns with strong smell of tar.

The TOC ranges from 10.90% in the composite sample to 12.97% in a grab sample. The other geochemical parameters also indicate good source rock characteristics and are identical to other oil shale occurrences in the area (Table 2).

The 6m thick oil shale beds as described by Rashid et al. (1965) at the top of Jatta Gypsum in this area could not be located by the present study.

Karak Oil Shale

(Figures 1 and 2)

Karak town (33°07' 5"N, 71°05' 30"E on Survey of Pakistan toposheet no. 38 O/4) about 115km southwest of Kohat, is connected with Kohat-Bannu road through Sur Dag by an all weather metalled road.

The area north of Karak town is characterized by a large syncline, which is bounded by faults on both the flanks. The fault at the northern flank of syncline is gravitational and brings Jatta Gypsum against Kamlial Formation. A thrust fault runs all along the southern flank

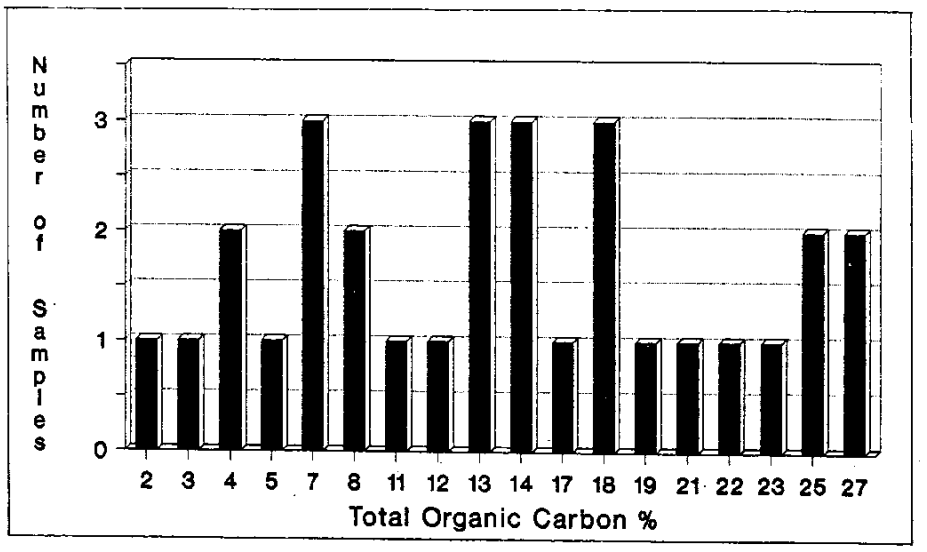

Figure 9– TOC distribution in oil shale deposits in Kohat-Karak region.

of the syncline due to which Bahadur Khel Salt is found overriding the Nagri Formation.

The oil shale horizon in Karak area has been observed at the following four locations.

Kundal Location.–It is about 1.5km north of Karak in a tributary of Tarkha Algad. Jatta Gypsum exposed near the plunge of the syncline shows complex structural deformation and is found in widely scattered imbricate wedges. The Jatta Gypsum in its lower part is intercalated with a 3 to 4m thick greenish grey shale containing oil shale horizon. Oil shale had been mined from small pits at this location. In a 6m deep mining ditch, the cumulative thickness of a the oil shale horizons is measured as 3.7m. Due to scattered and imbricate wedge nature of the outcrops it is rather difficult to ascertain the exact thickness and lateral extent of the oil shale at this location. However, the imbricate gypsum wedges are exposed in a belt laterally extending in east-west direction for more than one km. Further eastward the outcrop of Jatta Gypsum continues with much less structural disturbance. In this belt, several traverses were made upto Nari Idal Khel and Spina Banda area (Figure 1) in the east to locate oil shale horizons. The occurrence of oil shale could be located upto 3km eastward. The oil shale gives tar smell on burning. A 1.5m thick oil impregnated sand horizon occurs at Spina Banda.

The Kundal oil shale shows TOC ranging from 22.9% to 26.9%. However in samples with shale partings the TOC reduces to 12.31-13.15%. The oil yield is upto 20% weight of rock or 226 litre per tonne (Tables 2 and 3).

PMDC Salt Quarry Location.– PMDC salt quarry is located at about 1.5km north of Karak town. The Jatta Gypsum overlying Bahadur Khel Salt in the southern flank of the syncline is the westward continuation of Kundal location. The oil shale horizon occurring in the lower part of Jatta Gypsum is poorly exposed in the slope

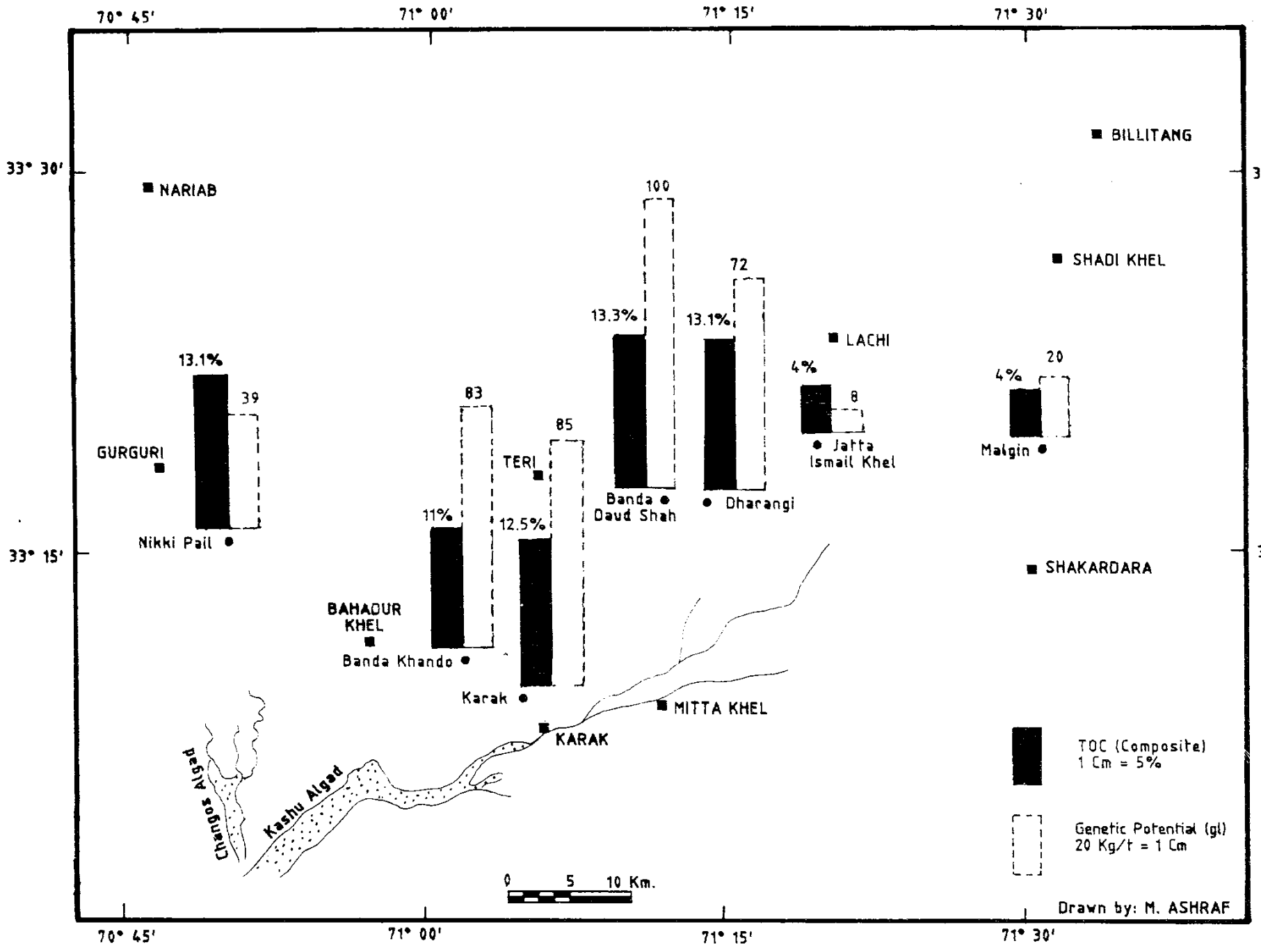

Figure 10– Variations in total organic contents and genetic potential of oil shale deposits in Kohat-Karak region.

of a stream valley. Its strike and dip depth extensions could not be traced due to thick heavy debris cover of the overlying sequence. In consideration of structural behaviour of Jatta Gypsum and oil shale horizon, the cumutative thickness of the oil shale horizon is 30cm.

The oil shale is of high quality and shows TOC upto 26.9% and oil yield of 19% of the rock weight equivalent to 214 litre per tonne of rock (Tables 2 and 3).

West Karak Location.– It is a relatively less disturbed stratigraphic section. Jatta Gypsum is exposed in a small tributary of Tarkha Algad at about 3.5km northwest of Karak town (Figures 1 and 8). Jatta Gypsum is mainly composed of massive gypsum beds, which contain a 5 to 6m thick gypsiferous shale horizon in lower part. The base of the shale horizon, at about 30m below the top of Jatta Gypsum is marked by an oil shale bed of 60cm thickness. The strike and dip extensions of the oil shale can be seen for about 500m and 100m respectively. The oil shale contains ferrugeneous cover. Though it is the western most exposed outcrop of oil shale in Karak region yet it exhibits persistent TOC content.

Laki Ghundaki.– The oil shale occurrence is located about 3 km north of Laki Ghundaki village in a small tributary of Tarkha Algad. The oil shale is exposed in a roll-over structure of Jatta Gypsum. It is about 50cm thick and traceable for a distance of about 100m. The occurrence seems to be the eastern extension of Kundal oil shale deposit occurring in similar stratigraphic position.

Jatta Salt Quarry Oil Shale
(Figures 1 and 2)

The Jatta Salt Quarry Section (33°10' 34"N, 71°17' 30"E on Survey of Pakistan topographic sheet no. 38 O/3) is located at about 8km south of Lachi. An all weather metalled road connects it with Kohat-Bannu road near Karapa.

Bahadur Khel Salt and Jatta Gypsum are exposed in the core of an east west oriented doubly plunging

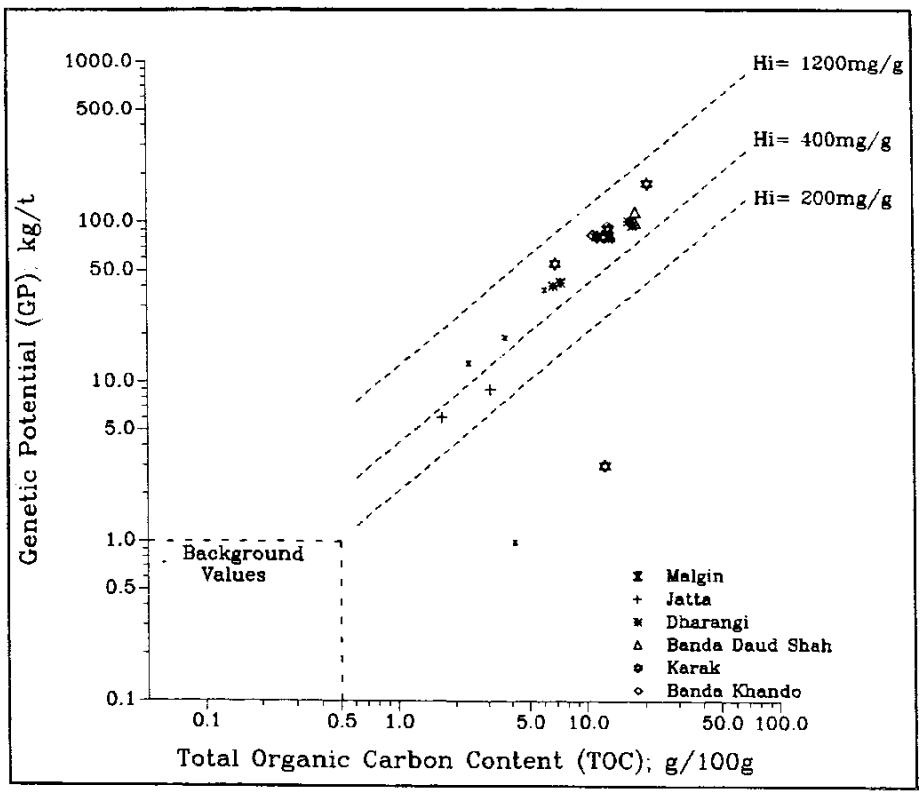

Figure 11– Organic richness vs. genetic potential of rock samples from Kohat-Karak region.

inverted anticline. The rock salt is generally greenish grey, and contains lenses of carbonaceous shale or even residue of hydrocarbon which gives hydrocarbon smell.

The upper contact of Bahadur Khel Salt is marked by a brecciated zone comprising green shale and loosely cemented sandstone. The Jatta Gypsum is whitish grey and thick bedded to massive. Its lower half is divided into distinct massive units by 3-4m thick greenish grey shale.

The outcrop of oil shale is generally covered under the debris of an abandoned salt quarry. The highly weathered and sporadically exposed outcrop is upto 50cm thick. It is light grey, loose and friable due to weathering effect and shows TOC upto 7.2% (Table 2).

NIKKI PAIL OIL SHALE

(Figure 1)

The village Nikki Pail, (70° 50' E, 33° 14' N on Survey of Pakistan topographic sheet No. 38 K/16) is at about 16 km west of Bahadur Khel and is linked with it through an unmetalled road. The oil shale occurrence is about 2km in the north of the Nikki Pail village. Locally the occurrence is called Katawa where previously coal was mined.

The oil shale occurs in a sequence of calcareous sandstone and sandy limestone unit marking the transitional zone between Kuldana Formation and Kohat Limestone. Its exposure is found on a steep scarp on the northern limb of a breached anticline. The oil shale is 1.5m thick, brownish-grey to black, silty, calcareous, sulphurous and highly weathered. It is overlain by greenish grey, highly calcareous mudstone with plant fragments grading westward into more calcareous sequence. The eastward lateral extent of the oil shale horizon is culminated by a strike slip fault. However it seems to extend considerably westward.

A 1m thick coal seam also occurs at about 6m above the oil shale horizon. A coal seam development at the same stratigraphic level has been reported form a location near Liaquat picquet in the vicinity of Shaheedan at about 4.5km west of Nikki Pail.

The geochemical result makes the area attractive as the average TOC of oil shale sample is 13%. The upper and lower portions of oil shale horizon are relatively lean in TOC content. While its middle part is richest with TOC upto 25.1% (Table 2).

SOURCE ROCK CONSIDERATIONS

Evaluation of oil shale in Kohat basin as potential source rock is based on the amount of total organic matter (TOC), its genetic potential (gP), hydrogen index (HI) and extractable organic matter EOM). The results are listed in Table 2.

Generally the shales containing less than 0.5% TOC do not have any potential for hydrocarbon generation, where as good potential source rocks should have a TOC of more than 1%. The TOC of 38 samples from oil shale deposits in Kohat basin shows variations from 1.71% to as much as 26.9% (Figure 9, Table 2). However the values of five composite samples (Sample No. BK/2, K/6, BD/4, D/5 and M/5) exhibit relatively less variation and range from 4.19% to 13.3%. Richest deposits occur in Banda Daud Shah and Karak regions while the leanest are in Jatta and Malgin areas (Figure 10).

The gP indicates maximum amount of hydrocarbons that could be generated under optimum thermal conditions. Since also the gP depends on the TOC of the analyzed sample, the gP/TOC ratio ("Hydrocarbon Index", HI) is used for source rock characterization. Samples with a gP smaller than 1 kg/tonne and an "HI" of less than 200 can be neglected as suitable source rock. Very good to excellent oil-source rocks should have gP above 6 kg/tonne and HI of more than 400. The pyrolysis yield of 21 oil shale samples from this region generally ranges from 6 to 174 kg/tonne (Table 3) which is much above pyrolytic hydrocarbon content in many rich potential petroleum source rocks of the world (Tissot and Welte, 1984). Variations in the hydrogen index of most of the samples are insignificant indicating homogeneity of the dispersed organic matter (Figure 5, 6 and 11). This is also exhibited by low vitrinite reflectance in most of the oil shale samples due to high percentage of bitumen and less than 5% of inertinite, vitrinite and liptinite.

Extractable organic matter (EOM) depends on the TOC content of the analyzed sample, as such the EOM/TOC ratio is used as a parameter for further source-rock characterization. The minimum EOM/TOC ratio for

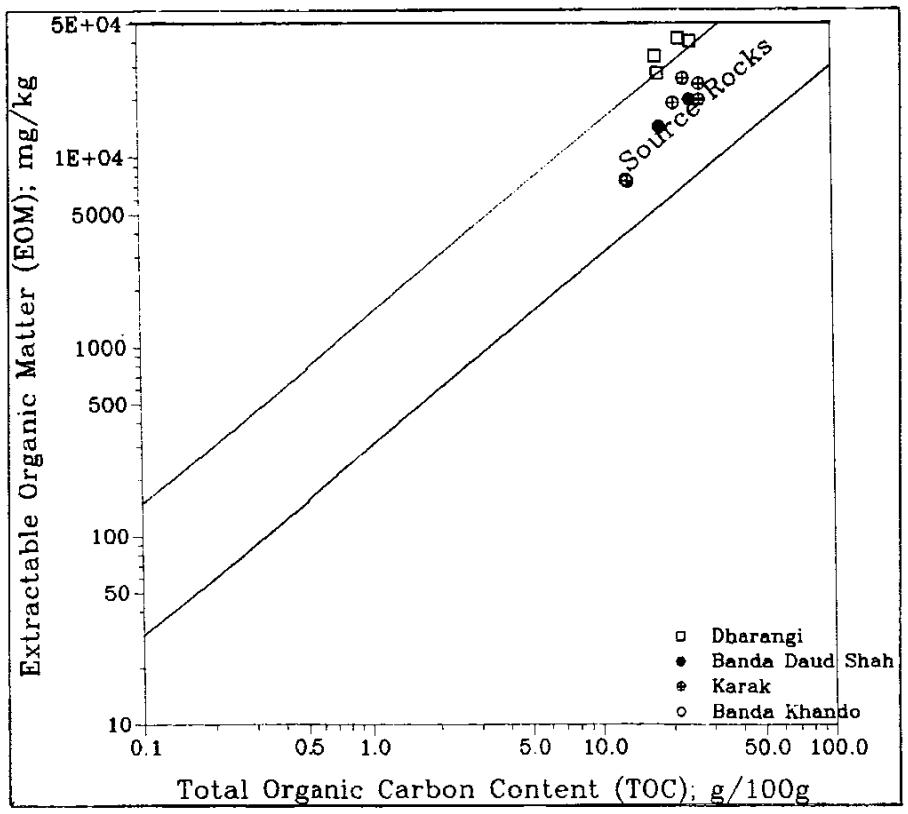

Figure 12– Rock samples from Kohat-Karak region.

potential source rocks is 25mg/g, while very good to excellent potential oil source rocks should have an EOM/TOC ratio of more than 100mg/g. The EOM/TOC ratio of Kohat-Karak oil shale ranges from 50 to 191 mg/g which characterises the oil shales of the area as excellent potential source rock (Figure 12).

CONCLUSIONS

The source rock data indicate that the Kohat-Karak oil shales could have an excellent petroleum source rock potential if matured in the subsurface due to burial overburden. The presence of oil and gas seepages and abundant occurrences of oil impregnation in Bahadur Khel Salt, Jatta Gypsum and various other stratigraphic horizons, however, indicate that some sediments in the area have already passed the zone of oil window. Some of the oil seeps in southern Kohat are apparently sourced by these oil shales (Porth and Raza, 1990). As such oil shales in the synclinal areas where there is thick accumulation of the Murree Formation and Siwalik Group, might have matured enough to form potential source rock for nearby stratigraphic and structural traps. As such they might form a petroleum kitchen in synclinal areas between the Banda Daud Shah/Jatta and Karak, as well as south and east of Karak.

The Bannu basin situated south of Kohat area is a real frontier area investigated by a few wells. Seismic sections show a thick, undisturbed sedimentary sequence with favourable structural development in the basin center and possible unconformity traps along the margins (Khan et al., 1986). Kohat-Karak oil shale deposits, if extended into this basin, can be considered as good source rock for most of these traps.

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