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On Cover: An outcrop of Talar Formation, at Talar Gorge, southwestern Makran, Pakistan. The formation is the thickest (~4500m) lithostratigraphic unit of southern Makran that is composed of fossiliferous (gastropods and bivalves) sandstone, mudstone and minor conglomerate. These sediments are interpreted to have been deposited in a rapidly subsiding and steeply dipping continental shelf during Miiocene-Pliocene. The sedimentary structures indicate the source of sediments north of the depositional site, but it is still unclear whether these were derived from rising Himalayas or the Chaghi-RasKoh arc. *(Photograph by M.A.Farooqui)*

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GEOCHEMISTRY OF ORGANIC MATTER IN HOLOCENE SEDIMENTS OF THE SOUTHERN MARMARA SEA SHELVES, TURKEY

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ABSTRACT

Six sediment cores (up to 340 cm in length) were taken from the southeastern Marmara shelves to determine the types and modes of distribution of organic matter in this sea. The primary objective of this study was to better understand: a) the effects of the land-based and marine sources; b) the influences from the adjacent marine inflows; and c) the diagenetic reactions. To do this, various petrographic and geochemical analysis are carried out which included the determinations of grain size, total organic carbon, C,H,O,N,S, C_{15}+ n-alkane and acyclic hydrocarbons.

The studied core sediments are low calcareous (<10% $CaCO_3$) and are mostly fine-grained, siliciclastic shelf mud (up to 99% of bulk sample) with varying silt (19-46%) and clay (44-80%) contents, except two cores 85 and 87 with considerably high sand and gravel portions at their downcore sections. It is most likely that the southerly two major rivers, coastal erosion and ephemeral rivers of the surrounding land masses are the principal terrigenous sources of the sediments in the cores.

The total organic carbon contents of the sediments ranged from 0.01 to 1.10 % with an average of 0.35%. The n-alkane exhibit a maximum occurrence at n-C_{27}, n-C_{29} and n-C_{31} with a strong odd-to even carbon number predominance indicating allocthonous higher plant wax source. This was supported by the results of pyrolysis, microscopical and elemental analysis of the kerogen.

INTRODUCTION

The Sea of Marmara, a semi-enclosed basin, forms a transition between the organic-rich Black Sea in the northeast and organic-poor Aegean-Mediterranean Sea in the southwest (Fig. 1). Thus, the physical, chemical and biological properties of this sea are greatly influenced by the hydrochemistry of these two adjacent water masses (Bastürk et al. 1988; Özsoy et al. 1988; Ergin et al. 1991, 1992 and 1994).

Previous studies have shown that the Marmara Sea receives large quantities of organic matter not only from these two adjacent water masses; the Black

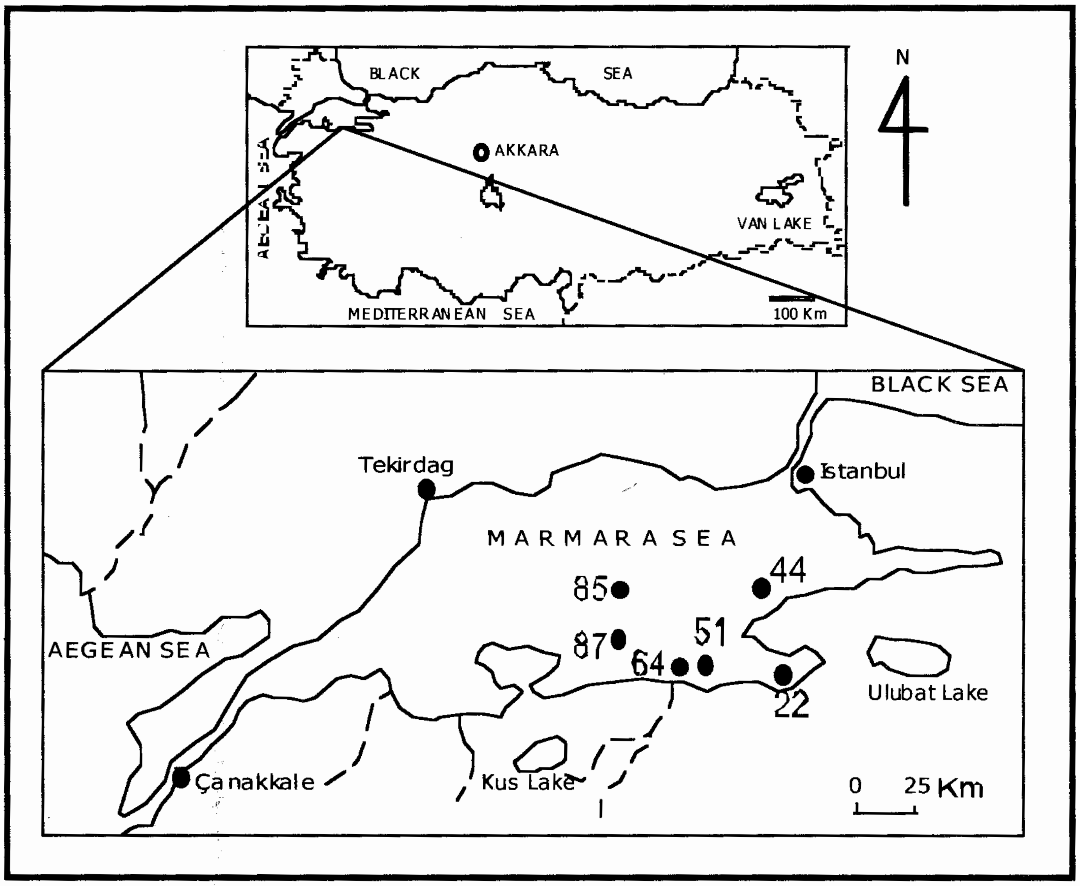

Figure 1. Map showing the location of the studied sediment cores (top) of Maramara Sea

Table 1. Locations of Marmara sediment cores used in this study

Station	Water Depth (m)	Longitute N	Latitute E
22	110	40° 24' 16"	28° 57′ 57″
44	134	40 37 42	28 55 54
51	60	40 26 56	28 40 45
64	49	40 25 57	28 33 49
85	90	40 38 14	28 19 01
87	49	40 31 02	28 19 03

Sea and Aegean Sea (Ergin et al. 1992) but also from the southerly major rivers (Ergin et al. 1992; 1994; Cagatay et al. 1996) and surrounding anthropogenic sources (Polat and Tugrul 1995). It is also shown that the southern Marmara shelves are sites of highest primary organic production within the basin although the sediments here on the sea floor are markedly low in organic carbon contents (Ergin et al. 1992). This was linked to the loss of organic matter from the Marmara Sea water column through the permanent, horizontal and opposite transports of the upper and lower water layers (Ergin et al. 1994). That is why the commonly used empirical expression for the relationship between surface productivity and organic carbon contents of sediments (Müller-Suess formula; Müller and Suess 1979) was not applicable on the southern Marmara shelves.

Although studies exist on the distribution of organic carbon contents in both bottom sediments (Ergin et al. 1992; Cagatay et al. 1996) and water column (Polat 1989), no such a work presented here is known concerning with geochemistry of organic matter. The main purpose of this research is, therefore, to investigate the type, source and diagenesis of organic matter in recent or unconsolidated Holocene sediments and the factors controlling its distribution in the Marmara Sea. This has been achieved by the pyrolisis, gas chromatography, microscopical and elemental analysis of the kerogen of selected sediment samples.

GENERAL SETTING OF THE MARMARA SEA

The Marmara Sea has a surface area of approx. 11500 km^2 and a volume of 3400 km^3. It is connected to the Black Sea and the Aegean Sea via the narrow (0.7-7 km) and shallow (<110 m) straits, the Istanbul Strait ("Bosphorus") and Canakkale Strait ("Dardanelles"), respectively (Fig.1). The Marmara Basin forms the western extension of the North Anatolian Fault Zone which is seismically active (Görür et al. 1997). Thus its evolution is related to the Neogene tectonic movements (Görür et.al.1997). However its present bottom morphology must largely be the result of late Quaternary sea level changes and some associated tectonic uplifts (Stanley and Blanpied 1980; Erol and Cetin 1995; Meric et al. 1995; Ergin et al. 1997). The east-west-trending Marmara trough which is divided into three small depressions of 1152-1276m water depths separates the narrower northern shelf (2-13 km wide) from the broader southern shelf (approx.30 km wide).

The hydrography of the Marmara Sea is governed by the permanent opposite flows of two water layers (Besiktepe et al.1994). An upper water layer of Black Sea origin of low salinities (18-22 ppt) moves towards the Aegean Sea and a bottom water layer of Mediterranean origin of high salinities (38.5 ppt) moves from the Aegean Sea towards the Black Sea (Besiktepe et al. 1994). Thus a permanent boundary occurs between the upper and lower water layers at about 20-25m water depths (Ünlüata et al. 1990). Although deeper Marmara waters seasonally lack of oxygen where suboxic conditions occur, shelf regions are always well oxygenated (Ünlüata and Özsoy 1986). The primary productivities measured in the Black Sea range from 52 to 250 g cm^{-2} y^{-1} ; these values vary between 60 and 100 in the Marmara Sea and around 36 in the Aegean Sea and 16 to 25 in the eastern Mediterranean Sea (Murdoch and Onuf 1974; Sorokin 1983; Yilmaz 1986; Göcmen 1988; Ergin et al. 1992). It is therefore obvious that primary organic production in the Marmara Sea is greatly influenced by Black Sea waters whilst sinking and sedimentation of dead organic matter is controlled by the Aegean or Mediterranean bottom waters.

In addition to the fluxes of suspended solids from the adjacent Black Sea (includind Golden Horn Estuary; 14×10^{5}t/y) and Aegean Sea (9×10^{5}t/y), three major rivers Kocasu, Gönen and Biga entering the Marmara Sea from the south discharge approx. 6×10^{5}t/y materials (compiled by Ergin et al. 1991). Thus the southerly rivers seem to be important suppliers of sedimentary material to be deposited on the sea floor.

MATERIAL AND METHODS

In this study, six gravity cores with up to 340 cm sediment recovery were used (Table 1; Fig. 1). Sediment cores were obtained during the 1995 cruise of R/V Sismik 1-MTA on the southeastern Marmara shelves at 48-134 m water depths. In the laboratory, the sediment cores were divided into 2 slices and air-dried in dark rooms to prevent any chemical reactions between solid material and pore water. The visible characteristics (texture, color etc) of the sediments were determined while wet.

For organic matter analysis, a total of 30 sub-samples were selected from six cores (five sample from each core) and subjected to determine: the total

Table 2. Pyrolisis results for the Marmara Sea Holocene sediments

Sample	S1	S2	Tmax	TPI	HI	TOC	PY
85/28	210	470	398	0.31	261	0.18	680
85/56	500	1740	422	0.22	158	1.10	2240
85/84	590	1170	419	0.34	124	0.94	1760
85/112	370	620	403	0.38	106	0.58	990
85/140	210	360	370	0.37	105	0.34	570
87/41	190	420	387	0.32	1050	0.04	610
87/83	160	410	399	0.29	683	0.06	570
87/124	230	740	411	0.24	185	0.40	970
87/166	300	1240	417	0.19	163	0.76	1540
87/207	40	90	406	0.33	-	0.01	130
44/40	160	370	396	0.31	264	0.14	530
44/80	230	720	410	0.24	163	0.44	950
44/120	350	1290	417	0.21	150	0.86	1640
44/160	280	790	411	0.26	119	0.66	1070
44/200	210	640	414	0.25	136	0.47	850
51/36	270	630	572	0.3	225	0.28	900
51/72	200	510	384	0.29	159	0.32	710
51/108	170	330	377	0.34	165	0.20	500
51/144	210	460	388	0.32	153	0.30	670
51/180	210	440	381	0.33	141	0.31	650
64/54	200	420	383	0.32	116	0.36	620
64/108	170	310	368	0.35	110	0.28	480
64/162	100	200	405	0.33	500	0.04	300
64/216	70	180	389	0.29	257	0.07	250
64/270	120	240	382	0.33	300	0.08	360
22/42	200	470	387	0.30	156	0.30	670
22/84	200	370	383	0.36	154	0.24	570
22/126	140	290	375	0.33	193	0.15	430
22/168	160	370	487	0.31	205	0.18	530
22/210	220	470	389	0.32	142	0.33	690

* S_1 and S_2 : ppm; Tmax : ^{0}C ; TPI : S_1/ S_1+S_2 ; TOC : wt % ;
HI : S_2 / TOC (mg HC/g TOC)
PY: S_1+S_2 (ppm)

Table 3. Organic petrography results for the Marmara Sea Holocene sediments

Sample	Amorphous %	Herbeceous %	Woody %	Coaly %	R_0	R_0 mean
85/140	-	25	70	5	0.35-0.47	0.39
87/166	-	60	30	10	0.35-0.56	0.48
44/200	-	25	70	5	0.41-0.65	0.52
51/180	5	30	60	5	0.37-0.51	0.47
64/270	-	35	55	10	0.37-0.52	0.45
22/210	-	20	60	20	-	-

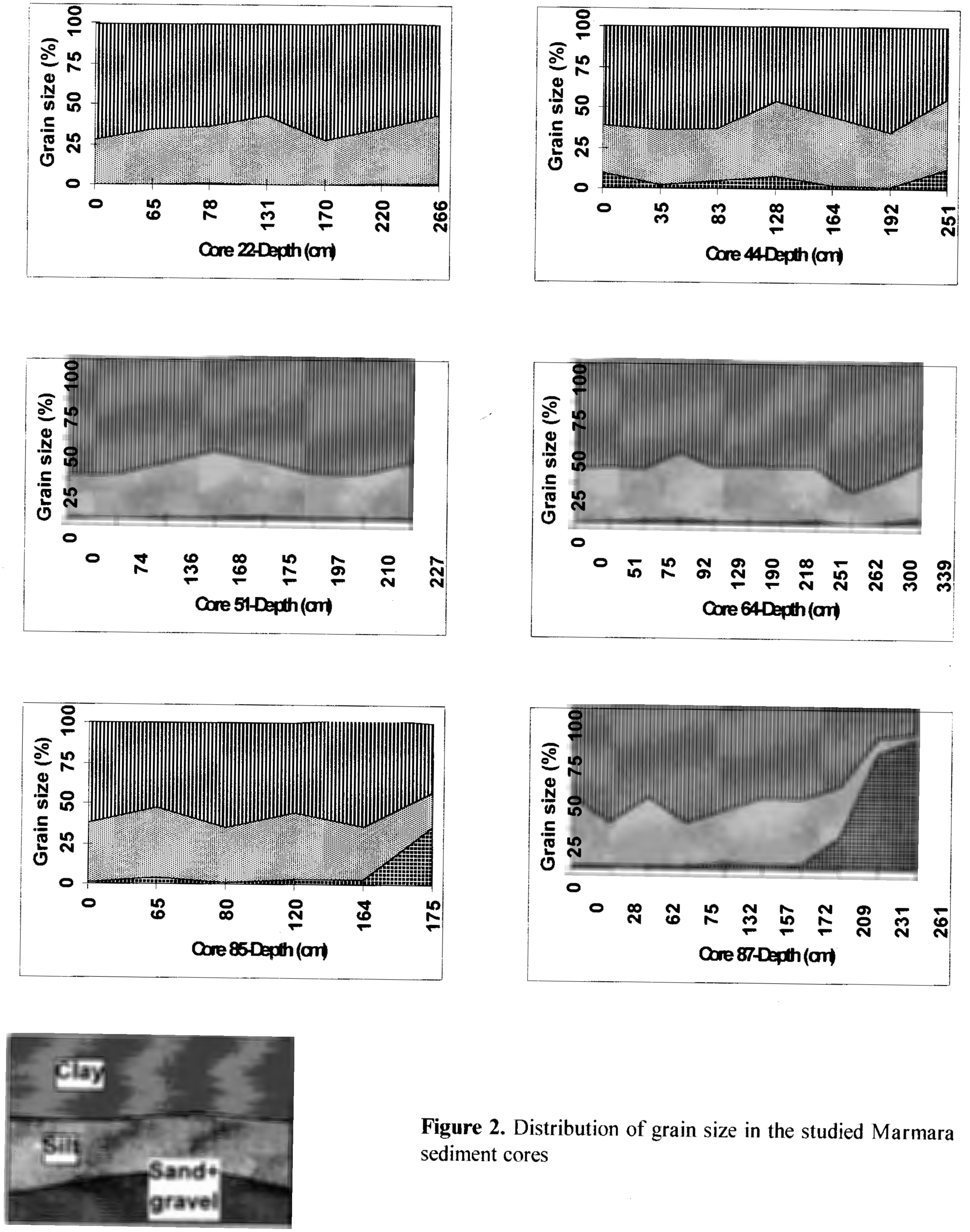

Figure 2. Distribution of grain size in the studied Marmara sediment cores

organic carbon using Leco Carbon Analyzer; n-alkane distribution using solvent extraction followed by gas chromatography (Varian 3700 GC, 30M, SE 30 capillary column); and the type of organic matter using pyrolysis experiments (Fina Oil Show Analyzer) and microscope on the isolated kerogen slides.

A large number of sub-samples were selected from the cores to determine sediment texture and analyzed for grain size distribution using the standard sedimentary petrographic techniques as described by Folk (1980). Following grain size fractions are considered: clay (< 0.002mm), silt (0.002-0.063mm), sand (0.063-2mm), and gravel (> 2mm), as well as mud (silt + clay < 0.063 mm).

RESULTS

Sediment Texture

Grain size data obtained in cores 22, 44, 51, 64, 85 and 87 is illustrated in Figure 2. As shown, sediments in cores 22, 51 and 64 taken between the Kocasu River mouth and Gemlik Bay consist entirely of fine-grained mud with roughly uniform silt and clay contents (Fig. 2). Core 44 represents a shelf break zone and thus subject to open-marine conditions contained small amounts of sand and gravel (1-11%). However, cores 85 and 87 interestingly display changing coarse-grained fractions (Fig. 2). Here, sand and gravel fractions rapidly increase in the lower core sections (below 135cm in core 85 and below 195 cm in core 87). Fine-grained silt and clay fractions reflect rather homogenous conditions, except at levels where sand and gravel portions start to increase downward. It is obvious that such downcore changes from fine-graine to coarse-grained texture are normally suggestive for changes in depositional or/and source conditions, i.e., from deeper water and lower energy to shallow water and higher energy depositional conditions.

Organic Matter Composition

The total organic carbon contents of sediment samples varied between 0.01 and 1.10 wt % with an average of 0.35 wt % (Table 2). The total organic carbon contents determined in the sediment cores of this study are comparably lower than those found in surface (top 15cm of sea floor) sediments (1-1.5 wt%; Ergin et al. 1993; Cagatay et al. 1996). Latter results are obtained from the wet-oxidation method so that higher C_{org} values could possibly be derived from measurements of oxidized and non-organic carbon related materials. In this study, one of the primary objectives was to determine the relative distribution of organic carbon down the cores; hence, further discussions with respect to C_{org} values of surface sediments from previous studies are omitted.

Organic carbon contents of sediments can also be used to determine the degree of source potentiality (Jonathan et al. 1976; Thomas 1979; Kraus and Parker 1979). The studied core sediments of the Marmara Sea bear weak to good source potentiality.

Organic Matter Type

Figure 3 shows T_{max} versus Hydrogen Index (HI) cross-plot diagram which is commonly used as a rapid means of organic matter characterization (Tissot and Welte 1984). Accordingly the type of organic matter in all of the samples is type III kerogen. The application of organic petrographic methods in this study revealed that the sediment samples contain 40-80 % vitrinite (woody+coaly), 20-60 % exinite (herbaceous) types of materials (Table 3). Also the organic mater abundances in the studied core samples are given in Figure 4. For further characterization of the organic matter, a ternary diagram of percentages of amorphous kerogen+exinite (spore+pollen+algae), vitrinite, and inertinite is also prepared (Fig. 5). As seen from this diagram, majority of the samples contain 40-80 % vitrinite (woody+coaly; terrestrial organic matter), lower amounts of spore+pollen+algae which are agreement with the the pyrolisis data.

The elemental analysis of kerogen is another parameter used to determine the type of kerogen (Table 4). The hydrogen percentages of sediments are low (0.5-1.3 %), and the oxygen values are rather high (95-97 %). The low H/C ratios and high O/C ratios indicate that organic matter in the studied sediments is made mostly of woody (terrestrial type) organic materials (type III kerogen). This also supports the results obtained from pyrolisis data, organic petrography, and the gas chromatograms of the samples. The woody type organic materials are composed of both cellulose and lignite thus their oxygen contents are high (high O/C ratios) and hydrogen contents are low (low H/C ratios; Waples 1981).

Gas Chromatography Analysis

The gas chromatography results for the studied core sediments are given in Figures 6 and 7. The most

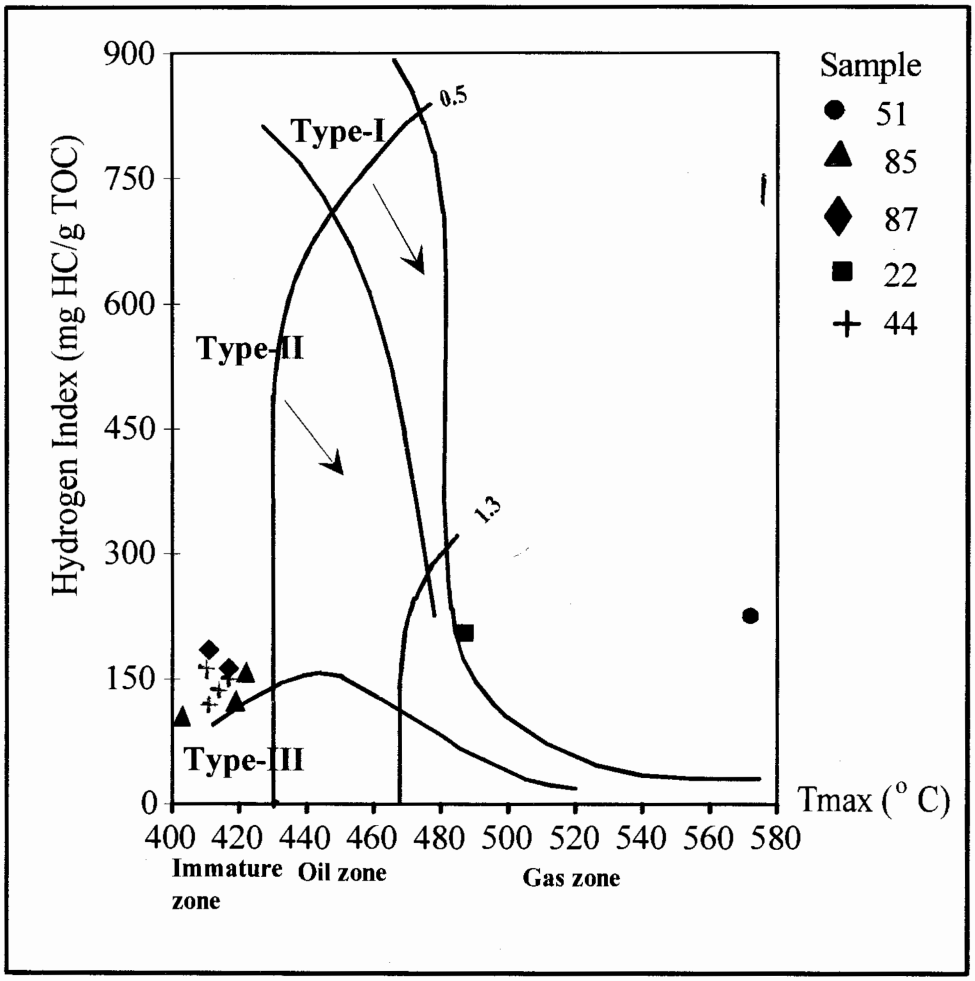

Figure 3. Kerogen typing using HI VsT_{max} (after Espitalie at al. 1986).

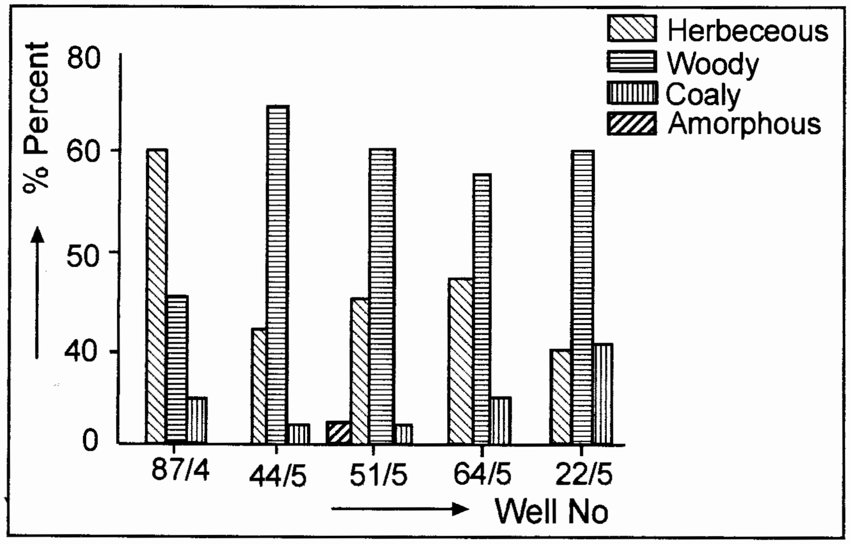

Figure 4. Organic matter distribution for the Holocene sediments of Marmara Sea

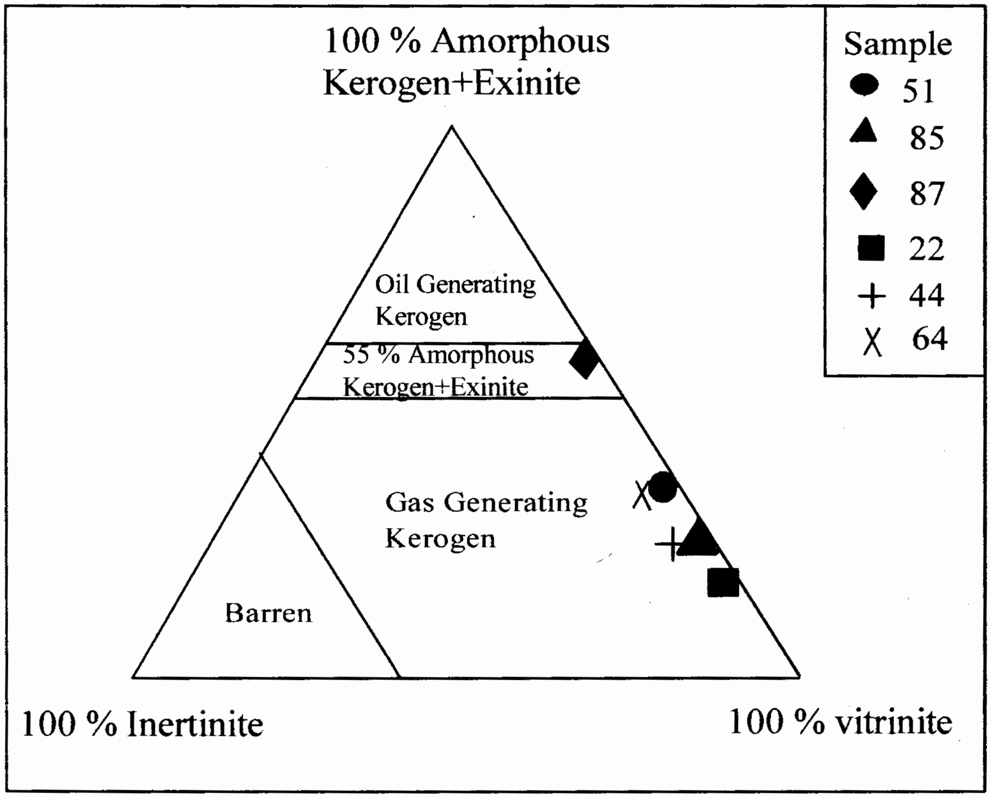

Figure 5. Hydrocarbon potential for the Marmara Sea Holocene sediments.

Table 4. Elemental analysis results of kerogen.

Sample	%C	%H	%N*	%S	%O	H/C	O/C
22/42	1.87	1.25	-	0.071	96.80	7.99	38..91
22/84	2.17	1.33	-	0.176	96.32	7.34	33..39
44/40	1.89	1.11	-	0.104	96.89	6.33	38..64
44/80	2.50	1.03	-	0.232	96.22	4.92	28..83
51/36	1.99	1.26	-	0.066	96.67	7.53	36..33
51/72	1.755	1.20	-	0.139	96.90	8.17	41.48
85/28	2.04	1.21	-	0.105	96.63	7.10	35..51
85/56	2.98	0.91	-	0.267	95.83	3.67	24.12
87/41	1.92	1.17	-	0.048	96.85	7.27	37.76
87/83	1.99	0.53	-	0.171	97.30	3.22	36.77
64/54	1.72	1.36	-	0.093	96.83	9.41	42.26
64/108	1.69	1.14	-	0.088	97.08	8.05	43.19

characteristics properties are the presence of maximum peaks for n-C_{27}, n-C_{29} and n-C_{31} n-alkane and phytane (Ph) as well as the presence of undissolved organic matter complexes (UOMC). UOMC reflect the immature characteristic of organic matter. The distribution of n-alkane, isoprenoid ratios and carbon preference index (CPI) values are given in Figure 8. As shown in Figures 6 and 7, even numbered n-alkane are more abundant than odd-numbered n-alkane. The CPI values calculated for n-alkanes between C_{16}-C_{24} and C_{26}-C_{32} (Cruiale 1983) are greater than 1 that reflects the dominance of even-numbered alkane over odd-numbered alkane. In particular, CPI values (1.09-4.39) between C_{26}-C_{32} indicate organic matter transported from land-based sources (Simoneit 1982). The CPI values (1.15-3.02) in the C_{16}-C_{24} n-alkane greater than 1 indicates organic matter derived from marine plankton (Hunt 1979). In the studied samples, n-C_{25} are present in high concentrations which could probably be derived either from the higher plant waxes on land or nonphytosythetic bacteria.

The Pr, Ph, n-C_{17} and n-C_{18} values calculated from the gas chromatographs to determine the depositional environment and source lithology are shown on the Pr/n-C_{17} - Ph/n-C_{18} diagram (Fig. 9). The sediments of cores 64, 51, and 87 are deposited in transition zones; whereby core 64 represents shale and others carbonates lithology. The sediments of core 85 must have been deposited in open-sea belonging to carbonate lithology and sediments of core 44 must have been deposited in marshland environment of shale lithology.

The pristane / phytane ratios in the four cores are found to be <1 and in other two cores >1 (Fig. 8). The pristane/phytane ratio reflects either the depositional environment of the organic matter of the sediments was anoxic (Pr/Ph < 1) or oxic (Pr/Ph > 1) (Didyk et al. 1978; Tissot and Welte 1984). The Pristane and the Phytane are both derived from Phytol; the phytol changes to the phytane in anoxic environments and the pristane in the oxidizing environment. Of the studied samples, sediments of core 64 and 44 are deposited in oxic (Pr/Ph >1); cores 22, 51 and 85 in anoxic (Pr/Ph <1) environments. These results show that the studied core sediments reflect depositional environments changing from oxic to anoxic conditions.

Maturity Studies

The results of vitrinite reflection measurements made on kerogen slides from the studied six sediment cores are given in Table 3. The vitrinite reflection values as a function of depths are shown in Fig.10. The vitrinite reflection values varied between 0.39-0.52% which show diagenetic changes of organic matter in the core sediments.

T_{max} (°C) Evaluation

The T_{max} values for the studied core sediments are shown in Table 2 and the distribution of Tmax values as a function of depth is presented in Fig. 10. As shown (Fig. 10), the maturity of all the samples, except for 22/168 and 51/36 are suggestive for diagenesis (370-422°C). Two samples (e.g. 22/168 and 51/36) show higher values of T_{max} (487-572°C) compared to those of the recent sediments in general. Higher T_{max} values (> 440°C) for recent sediments results most likely from the recycling of organic matter during transportation or deposition (Barker 1984). Some of the samples show relatively low values of T_{max} and higher S_1/S_1+S_2 ratios (Table 2). Lower T_{max} and higher S_1/S_1+S_2 values are observed particularly when the sediments are contaminated by the oil like hydrocarbons (Peters et al. 1989). As shown (Fig.11), most of the samples of this study are contaminated which contain higher amounts of clay minerals which may absorb the hydrocarbons better than the other minerals.

DISCUSSION

The T_{max} values especially those from samples 51/36 and 22/168 are very high (487-572 °C) when compared with those from modern sediments. The very high T_{max} values in recent sediments are probably resulted from recrystallization during the transportation and sedimentation of organic matter (Barker 1984). Some samples are marked by low T_{max} values (<400°C) although they have high S_1/S_1+S_2 ratios (Table 2; Fig.11). The low T_{max} and high S_1/S_1+S_2 values are observed when contamination occurs with petroleum-like hydrocarbons (Peters et al. 1989). As shown in Figure 11, most of the samples which are rich in clays are contaminated because clay minerals are able to adsorb hydrocarbons more easily than the other minerals. Barker (1979) claimed that if the input of the organic matter into the basin is kept constant, the sediments with high clay content will become richer in TOC content because of the higher surface area of the clay minerals. Figure 12 shows the distribution of methane (CH_4), ethane (C_2H_6) and

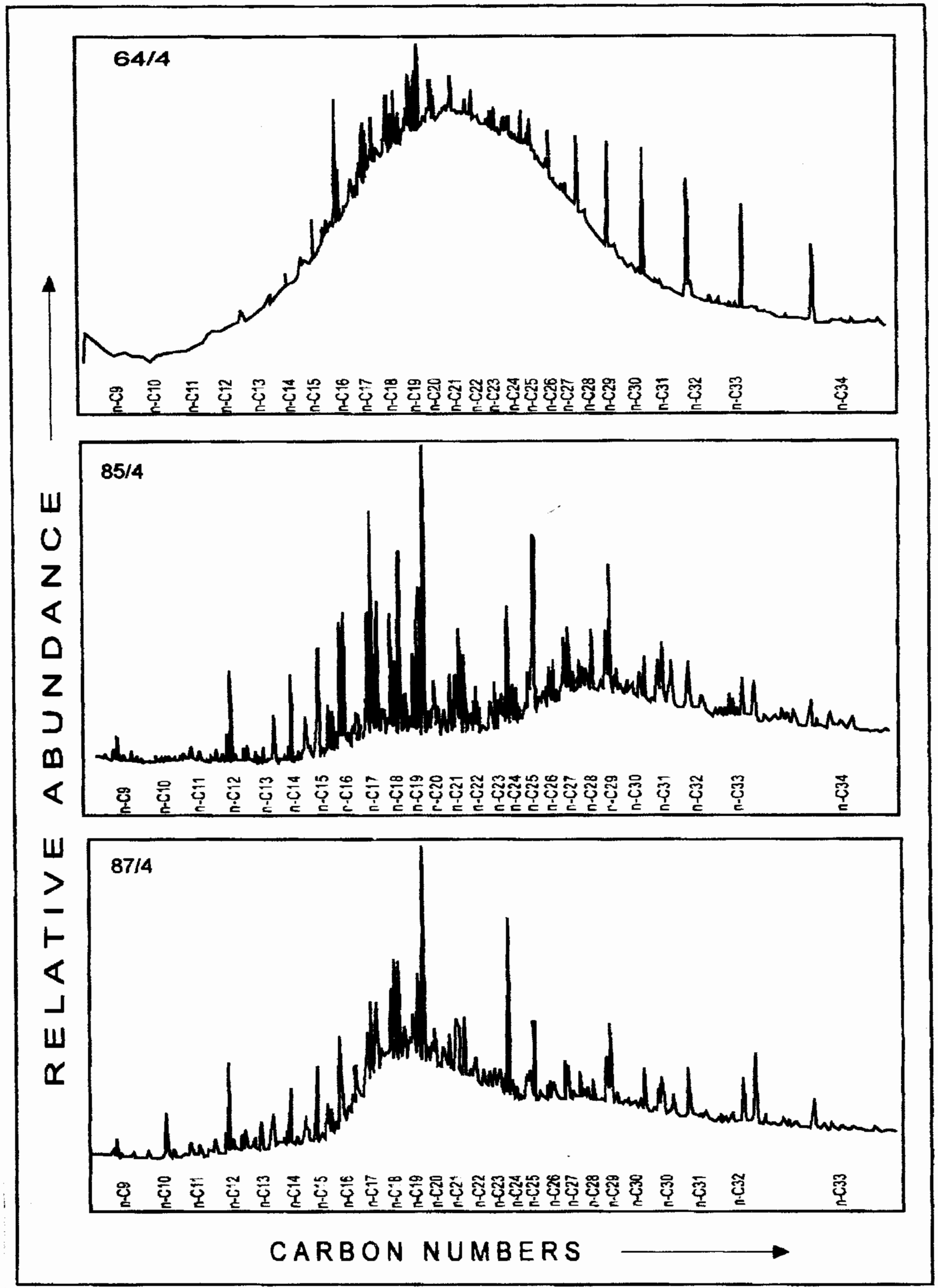

Figure 6. Gas chromatography results for sample Nos. 64/4, 85/4 and 87/4.

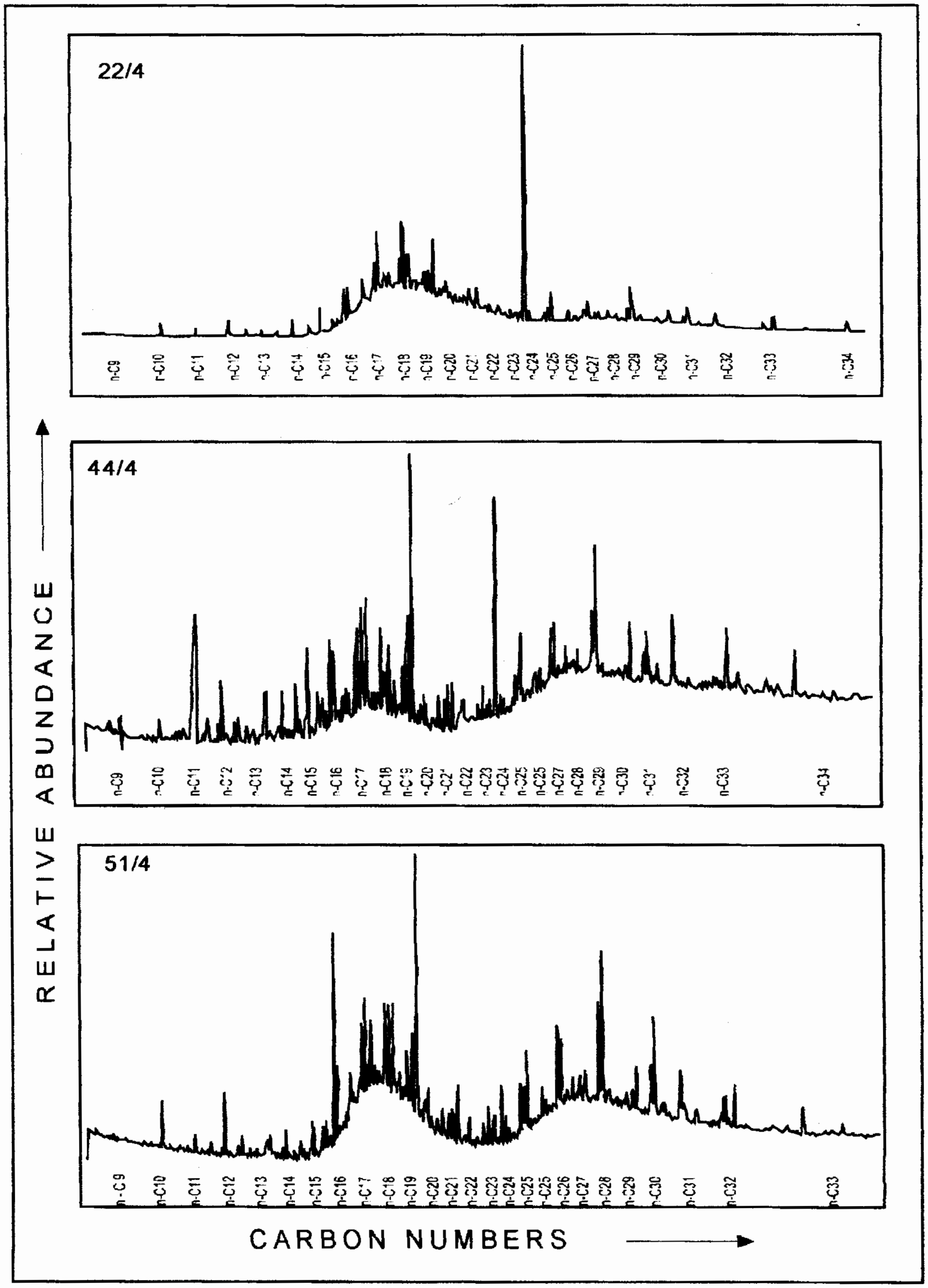

Figure 7. Gas chromatography results for the 22/4, 44/4 and 51/4 samples.

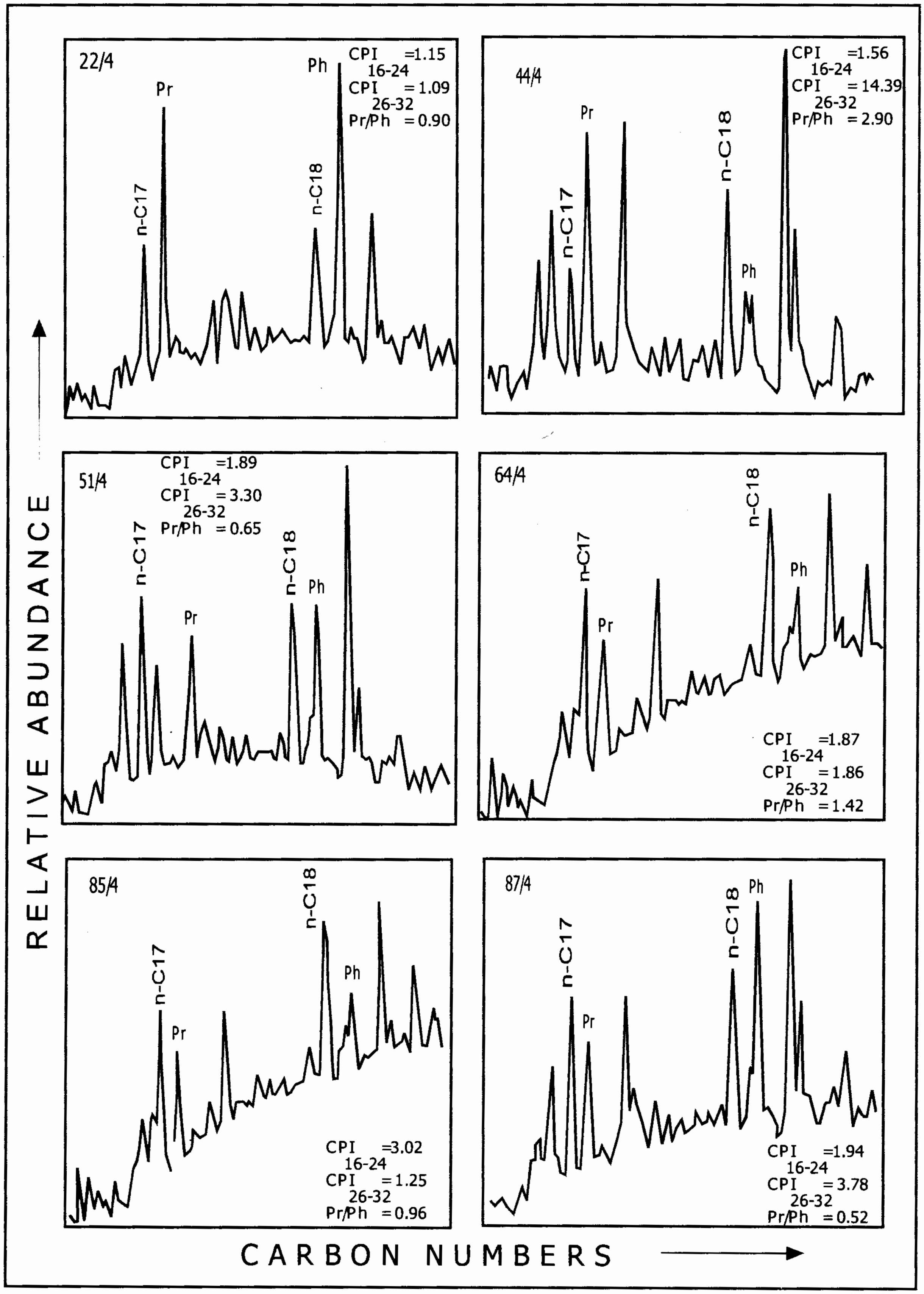

Figure 8. n-alkane distributions for the 22/4, 44/4, 51/4, 64/4, 85/4 and 87/4 samples.

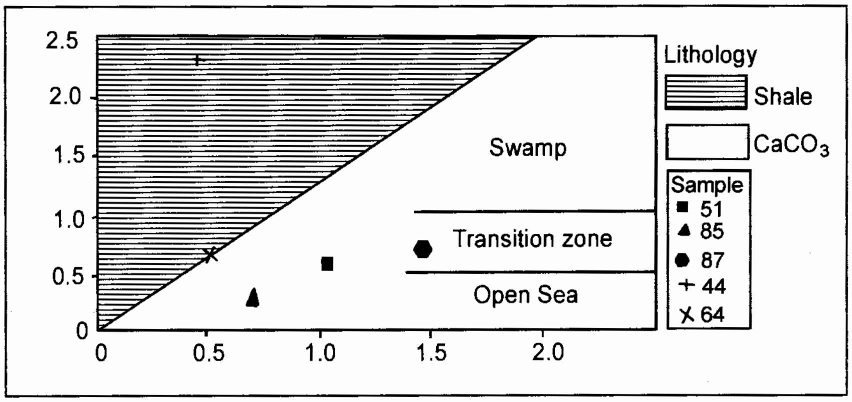

Figure 9. Pr/n-C17 - Ph/n-C18 Diagram (after Mathur et al. 1988).

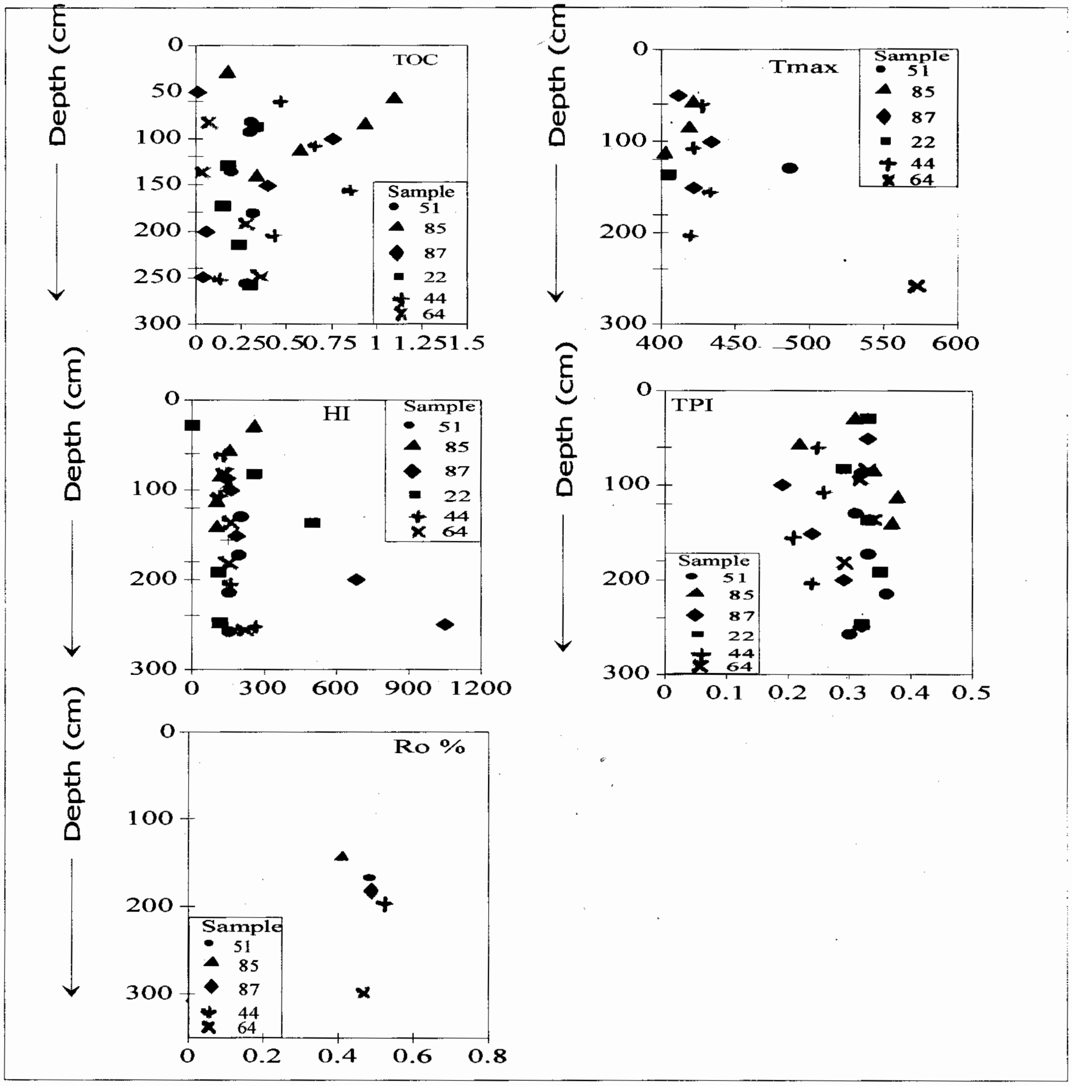

Figure 10. Evaluation of pyrolisis results for the Marmara Sea Holocene sediments.

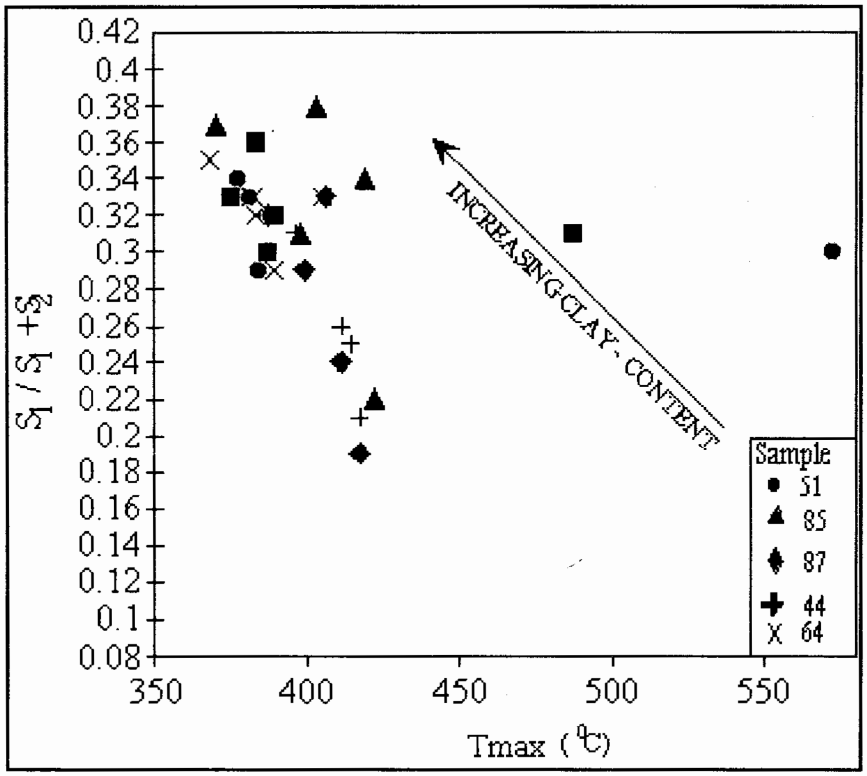

Figure 11. T_{max} - S_1/S_2+S_2 Diagram (after Peters et al. 1986).

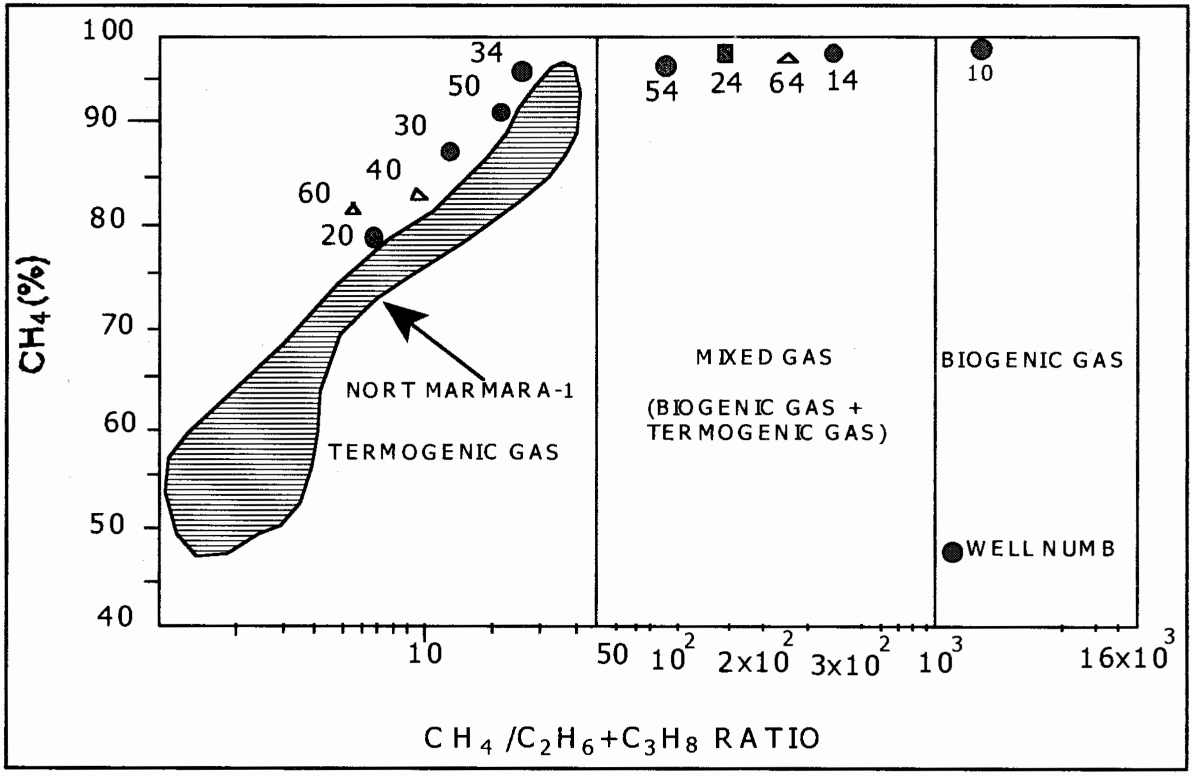

Figure 12. CH_4 (%) - $CH_4/C_2H_6+C_3H_8$ Diagram ((after Simoneit 1982).

propane (C_3H_8) gases on the CH_4-CH_4/ C_2H_6+C_3H_8 diagram. As shown in Figure 12, only one sample has a biogenic source, six samples are thermogenic and four samples are of mixed (biogenic+thermogenic) origin-related gas zone (Gürgey and Sayili 1990).

CONCLUSIONS

1. The total organic carbon contents of Holocene sediments of the southern Marmara shelf range between 0.01-1.10 wt % (avg. 0.35 %).
2. The kerogen types of samples are type III; organic matter consists of 40-80 % vitrinite (woody+coaly) and 20-60 % of exinite (herbeceous) type materials.
3. The elemental analysis of kerogen show low hydrogen (0.5-1.3 %) and high oxygen (95-97 %) contents indicating the dominance of woody type (type III kerogen) organic materials.
4. The vitrinite reflection values (Ro: 0.39-0.52 %) indicate organic matter maturation at the diagenesis stage.
5. Except for sample No. 51/36 and 22/168, the T_{max} values of samples range between 370-422°C and indicating their diagenetic stages; the T_{max} values of core samples 51/36 and 22/168 vary between 487-572°C and fall into the anchimetamorphism zone.
6. Higher T_{max} values ($>$ 440°C) for recent sediments most likely result from the recycling of organic matter during transportation or during deposition.
7. The T_{max} values less than 400 °C in the samples and the very high PI values indicate that these samples were subjected to organic contamination.
8. The n-C_{27}, n-C_{29} and n-C_{31} n-alkane in the sediments are dominant and CPI values are >1 indicating dominance of terrigenous organic matter sources.

ACKNOWLEDGEMENTS

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THE CLAY MINERALOGY AND PALEO-ENVIRONMMT OF THE WARCHA FORMATION EXPOSED AT BURIKHEL, WESTERN SALT RANGE PAKISTAN

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ABSTRACT

The clay mineral composition of ten selected samples from Warcha Formation exposed at Burikhel was investigated to understand their distribution from base to the top of the Formation. The most abundant clay minerals present are illite, kaolinite, and the mixed-layer clay mineral, recognized as illite-vermiculite. The minor clay minerals are chlorite, smectite, vermiculite, and the mixed-layer clay mineral identified as chlorite-vermiculite. The clay mineral composition from base to top indicates depositional and diagenetic changes in the Warcha Formation. The presence of kaolinite in most of the samples reflects fresh water to brackish water environment. The clay mineral kaolinite is partly detrital and partly diagenetic in origin. The clay minerals illite and chlorite are detrital in origin. The detrital nature of the clay minerals e.g. illite, chlorite and smectite suggests the active and deep erosion of the continental areas during the deposition of the Warcha Formation.

INTRODUCTION

The Warcha Formation, speckled sandstone of the earlier workers, has been the subject of attention by numerous workers e.g. Mounsuart Elphinstone 1808, Waagen 1881 and 1891, Wynne 1887, Noetling 1901, Gee 1945, Wadia 1957, Pascoe 1959, Hussain 1967, (as cited by Fatmi 1973, Shah 1977).

The Warcha Formation, exposed at Burikhel, consists mainly of medium to coarse-grained sandstones and interbedded shales and clays. The sandstones occasionally contains pebbles and gravels. It has a maximum thickness at Burikhel (199 m) and overlies the Tobra Formation. The Sardhai Formation conformably overlies the Warcha Formation. It has been assigned an early Permian age (Fatmi 1973, Shah 1977).

The present studies were carried out on ten selected samples to understand distribution of clay minerals from base to the top of the Formation, to

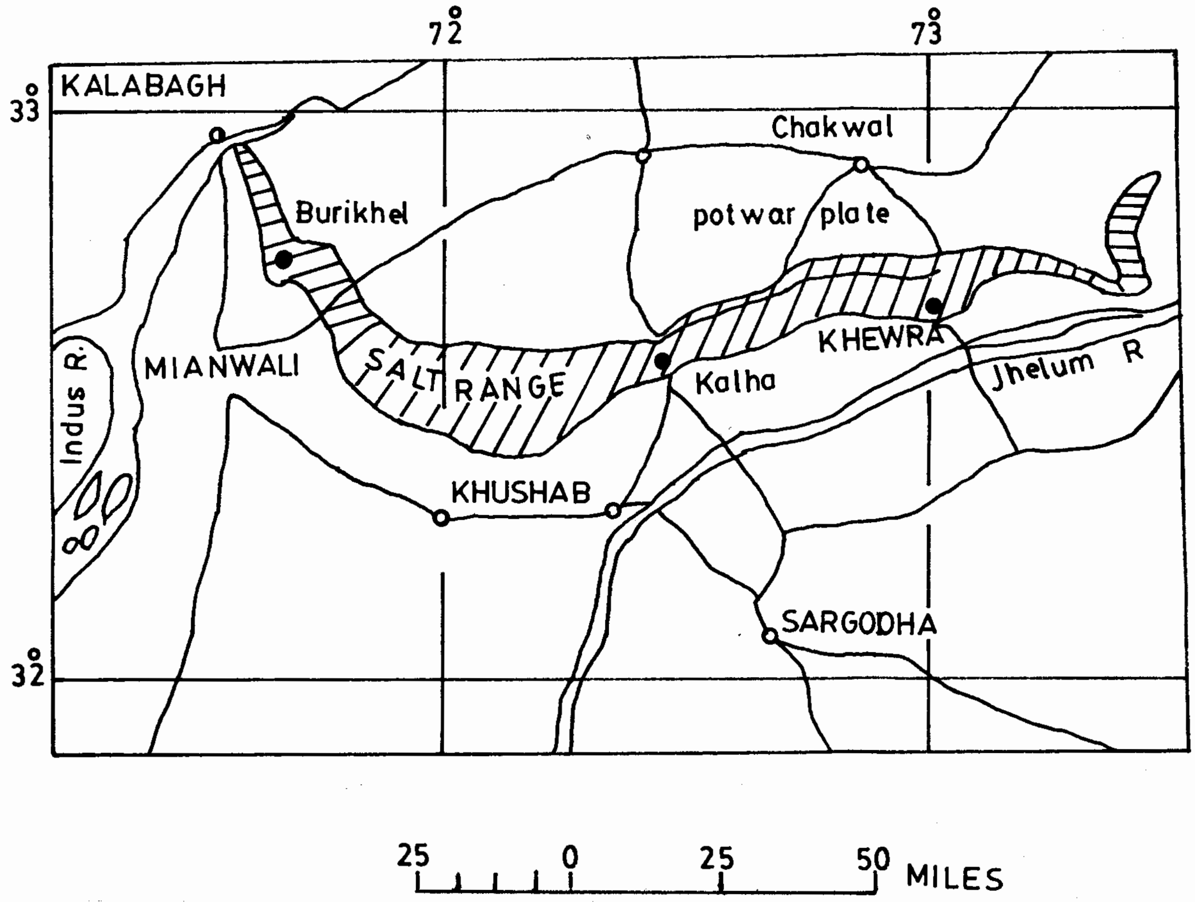

Figure 1. Map showing the location of Burikhel in the Salt Range, Punjab, Pakistan.

observe their detrital and diagenetic origin, and to infer their palaeo-depositional condition. Figures 1 and 2 provide the location map of the area and lithological log of the Formation with sample numbers respectively.

METHODOLGY

About 30-50 grams of the powdered samples were soaked in de-ionised water, followed by shaking and mixing for about six hours in an electric shaker. After the processes of sedimentation four types of oriented slides were prepared of each samples. Each sample was scanned on the X.R.D for the identification of the clay minerals between 2°2θ to 20°2θ smaller than two microns grain size according to the method of Holtzapffel (1985). The percentage of the different clay minerals was calculated using their mean height. The x-ray diffractrometer traces were called as (1) natural or normal e.g., air-dried, (2) heated, (3) glycolated and (4), hydrazine's slides. All the traces were also run from 2°2θ to 20°2θ to study the changes after respective treatment. The mixed-layer clay mineral recognized as illite-vermiculite (I-V) was recognized due to its reflections between 10-12 Å. The mixed layer clay mineral chlorite-vermiculite (C-V) was recognized due its reflection between 14-12 Å after heating and glycolation. The clay mineral illite was recognized due to its reflection at 10Å. The mineral kaolinite and chlorite were recognised due to their reflections at 7Å and 14Å, respectively.

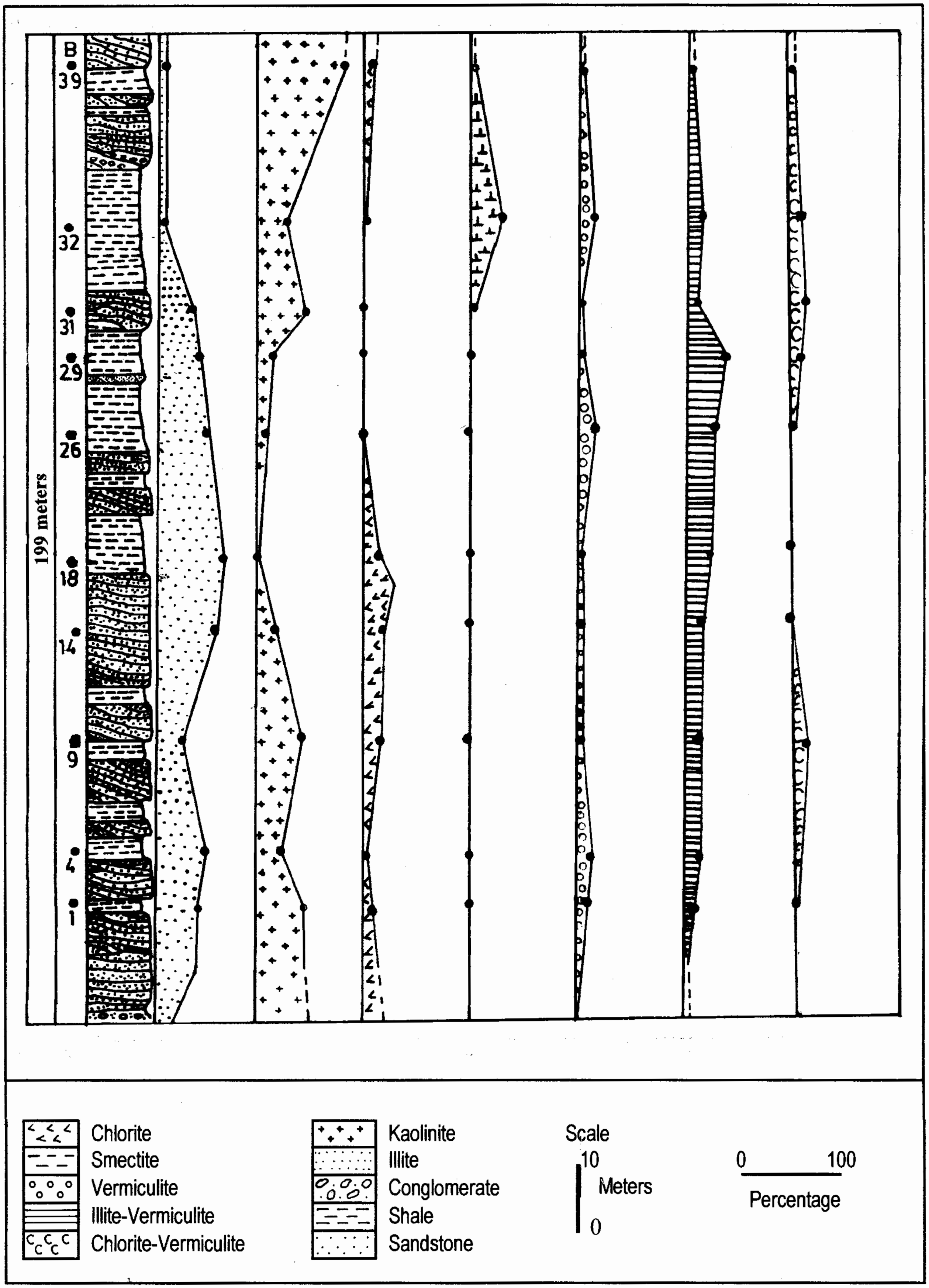

Figure 2. Distribution of clay minerals in the Warcha Formation exposed at Burikhel, Salt Range, Pakistan

RESULTS

The results of the present study have been summarized in the table 1. Figure 2 gives the details of the distribution of the percentage of the different clay minerals from bottom to the top of the Warcha Formation, exposed at Burikhel. The black dot represents the sample position on the log. The most abundant clay minerals are illite, kaolinite, mixed-layer clay mineral and illite-vermiculite. Clay minerals, chlorite, smectite, vermiculite and mixed layer clay mineral recognized as chlorite-vermiculite are present in minor amounts. Illite is present in all samples, it is maximum in the middle part of the Formation. The clay mineral kaolinite was observed in most of the samples. Figures 3A, 3B and 3C provide the x-ray diffraction traces of the selected samples, B14, B18 and B29, respectively. The nature of the clay mineral reflections after glycolation, hydrazine and heat treatment obvious and useful for the identification of the above minerals.

DISCUSSION

Many workers have conducted the clay mineral studies for the Palaeozoic sediments. Grim (1951) investigated the Palaeozoic shales in Illinois and stated that illite was the most dominated detritus mineral. Weaver and Polard (1973) also indicated the detritus nature of the mineral chlorite. Burst (1959) found evidences of the systematic diagenetic changes in the subsurface samples of the Wilcox Formation. Baqri and Rajpar (1991) observed that the mixed-layer clay mineral was originated diagenetically due to the degradation of illite and chlorite in the presence of sodium ions in the Khewra sandstone of Cambrian age exposed in the Salt Range, Pakistan. Weaver (1964) stated that much of the Pre-Cambrian illite was derived from the land due to the erosion of the continental rocks. Dunoyer De Segonzac (1970) also observed that most of the clay minerals present in the Palaeozoic shales and siltstones are illite and chlorites.

The Warcha Formation exposed at Burikhel displays illite, kaolinite, chlorite, vermiculite, and the mixed-layer clay minerals illite-vermiculite (I-V) and chlorite-vermiculite (C-V). The mineral illite and chlorite are generally not well crystalline and most likely were degraded during their transportation from the source area. The provenance was mainly metamorphic and acid igneous rocks. Therefore, the mineral illite and chlorite were mostly likely detritus in nature (Weaver and Pollard, 1973). The mineral kaolinite most likely was formed due to diagenetic alteration of feldspar, commonly found in the Warcha Formation. It is also possible that kaolinite was transported due to erosion and weathering of the continental rocks such as granites and other acid igneous rocks exposed in the source area. It is therefore most likely that kaolinite was partly detritus and partly diagenetic in nature.

According to Millot (1964) kaolinite is formed in hot, dry, or humid climate. The mixed-layer clay minerals identified as illite-vermiculite (I-V) and the chlorite-vermiculite (C-V) may have been formed diagenetically due to weathering of illite and chlorite bearing rocks. They may also be the result of late diagenesis due to action of the magnesium ions and sodium rich ions on the illite and chlorite minerals. Weaver (1967) observed that most of the mixed-layer clay minerals are derived from the degradation of pre-existing clay minerals, particularly illite. The mineral smectite was transported most likely due to the erosion of the continental soils in the depositional basin. According to Chamley et al. (1990) and Deconinck et al. (1991) mineral smectite originates from alteration of the soils developed on the continental areas. The detritus minerals illite, and chlorite suggests erosion of the continental areas.

SUMMARY AND CONCLUSIONS

The clay minerals in the Warcha Formation exposed at the Burikhel were identified as kaolinite, chlorite, illite, smectite, vermiculite, the mixed-layer clay minerals as illite-vermiculite (I-V) and the chlorite-vermiculite (C-V). The most dominant clay minerals are kaolinite, and illite. The clay minerals illite and chlorite are detrital in nature. The mineral kaolinite was most likely partly diagenetic and partly of detrital origin. The mixed layer clay minerals illite-vermiculite and chlorite-vermiculite are most likely of diagenetic origin.

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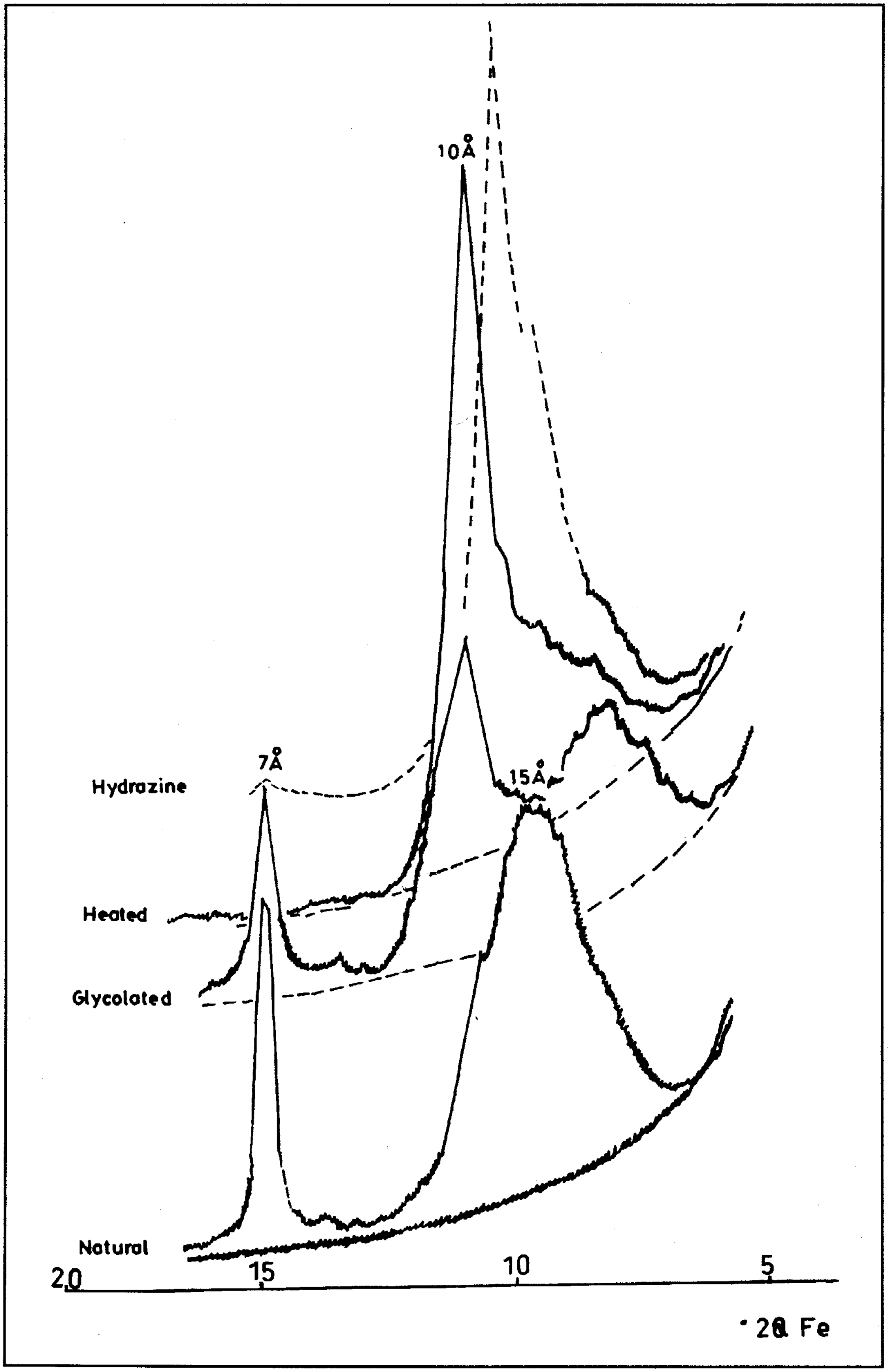

Figure 3A. Diffractogram of different clay minerals in Sample No. B29 of Warcha Formation, Burikhel, Salt Range, Pakistan.

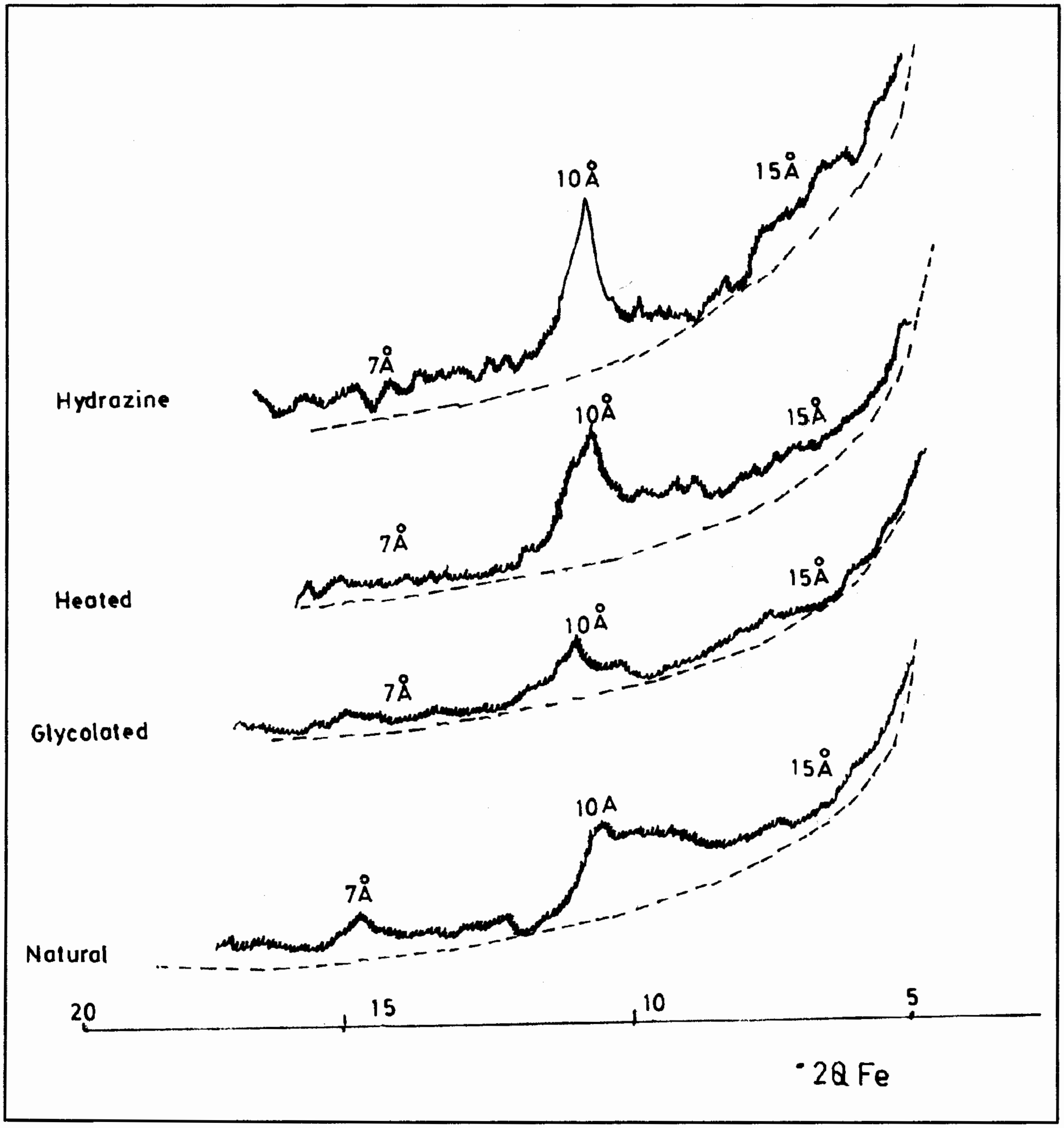

Figure 3B. Diffractogram of different clay minerals in Sample No. B18 of Warcha Formation, Burikhel, Salt Range. Pakistan

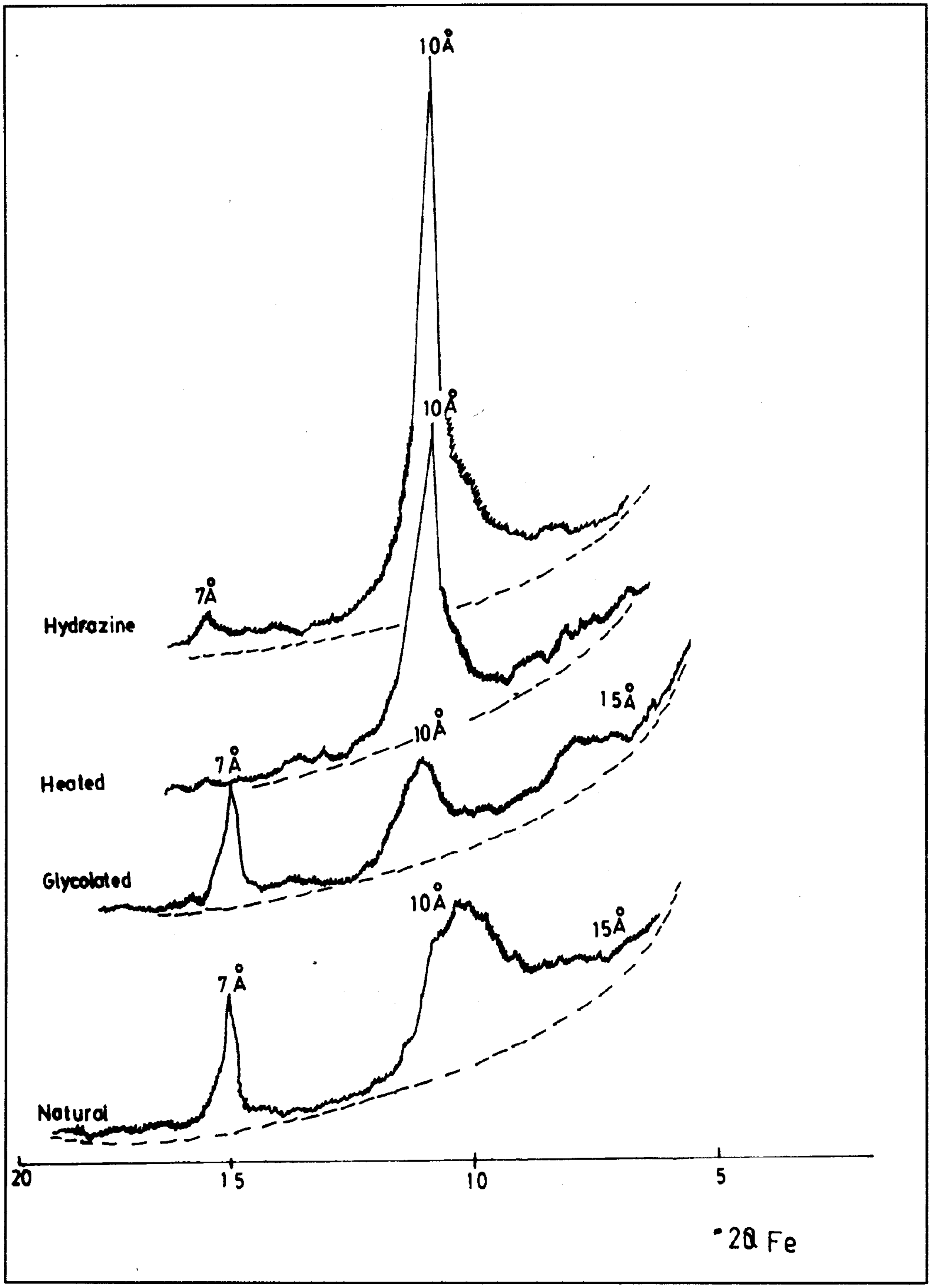

Figure 3C. Diffractogram of different clay minerals in Sample No. B14 of Warch Formation, Burikhel, Salt Range, Pakistan

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TRACE AND RARE EARTH ELEMENTS GEOCHEMISTRY OF THE BASEMENT COMPLEX IN MADHYAPARA, DINAJPUR, BANGLADESH

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ABSTRACT

The geochemical characteristics of the sub-surface Basement Complex in Madhyapara have been carried out to synthesize its petrogenesis. The Basement Complex is composed of tonalite, granodiorite, granodiorite gneiss, granite, adamellite and quartz-monzonite. Granites, adamellite and quartz-monzonite are intruded as vein into the tonalite-granodiorite (TG) suite with sharp contact. In silica variation diagrams the trace elements Sc, V and Cr of the TG suite show linear negative trends with increasing SiO_2, while most of the trace elements concentrate as clusters. A large variation of the incompatible element content (e.g. Ba) as compared to compatible elements (e.g. Cr and Ni) suggests that partial melting played the dominant role for the evolution of the TG suite. Correlation between Sr and Rb/Sr versus SiO_2, indicate insignificant role of plagioclase fractionation.

The chondrite normalized rare earth element (REE) patterns shows that the TG suite is enriched in light-REE, moderately fractionated and characterized by no Eu anomalies. The Primitive Mantle normalized trace and REE patterns show negative Nb anomalies suggesting a subduction related magmatism. The Ocean Ridge Granite normalized trace and REE patterns marked a Nb-Ta negative anomaly i.e. forming a trough, indicating continental arc granitoid signature. Minor differences in LaN/SmN, GdN/YbN and LaN/YbN ratios and more or less parallel REE pattern indicate that the TG suite is possibly derived from a single source. Most of the REE patterns of this suite show a concave form at the HREE end. The geochemical characters of the TG suite suggests that both partial melting of the granitoid basement (amphibolite source rock) and fractionation of Fe-Mg phase, are responsible for the evolution of this suite in Madhyapara.

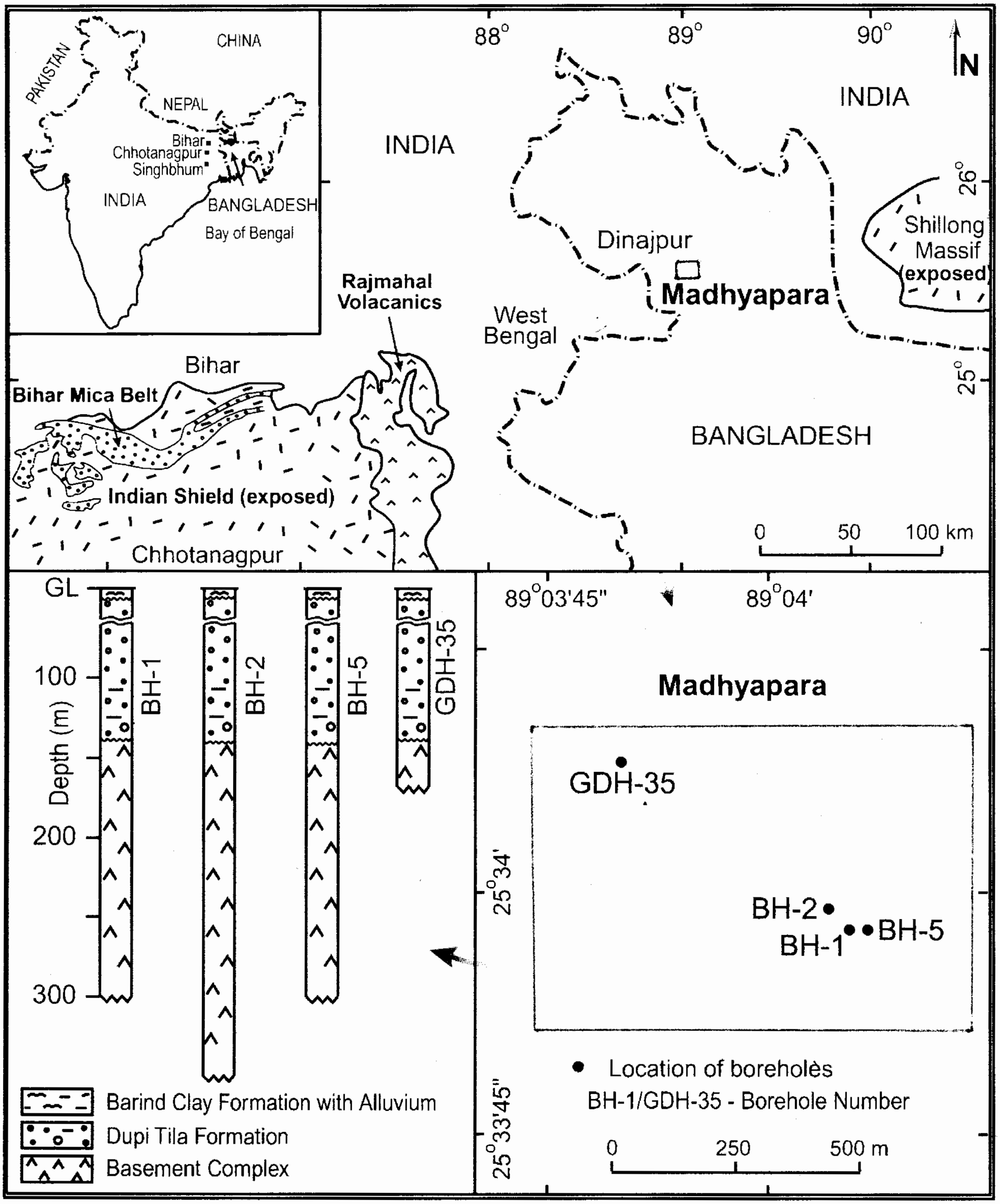

Figure 1. Location map of Madhyapara with the boreholes and subsurface geological formations.

INTRODUCTION

The Precambrian basement rocks of the Indian Shield are exposed as Singhbhum Craton, Chhotanagpur Gneissic Complex in the west and southwest of Madhyapara. In the northeast, the basement rock is exposed as Shillong Massif. Geophysical and drilling data indicate that in Madhyapara the basement rocks occur at a shallow depth (128 m) from the surface with a thin cover of Pliocene Dupi Tila Formation, Pleistocene Barind Clay Formation and Alluvium of Recent age (Fig. 1). The Singhbhum Craton comprises granodiorite-trondhjemite and granodiorite-adamellitic granite (Saha et al. 1988). The geochemical modeling suggest that the parental melt of the basement rocks of Singhbhum Craton was generated by partial melting of amphibolites and subjected to fair degree of fractional crystallization (Bose 1997). The Chhotanagpur Gneissic Complex is composed of granitic gneisses, granulites and migmatites (Naqvi and Rogers 1987). A number of granite plutons occurred within the gneissic country rocks of Chhotanagpur. Srivastava and Ghose (1992) defined that the intrusive granitoids of Bihar (north of Chhotanagpur) are mainly pink granite (granodiorite-granite-pegmatite), gray granite (granodiorite-granite) and leucogranite (tonalite-granodiorite) resulting from late tectonic acid intrusive within the gneissic country rocks. Bose (1997) stated that the petrochemical modeling of the intrusive granitoids in Bihar suggests derivation by partial melting of the granitoid basement (underlying Chhotanagpur Gneissic Complex) and the generated melt experienced variable degrees of fractional crystallization. The Shillong Massif comprises of granitic gneisses, schists and intrusive granites (Krishnan 1982). The Precambrian basement rocks in the northwestern part of Bangladesh (based on drilling information and petrography) comprise metamorphosed granitic rocks but amphibolite, gabbro, dolerite and schistose rocks are also common (Khan 1992). Till to date no detailed geochemical study (major, trace and rare earth elements) of the Precambrian Basement Complex in Madhyapara have been performed. The present research is the first attempt to carry out detail geochemical study of the Basement Complex in the northwestern part of Bangladesh to ascertain its possible origin.

ANALYTICAL TECHNIQUE

A total of 29 samples (boreholes BH-1, BH-2 and BH-5; Table 1) have been analyzed at the department of Geoscience, Shimane University, Japan. Out of these samples the trace element analyses of 26 samples were performed using X-ray Fluorescence Spectrometry (XRF) technique. A few trace elements of three samples (SB-07*, SB-23* and SB-35*; Table 1) were performed on fused glass beads with 5:1, flux : sample ratio technique. The rare earth elements of 10 samples were performed by Instrumental Neutron Activation Analysis (INAA) technique. The analytical methods are described by Ishiga et al. (1997). The trace and rare earth elements of three samples of the borehole GDH-35 (SB-50, SB-51 and SB-53; Table 1) were performed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) technique, at the department of Earth and Space Sciences, University of Science and Technology, China.

GEOCHEMISTRY OF TRACE ELEMENTS

The Basement Complex in Madhyapara is composed of tonalite and granodiorite associated with granodiorite gneiss, granite, adamellite and quartz-monzonite. granite, adamellite and quartz-monzonite intruded as vein (usually < 1 m, with an inclination of 66° to 85°) into the tonalite-granodiorite (TG) suite with sharp contact (Zaman et al. 2000). The trace and rare earth elements content of different rock types are listed in Table 1. In granodiorites an average concentrations of Sc is 16 ppm, V 135 ppm, Cr 75 ppm, Ni 64 ppm, Y 19 ppm, Zr 227 ppm, Nb 3 ppm, Th 7 ppm, Cu 42 ppm, Rb 72 ppm, Sr 780 ppm and Ba 945 ppm. Tonalites contain an average of Sc 17 ppm, V 162 ppm, Cr 69 ppm, Ni 56 ppm, Y 19 ppm, Zr 217 ppm, Nb 6 ppm, Th 7 ppm, Cu 103 ppm, Rb 68 ppm, Sr 749 ppm and Ba 568 ppm. Tonalites are characterized by higher concentration of Sc, V, Y, Nb, Cu and lower in Cr, Ni, Rb, Th, Sr and Ba than the granodiorites. In granites average concentrations of Sc is 2.7 ppm, V 10 ppm, Cr 15 ppm, Ni 28 ppm, Cu 14 ppm are like those of crustal granites (Mason and Moore 1985).

The trace elements versus SiO_2 variation diagrams have been shown in Figure 2. In the tonalite-granodiorite (TG) suite Sc, V and Cr show a well-defined variation against SiO_2. Yettrium usually concentrates as clusters but a slight decrease is

Table 1 Geochemical composition of the basement rocks in Madhyapara.

Borehole No.	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Nomenclature	Qz-mon	Gd	Tn	Tn	Gd	Gd	Tn	Gr	Gd	Gd	Tn	Ad	Gd	Gd	Gd	Gd
Sample No.	SB-02	SB-03	SB-04	SB-07*	SB-10	SB-11	SB-15	SB-16	SB-19	SB-21	SB-22	SB-23*	SB-25	SB-26	SB-27	SB-29
SiO_2 (wt.%)	72.79	54.65	51.47	49.63	58.08	57.34	58.28	75.53	66.77	58.40	59.92	71.37	64.72	58.27	64.43	59.73
TiO_2	0.22	0.82	1.04	1.03	0.75	0.74	0.91	0.07	0.43	0.76	0.58	0.43	0.51	0.76	0.63	0.95
Sc (ppm)	5	18	23		17	17	18	2	8	18	14		13	18	14	19
V	25	183	224		158	134	142	11	63	146	116		85	171	101	171
Cr	19	104	133		72	89	55	15	30	89	62		96	92	25	60
Ga	18	21	22		20	19	21	11	18	20	22		19	19	19	20
Ni	27	70	78		71	66	55	29	38	78	61		70	64	36	52
Y	21	19	22	20	18	19	16	16	12	21	13	23	19	17	16	23
Zr	149	229	206	209	212	231	192	227	303	230	213	131	145	230	248	220
Nb	9	1	3		2	3	13	1	1	1	1		5	2	5	12
Th	11	7	7		6	6	10	17	17	4	4		12	6	16	8
Pb	31	19	15		17	19	14	35	21	18	20		22	18	17	15
Cu	19	1	17		29	25	61	8	20	124	29		1	21	42	159
Rb	93	80	80	126	65	74	51	121	66	91	56	79	72	66	50	77
Sr	457	920	797	879	746	767	678	745	843	822	973	684	613	790	703	533
Ba	1351	1305	565		801	1035	421	2393	1295	852	1131		1306	1152	376	443
La	23.36		42.93		35.11			8.20								
Ce	35.67		89.66		68.14			14.90								
Sm	4.39		8.82		6.86			1.59								
Eu	0.94		2.00		1.58			1.47								
Gd	1.31		1.76		1.45			1.25								
Tb	0.71		0.79		0.57			1.54								
Yb	1.28		1.84		1.54			1.49								
Lu	0.21		0.27		0.31			0.08								
Rb/Sr	0.20	0.09	0.10	0.14	0.09	0.10	0.08	0.16	0.08	0.11	0.06	0.12	0.12	0.08	0.07	0.14
La_N/Yb_N	12.33		15.77		15.41			3.72								
La_N/Sm_N	3.35		3.06		3.22			3.25								
Gd_N/Yb_N	2.75		2.59		2.29			2.82								
Eu/Eu*	0.66		0.85		0.88			1.57								

continued.....

Table 1. Contd.....

Borehole No.	2	2	2	2	2	2	2	2	5	5	5	5	5	35	35	35
Nomenclature	Tn	Gd	Gd	Gd	Gr	Gd	Gd	Gd	Gr	Tn	Gd	Gd	Tn	Gd Gn	Gd Gn	Gd Gn
Sample No.	SB-30	SB-31	SB-33	SB-35*	SB-36	SB-37	SB-39	SB-40	SB-42	SB-43	SB-44	SB-45	SB-47	SB-50	SB-51	SB-52
SiO_2 (wt.%)	56.13	57.29	58.22	58.01	70.26	57.57	57.46	58.09	75.08	51.62	58.65	57.61	56.52	55.43	56.27	52.07
TiO_2	1.14	0.77	0.71	0.71	0.09	0.78	0.75	0.75	0.07	1.06	0.78	0.81	1.08	0.83	0.75	1.66
Sc (ppm)	19	20	18		3	15	17	19	3	25	16	17	21			
V	210	152	145		14	169	145	131	5	237	155	183	203			
Cr	74	95	84		12	71	86	83	18	86	88	104	70	66	72	76
Ga	20	19	21		10	20	20	22	11	12	20	19	20			
Ni	59	66	78		29	67	112	87	27	82	63	68	57	42	41	43
Y	23	19	16	23	21	20	23	16	12	17	19	17	21	18	18	30
Zr	233	238	223	186	114	244	212	228	93	237	255	231	232	151	166	201
Nb	14	3	2		1	2	3	1	1	2	3	1	12	11	10	17
Th	10	8	5		7	5	5	5	8	11	10	5	9	9	12	11
Pb	16	14	19		53	16	24	18	38	13	17	16	15	24	27	18
Cu	146	23	55		29	40	55	64	4	323	10	42	142	53	48	142
Rb	56	75	60	60	165	87	110	59	94	53	66	66	54	66	69	91
Sr	516	782	822	835	762	837	718	852	712	858	844	832	540	713	797	396
Ba	350	1133	1006		2384	883	1095	1124	1831	1075	1081	1170	433	911	1102	491
La	45.62	38.80			1.50	31.65					43.03	58.70		35.81	36.33	31.21
Ce	103.01	52.80			2.70	56.89					79.75	73.10		77.76	77.42	77.95
Sm	9.17	6.10			0.35	6.02					6.67	12.92		6.44	6.18	8.43
Eu	2.05	1.30			0.38	1.49					1.67	1.70		1.68	1.63	2.28
Gd	1.95	0.39			0.01	0.52					1.19	1.86		4.98	4.84	7.55
Tb	0.90	0.44			0.02	0.44					0.50	0.66		0.65	0.64	1.02
Yb	2.40	1.41			0.37	1.15					2.77	2.61		1.50	1.53	2.41
Lu	0.37	0.26			0.01	0.21					0.24	0.62		0.25	0.25	0.37
Rb/Sr	0.11	0.10	0.07	0.07	0.22	0.10	0.15	0.07	0.13	0.06	0.08	0.08	0.10	0.09	0.09	0.23
La_N/Yb_N	12.84	18.60			2.74	18.60					10.50	15.20		16.13	16.05	8.75
La_N/Sm_N	3.13	4.00			2.70	3.31					4.06	2.86		3.50	3.70	2.33
Gd_N/Yb_N	2.19	2.02			0.38	2.47					1.15	1.84		2.51	2.40	2.31
Eu/Eu*	0.81	0.86			4.74	0.99					0.99	0.59		0.94	0.94	0.92

Qz-mon: Quartz-monzonite, Gd: Granodiorite, Tn: Tonalite, Gr: Granite, Ad: Adamellite, Gd Gn: Granodiorite Gneiss.
Eu/Eu* = $Eu_N/(Sm_N{}' Gd_N)^{1/2}$ and where $Gd_N = (Sm_N{}' Tb_N{}^2)^{1/3}$ are after Condie (1993).

observed with increasing silica. Y behaves as incompatible element throughout the tholeiitic series but remain constant or decrease with fractionation during much of the calc-alkaline series, where it can be accommodated within amphibole, biotite and zircon. The granodiorites and tonalites are depleted in Nb and Y and such depletion necessitates fractionation of amphibole and/or garnet from the melt. The slight decrease to cluster concentrations of Y (rather than increase) with increasing SiO_2 may have been related to the fractionation of clinopyroxene and hornblende, because Y is highly compatible to both minerals (Pearce and Norry 1979). Rb, Th, and Ba concentrate as clusters with increasing SiO_2. Lack of strong negative trend of Sr with increasing SiO_2, indicate insignificant role of plagioclase fractionation because Sr commonly shows a strong negative correlation with increasing SiO_2. Least fractionation of plagioclase is also evident from Rb/Sr versus SiO_2 plots (Fig. 3). The diagram shows a wide scattering and slight negative correlation with increasing SiO_2. Usually a 'J' shaped trend with positive correlation suggests the importance of fractional crystallization process with plagioclase as the major precipitating phase (Atherton 1993). On the AFM diagram the TG suite occupied the calc-alkaline field (Zaman et al. 2000). However the classification scheme based on immobile trace elements Y+Zr - TiO_2´100 - Cr (Davies et al. 1979) used to identify the nature of the TG suite. In this diagram, the TG suite following the calc-alkaline trend and granites concentrated in the Y+Zr corner because of their higher concentration (Fig. 4).

The variation of Zr abundance, as a function of TiO_2 is shown for the TG suite and granodiorite gneisses (Fig. 5). A positive correlation is expected if both behave as incompatible elements during partial melting. The lack of prominent positive correlation between TiO_2 and Zr in the TG suite indicating presence of titanium-bearing phase was present in the residue (Sahoo and Balakrishnan 1994). Plots of Ba versus Sr exhibit a positive correlation (Fig. 6). A cogenetic suite of rocks, related by partial melting and fractional crystallization, would be expected to show a positive correlation (Sahoo and Balakrishnan 1994). The suite of rocks generated by partial melting would show large variations in incompatible element abundance and little or no variation in the content of compatible elements (Martin 1987). During crystallization, the incompatible elements become progressively more enriched in the decreasing volume of the residual liquid. Plots of incompatible element Ba versus compatible element Ni and Cr are shown in Figure 7. The variation of incompatible elements with compatible elements suggests that partial melting played an important role for the evolution of the TG suite. The Rb versus Sr diagram shows a greater dispersion with Rb/Sr ratio (Fig. 8). In granodiorites, the Rb/Sr ratio is low and ranges from 0.07 to 0.15 (average 0.09), in tonalites 0.06 to 0.14 (average 0.09), in granodiorite gneisses 0.09 to 0.23 and in granites 0.13 to 0.22. It is observed that rubidium increases from tonalite to granodiorite (except sample SB-07*, which is analyzed by 5:1, flux:sample ratio beads technique). The crustal depth at the time of generation primary melt, could be estimated by the Rb versus Sr plot (Condie 1973). It is assumed that the primary melt of the TG suite might have been generated from depth of more than 30 km and probably around 35-40 km (Fig. 9). Now considering a generally accepted geothermal gradient of about 20°C/km, a temperature level of about 800°C can be expected at such depth and this order of temperature is sufficient to generate the granitoid melt.

GEOCHEMISTRY OF RARE EARTH ELEMENTS

The chondrite normalized rare earth element (REE) patterns of the basement rocks are shown in Figure 10. The TG suite and granodiorite gneisses are enriched in light rare earth element (LREE), moderately fractionated (LaN/YbN = 12.84-18.60) and characterized by no europium (Eu) anomalies (average Eu/Eu* = 0.82). The normalized patterns show that the heavy rare earth elements (HREE) are moderately depleted and slightly fractionated. Granites are less enriched in LREE, less fractionated (LaN/YbN = 2.74-3.72) and characterized by positive Eu anomalies (Eu/Eu* = 1.57-4.74). In quartz-monzonite the REE pattern shows 'V' shaped Eu anomaly (Eu/Eu* = 0.66). The REE patterns of granites and quartz-monzonite distinctly indicate that these rocks are not related with the same parental melt of the TG suite. The depletion in HREE can be caused by zircon because it has high partition coefficient of HREE relative to LREE (Michael 1988). If zircon controls the HREE fractionation, there should be a change in Zr content of the rock suite. However, granodiorites have higher content of Zr than tonalites and zircon fractionation is not observed in this suite (Fig. 2; Table 5.3). The relative

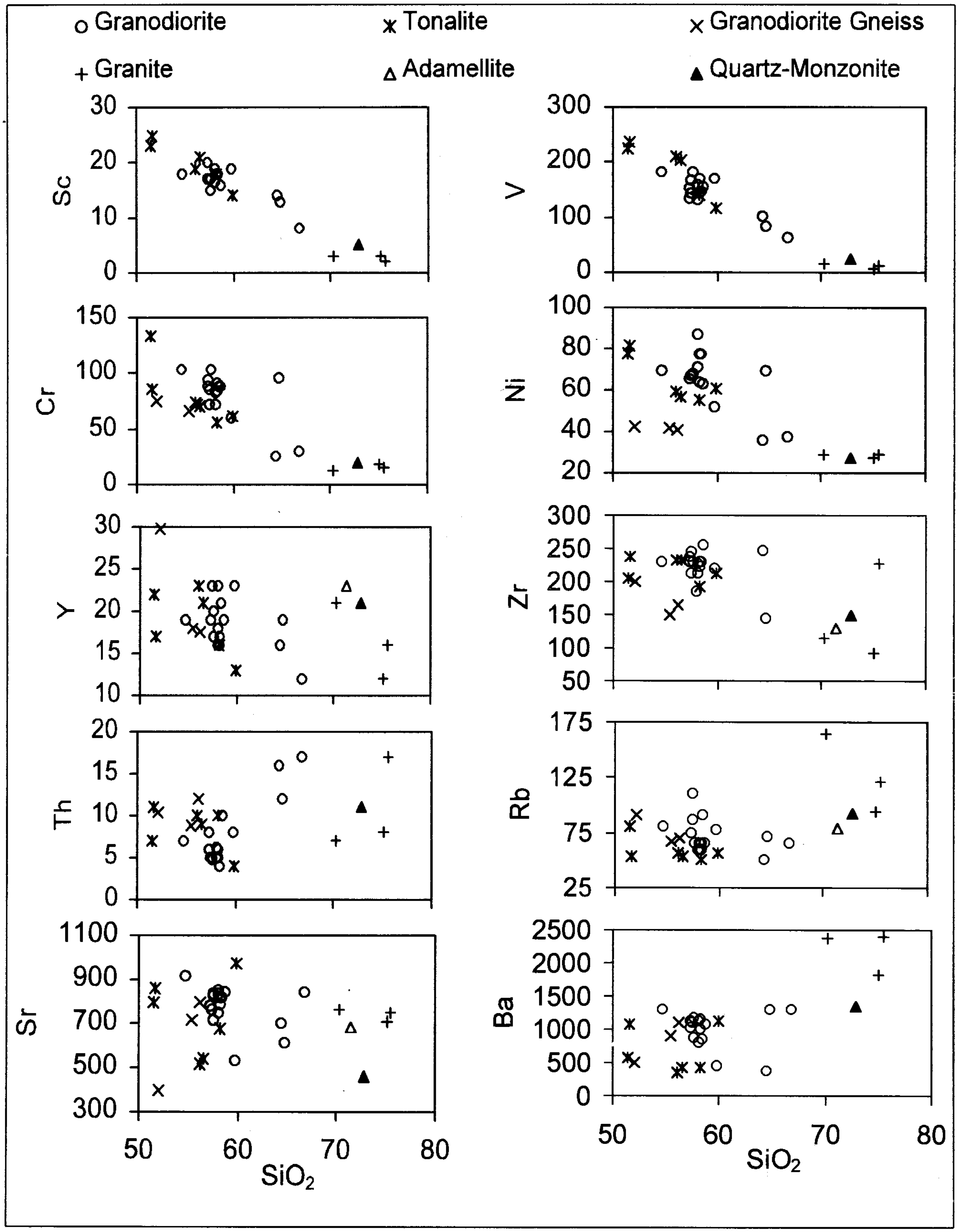

Figure 2. Trace elements (ppm) variation diagrams against SiO_2 (wt%) for the basement rocks in Madhyapara.

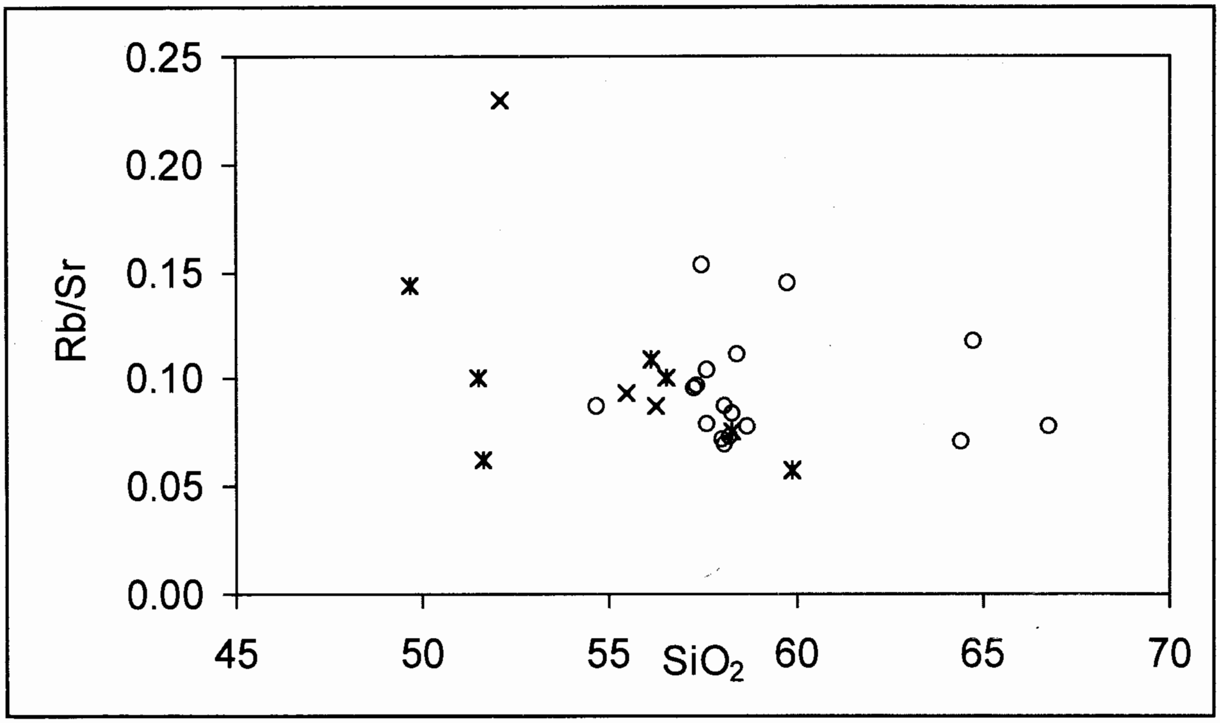

Figure 3. Plots ratio of Rb/Sr versus SiO2 (wt.%) for the TG suite and granodiorite gneisses in Madhyapara. Symbols of rock type as in Figure 2.

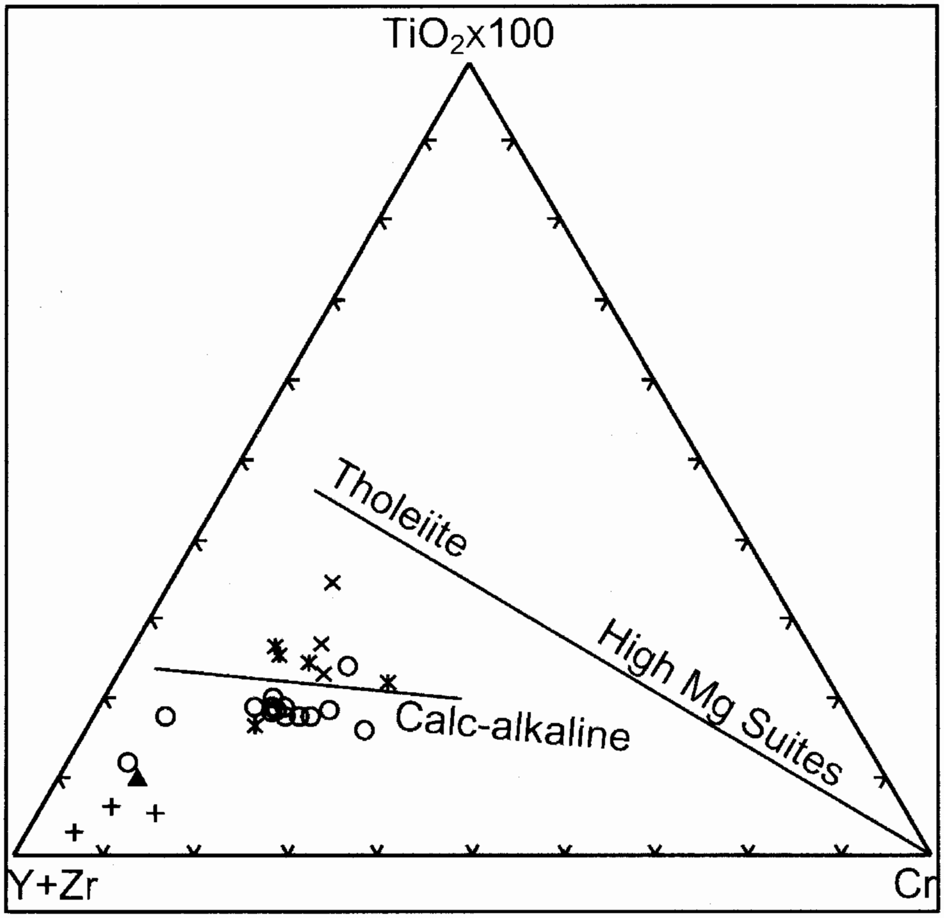

Figure 4. Y+Zr - $TiO_2 \times 100$ - Cr ternary diagram indicating calc-alkaline nature of the TG suite in Madhyapara. Symbols of rock type as in Figure 2.

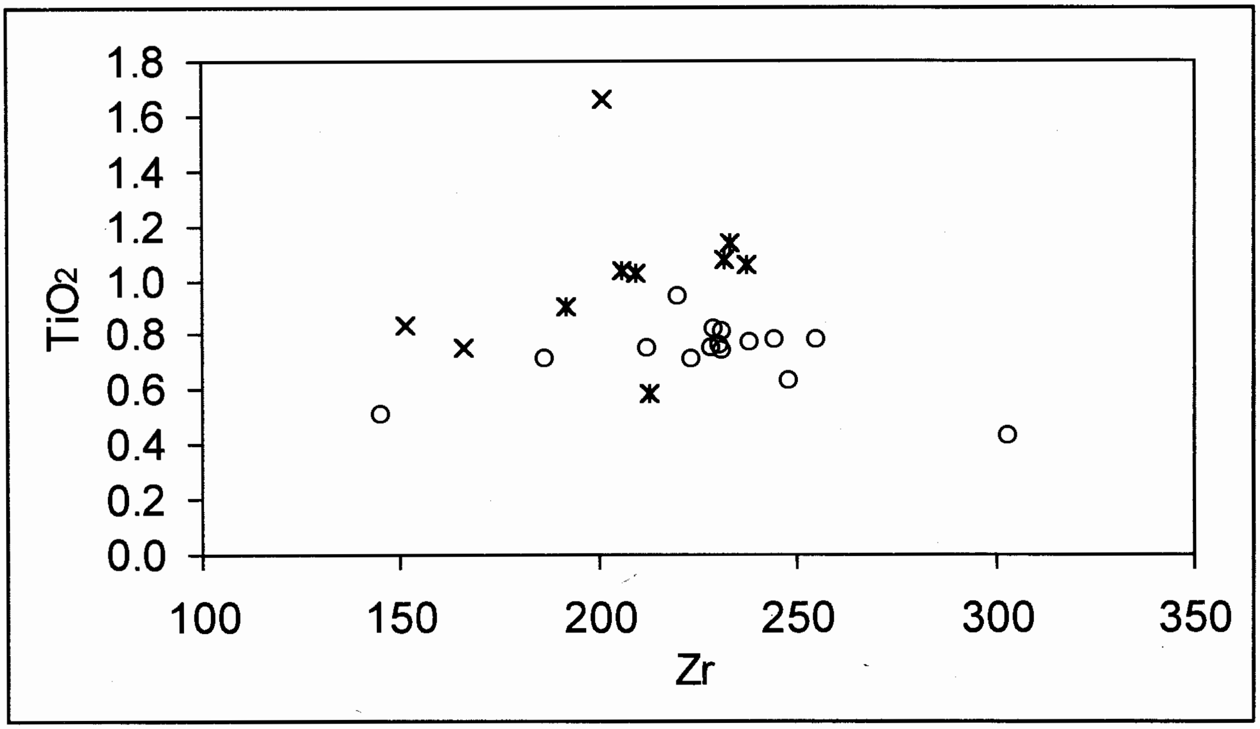

Figure 5. Zr (ppm)-TiO_2 (wt.%) variation diagram shows the position of the representative samples of the TG suite and granodiorite gneisses in Madhyapara.

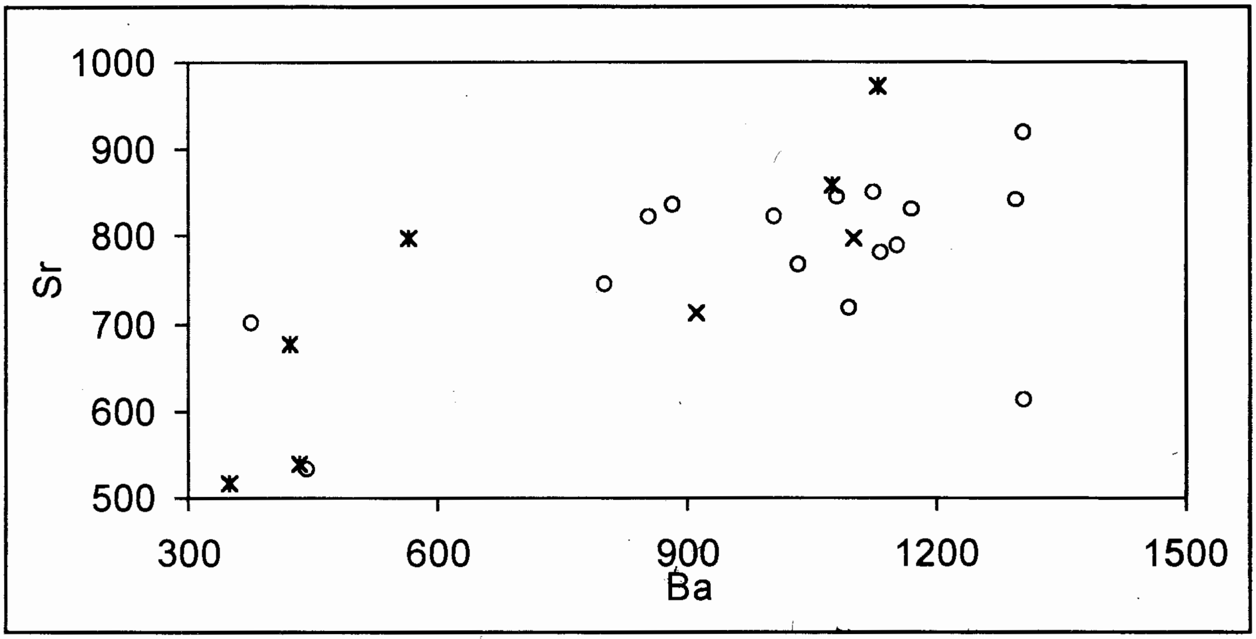

Figure 6. Ba (ppm) - Sr (ppm) relation for the TG suite and granodiorite gneisses in Madhyapara. Symbols of rock type as in Figure 2.

depletion and slight fractionation of HREE in the TG suite is probably due to garnet. Most of the REE patterns of the TG suite marked a concave form at the HREE end. It is noticed that garnet and hornblende are stable constituents in the residue and that these residual phases explain the fractionation of the REE patterns as well as the concave form of the HREE end (Taylor and McLennan 1985).

PETROGENESIS

The tectonic discrimination diagrams of Pearce et al. (1984) indicate that the TG suite and granodiorite gneisses formed in volcanic arc granitoid environment (Fig. 11). The TG suite is metaluminous, calc-alkaline and I-type granitoid while granite, adamellite and quartz-monzonite are peraluminous and S-type granitoid (Zaman et al. 2000). In volcanic arc environment the potential source rock are wide ranging in the lower crust and the mafic igneous rocks or their metamorphic equivalents are the most possible protoliths for the generation of large volume metaluminous, I-type tonalite magma (Chappell and Stephens 1988). It is evident from experimental partial melting of tholeiites and melting of trondhjemites that tonalitic melts are formed by partial melting of hydrous mafic rocks at temperature level of about 800°C to 900°C and at 15 kilobar pressure (Johnston and Wyllie 1988). During hydrous melting, the amount of amphibole increases and plagioclase decreases in the residue (Beard and Lofgren 1989).

The Primitive Mantle (PM) normalized trace and rare earth element patterns of the TG suite in Madhyapara shows pronounced negative Nb anomalies (Fig. 12) indicating that these rocks are the products of subduction related magmatism (McCulloch and Gamble 1991). The Ocean Ridge Granite (ORG) normalized trace and REE patterns of the basement rocks are shown in Figure 13. The patterns shows typical volcanic arc granitoid nature and are characterized by enrichments in K, Rb, Ba, Th, Ce and Sm relative to Ta, Nb, Hf, Zr, Y and Yb (like calc-alkaline series).

Generation of abundant granodiorite and tonalite rocks requires partial melting of lower crust with dominant mafic component (Johnston and Wyllie 1988). The generation of high aluminium-tonalites-trondhjemites-granodiorites (Al-TTG) and related volcanic rocks has been explained by several processes, including fractionation of basic magma, melting of a peridotitic mantle source, melting of a basaltic source, viz., either amphibole, garnet-amphibole or eclogite (Barker 1979, Jahn et al. 1981, Martin 1987, Drummond and Defant 1990).

During melting of the above said source rocks, different proportions of garnet and amphibole remain in the residue leading to variable depletion of HREE and middle rare earth element (MREE). According to Taylor and McLennan (1985) the typical Early Archean trondhjemites, tonalites and Na-rich granodiorites are characterized by steep LREE enriched and HREE depleted patterns generally with no Eu anomalies. The fractionated REE patterns with HREE depletion are a consequence of equilibration with garnet as a residual phase. The post-Archean TTG is characterized by shallower patterns with less HREE depletion indicate lesser amount of garnet in the residue. According to Martin (1987) melting of eclogitic source rock produce liquids with very high LaN/YbN ratios (>100). But in granodiorites LaN/YbN varies from 10.50 to 18.60 and in tonalites is 12.84 to 15.77. Janh et al. (1981) and Martin et al. (1983) used LaN/YbN versus YbN plots to characterize the TTG source regions. Superimposed on the diagram are the reference field of the Upper Continental Crust with an estimated average of Taylor and McLennan (1985) and Archean TTG, complied by Jahn et al. (1981) and Martin (1986). On the YbN versus LaN/YbN diagram of Jahn et al. (1981), the TG suite and granodiorite gneisses concentrated in the Upper Continental Crust field along the amphibolite melting curve (Fig. 14).

The REE pattern of the TG suite and granodiorite gneisses are moderately fractionated and less depleted in HREE with no Eu anomalies. The common assumption is that less fractionation of REE was acquired during melting of a source region, which left hornblende and clinopyroxene in the residue. If the residue is dominated by garnet (and less so amphibole) the REE will be highly fractionated. Hence, the source rocks for the TG suite in Madhyapara were possibly basaltic/gabbroic or amphibolitic in composition. LREE enriched, unfractionated HREE and negative ('V' shaped) Eu anomaly suggests melt generated from abundant plagioclase source materials (Gromet and Silver 1987). If hornblende were more abundant than plagioclase in the source, the melt would have a relatively middle REE depleted pattern (Gromet and Silver 1987). Four granodiorites, one tonalite and two granodiorite gneisses marked a concave

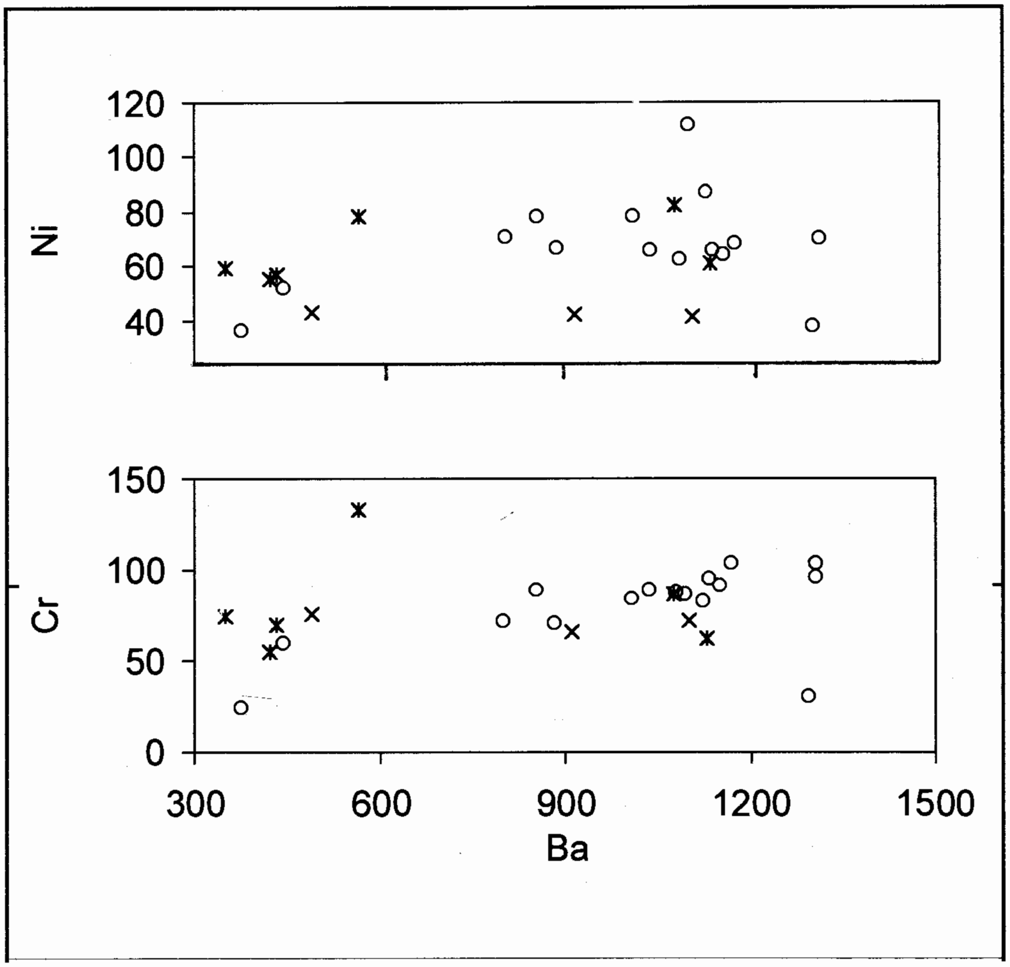

Figure 7. Variation of compatible elements Ni and Cr (ppm) versus incompatible element Ba (ppm) for the TG suite and granodiorite gneisses in Madhyapara. Symbols of rock type as in Figure 2.

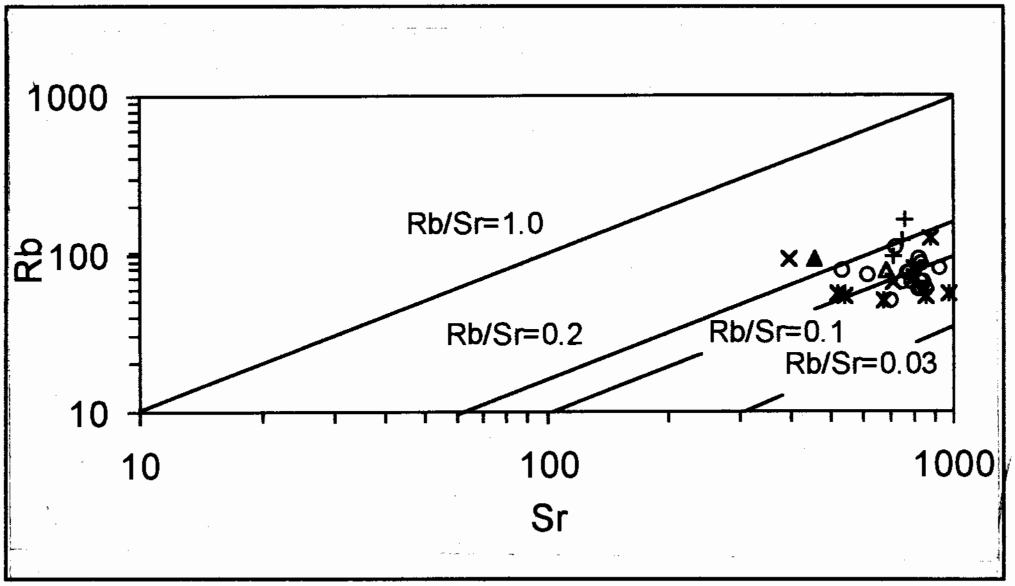

Figure 8. Rb (ppm) versus Sr (ppm) variation diagram for the basement rocks in Madhyapara. Symbols of rock type as in Figure 2.

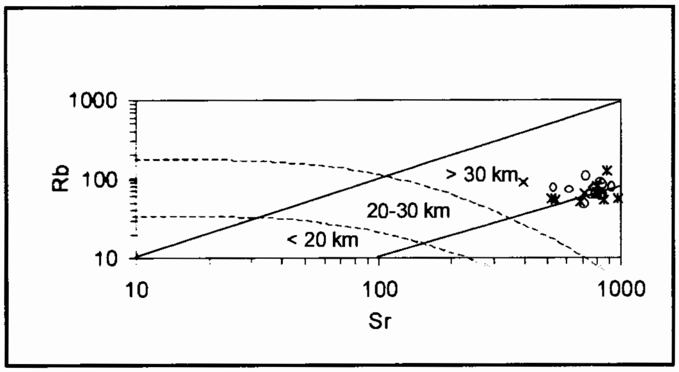

Figure 9. Rb (ppm) versus Sr (ppm) variation diagram to determine the depth of primary melt of the TG suite in Madhyapara. Symbols of rock type as in Figure 2.

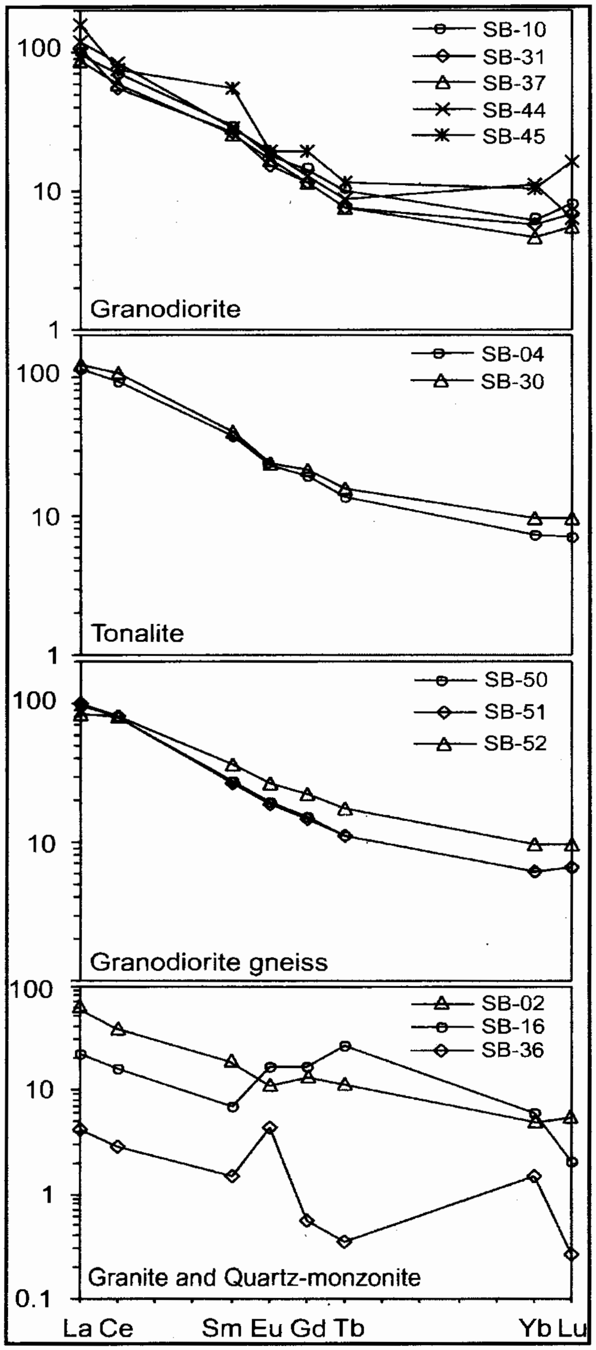

Figure 10. Chondrite normalized REE patterns for the basement rocks in Madhyapara. Normalizing values are after Taylor and McLennan (1985). SB-10: sample number, Table 1.

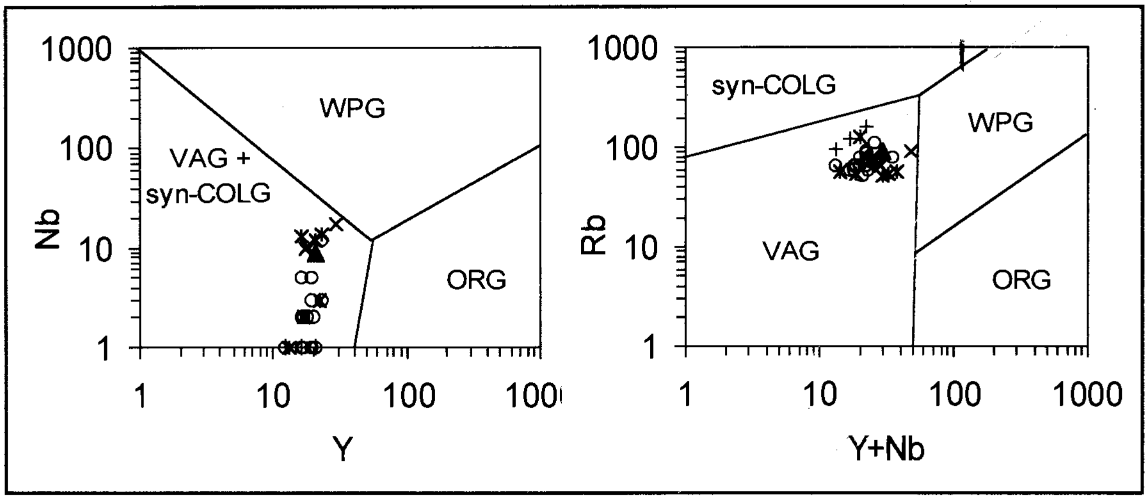

Figure 11. Tectonic discrimination diagrams of Nb (ppm) versus Y (ppm) and Rb (ppm) versus Y+Nb (ppm) of Pearce et al. (1984) for the basement rocks in Madhyapara. VAG: volcanic arc granitoids, syn-COLG: syn-collision granitoids, WPG: within plate granitoids, ORG: ocean ridge granitoids, COLG: collision granitoids. Symbols of rock type as in Figure 2.

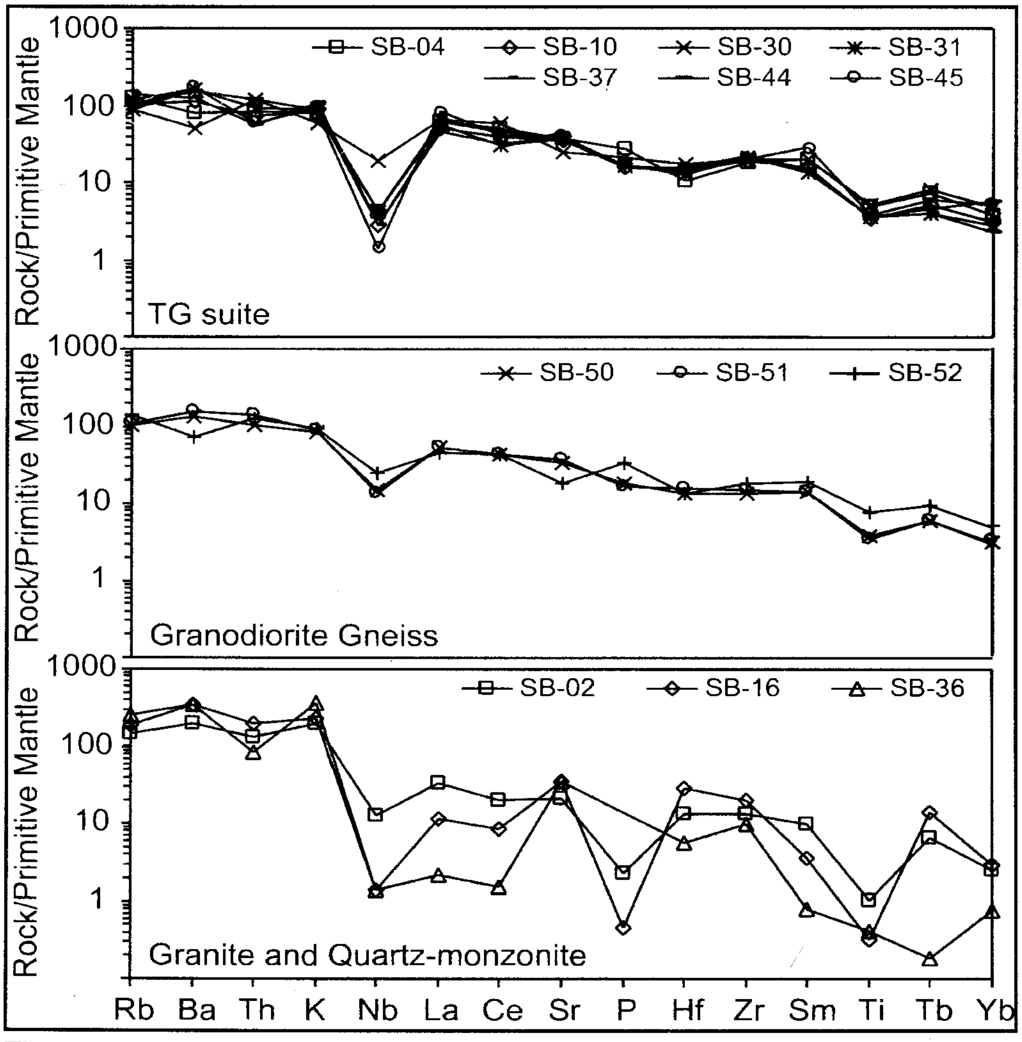

Figure 12. Primitive Mantle (PM) normalized trace and rare earth element patterns for the basement rocks in Madhyapara. Normalizing are after Sun and McDonough (1989). SB-10: sample number, Table 1.

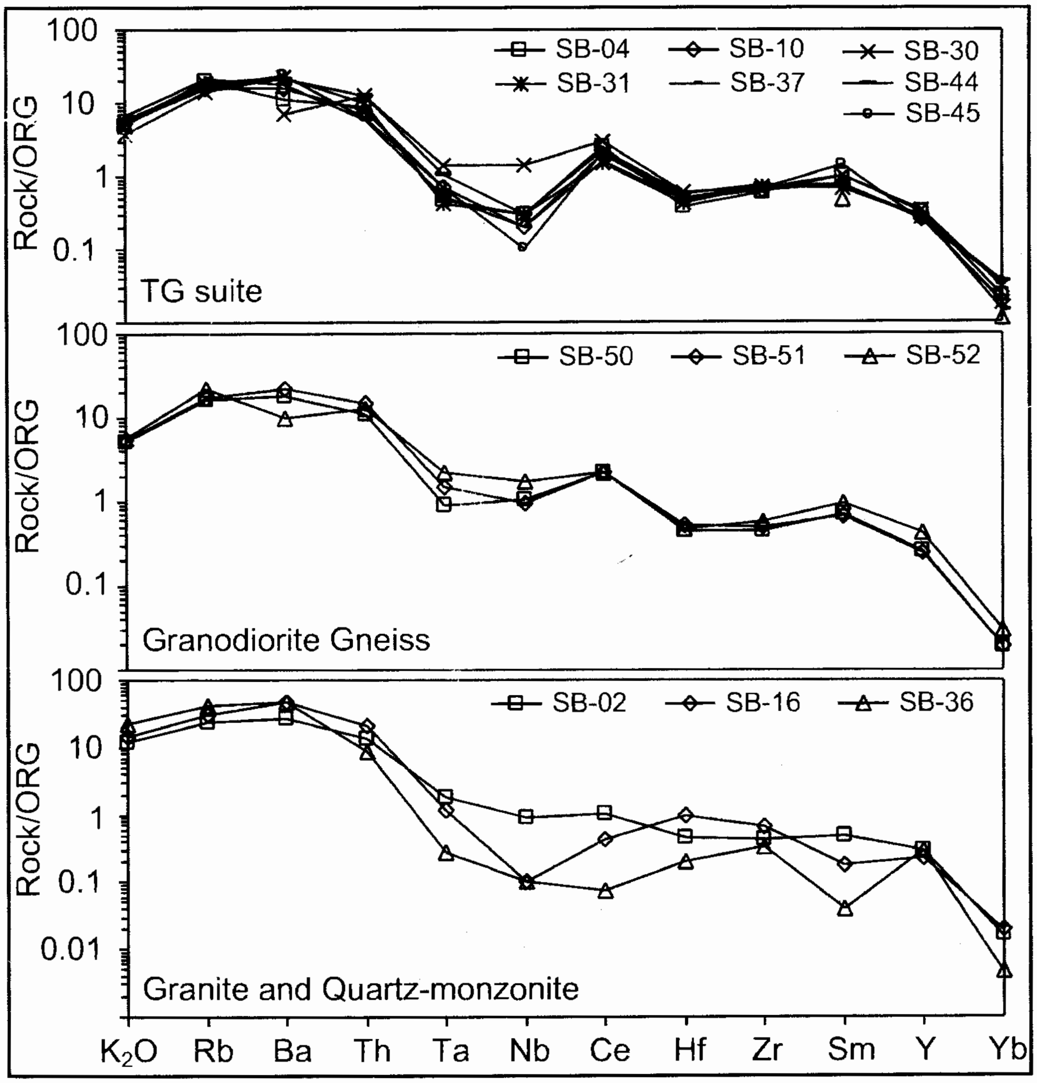

Figure 13. Ocean Ridge Granite (ORG) normalized trace and rare earth element patterns for the basement rocks in Madhyapara. Normalizing values are after Pearce et al. (1984). SB-10: sample number, Table 1.

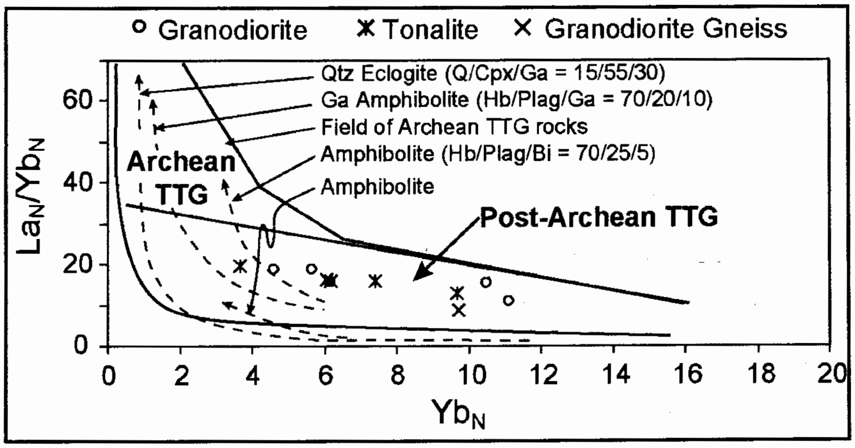

Figure 14. La_N/Yb_N versus YbN diagram of Jahn et al. (1981) used to identify the source characteristics of the TG suite in Madhyapara. Field of Archean and Proterozoic TTG (dotted lines) are after Condie (1997). Symbols of rock type as in Figure 2.

form at the HREE end. Taylor and McLennan (1985) defined that garnet and hornblende as residual phase can explain the fractionation of REE and as well as the concave form at the HREE end. Thus the LREE enriched, slightly fractionated HREE together with no Eu anomalies in the TG suite indicate that the most possible source rock is amphibolitic in composition.

CONCLUSIONS

The TG suite is intermediate in composition with moderate content of ferromagnesian elements while granite, adamellite and quartz-monzonite are acidic in composition with low content of ferromagnesian elements. The variation in incompatible elements compared to compatible elements indicate that partial melting played the dominant role to generate primary melt phase. Low concentration of Nb and Y suggesting fractionation of amphibole and clinopyroxene. The chondrite normalized REE patterns indicate that the TG suite and granodiorite gneiss is enriched in LREE, moderately fractionated with no europium anomalies. More or less parallel REE patterns in this suite suggest a single source. Granites are less enriched in LREE and less fractionated, with positive europium anomalies. Geochemistry of the tonalite-granodiorite suite of the Basement Complex in Madhyapara suggests derivation by partial melting of the granitoid basement (amphibolite source rock) and fractionation of Fe-Mg phase.

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BALOCHISTAN - POLICIES AND POSITION OF WATER SUPPLY FOR DOMESTIC AND INDUSTRIAL USE

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ABSTRACT

The population of Balochistan was 6.51 million during 1998, out of which 3.66 million urban and rural populations have domestic piped water facilities. The available water resources were 18,311 Million Cubic Meter (Mm3) during 1998; out of which the domestic water utilization was about 147 Mm3 and industrial/mining utilization was 33 Mm3. Upto the year 1970, throughout Balochistan, a circumscribed population was served by 18 Water Supply Schemes (WSS). The number of mechanized WSS was increased to 701 by 1992 and 1410 by 1997. Presently 3.1 million rural population achieves their domestic water requirement through aforesaid WSSs. Quetta is the only urban center in Balochistan, where its 0. 56 million populations are served with domestic supply through house connections. The remaining population is relying upon springs, open surface wells, handpumps, and rainwater collection ponds etc. The township WSS are designed for 60-80 liter per capita per day (lpcd) domestic water consumption by the year 2000 and 2015 respectively. The Quetta WSS is designed for 130 lpcd and estimated that water consumption will increase continuously upto 180 lpcd by the year 2020; thereafter it will remain constant. The domestic water consumption of Balochistan was about147 Mm3 during the year 1998; whereas for 2010 it will be 530 Mm3 and expected to increase upto 860 Mm3 for the year 2025. No remarkable industrial and mining activities were reported in Balochistan uptill 1960; while about110 industrial units have been reported during 1992. All township and Quetta WSS have a provision of 5% and 7% of the total domestic consumption for industrial demand upto the year 2015, this is expected to increase by 13% by the year 2020. The industrial plus mining water demand was about 33 Mm3 during 1998, which is expected to be increased from 50-98 Mm3 upto 2010 and 2025 respectively.

In Balochistan, the dry spell of 1998 that is still continuing, the estimated water balance scenario has been changed completely. The surface and groundwater resources dried and depleted to their extreme limits. Majority of the industrial units of Lasbella Industrial Estate has been closed due to water shortage and all water supply schemes severely effected. The communities not served with piped water, migrated to nearby schemes, relief camps established and water supply system revitalized. To combat the

drought, immediate, short, medium and long-term strategies were conceived to supply water to all effectees. The strategies embrace, energization of 101-installed tubewell and operationalization of 321 existing WSS. Rehabilitation, renovation, extension and upgradation of 142 rural and township schemes, development of new water resources and construction of 263 new WSS. To augment the Quetta WSS, installation of 100 new tubewell are proposed in Karstic and Hard Rock aquifers. An estimated amount of Rs. 1,473.0 million and US$ 14.56 million proposed to invest on drought related water supply packages. The program will help to provide drinking and domestic water facilities to an additional population of about 0.9 million. To fulfill the domestic and industrial water demands of present and future generations, proper management of water resources is indispensable.

INTRODUCTION

Construction of a water supply scheme is a preeminent demand of communities in the entire province. Provision of drinking water facilities to the rural inhabitants of Balochistan is the topmost priority of the provincial Government. Balochistan Water and Sanitation Authority (B-WASA) and the Public Health Engineering Department (PHED) are the major public sector agencies constructing mechanized WSS to provide drinking water facilities to the urban and rural population respectively. A number of national and foreign assisted projects were initiated and completed by both agencies to increase the water supply coverage. Technical, financial and supervisory services have been acquired from time to time and considerable progress has been achieved. Local Government and Rural Development Department is also engaged in providing drinking water facilities to rural inhabitants in the form of dug wells and hand pumps. The water supply coverage through the said means is considerable but the overall water supply coverage and access to safe drinking water of the rural population is still very destitute. The Lasbella Development Authority is managing the biggest industrial estates of the province near Karachi; it has its own water supply system. In other parts of the province the small industrial units and mining sector have little concern about the availability and future demand of water. The estimated total water potential of Balochistan is 18,311 Mm^3, out of which 1,071 Mm^3 is groundwater, 12,480 Mm^3 is surface water and 4,780 Mm^3 is the Indus River's water share to Balochistan (Majeed and Qureshi 2000). It is expected that during the year 2010 the available water will become 20,581 Mm3 because the share of Indus water will increase to 7,050 Mm3 and thereafter the available water quantities will remain the same in succeeding years. This paper is divided into three parts, the first part comprises of domestic water supply systems, the second is related to industrial water demands and the last one deals with the strategies recommended to combat drought in water supply sector.

DOMESTIC WATER SUPPLY SYSTEM

Settlement Patterns and Domestic Water Demand

The domestic water utilization habitats of deviant communities are directly related to the livelihood, cultural behavior, environmental circumstances, climatic conditions, financial standings, socioeconomic conditions, metering of supply, quality of water, population characteristics, sewerage and drainage facilities etc. In Balochistan, the human settlement patterns are classified into semi-nomadic, rural, township and urban. The semi-nomadic pattern of life requires extremely limited quantities of water for their survival. The remote rural settlements require just a few liters of water per capita per day for their domestic utilization. The township and urban settlements have a high rate of water utilization in their daily life. The city dwellers (*Kachi Abadees*) and communities living below poverty line have a life style similar to the rural communities. The new settlements all around urban centers have extraordinary high rates of water utilization, which is highest in the province. The domestic water demand comprises of drinking, bathing, cooking, dishwashing, cleaning, laundry, closet flushing and watering small lawns etc. The average water consumption of a family is based on the size of the household, standard of living, social and hygiene habits, seasons of the year and water tariff etc. Keeping in view the above mentioned factors, the average water consumption of rural WSS would ranges from 35-60 liter per capita per day (lpcd), township water supply schemes would be 60

Table 1. Estimated water demands of various communities from different sources.

SETTLEMENT PATTERNS		WATER REQUIREMENTS (lpcd)
Semi-nomadic		10 - 20
Rural	Communities having no WSS	20 - 35
	Communities with piped WSS	35 - 60
Township	House connection demand	60 - 80
	Stand Post demand	20 - 30
Urban	House connection demand	130 - 180
	Public Tap demand	20 - 30
	Kachi Abadees (City Dwellers)	60 - 80
	Modern Housing Societies (Satellite Towns)	> 200

and 80 lpcd by the year 2000 and 2015 respectively (NESPAK 1996 a-e). The estimated stand post water requirements are about 20 and 30 lpcd for the same periods. The Quetta WSS is designed for 130 lpcd and it has been estimated that the domestic water demand will increase continuously up to 180 lpcd by the year 2020; thereafter it will remain constant (GKW 1999). For residents of the Quetta city, the proposed water demands are 50 lpcd for yard connections and 20 lpcd for public tap. The estimated designed water demands for various communities from different sources are given in Table 1.

Water Extraction and Supply Technologies

As per current government policy, water is supplied to small communities by community tanks; piped water is supplied to villages greater than 500 people or village cluster greater than 1500 souls. The major water supply sources and technologies in use are tubewell, springs, dug wells, streams, rivers, canal waters, *Karez*, infiltration galleries, rainwater collection ponds and hand pumps. The water supply technologies are composed of groundwater pumping, boosting, transmission and distribution system. Water collection tanks, appropriate filtration and treatment systems are also a part of supply wherever required. Electric and diesel operated machinery are the major source of energy for water pumping, the major techniques of water extraction in use are given in Table 2. The tubewell are the major source of rural as well as urban water supply, from 1970 to onward, the PHED installed hundreds of tubewell with a depth ranges from 100-500 m. It is estimated that about 15,000 tubewell exists in the province. Local Government and Rural Development Department introduced modern deep hand pumps in the province, the communities not supplied piped water rely self-operated systems. The dug wells are traditional mean of domestic water utilization and are common every where, about 3,000 dug wells are present in Balochistan. In Chaghi, Gwadar and Kharan districts the quality of groundwater is not fit for drinking and domestic utilization. In such areas the shallow dug wells are the major source of domestic waters. Pasni town WSS and some rural schemes are also based on shallow dug wells, the fresh groundwater skimmed and supplied to the communities. The *Karezes* are the man made underground channels with a series of vertical shafts (wells), the groundwater seep into the channel and flows towards the valley floor by gravity. The Karez system was developed in about all parts of Balochistan and is a common source of domestic water. In some areas where no alternate source of ground and surface water is available, the water supply schemes are based on Karezes. In upland areas of Balochistan like, Zhob, Ziarat and Kalat Districts natural springs of considerable discharge are present, in such areas some gravity-based schemes are in operation. In coastal areas of the province, the geological formations are not feasible for the formation of appropriate aquifer systems. In coastal plains and adjacent sandy areas the sea water intrusion into freshwater aquifers is common. In these areas some small and large dams have been constructed exclusively for water supply purpose. These dams are the source of domestic water supply system of many townships like, Gwader and Hub. In Nasirabad and Jafferabad Districts, the fresh groundwater is not available, in these areas the quality of groundwater is moderately to highly saline. In these districts the canal water is supplied from Indus River and a number of rural and township water supply schemes are based on canal waters. A number of WSS are based on a combination of water

Table 2. Water extraction techniques used for domestic supply.

Water Sources	Dominant Areas	Characteristics
Hand pumps	Small valley floors	15-50 m (Deep)
Tubewell	All River Basins	100-500 m (Deep)
Dug well	All River Basins	20-50 m. (Deep)
Natural springs	Mountainous areas	2->100 l/s (Discharge)
Karezes	All River Basins	10->200l/s (Discharge)
Infiltration galleries	Stream & River beds	- - -
Rain water collection pools	Plains	- - -
Flood water collection ponds	Riverbeds	- - -
Irrigation canal waters	Nasirabad Division	- - -
Reservoir water of small dams	Coastal areas	- - -
Sea water desalination	Coastal areas	Reverse Osmosis

Table 3. Construction of water supply schemes from 1947-1997.

S. No.	Departments	Financial Year	Number of WSS
1	Military Engineering Services	1947 - 1970	18
2	Irrigation and Power	1970 - 1987	267
3	Public Health Engineering		
	Pre-SAP WSS	1987 - 1992	416
	Sub Total		**701**
	SAP WSS	1992 - 1993	125
		1993 - 1994	113
		1994 - 1995	235
		1995 - 1996	170
		1996 - 1997	66
	Sub Total		**709**
Grand Total (Nos.)			**1410**

Table 4. Categorization of PHED's water supply schemes.

PHE Division	Township	Complex	Gravity	Community	Rural	Non-functional	Total
Bela/Uthal/Hub	2	7	0	10	16	23	58
Dera Allah Yar	4	5	0	14	18	21	62
Dera Bughti	2	3	15	0	13	13	46
Gwader/Pasni	3	5	0	2	23	1	34
Kalat	1	6	2	8	16	1	34
Kharan	1	4	0	13	20	2	40
Khuzdar/Awaran	1	11	4	22	44	14	96
Kohlu	2	4	1	16	16	13	52
Loralai	7	7	4	23	50	21	112
Mastung	1	3	1	16	17	3	41
Nushki	3	7	3	10	10	5	38
Panjgur	1	3	0	9	16	1	30
Pishin	11	8	9	93	46	53	220
Quetta	7	8	0	33	32	0	80
Sibi	6	4	0	19	26	54	109
Turbat	2	5	0	26	54	12	99
Zhob	3	4	52	74	20	46	199
TOTAL (Nos.)	**57**	**94**	**91**	**388**	**437**	**283**	**1350**

sources like spring plus dug wells and tubewell. The B-WASA is responsible for the water supply system of the urban areas of Quetta City, while Cantonment Board and PHED are responsible for cantonment and rural areas of Quetta. The Quetta water supply system was based on springs, dug wells and *Karezes* up to 1889. In 1890 the government acquired 50% water rights of Urak waters and piped water supply was initiated to Quetta City and Cantonment. To augment the supply system many tubewell were installed in the Quetta Valley during 1960, and drilling of new bore holes are still continuing. Ground water is the source of about 95% of all WSS of Balochistan. Tubewell based schemes are about 84% and dug well based are about 4% etc. Tubewell based schemes are preferable because it includes direct pumping and supply system and no water treatment is required. Spring based schemes are about 7%, the operation and maintenance (O&M) of gravity based schemes are effortless and the communities prefer such schemes. Water supply schemes based on other type of water sources are about 5%.

Mechanized Water Supply Schemes

A circumscribed population of Balochistan was served through 18 WSS upto 1970 by Military Engineering Services. In 1970, the Irrigation and Power Department took over the responsibilities for supplying domestic water, and 267 schemes were constructed from 1970-1987. The Public Health Engineering Department (PHED) was created by the bifurcation of Irrigation and Power Department in 1987 exclusively for the construction of rural and township water supply schemes. PHED is responsible for preparation, operation and maintenance of all mechanized water supply schemes; PHED constructed 416 WSS in far-flung remote areas of the province form 1987-1992. To extend the water supply coverage Social Action Programme (SAP-I) was initiated during 1992-93 with the financial assistance of the donor agencies. Under SAP-I, 709 water supply schemes were constructed from 1992-97. Presently 1,410 water supply schemes exists in the province, the breakup of the construction of schemes are given in Table 3.

The schemes are categorized as township, complex and rural, some schemes are gravity based termed as simple. PHED staff is operating and maintaining 57 township, 94 complex, 91 gravity based and 437 rural water supply schemes. Township and complex WSS are the large schemes, which includes water pumping, boosting, treatment and long transmission and distribution systems. The categorized list of WSS is given in Table. 4, whereby the breakups of 1,350 schemes are given, the record of 60 nonfunctional schemes was not available at the time of the preparation of this paper. SAP-II was initiated during 1997-98, and a moratorium was imposed on the construction of new WSS. A uniform policy for water supply sector was introduced with the aim and objective to minimize the Operation and Maintenance (O&M) costs of the schemes and to increase the revenue collection. The main points of the uniform policy and scheme selection procedure are as follows:

i. PHED will prepare schemes for population not less than 500 souls.
ii. No new scheme shall be undertaken / rehabilitated unless the communities have established a Village Organization / Water Management Association (WMA) and signed a Memorandum of Understanding (MOU) with the Department.
iii. Only such a scheme will be eligible for consideration where the community agrees to provide land free of cost.
iv. The applications for new WSS will be invited through province wide advertisements.
v. The 100% new schemes will be taken in hand on the basis of criteria for priority rating to the communities' request for the construction of new WSS.
vi. PHED will verify technical feasibility and social viability of the schemes.
vii. A community situated away from the concentrated rural population with no available water source will be given priority.
viii. PHED will maintain only complex water supply schemes, the monthly water tariff will be fixed and amended by the department.
ix. PHED would initially responsible for O&M and collection of revenue, subsequently Township Water Users Associations will be created and schemes will be handed over to the management.
x. PHED would contract out township WSS to the private sector for revenue collection, based to the competitive bids.
xi. Revenue generated from water tariff would be applied to O&M of the township schemes.

As per policy, PHED is shifting the O&M

responsibilities to village organizations and handing over the simple rural WSS to the communities. In this context, the communities motivated, mobilized and so far 388 rural WSS have been handed over to Water Management Associations. The scheme transfer process is in progress and PHED has still to transfer 343 additional rural WSS to the respective communities. In this regard institutional strengthening of PHED was made, a Community Relations Unit was established, male and female community mobilization staff was recruited like Community Relations Officers, Community Development Officers and Community Development Workers. Community awareness campaigns and training packages were initiated to motivate and mobilized the communities to take over the responsibilities for the O&M of rural WSS. To increase the water tariff collection efficiency in some selective Townships, connection survey and computerized billing system have been introduced, private contractors are also engaged for water tariff collection etc.

Population and Domestic Water Demand

The population of Balochistan was 4.33 and 6.51 million according to 1981 and 1998 census respectively (PHC 1998). The average growth rate is 2.42%, with this rate of increase the population will become 9 and 14 million by the year 2010 and 2030. The population living in urban areas increased from 16% to 23% of the total with an average increase of 4.8% per annum. The urban population will reach to 14 million by the year 2030, with 50% living in urban areas and majority of them in Quetta. From water supply point of view Quetta is the only urban center of Balochistan. The population of Quetta City, which includes Quetta Municipal Corporation and Quetta Cantonment, is 560,307 that are about 10% of the province's population (GKW 1999). For township WSS, keeping in view the socio-economic conditions of the town a mix ratio is adopted for providing house connections and stand posts. In 1993 about 50% of population of all township WSS have excess to house connections and 50% used public stand posts. It has planned that upto 2010 about 80% population will get water through house connections and 20% through public stand posts, with the increase of population these figures will remain constant in the subsequent years (NESPAK 1996 a-e). In Quetta City WASA is providing to about 30% of the population residing in the service area is connected to the public water system. WASA intend to introduce a centralized water system. Considering the connection approach, it has been assumed that over the next decades the population served and connected to the public water system will increase from 57% to be served in 2005 to 70% in 2010 and 80% by 2015 and ultimately 90% in 2020 (GKW 1999). Presently about 3.51 million rural plus township population of Balochistan received domestic piped water supply from 1410 water supply schemes, which is about 57% of the total population of Balochistan. As an aggregate 67% population of Balochistan have an access to safe domestic water supply. The population and access to domestic supply figures are enumerated on the basis of certain studies and assumptions, no detailed survey and or authentic record is available with the agencies involved in the water supply sector.

INDUSTRIAL WATER SUPPLY SYSTEM

Industrial Development

The pace of industrial development is quite slow in Balochistan. Prior to 1960 only a pharmaceutical and an alcoholic beverage factory in Quetta, a woolen mill in Harnai and only 14 other industrial units were existed in the province. For industrialization during 1970 establishment of eleven industrial estates were proposed some could not succeed due to a number of reasons, only Quetta, Hub, Uthal and Winder Industrial Estates were established on inadequate planning and infrastructure and still struggling for their survival. In all the four industrial estates against a total of 622 industrial units proposed to be establishing, only 168 were established from 1980-1992. Reported status of industrial estates upto 1992 is shown in Table 5.

After late 1970s numerous small industrial units such as flour mills, handicrafts, livestock products, auto repair, agricultural engineering workshops, shoe making, carpet weaving and blanket making were established allover the province. From 1971-1980 a total number of 117 industrial units were established in the province. During this period numerous small industrial units such as flour mills, engineering industry, textile mills, ice factories were established. A labor force of 5,841 was employed in said industrial units, and an investment of Rs. 1.5 billion were estimated. From 1981-1993, about 199 industrial units were registered including textile, engineering, pharmaceutical, floor and rice mills, food processing, chipboard and plastic industry (P&D 1998). During the mentioned period the employment

Table 5. Status of established industrial units in different estates from 1980-92.

S No.	Industrial Estates	Established (Nos.)	Proposed (Nos.)
1	HUB	150	1440
2	QUETTA	6	160
3	UTHAL	5	152
4	WINDER	7	170

Table 6. Status of different industrial units established from 1970 to 1993.

Specific Industry	Upto 1970	1997-1980	1981-1993
Textile	0	3	22
Engineering	8	5	22
Electrical	0	1	7
Pharmaceuticals	0	0	23
Plastic	0	0	12
Edible Oil	0	1	5
Chipboard	0	1	9
Beverages	0	0	2
Leather	0	0	6
Rice Mills	0	0	16
Floor Mills	12	86	42
Furniture	2	3	3
Food	1	4	12
Printing	5	1	0
Ice Factories	1	6	7
Cement	0	0	1
Miscellaneous	6	6	10
Total (Nos.)	35	117	199
Employees (Nos.)	155	5,841	8,827
Investment (Rs. Million)	16.0	1,517.0	10,403.0

Table 7. Mineral and rock production and royalties up to 1997.

Mineral / Rock	Production (million tones)	Royalties (Rs. Million)
Coal	1.67	33.35
Shale	0.92	9.20
Limestone	0.15	1.50
Marble	0.14	2.86
Chromite	0.04	1.33
Barite	0.03	0.58
Travertine	0.03	3.00
Building stone	0.02	0.22
Total	**3.00**	**52.04**

opportunity of 8,827 jobs and the total investment of about Rs. 10.4 billion were recorded. As a whole in 351 reported industries a labor force of 14,923 were employed upto 1993 and a sum of Rs. 11.9 billion were invested in the industrial sector (Siddiqui 2000). Reported status of industrial units is given in Table 6.

Mining activities in the province is limited to the local industry. In spite of large mineral potentials in the province, the mining sector has not been established on strong footing due to a number of political, administrative, financial and technical reasons etc. Copper, lead and zinc have been known from Chagai, Khuzdar and Lasbella Districts. Silver and gold mineralization are associated with Saindak copper ore. Barite deposits are found in Khuzdar and Lasbella Districts. Sui, Pirkoh and Loti are the major natural gas fields of Balochistan. It has been estimated that about 10.4 Trillion Cubic Feet (TCF) of recoverable gas reserves are present in said gas fields. Production of 0.3 TCF of gas has been reported upto 1996-97 from the gas fields of Balochistan. New gas reservoirs have been discovered from Uch, Zin, Savi Ragha, Jandran and from Zarghoon Valley of Quetta District, no production have been reported upto 1996-97 from said gas fields. Coal deposits are found in Quetta, Harnai and Duki region. Granite, lead, zinc, vermiculite deposits found in Chagai District. It has been estimated that about 195 million tones of mine able coal reserves are present in five major cola fields of Balochistan . (M. Soddiquie, 2000). According to 1997 figures, the production of coal was 1.67 Million Tons (MT), which is maximum among all mineral and rocks. The shale, limestone, marble chromite, barite, travertine and building stones are among the major minerals presently mining in the province. The total production of these minerals are about 3.0 MT and royalties paid to the government are about Rs. 52 millions, the production of some important minerals and rocks are given in Table 7. Large reserves of copper-gold, lead-zinc and iron ore have been identified and mapped by the Geological Survey of Pakistan, investment of the public and private sector is required to exploit these reserves. It has been estimated that in mining industry a labor force of about 40,000 is presently engaged while it has a capacity to generate 30,000 more jobs.

Industrial Water Demand

Lesser-developed small industrial and mining sector of Balochistan has little concern with water availability, demand and consumption problems. Groundwater is the source of about all the small industrial units and mining sector of the province except for the industrial units of the Lasbella District where the Lasbella Industrial Development Authority (LIDA) which comprises of Bela, Hub and Winder Industrial Estates. The LIDA has managed its own water supply system. The requirement of sustainable water sources is always a governing problem of large industrial units and mining ventures. Small industrial units of all kind are established within the residential limits of different cities and townships and they got benefit of the water supply systems. PHED in some township WSS of Balochistan Rural Water supply and Sanitation Project (BRWSSP) has fixed an allowance of 5% of the total domestic consumption as industrial and commercial demands. The actual and enumerated industrial and commercial water requirements of Hub, Kharan, Kuchlak, Mastung and Ziarat townships (NESPAK 1996 a-e) are given in Table 8. During 1993 the industrial water utilization were ranged from 0.003-0.023 Mm3, it is expected that it will become 0.004-0.04 Mm3 during 2000 and in 2015 it will increase from 0.013-0.244 Mm3. For industrial consumers of the Quetta City it has been estimated that about 5.4 Mm3 was utilized during 1993 (GKW. 1999). The industrial requirement will increase to 5.55 Mm3 by 2000 and ultimately 6.21 Mm3 by 2015. The industrial requirements of Quetta City are about 10% of the total domestic consumption as compared to 5% of township schemes.

CURRENT AND FUTURE DOMESTIC AND INDUSTRIAL WATER DEMANDS

Majeed and Qureshi (2000) provide a extended overview of the water resources of Balochistan and reported that in 1998 the available water resources were 18,311 Mm^3, which includes the surface and groundwater potentials and Balochistan's share from the Indus River. The water share from Indus River will increase from 4,780 to 7,050 Mm^3 by the year 2010, while the surface and groundwater potentials will remain the same. The available water will become 20,581 Mm^3 by the year 2010 and thereafter this figure is assumed to be constant for succeeding years (Majeed and Qureshi 2000). The drinking water demand in 1998 was 147 Mm^3, which comes exclusively from groundwater. It is expected that the total drinking water demand will become 530 Mm^3 during 2010, out of which 170 and 360 Mm^3 comes

Table 8. Industrial water demands in million cubic meter.

Townships	1993	2000	2015
Hub	0.023	0.040	0.244
Kharan	0.012	0.020	0.054
Kuchlak	0.018	0.026	0.064
Mastung	0.021	0.036	0.100
Ziarat	0.003	0.004	0.013
Quetta	5.400	5.550	6.210

Table 9. Current and Future Domestic and Industrial Water Demands (Mm^3) (Majeed & Qureshi 2000).

Water Source	1998	2010	2025	2050
DOMESTIC WATER DEMAND				
From Surface Water	--	360	660	1070
From Groundwater	147	170	200	280
Sub Total	147	530	860	1350
INDUSTRIAL WATER DEMAND				
From Surface Water	9	16	33	60
From Groundwater	24	35	65	125
Sub Total	33	51	98	185
GRAND TOTAL	**180**	**581**	**958**	**1535**

Table 10. Precipitation values (mm) of selected meteorological stations. The reduction % is of 30 years average values in mm.

Year	Lasbella	Jiwani	Nokkundi	Quetta
1994	426.1	110.6	57.5	304.8
1995	205.6	237.5	28.6	33.7
1996	169.8	5109	65.8	134.0
1997	308.3	283.6	73.8	309.0
Dry Spell				
1998	80.5	54.9	Traces	187.0
1999	104.0	24.0	16.5	106.0
Average				
1961-1990	215	113.9	35.3	260.8
Reduction %	**37-48**	**21-48**	**0-46**	**41-71**

from ground and surface water respectively. The surface water demands for drinking purpose are estimated to be double the quantities of groundwater in 2025 and will increase continuously. The drinking water demand will be 860 and 1,350 Mm^3 in 2025 and 2050 respectively. The current and future demand of domestic and industrial utilization is given in Table 9. The major shares of industrial and mining waters come from the groundwater. The industrial and mining water demands were 17 and 16 Mm3 respectively during 1998. The industrial water requirements will increase to 51 and 98 Mm^3 during 2010 and 2025 respectively. During the same periods the mining water share will 26 and 38 Mm^3. By the year 2050 the industrial and mining water requirements are anticpated to be 185 Mm^3 and these figures will increased continuously with the introduction of heavy industry in the province. The total domestic and industrial water consumption was about 180 Mm^3 during 1998. It is expected that with the estimated average population increase rate and industrial development the water demand in the province will become 581 Mm^3 during 2010, about 958 Mm^3 during 2025 and ultimately 1,535 Mm3 in the year 2050. The domestic and industrial water utilization during 1998 was about 1 % of the total water potential of the province. The domestic and industrial water utilization of available water will became 2.8% during 2010, 46% in 2025, and 74% during 2050.

Table 11. Strategies to combat drought in water supply sector, Rs. in Million, the (*) represents the US$ in Million.

Strategy	Components	No.	Rs.
Immediate			
Relief measures for relief camps.	Tractor mounted water bouzers and galvanized water tanks	350	104.5
Short term			
Conversion of existing tubewell into WSS	New schemes	101	203.0
Short term			
Desalination of sea water for Pasni Town	Installation of reverse osmosis plants.	03	8.0
Short to Medium Term			
Development of Limestone and Hard Rock aquifers for Quetta city.	Installation of tubewell.	100	14.56*
Medium Term			
Strategy to provide drinking water through existing and proposed sources in the drought effected areas.	Schemes development on existing tubewell.	28	30.2
	Schemes development on new tubewell.	26	40.6
Medium Term			
Proposal for Japanese social development funds for rural water supply sector	New schemes on existing tubewell.	30	87.1
Long Term			
Planning for drought toward reduction in drinking water vulnerability in Balochistan	New and rehabilitation of existing schemes.	349	1000

STRATEGIES TO COMBAT DROUGHT IN WATER SUPPLY SECTOR

The dry spell in Balochistan is initiated during 1998 and still continuing in many regions. The precipitation reduced to considerable limits, average reduction in precipitation of Jiwani, Lasbella, Nokkundi and Quetta meteorological station are given in Table 10. In last two years the average precipitation values decreased from 41-71% in Quetta, 0-46% in Nokkundi, 21-48% in Jiwani and 37-48% in Lasbella. Due to scarcity of rainfall surface water reservoirs dried-up, groundwater resources depleted, range lands deserted and rain fed *(barani)* agriculture diminished. Majority of the rural population severely effected either in one way or the other. Communities migrated to other places and nearby existing WSS, relief camps are established and relief measures are underway. Hub Dam reservoir depleted to its dead storage level, many of the industrial units of Hub Industrial Estate closed due to shortage of water. Numerous WSS effected, water shortage crises is eminent every where in the province. Out of 26 districts, 8 severely effected by the drought, 4 moderately effected, 11 less effected while remaining 3 are mildly effected (Fig. 1). To combat the drought in water supply sector immediate, short, medium and long term strategies were prepared. The strategies comprises conversion of existing tubewell into WSS, rehabilitation of existing WSS and construction of new WSS, exploration of new water resources etc. It has been estimated that Rs. 1473.4 million and US$ 14.56 million will be invested on proposed drought packages. A summary of the strategies is given in Table 11. It has been estimated that with the implementation of the drought related strategies, supplementary water will be available to the residents of existing WSS and an additional population of about 0.9 million will also get domestic water supply facilities.

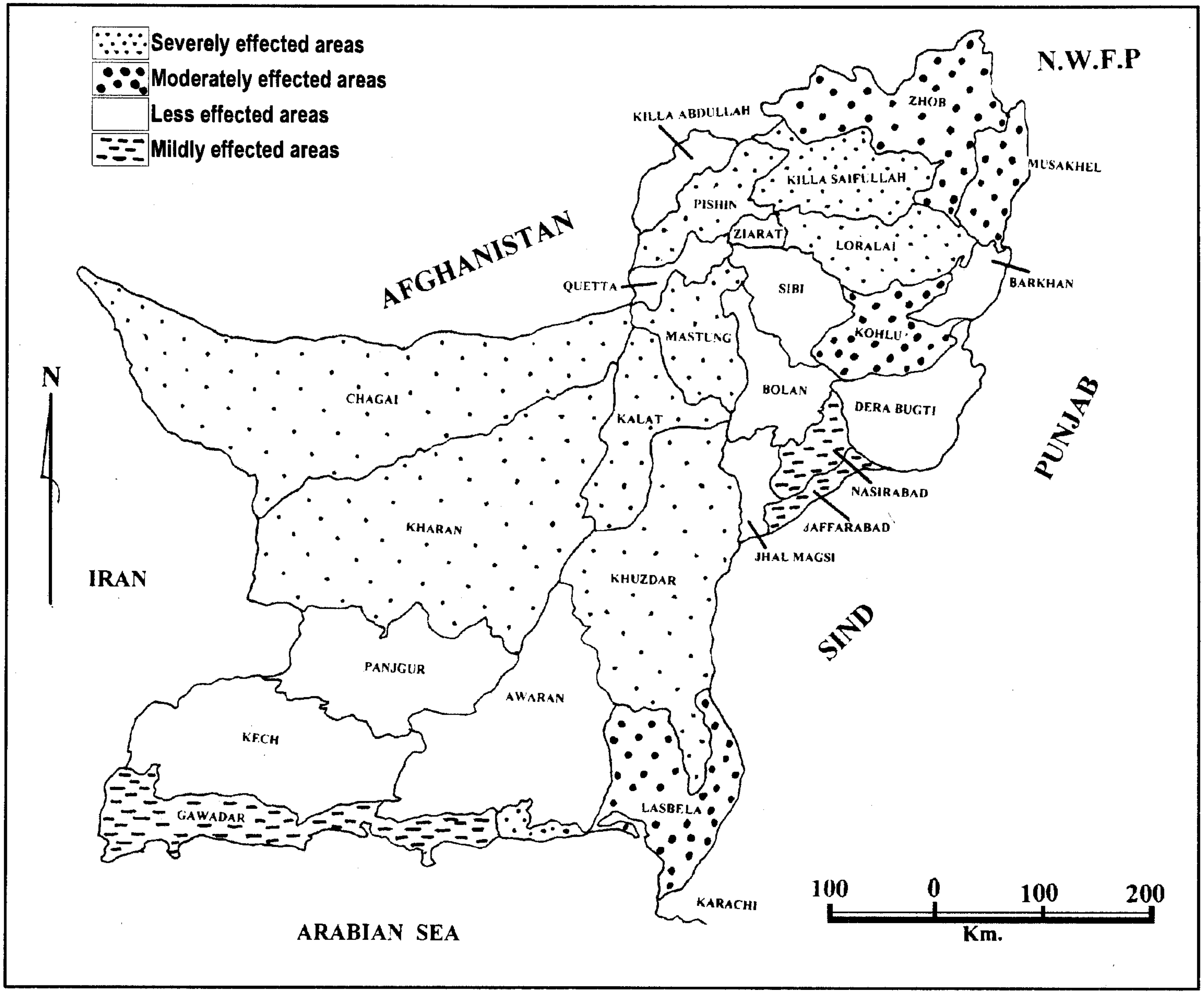

Figure 1. Drought effected areas of Balochistan (June 2000 situation).

CONCLUSION AND RECOMMENDATIONS

To fulfil the present and future demands of domestic and industrial water in Balochistan, proper management of water resources is indispensable. A sustainable strategy is required which should comprise enormous broad-based objectives as:

1) Provision of piped water to the remote rural communities by selection of low cost appropriate technologies compatible with the local environment.
2) Implementation of water conservation strategies for domestic supply; with water metering, realistic water tariff and effective cost recovery system.
3) Establishment of small industrial units with homogenous aerial spread near available raw material and settlements compatible with traditional and cultural aspects.
4) Introduction of a comprehensive mechanism for the selection and establishment of industry which may accommodate little water of low quality.
5) Environmental aspects in industrial and mining sector should be adopted; recycling and reuse of wastewater should be an integral part of the system.
6) Institutional establishments, pooling of resources, coordination of experts and sharing of experiences should be a core policy of all public sector organizations.
7) Planning and management of all water resources is indispensable to combat extended period of dry spells by storing and utilizing the surface water resources.

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GEOLOGY OF SHAMOZAI AREA IN LOWER DIR DISTRICT, NWFP, PAKISTAN

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ABSTRACT

Rocks of the Main Mantle Thrust and associated suites have been investigated in a 100 sqkm area in southwestern Dir district. Field investigations and thin sectiion study reveal that the succession of rock units from south to north is that of the Indian plate rocks, ophiolitic melange zone, and Kohistan are terrane. The Indian plate rocks comprise granitic genieses pelitic, calcareous, graphitic and psammitic shelf and platform sediments along with minor calcareous schists and phyllites. The ophiolitic melange zone, which is reported for the first time from the area, mainly comprises serpentinized dunite, talc-carbonate schist and crystalline limestone blocks in a matrix of phyllite and minor graphitic schist. The arc terrane is represented by amphibolites intruded intruded by quartz porphyries and tonalities in number of places.

INTRODUCTION

Northern Pakistan is conveniently divided into three tectonostratigraphic blocks; the Indian plate sequence in the south, the Indus suture melange group in the middle and the Kohistan arc sequence in the north (Kazmi et al. 1986, Lawrence et al. 1989). The Indian plate metasedimentary sequence comprises deposited on the northern margin of Gondwanaland before and after its Permo-Triassic breakup.

The Kohistan terrane represents a magmatic arc sequence. It is bounded by two major faults; the Main Karakoram Thrust (MKT) or the Shyok suture in the north, and the Main Mantle Thrust (MMT) or Indus suture in the south. Both these sutures contain discntinuous outcrops of melanges with blocks of ophiolites and a range of other rocks (Tahirkheli et al. 1979, and 1983, Kazmi & Jan 1997). In Dir area, the southern amphibolite belt rocks of the Kohistan island arc were regarded as Dir amphibolites (Chaudhry et al. 1974). Rocks of this belt range from amphibolites to hornblende gneisses and have been classified into banded and non-banded types. The belt also contains a variety of other lithologies such as metamorphosed gabbros/norites, troctolites, ultramafites, granitic rocks and minor calcareous and siliceous rocks

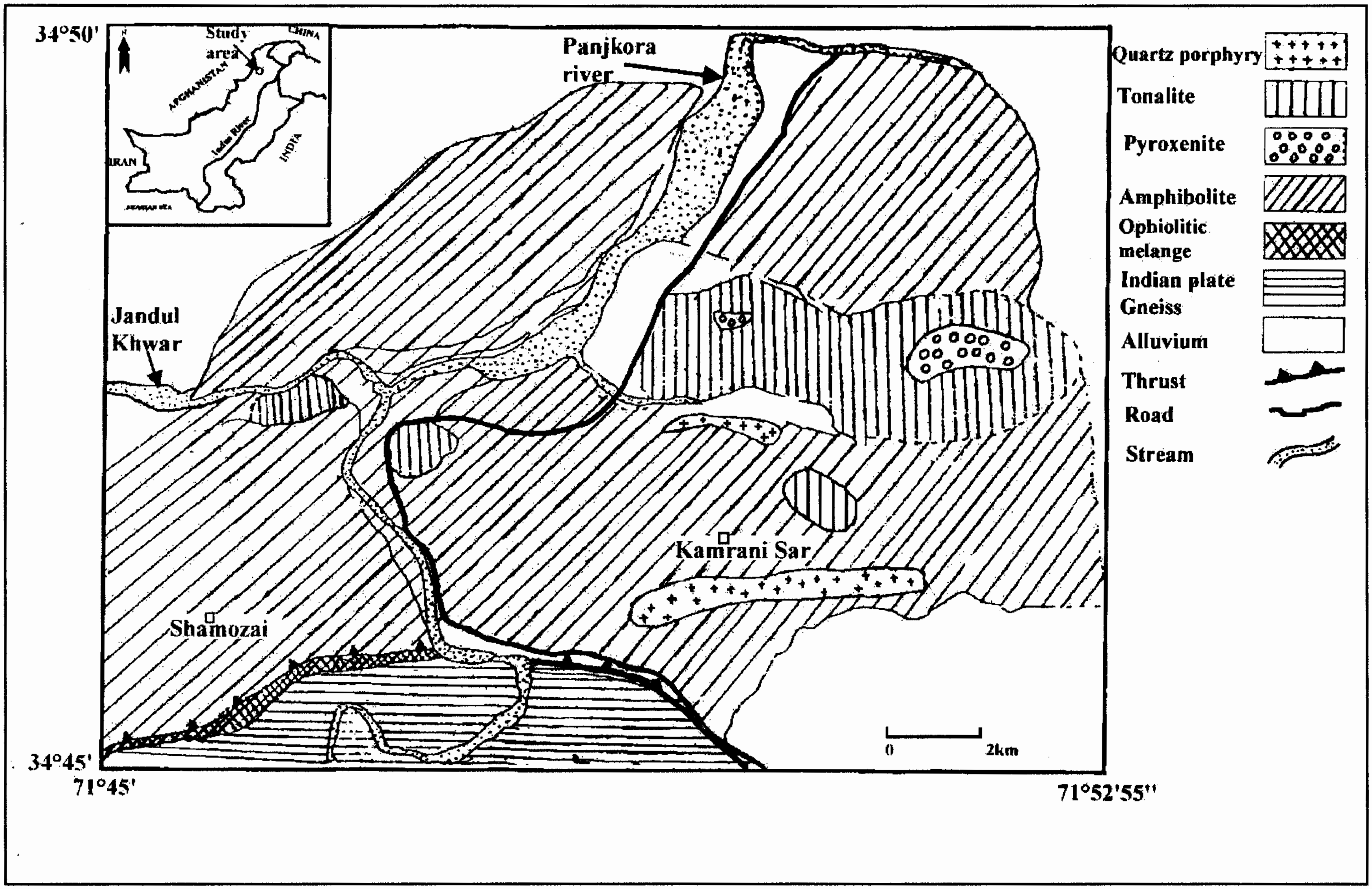

Figure 1. Geological map of Shamozai area in Lower Dir district, NWFP, Pakistan. Inset: Index map of Pakistan showing the location of the study area.

(Jan 1990). This belt is structurally complex and has undergone at least three phases of deformation and two of metmorphism. Isoclinal folding and shearing are common (Bard 1983, Coward et al. 1982, 1986).

The MMT zone is largely composed of metamorphosed ophiolites and melanges which have been wedged between the Kohistan island arc and the Indian plate (Baig et al. 1989, DiPietro et al., 2000). Rocks of this suture are subdivided into three fault-bounded melange groups (ophiolite, blueschist and greenschist) BY Kazmi et al. (1984) in Mingora-Shangla area. Various fault-bounded melange units, present in Allai-Kohistan have als been similarly divided (Baig et al. 1989). Those in Bajaur Agency have been described as Titobai ophiolitic melange by Hussain et al. 1989).

As the first record of field observation of the suture zone, southwest of Timargara, district Dir, this paper presents the geology of the Shamozai area and refers to it as the Shamozai ophiolitic melange.

FIELD FEATURES AND PETROGRAPHY

The Indian Plate

Rocks of the Indian plate occupy the southwestern portion of the study area. They are represented by medium-grained granitic rocks with a well-developed gneissose fabric, striking N 45° E and dipping 75° SE. These rocks underplate the melange with a thrust contact (Fig. 1). The rocks are medium to thick- bedded, highly fractured, weathered and locally crushed and mylonized. Deformed veins of quartz and feldspar are common in thee rocks. Major minerals in the rocks include quartz and feldspar with minor amounts of mica, garnet, epidote, hornblende, chlorite and sphene. Quartz (40 modal %) is anhedral and shows an undulatory extinction. Alkali feldspar (25%) is subhedral and has grown perthite and myrmikitic textures. Plagioclase (24%) ranges from albite to oligoclase in composition. The feldspar is generally kaolinized and susseritized. Garnet is subhedral and intensely fractured.

The Shamozai Ophiolitic Melange

The Shamozai ophiolitic melange (SOM) is exposed as a tectonic slice between gneisses of the Indian plate and southern amphibolites of the Kohistan island arc. It is 150m to 200m thick and extends generally east-west for about 5 km in the area (Fig. 1). The melange zone consists of talc-carbonate schists (derived from ultramafic rocks), recrystallized limestones, metacherts, along with exotic blocks of ultramafics rocks (mostly serpentinized dunites). These rocks are set in a matrix of phylllite and minor graphitic schist in the area (Fig. 2). The talc-carbonate schist is a fine-grained, light green rock with greenish grey color on weathered surface. Talc and magnesite are the main constituents in this rocks. Serpentinized dunites show a fine-grained granular texture with serpentine and olivine as the major minerals. Olivine is subhedral to anhedral. It shows deformation (undulose extinction, kink bands) and alteration to serpentine (mainly antigorite) along grain boundaries and fractures. Ore minerals include chromite and secondary magnetite (10% by volume). The phyllite matrix is fine-grained. It is olive green on weathered surface and dull green on fresh surface. It is composed of quartz, chlorite, albitic plagioclase and calcite with biotite and actinolite as the minor constituents. Sericite and epidote are the major alteration phases in the phyllite. The graphitic schist consists of quartz, sericite, graphite, albite and opaque oxides.

The Kohistan arc

The Kohistan arc sequence in the study area is represented by amphibolites. A continuatiion of the southern amphibolite belt exposed elsewhere in the regiion, they are widely exposed here too. These rocks strike east-west and have an almost vertical dip. The rocks are medium-grained and range from plagioclase- to epidote-amphibolites, locally containing garnet. The rocks range from massive to banded, and much of the banding may be related to shearing. In addition to amphibolite bands, there are excellent examples of rocks containing bands of amphibolitic and granitic composition (Fig. 3).

The amphibolite sequence contains acidic to mafic and ultramafic bodies. These bodies are present either as relics (norites and pyroxenites) or as minor intrusions (quartz-porphyries and tonalites). There is no evidence to suggest that these are tectonically transported blocks. These bodies vary in size from a few metres to a few hundred metres. In quartz-porphyries, phenocrysts of quartz (and rare feldspar) are surrounded by a matrix of quartz and feldspar. Epidote has developed at the expense of plagioclase. The abundance of alkali feldspar and quartz suggest that these rocks ay be rhyolitic in composition. The tonalies consist of andesine, quartz, and hornblende alongwith minor amounts of biotite,sphene, and opaques. Epidote and chlorite are the common

Figure 2. Recrystallized limestones and serpentinized dunites demarcate the suture zone in the Shamozai area.

Figure 3. Banded amphibolites exposed 2 km west of Shamozai along the Timargara- Bajaur road.

alteration products in these rocks. Corundum-bearing pyroxenite bodies occur in amphibolites at various places. The rocks is grey on weathered surface while greenish grey on fresh surfac. Light pink corundum crystals with whitish margins are present in this rock. The rock is extremely altered and shows hypidiomorphic texture. The corundum grains are surrounded by a shell of alteration products. Major alteration products include margarite, antigorite, talc, chlorite and epidote, Corundum bearing amphibolites, having similar alteration, have been reported near Timargara by Jan et al. (1971).

DISCUSSION

The Shamozai ophiolitic melange is exposed along the collision zone between the Indian plate basement gneisses and southern part of amphibolites of the Kohistan island arc. The SOM is almost linear and strikes approximately eat-west in the area. The matrix for ophiolitic melanges is mostly phyllite and graphitic schist along the entire length of the MMT (Irshad Ahmed, Pers. Comm.). The SOM is hosted by the same matrix and it is similar to the ophiolitic melange described by Kazmi et al. (1984) from Mingora area, therefore, we regard it to be a normal ophiolitic melange. Seemingly, this zone is the continuation of the Mingora-Shangla collision zone. The SOM is a schistosity-parallel but strongly deformed tectonic contact between the gneisses of Indian plate and amphibolites of Kohistan island arc. It is evident by the foliation of gneisses and amphibolites near the thrust contact.

The amphibolites are the most voluminous rocks in the studied area and have been distinguished into the banded and non-banded types. The granitic component in these rocks is indicative of deformation, e.g., granulation, mylonitization, boudinaging, and Isoclinal folding. It is not clear whether the granitic material is a result of shear segregation, partial melting of the amphibolites during high-grade metamorphism or unrelated "lit-par-lit" syn-or pre-kinematic injections.

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PETROGRAPHY OF GONDWANA SANDSTONES IN THE BOREHOLE GDH-45 OF THE KHALASPIR BASIN, BANGLADESH

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ABSTRACT

Petrographic study of the Permian Gondwana sandstones in the borehole GDH-45 of the Khalaspir basin was performed with a view to provide mineralogical characteristics and classification of sandstones and to interpret their provenance. The sandstones are coarse to fine-grained, sub-angular to sub-rounded and moderately to poorly sorted. The detrital components include quartz (48%), feldspar (12%), rock fragments (1.5%), mica (3%), etc. while kaolinite, haematite, siderite, calcite etc. are the authigenic components (19%). Monocrystalline quartz dominates over polycrystalline type. Both the altered and unaltered feldspar are present. Alkali feldspar are more abundant than plagioclase feldspar. Mineralogical composition at the middle part of this sequence is more or less same but percentage of quartz, feldspar and rock fragments are randomly rather than uniform at the upper and lower parts. About 80% of these sandstones are sub-arkoses and 20% are arkoses/arkosic arenites with an average modal composition of $Q_{81\%}$ $F_{17\%}$ $L_{2\%}$ and $Q_{71\%}$ $F_{27\%}$ $L_{2\%}$ respectively. Petrographic characteristics of the general observation are mainly derived from igneous and comparatively small metamorphic as well as sedimentary sources. Plotting in different diagrams reveal that the detrital components of the Gondwana sandstones had been derived mainly from plutonic igneous rocks and metamorphic rocks of cratonic interiors and transitional continental blocks provenances with a minor share from sedimentary sources.

INTRODUCTION

The Khalaspir basin is located in the Pirgonj Upazilla under Rangpur District in the northwestern part of Bangladesh (Fig. 1). The total coal bearing area of the basin is about 12.25 sq. km (Islam et al. 1992). This Gondwana basin is NW-SE, NE-SW and N-S trending faults bounded graben within the Basement Complex. The basin contains more than 815 m thick Gondwana sedimentary sequence, which is overlain by the Surma Group, Dupi Tila Formation, Barind Clay and Alluvium of Miocene, Pliocene, Pleistocene and Recent ages respectively (Islam et al. 1992, Uddin and Islam 1994). The

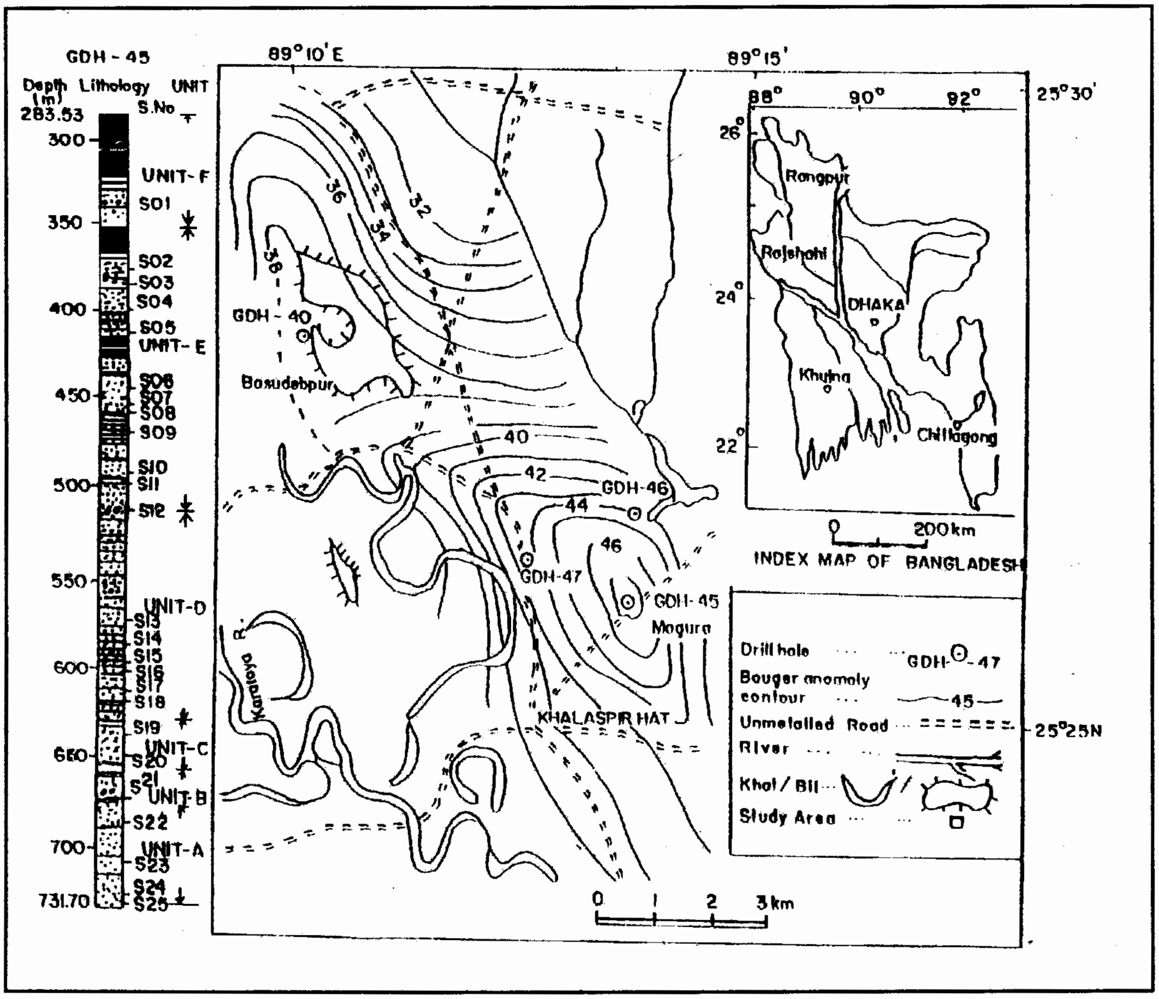

Figure 1. Map showing the location of the borehole GDH-45 and sample positions in the borehole, Khalaspir basin, Rangpur.

Permian Gondwana rocks (+815 meters) in the borehole GDH-45 of the Khalaspir basin is broadly divided into six litho-stratigraphic units (unit A, B, C, D, E and F) based on their dominant lithologic associations. Petrographic studies of the Gondwana rocks of Bangladesh are sporadic (Rahman and Ahmed 1995, Hossain et al. 2000) as compared to the stratigraphy and sedimentological works (Alam 1992, Islam et al. 1992, Uddin and Islam 1992, Islam 1992, 2001). On the other hand, various petrographic works on the Gondwana rocks of India have been carried out since few decades (Banarjee 1963, Rizvi 1972, Qidwai 1972, Khan 1991 etc.). However, no such study has yet been done on Gondwana rocks of the Khalaspir basin. An attempt has been made to study mineralogical and petrographic characteristics of the Gondwana sandstones for petrographic classification and to determine the nature of provenance.

PETROGRAPHIC PROCEDURE

In the present study, 25 representative core samples of the Gondwana sandstones were collected randomly from the borehole GDH-45 for the preparation of thin section slides (Fig. 1). Standard thin sections were prepared from slabs cut perpendicular to bedding. A detailed qualitative and quantitative analysis has been carried out using petrographic microscope. Both the major and minor components such as quartz, feldspar, rock fragments, mica and heavy mineral, matrix, organic matter, sericite and authigenic components were identified. Proportions of various rock components were calculated by counting at least 300 grains per slide following the profile traverse methods generally uses in conventional petrographic microscopy (Kerr 1959, Moorehouse 1959, Adams et al. 1984). Relative frequencies of mono- and polycrystalline, and undulose and non-undulose quartzs were also determined. Apart from diagenesis, other important features such as natural grain contacts and grain-matrix relationship were carefully studied.

PETROGRAPHIC CHARACTERISTICS

Texture

Textural properties of sandstones were determined from thin sections by means of visual comparison (Wentworth 1933, Power 1952, Compton 1962). The present study shows that 36% of these sandstones are coarse to medium grained, 44% medium to fine grained and 20% fine to very fine grained. About 52% of these sandstones are poorly sorted, 20% moderately to poorly sorted and 28% moderately to well sorted. About 72% of these sandstones are sub-angular to sub-rounded and 28% angular to sub-rounded. Generally the studied sandstone represents low sphericity.

Mineralogical Composition

The mineralogical composition of the Gondwana sandstones are described as detrital components (quartz, feldspar, rock fragments etc.) and authigenic components (kaolinite, sericite, calcite, siderite etc.). The petrographic results of the Gondwana sandstones are given in the Table 1.

Detrital Components

Quartz is the most abundant detrital constituent of these sandstones. It constitutes about 33 to 64% of the total rock components with an average of 48% (Table 1). Percentage of quartz increases gradually with increasing depth of burial. The quartz grains are sub-angular to sub-rounded and moderately to poorly sorted. Both of the monocrystalline (Q_m) and polycrystalline (Q_p) quartz are present in these sandstones.

Monocrystalline quartz is either non-strained or strained types. Strained quartz is less abundant than non-strained type. On average, the Q_m is about 92% of the total quartz. The Q_p consisting of two or more crystals have straight or sutured boundary. It is commonly less abundant with an average percentage of about 8%. Few quartz crystals contain irregular inclusions of biotite, zircon and tourmaline. Other few grains are fractured, crenulated and cloudy in appearances.

Feldspar is the second abundant detrital constituent of the Gondwana sandstones which constitutes about 11% of total constituent of the sandstones (Table 1). About 56% of the total feldspar grains are partially altered, which appear cloudy or turbid in nature with diffused outer lines but the unaltered grains are relatively clear in appearance. Unaltered feldspar are sub-angular to sub-rounded grains with clear twining. Alkali feldspar (orthoclase and microcline) is more common than plagioclase feldspars because of their more stability. On average, the alkali feldspar and plagioclase feldspar constitute about 33% and 11% of total feldspar respectively. Few feldspar grains show perthitic intergrowth. In partially decomposed feldspars, the alteration

Table 1. Petrographic results of the Gondwana sandstones of the borehole GDH-45 in the Khalaspir basin.

	QUARTZ			FELDSPAR						MICA								CEMENT			
Sample No.	Monocrystalline %	Polycrystalline %	Total Quartz %	Alkali Feldspar %	Plagioclase %	Altered Feldspar %	Total Feldspar %	Rock Fragments %	Chert %	Muscovite %	Biotite %	Total Mica %	Heavy Minerals %	Organic Matter %	Sericite %	Chlorite %	Matrix %	Argillaceous %	Siliceous %	Ferruginous %	Calcareous %
S01	62	2	64	7	1	5	13	1	-	-	1	1	-	3	5	-	3	5	-	4	1
S02	52	7	59	3	1	9	13	2	1	-	-	-	-	2	1	-	2	16	-	2	-
S03	42	5	47	3	2	5	10	2	1	1	2	3	-	10	5	-	5	6	1	8	2
S04	43	4	47	4	1	8	13	1	-	-	2	2	1	10	-	1	5	8	1	10	1
S05	38	2	40	2	1	7	10	1	-	-	-	-	-	12	1	-	4	8	1	23	-
S06	34	4	38	3	1	5	9	1	-	1	3	4	-	5	14	2	5	6	-	11	5
S07	57	5	62	4	2	2	8	2	-	1	-	1	-	6	2	-	3	3	-	5	8
S08	37	5	42	2	1	5	8	1	-	-	3	3	-	20	-	1	5	5	1	12	2
S09	47	2	49	5	2	7	14	1	-	-	2	2	-	5	3	-	9	7	1	8	1
S10	50	3	53	5	1	3	9	2	1	1	1	2	-	7	1	-	6	5	1	10	3
S11	45	5	50	4	1	5	10	1	-	-	1	1	-	5	10	-	6	7	2	8	-
S12	34	1	35	2	-	10	12	1	-	2	1	3	-	5	20	-	5	10	1	8	-
S13	49	4	53	5	2	3	10	1	-	1	4	5	1	6	8	2	3	4	1	5	1
S14	30	3	33	3	1	11	15	1	1	-	2	2	-	7	17	-	5	11	1	5	2
S15	50	3	53	6	2	5	13	1	2	-	1	1	-	10	2	-	2	5	2	7	2
S16	52	1	53	3	-	4	7	1	-	-	2	2	-	16	1	1	4	4	-	10	1
S17	52	4	56	4	1	8	13	1	1	-	1	1	-	3	3	-	3	8	-	10	-
S18	38	12	42	4	-	7	11	1	-	1	2	3	-	9	5	1	7	7	2	10	2
S19	40	7	47	3	-	5	8	1	-	-	4	4	-	5	3	2	4	6	2	14	4
S20	45	5	50	4	1	5	10	3	-	-	1	1	1	5	9	2	6	6	2	7	-
S21	55	3	58	5	2	6	13	2	-	1	4	5	-	2	4	2	3	5	1	3	2
S22	35	2	37	2	-	13	15	1	-	1	3	4	-	4	10	1	7	12	1	7	2
S23	38	4	42	7	1	5	13	3	1	1	4	5	1	5	8	1	5	6	2	6	2
S24	34	3	37	2	4	7	13	1	-	1	3	4	-	6	9	-	7	14	2	5	2
S25	40	2	42	3	2	10	15	1	-	1	2	3	-	4	7	1	6	14	1	5	2
Avg.	44	4	48	4	1	6	11	2	<1	<1	2	2	<1	7	6	1	5	8	1	8	2

products tend to concentrate on surface and formed microcrystalline aggregates of kaolinite.

Rock fragments are clusters of many mineral grains, which constitutes about 1 to 3% of the total rock components (Table 1). All types of rock fragments are identified in these sandstones. Metamorphic rock fragments are more abundant and consists of metaquartzite, phyllite, schists etc. Sedimentary rock fragments are mainly fine-grained sandstone, siltstone, shale, chert etc.

Mica is the minor detrital grain, which occurs as well-defined plates to very finely comminuted flakes and shreds. Mica flakes are commonly larger than the associated detrital grains and are generally oriented parallel to the bedding. These are more common in fine-grained sandstones. Because of their thin sheet shape and consequent lower settling velocity, these are associated with quartz and feldspar grains of smaller sand and silt size (Doyle et al. 1983). Various twisting of mica are the indication of the degree of physical compaction. It ranges upto 5% of the total rock components with an average of 2% (Table 1). Both muscovite and biotite are present but the later is more abundant than the former (Table 1). In few instances, sericite and chlorite are present, which most probably altered from mica.

Heavy minerals are the minor constituents. Only a few grains such as garnet, zircon, tourmaline, rutile, epidote, magnetite, haematite etc. are rarely present, which generally constitutes less than 1% (Table 1).

Organic matter is the accessory detrital component of sandstones, which is most abundant in carbonaceous sandstones than feldspathic or any other sandstone. It constitutes about 1 to 20% of the total rock components with an average of about 7% (Table 1). In thin sections, organic matter is characterised by its dark yellowish brown to black coloured isolated grain or grain clusters with translucent edges.

Mechanically deposited syndepositional fine-grained detrital materials (<30m) are collectively known as matrix (Dott 1964). It constitutes about 2 to 9% of the total rock components with an average of 5% (Table 1). Generally the matrix comprises quartz, clay minerals and other argillaceous materials. In most cases, it is very difficult to separate matrix from cement.

Authigenic Components

Kaolinite ubiquitously occurs as small vermicular or irregular and dispersed aggregates in pore spaces of these sandstones. It is more abundant in feldspathic sandstones than others. Dissolution and decomposition of feldspar are thought to be the major source of kaolinite precipitation. It constitutes about 3 to 16% of the total rock components with an average of about 8% (Table 1). In slides, kaolinite shows colourless or milky shade under plane polarized light and grey to dark grey interference colour with higher birefringence under crossed nicols.

Siliceous cement is present as secondary overgrowth deposited in optical continuity with detrital grains or as cementing materials filling the pore spaces. It constitutes up to 2% of the total rock components with an average of about 1% (Table 1). It is less abundant than other cements. It might has been chemically deposited from solution.

Ferruginous cement (haematite and siderite) is most common in the sandstones. It constitutes about 2 to 14% of the total rock components. Haematite is readily identified by its brown to steel grey colour under plane polarised light and dark brown to black colour under crossed nicols, whereas, siderite shows colourless to pale brown colour with high relief under plane polarized light and high birefringence under crossed nicols. Siderite indicates an involvement of reducing agents, like organic matter. Haematite occurs as discrete disseminated grains and masses along the fracture, whereas, siderite occurs as small individual or clusters of rhombohedra.

Calcareous cement is present as distinct untwinned mosaic of interlocking crystals that fills pore spaces or fracture planes or along the corroded detrital framework grains. On average, it constitutes about 2% of the total rock components (Table 1). In thin sections, calcite is identified by its colourless and variable relief under plane polarized light and rhombohedral cleavage with higher order pink and green birefringence under cross nicols.

Sericite is the altered product of muscovite or feldspar. On average, it constitutes about 6% with a maximum of 14% of the total rock components (Table 1). In thin sections, sericite is commonly identified by its clayey microflakes with first order white to yellow interference colour and low birefringence. Sericite is most abundant in middle part of the Gondwana sequence.

Chlorite is the less common detrital components of the Gondwana sandstones. On average it constitutes less than 1% with maximum of 2% of the detrital components (Table 1). Chlorite is abundant in the lower part of the sequence and is frequently

Table 2. Unit-wise distribution of the Gondwana sandstone classes in the borehole GDH-45, Khalaspir basin.

Unit	Pettijohn (1975)		Folk (1980)	
	Percentage	Class	Percentage	Class
F	4	Sa	4	Sa
E	40	Sa	40	Sa
	4	AA	4	A
D	20	Sa	20	Sa
	4	AA	4	A
C	8	Sa	8	Sa
B	4	Sa	4	Sa
A	4	Sa	16	A
	12	AA		

(Sa; Sub-arkose, AA; Arkosic arenite, A; Arkose)

Table 3. Detrital compositional modes of the Gondwana sandstones of the borehole GDH-45. Quantitative modes are recalculated from thin section data. (Q; total quartz, F; feldsper, L; lithic fragments, Q_m; monocrytalline quartz, L_t; total lithic fragments etc.)

Sample No.	Q F L			Q_m F L_t			Diamond Diagram				
	Q (%)	F (%)	L (%)	Q_m (%)	F (%)	L_t (%)	Q_n (%)	Q_S (%)	$Q_{p(2-3)}$ (%)	$Q_{p(>3)}$ (%)	Q_p Total
S01	82	17	1	82	17	1	93	3	3	1	4
S02	79	18	3	78	19	3	92	1	6	1	7
S03	80	17	3	78	19	3	85	3	10	2	12
S04	78	20	2	75	23	2	89	3	6	2	8
S05	78	20	2	78	20	2	94	2	3	1	4
S06	79	19	2	77	21	2	88	3	8	1	9
S07	86	11	3	85	12	3	86	3	9	2	11
S08	82	16	2	80	18	2	87	2	10	1	11
S09	77	21	2	76	22	2	93	3	3	1	4
S10	84	14	2	83	15	2	92	2	5	1	6
S11	79	16	5	78	17	5	88	4	5	3	8
S12	73	25	2	72	26	2	96	1	2	1	3
S13	83	16	1	81	17	2	90	2	7	1	8
S14	67	31	2	65	33	2	90	2	7	1	8
S15	79	19	2	78	20	2	92	2	5	1	6
S16	85	12	3	87	12	1	94	3	2	1	3
S17	80	19	1	79	20	1	88	3	8	1	9
S18	78	20	2	76	22	2	72	3	23	2	25
S19	84	14	2	82	16	2	83	2	13	2	15
S20	79	16	5	78	17	5	88	4	5	3	8
S21	79	18	3	78	19	3	89	4	5	2	7
S22	69	28	3	69	29	2	93	2	4	1	5
S23	72	23	5	70	24	6	88	1	8	3	11
S24	73	25	2	71	27	2	87	5	6	2	8
S25	72	26	2	71	27	2	94	2	3	1	4

lumped with the fine clay fraction. In thin sections, it is characterized by pale green colour, perfect basal cleavage and low birefringence.

PETROGRAPHIC CLASSIFICATION

The standard classification schemes are followed to classify the Gondwana sandstones (Krynine 1946, Dott 1964, Pettijohn 1957,1975, Pettijohn et al. 1987, Folk 1954, 1956, 1980, Folk et al. 1970, Williams et al. 1972). Major detrital framework components of sandstones, especially quartz, feldspar and rock fragments have been recalculated into percentage among themselves (Table 3) for QFL diagram allowing these to occupy one of the three poles (Fig. 2).

Plot in the ternary diagrams (QFL) given by Pettijohn (1975) and Folk (1980) show that these sandstones are sub-arkose and arkose/arkosic arenites. Arkose/arkosic arenites constitutes about 20%, whereas, sub-arkose is about 80% of the total sandstones. The average modal composition of sub-arkose is $Q_{81\%}$ $F_{17\%}$ $L_{2\%}$ and that of arkose/ arkosic arenites is $Q_{71\%}$ $F_{27\%}$ $L_{2\%}$. On the basis of above classification the unit-wise distributions of these sandstones are shown in Table 2.

PROVENANCE

Detrital framework modes of sandstones suites provide information about the composition and tectonic settings of the provenance as well as the basin of deposition (Dickinson et al. 1983). Quartz (mono-and polycrystalline) is the principal product of rock disintegration and decomposition, which may be derived from plutonic and volcanic igneous rocks, metamorphic rocks and sedimentary rocks (Pettijohn et al. 1987). Fine-grained quartzite and cherts may be of acid volcanic rocks (Wolf 1971). Quartz grains with regular, irregular and acicular inclusions indicate its derivation from crystalline and metamorphic rocks (Krynine 1946). Abundance of K-feldspar indicate acid igneous source rocks (Ghosh and Kumer 2000). Perthitic feldspar is indicative of slow cooling and characteritic of plutonic sources. Detrital micas are believed to be derived from low grade metamorphic rocks, like quartzite schists and gneisses and from plutonic igneous rocks of granitic composition (Folk 1980, Khan 1991). Minor amounts of sedimentary rock fragments like that of shale, siltstone fragments and altered feldspar grains are indicative of sedimentary provenance.

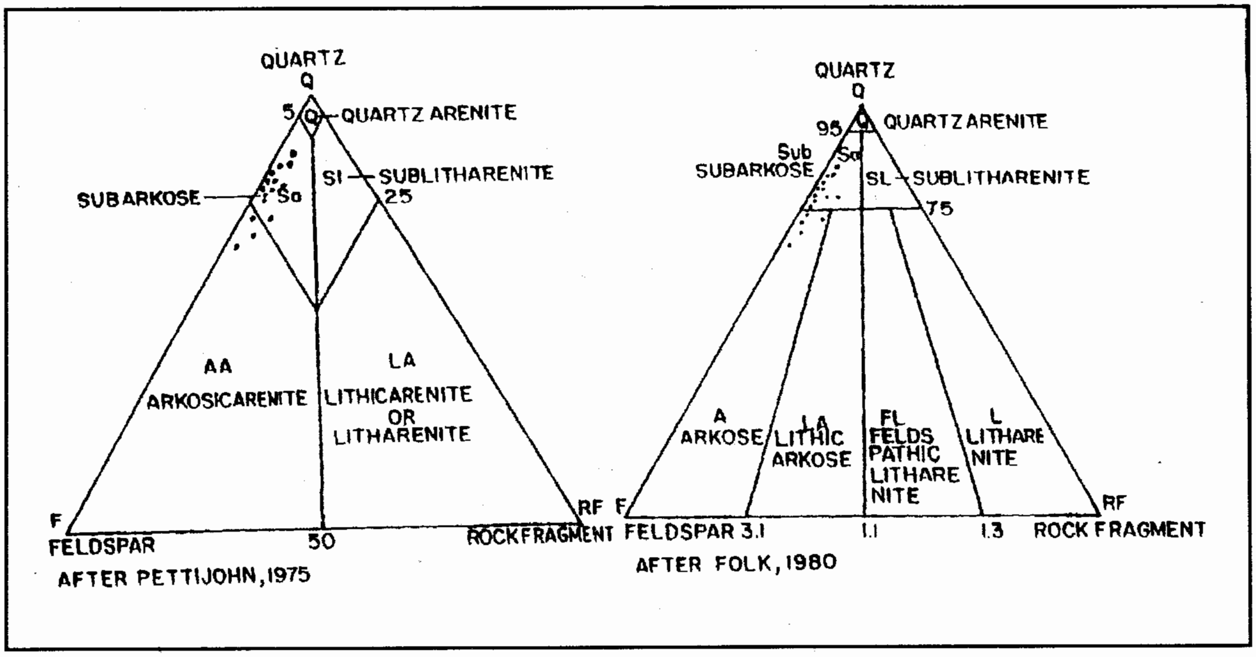

Figure 2. Triangular diagrammes for the classification of the Gondwana sandstones (after Pettijohn 1975, and Folk 1980).

The most significant compositional variations among the detrital sandstones can be displayed on QFL and Q_mFLt triangular diagrams (Graham et al. 1976, Dickinson and Suczek 1979, Dickinson 1985 and Dickinson, et al. 1982). The mean compositions of sandstone suites derived from different kinds of provenance terrain's controlled by plate tectonics tend to lie or form cluster within discrete and separate fields on QFL and Q_mFL_t diagrams (Fig. 3). In triangular diagrams, these sandstones are plotted on stable shields and platforms or in uplifted continental blocks provenance (Dickinson et al. 1983). The basement uplifts occur along incipient rift belts, transform ruptures, deep-seated thrusts and zones of wrench tectonism (Dickinson et al. 1983). The most quartzose sands of the area derived from stable cratonic areas within interior basins having low relief, on platforms and open ocean basins bounded by passive margins. Whereas the feldspathic sands derived from a transitional block and arkosic sands from uplifted basement blocks occurs locally in rift grabens. The triangular diagram shows that the studied sandstones are derived from cratonic interiors and transitional continental blocks. In QFL and Q_mFL_t diagrams, the plotted samples are concentrated along the Q-F/Q_m-F lines within the stable cratonic and transitional areas in the continental block provenances.

Different varieties of detrital quartz provide an important clue to provenance. The ratio of polycrystalline to monocrystalline quartz being perhaps the most important parameter following that are the ratio of undulose to non-undulose grains and grain shape. Quartz from a variety of source rocks could be distinguished on the basis of undulosity in detrital monocrystalline quartz (Blatt and Christie 1963, Basu et al. 1975). The average number of crystal units in sand-size grains of polycrystalline quartz varies depending on the source rock of the quartz (Blatt, Middleton and Murry 1980).

The diamond diagram (Fig. 4) having four parameters, like amount of undulose quartz, non-undulose quartz, polycrystalline quartz and number of crystal units per single polycrystalline grains are widely used as effective mean to distinguish source rock types (Basu et al. 1975). Monocrystalline quartz are derived from igneous (Plutonic) and metamorphic rocks (Pettijohn et al. 1987). Polycrystalline quartz having 2-3 years grain are derived from a plutonic source and having more than 3 crystals per grain are metamorphic source (Blatt et al. 1972). Polycrystalline quartz with straight boundaries are indicative of igneous sources but that with crenulated or irregular boundaries are more suggestive of metamorphic source rocks. From diamond diagram and above discussion it is concluded that the studied sandstones are derived from plutonic rocks of igneous origin situated in the stable cratonic and transitional block of provenances. Metamorphic sources also played an important role in the sediment supply.

CONCLUSIONS

The Khalaspir basin is a NW-SE elongated and fault bounded asymmetric half-graben within the Basement Complex. Petrography has been done to classify the sandstones within the sequence and to provide the idea about the possible provenances. The Gondwana sandstones at the basin are coarse to fine-grained, sub-angular to sub-rounded and moderately to poorly sorted. Average composition of these sandstone is 48% quartz, 11% feldspar, 2% rock fragments, 2% mica, <1% heavy minerals, 5% matrix, 7% organic matter, 6% sericite and 18% authigenic components. The authigenic components are argillaceous, siliceous, ferruginous and calcareous cements. These sandstones are classified as sub-arkose (80%) and arkose/arkosic arenites (20%). An average modal composition of sub-arkose is $Q_{81\%}$ $F_{17\%}$ $L_{2\%}$ and arkose/arkosic arenites is $Q_{71\%}$ $F_{27\%}$ $L_{2\%}$. Diagenetic effects especially, twisting of mica and bending of ductile grains are the indication of the degree of physical compaction. Pressure solution, at few instances, is the result of detrital grain compaction and development of stress along the grain margins. Cementation plays a role in the reduction of intergranular pore spaces. Alteration of feldspar to kaolinite is a very common phenomenon in these sandstones. Dissolution and decomposition of feldspar are thought to be the major source of kaolinite precipitation. Siderite indicates an involvement of the reducing agents like iron and organic matters. Chlorite is the alteration product of mica. Calcite is formed within fracture planes or corroded boundaries of detrital grains as a result of post-depositional infiltration and deposition. Different triangular diagrams, diamond diagram and detrital components have been used for provenance interpretation which suggest that these sandstones were derived from cratonic interiors and transitional continental blocks of plutonic origin. Igneous, with

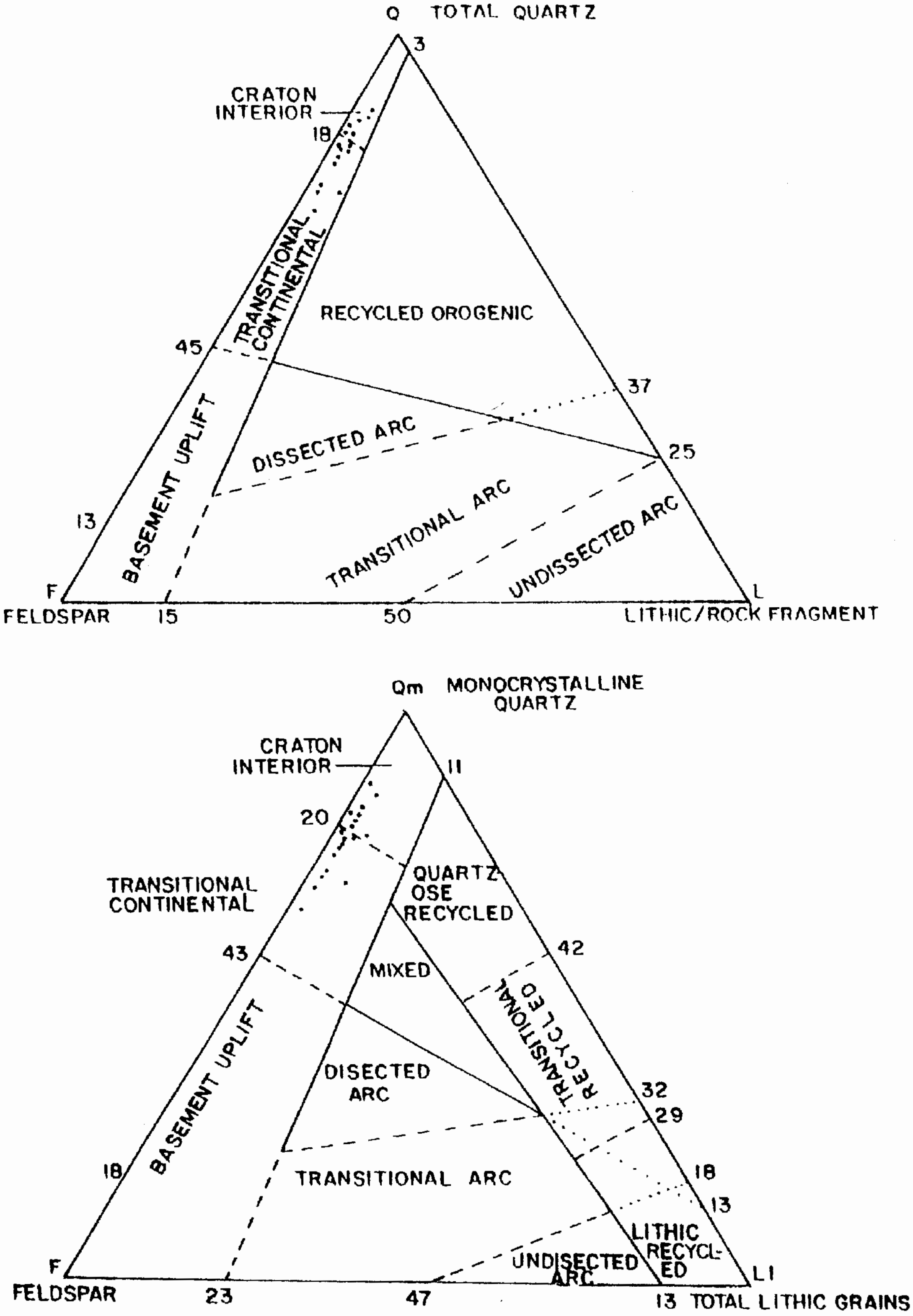

Figure 3. Standard triangular plots for interpretation of provenance of the Gondwana sandstones (after Dickinson et al. 1983).

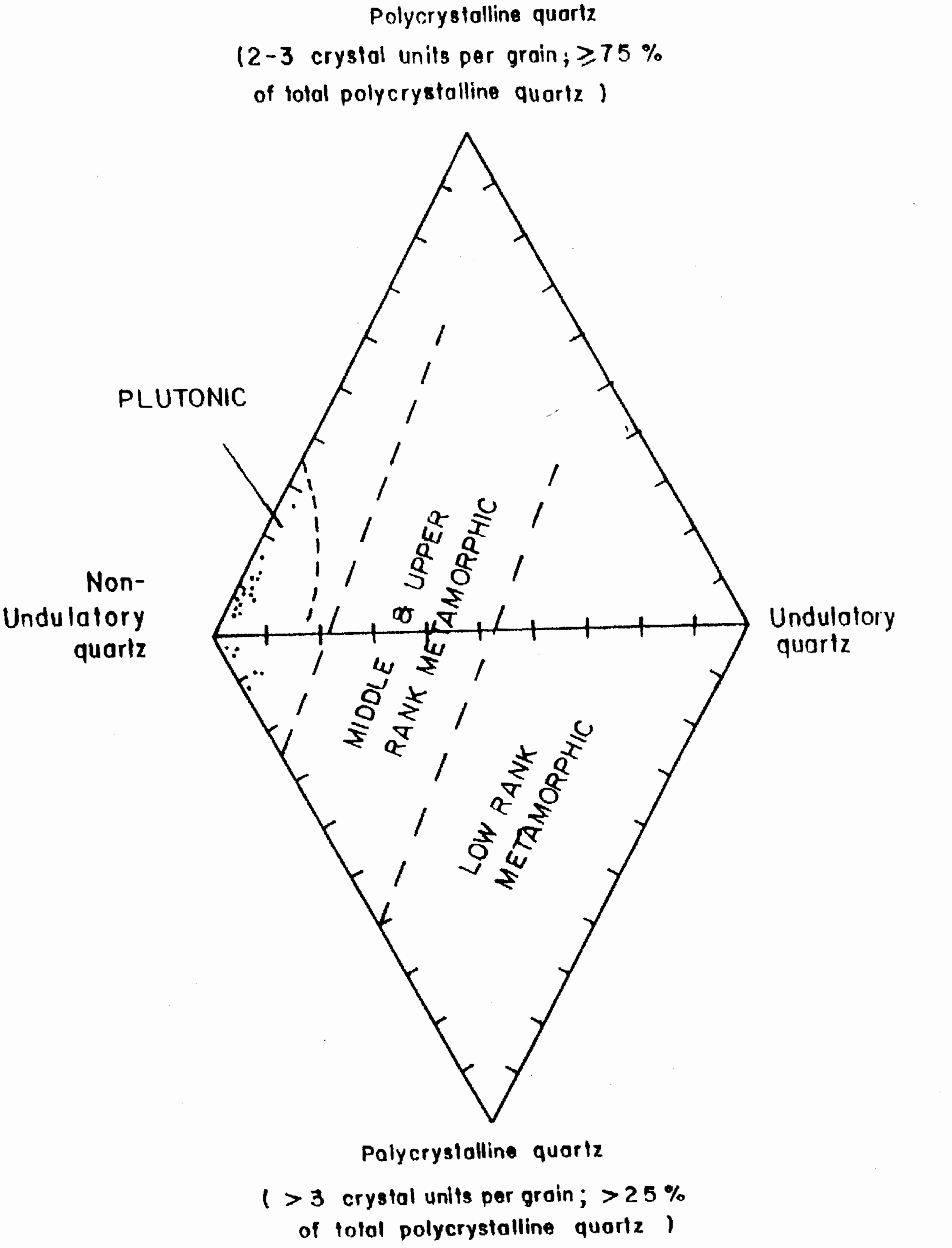

Figure 4. Diamond diagram for interpretation of provenance of Gondwana sandstones (after Basu et al. 1975).

less extent metamorphic source, provided the lion share to constitute these sandstones.

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ANNUAL REPORT

(Jan. to Dec. 2001)

NATIONAL CENTRE OF EXCELLENCE IN MINERALOGY, QUETTA

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Dr. Akhtar Mohammad Kassi, Professor of Geology, University of Balochistan continued working as Acting Director, C.E.M. The appointment of a permanent Director is still awaited. Dr. Kassi is Ph.D. from U.K. and has been teaching geology at the Department of Geology for the last 25 years.

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3. Jawed Ahmad	Clay Mineralogy, M.Phil. (Univ. of Balochistan)	01-Apr-1980
4. Khalid Mahmood	Ophiolites, Ph.D. (France)	05-Nov-1989
5. Muhammad Ahmed Farooqui	Sedimentary Geology and Tectonics, Ph.D. (U.S.A.)	05-Nov-1989
Assisstant Professors		
6. Mehrab Khan	Ophiolites, Ph.D. (Univ. of Balochistan)	05-Nov-1989
Visiting Professors		
7. Din Mohammad Kakar	Sedimentology, M.Phil. (Univ. of Balochistan), Assistant Professor, Geology Department, University of Balochistan, Quetta.	

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5.	Lal Mohammad	Superintendent	12-May-1973
6.	Hussainuddin	Photographer	16-Jun-1981
7.	Syed Rasool Mahjoor	Stenographer	06-Jun-1990

	Name	Designation	Date of joining C.E.M.
8.	Ghalib Shaheen	Stenotypist	17-Jul-1985
9.	Ahmad Khan Mangi	Draughtsman	01-Jul-1981
10.	Musa Khan	Laboratory Supervisor	20-Aug-1977
11.	Sher Hassan	Store Keeper	22-Aug-1977
12.	Mohammad Anwar	Assistant	18-Sep-1973
13.	Juma Khan	Assistant	12-Jun-1985
14.	Ikram Ali	Laboratory Assistant	13-Sep-2000
15.	Hameedullah	Laboratory Assistant	09-Dec-2000
16.	Abdul Malik	Senior Clerk	28-Apr-1987
17.	Manzoor Ahmad	Junior Clerk	26-Apr-1995
18.	Mohammad Tariq	Junior Clerk	09-Dec-2000
19.	Ali Mohammad	Driver	17-Jul-1984
20.	Saleh Mohammad	Driver	18-Aug-1990
21.	Ghulam Rasool	Junior Mechanic	20-Aug-1977
22.	Mohammad Rafiq	Peon *(Naib Qasid)*	12-Oct-1978
23.	Sikandar Khan	Peon *(Naib Qasid)*	30-Apr-1976
24.	Atta Mohammad	Peon *(Naib Qasid)*	25-Mar-1986
25.	Shabbir Ahmed	Peon *(Naib Qasid)*	01-Aug-1998
26.	Abdul Salam	Peon *(Naib Qasid)*	12-Dec-2000
27.	Mohammad Din	Peon *(Naib Qasid)*	12-Dec-2000
28.	Murad Baksh	Peon *(Naib Qasid)*	15-Nov-2000
29.	Abdul Wadood	Chowkidar	26-Jan-1992
30.	Amir Bakhsh	Chowkidar	11-Sep-2000
31.	Nazir Masih	Janitor	01-Apr-1977

ACADEMIC/RESEARCH ACTIVITIES

By the end of December 2001, the C.E.M had the following Ph.D. and M.Phil. students working on various aspects of the geology of Balochistan:

	Student	Supervisor	Co-Supervisor	Project Title
			Ph.D. PROJECTS	
1.	Din Muhammad Kakar	Akhtar M. Kassi	Muhammad Ahmed Farooqui	Geology of the Tertiary Khojak Formation of Pishin, Muslimbagh and Chaghi Districts, Balochistan
2.	Ghulam Nabi	Abdul Salam	Jawed Ahmad	Petrography and depositional environment of Ghazij Formation (Eocene) Balochistan.
			M. PHIL. PROJECTS	
1.	Khalil-Ur-Rehman	Muhammad Ahmed Farooqui	Akhtar Mohammad Kassi	Petrology and provenance of Paleocene (?) Ispikan Conglomerate, SW Makran and its implications on the tectonic evolution of Makran Region.
2.	Mohammad Zahir Kakar	Muhammad Ahmed Farooqui	Din Mohammad Kakar	Depositional environment and Diagen-esis of Lower Cretaceous Sembar Forma-tion, Balochistan.
3.	Syed Ashrafuddin	Muhammad Ahmed Farooqui	Mehrab Khan Baloch	Study of K-T Boundary in the western Sulaiman Foldbelt, Pakistan.

	Student	Supervisor	Co-Supervisor	Project Title
4.	Mohammad Rahim Jan	Muhammad Ahmed Farooqui	--	Geology and mineral resources of part of Makran Coast, Balochistan.
5.	Khawar Sohail	Abdul Salam	Muhammad Ahmed Farooqui	Petrology, sedimentology and diagenesis of Miocene-Pliocene Hinglaj Formation, District Khuzdar and Bela Balochistan.
6.	Arif Ali	Mobasher Aftab	Jawed Ahmad	Assessment of groundwater budget of Mangocher Valley, Balochistan.
7.	Mohammad Sarwar	Akhtar M. Kassi	Abdul Salam	Geology of the area west of Spera Ragha, District Ziarat, Balochistan.
8.	Muhammad Umar	Abdul Salam	Akhtar M. Kassi	Sedimentological studies of Upper Cretaceous Pab Sandstone, Kirther Fold Belt Balochistan.
9.	Abdul Razique	Shamim Ahmed Siddiqi	--	Copper mineralization in Chaghi metal-logenic province, Balochistan.
10.	Muhammad Ishaq	Mehrab Khan Baloch	Khalid Mehmood	Metamorphic rocks associated with Muslim Bagh Ophiolites, Balochistan.
11.	Mushtaq Ahmad Pathan	Khalid Mehmood	Mehrab Khan Baloch	Origin and mode of occurrence of chromites in the mantle section of Muslim Bagh Ophiolites..
12.	Razzak Abdul Manan	Shamim Ahmed Siddiqi	--	Iron ore deposits of Dilband area, Kalat.

Beside student's research projects, the faculty members remained involved in the following research projects:

	Title of the Research Project	Principal Investigator	Co-Investigators	Funded by
1	Structural and Textural studies of mantle rocks from Muslim Bagh ophiolites.	Khalid Mahmood	Mehrab Khan	UGC
2	Facies distribution, depositional environments and Petroleum prospects of the Foreland Basin sediments, Kirthar fold-belt, Balochistan, Pakistan.	Abdul Salam Khan	Akhtar M. Kassi	PSF
3	Study of Sedimentological and Structural Aspects of Selected Sites in the Makran Accretionary Belt, Pakistan.	Akhtar Mohammad Kassi	A. Salam Khan, M. A. Farooqui and Din Mohammad Kakar	UGC
6	Geology, geochemistry, and origin of iron ore deposits, Kalat District, Balochistan	Shamim A. Siddiqi	--	UGC
7	Metamorphic rocks associated with ophiolites	Mehrab Khan	Khalid Mahmood	UGC
8	Hypogene and supergene copper-gold systems around Koh-e-Dalil, Western Chaghi, Balochistan.	Shamim A. Siddiqi.	--	UGC
9	Geology of the Cretaceous-Paleocene succession, Sulaiman Thrust Belt, Pakistan	Akhtar M. Kassi	A. Salam Khan, M.A. Farooqui	UGC

10	Petrology and sedimentology of coal bearing Ghazij Formation, Balochistan	Abdul Salam Khan	Jawed Ahmed	UGC

(UGC; University Grants Commission. PSF; Pakistan Science Foundation).

After staying one year at Keele University, Abdul Salam returned in November 2001. He availed the postdoctoral Fellowship by the Commonwealth Organization (Association of Commonwealth Universities) for the year 2000-2001 and studied the sedimentology and depositional environment of Upper Cretaceous Pab Sandstone, Kirther Foldbelt Pakistan.

Khalid Mahmood proceeded to University of Cradiff, U.K. in October 2001 under the financial support of Commonwealth Organization (Association of Commonwealth Universities) to study the geochemistry and structural features of Muslimbagh ophiolites.

M.A. Farooqui also proceeded to Utah State University, Logan, (USA) in October 2001 after winning the Fulbright Grant for postdoctoral research. His research project is about the sedimentological and geochemical aspects of Miocene Diz Formation, Makran.

Mr. M. Azam Malik, Ex-Executive Director, Oil and Gas Development Corporation, Islamabad, was invited to deliver a series of lectures on "Petroleum Exploration in Balochistan" from June 28 to July 3, 2001. The lectures were attended by the students and faculty members of the C.E.M. and the Geology Department.

Compiled by M.A. Farooqui

INSTRUCTIONS FOR AUTHORS

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