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Cover Doleritic sills intruded in the Lower Jurassic sediments (Allozai Group). These sills are interpreted to have been the precursors of the hot spot volcanism that produced the volcanic rocks of Bibai Volcanic Group of Chinjan-Ziarat Valleys (northeastern Balochistan),and the Deccan Traps of India. These sills are exposed along the Quetta-Loralai Road near Qila Saifullah (68°20'N and 30°39').. For more details see article in this volume *(Photograph by Ghulam Nabi)*.

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SHEETED DYKE COMPLEX IN THE CRUSTAL SECTION OF THE UPPER TECTONIC UNIT OF BELA OPHIOLITE, BALOCHISTAN, PAKISTAN

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ABSTRACT

The Bela ophiolite consists of two tectonic units. The upper tectonic unit contains a complete ophiolite sequence, whereas the lower tectonic unit mainly comprised of mid-ocean ridge basalts (MORB) and also contain Fe-tholeiites and alkaline basalts related to reunion hotspot. The well developed ~ 1 km thick sheeted dykes are exposed in the upper tectonic unit. These are trending N 130° and dipping east and west. They are hydrothermally metamorphosed to green schist and amphibolites facies. The presence of a well- developed sheeted dyke complex is regarded as an evidence of a large, continuous and stable magma chamber beneath the mid ocean ridge during the generation of crustal section of upper tectonic unit. It also indicates that this unit originated in fast spreading ridge environment.

INTRODUCTION

The sheeted dyke complex is an essential component of complete ophiolite suite, lying stratigraphically above gabbroic rocks and below pillow lava flows. The presence of a well-developed sheeted dike complex is generally regarded as an evidence of ophiolite formation at oceanic spreading axis (Coleman 1977, Dewey and Kidd 1977). The sheeted dyke complex in Bela area has been reported by (Ahsan et al. 1988,Gnos et al. 1998, Khan 1999). Detailed and extensive fieldwork was carried out in the Bela and Khuzdar areas; to recognize the real sheeted dyke complex that represents the paleo-ridge. Sheeted dyke complex in Bela ophiolite are restricted in the upper tectonic unit (Fig. 1). The Bela ophiolite has been divided into upper and lower tectonic units. The upper tectonic unit formed during 68-70 Ma whereas lower tectonic unit was originated during Aptian-Albian (tholeiite E-MORB lavas) and Late Cretaceous (Maestrichtian) hotspot - related rocks (Gnos et al. 1998, Khan 1999). The tectonically dismembered sheeted dyke complex are exposed at different localities in Wad region and between Ornach-cross and Darkolo. In Wad region (27° 17' N; 66° 20' E), they are usually associated with granite

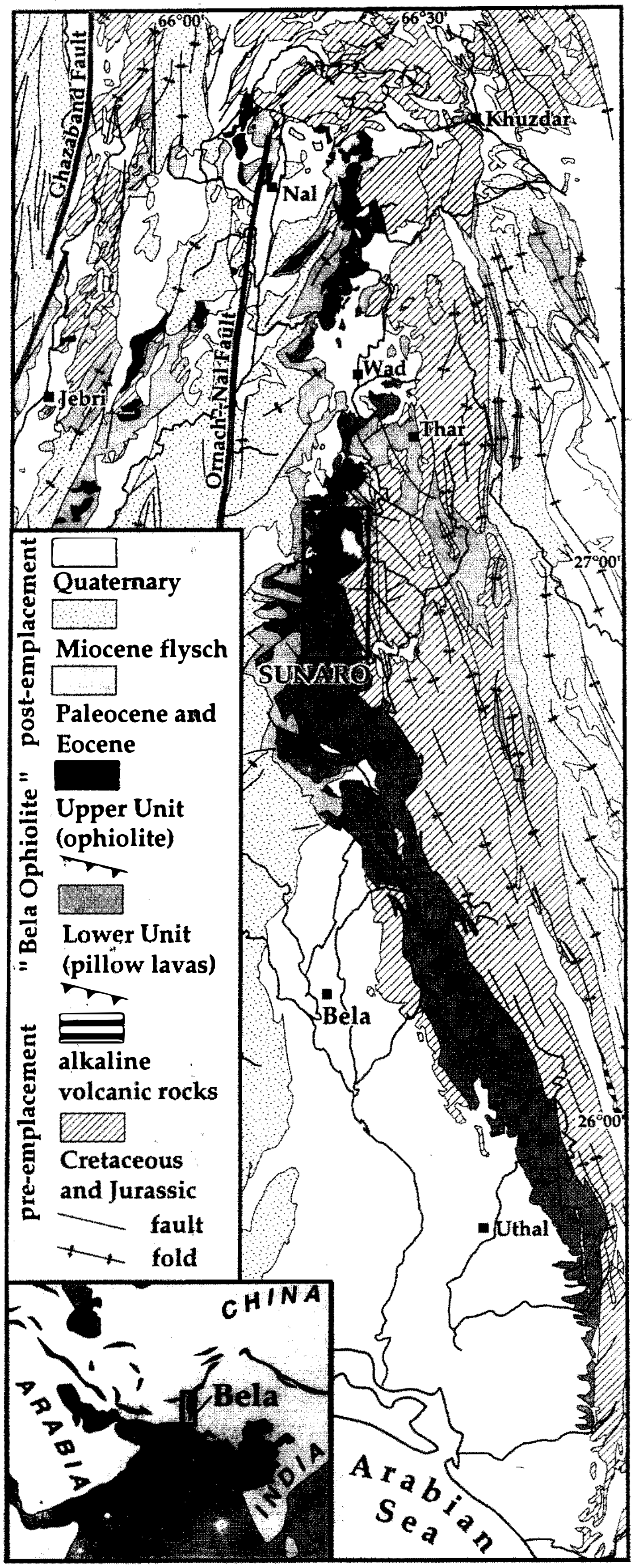

Figure 1. Overview map of Bela oceanic lithosphere assemblage based on HSC (1960), Ahsan et al.(1988) and Gnos et al. (1998).

intrusions. The best exposed sheeted dyke complex are present about 5 km northwest of Sunaro village (Fig. 2). These are underlain by 1.5-2.0 km thick gabbroic rocks (Gnos et al. 1998, Khan 1999).

SHEETED DYKE COMPLEX IN THE UPPER TECTONIC UNIT

The sheeted dykes of upper tectonic unit have been originated by successive multiple intrusions in such a way that the first dyke intruded has chilled margins against the wall rocks, the next dyke intruded the first dyke in the middle having chilled margins against the first dyke. This phenomenon has been repeated several times (27° 2' 4" N; 66° 23' 2"), in (Fig. 3 and 4).The sheeted dykes are oriented N 130° (Fig. 7) and dip east and west. The dipping angle varies from 40° to 70°. These sheeted dykes are originally basaltic in composition, which have been hydrothermally metamorphosed to green schist or amphibolites facies particularly near the base of the sheeted dike complex (Fig. 2). The sheetd dykes penetrate locally upwards into pillow lavas. The stratigraphic thickness of the sheeted dike complex is 0.5 to 1km in cross section through the gabbroic section in the northwest of Sunaro village (Fig. 2). The base of sheeted complex is shapely truncated by the gabbroic rocks, which are scare of sheeted dykes. Therefore, no sheeted dike is traceable into the underlying gabbroic section. Gabbroic rocks are present as screens in the lower part of the sheeted dike complex (roots of the sheeted complex). This could be attributed to the mingling of the magma (Fig. 5). The earlier dykes are often split by later ones, showing preferred orientation of well developed chilled margins and are easily distinguished as very fine grained selvages, typically <3 cm thick. Most of the dykes are medium to fine grained. It seems that the time gap between dikes injections is sufficient to allow the dikes to cool. Therefore, each dike is chilled against those it intrudes. The dykes becoming markedly finer or crypto crystalline towards their margins (Moors et al. 1971, Kidd and Cann 1974). More than two hundred chilled margins of the dikes were measured in the field. Most of these dykes are trending N 130° -140° dipping east and west which also mark the orientation of the paleo-ridge (Fig. 3). However, vertical dykes showing a typical exposure of sheeted dykes are also noticed. The parallel sheeted dykes are generally between a cm to a meter thick in the study area.

MINERAL COMPOSITION

The sheeted dykes are either green or gray on fresh surfaces. In thin section, the gray dykes comprise a green schist assemblage of albitized plagioclase variably actinolized clinopyroxene (±chlorite ± quartz, epidote and actinolite). Change in the color of these dykes due to the formation of the secondary phases can be attributed to the varying degree of sub-sea floor metamorphism (Pallister 1981, Nicolas and Boudier 1991). The more severely altered dikes, where original clinopyroxene has been replaced entirely by epidote (Fig. 6) and original calcic plagioclase by quartz, are regarded as having been subjected to more hydrothermal sea- water interaction than the less altered plagioclase- bearing dykes. Some of the dykes are internally brecciated and highly epidotized, which represent the extensive alteration due to the penetration of hydrothermal fluids. A few veins of dark green amphiboles (a millimeter thick) of quartz-epidote (a centimeter thick) have also been observed in the study area.

DISCUSSION

The crustal section of upper tectonic unit of Bela ophiolite is well developed and is ~ 3 km thick. The crustal section consists of layered peridotite/gabbro, layered/foliated and isotropic gabbros, sheeted dyke complex and >100 m extrusive basaltic rocks. The presence or absence of sheeted dyke complex in ophiolites now gives a clue to determine the spreading rate of ridges. Lemoine et al, (1995) defined two types of oceans which produce ophiolites with different characteristics: a) Pacific type, where a rapidly spreading ridge (10 cm yr^{-1}) produces the "normal" layered oceanic lithosphere with a sheeted dyke complex, and b) Atlantic type, which has slow spreading ridge (1-3 cm yr^{-1}) and lack of sheeted dyke complex. Later Winterflood (2001) concurred with these definitions. Furthermore, it has also been recognized that in the fast spreading ridge there is stable and continuous magma chamber below the ridge, whereas in slow spreading ridge there is episodic and discontinuous magma chamber below the ridge (Nicolas 1989, Lemoine et al. 1995, Winterflood 2001). The crustal section with well developed sheeted dyke complex of upper tectonic unit of Bela ophiolite indicate that the stable and continuous magma chamber may have originated it. The presence of sheeted dyke complex further

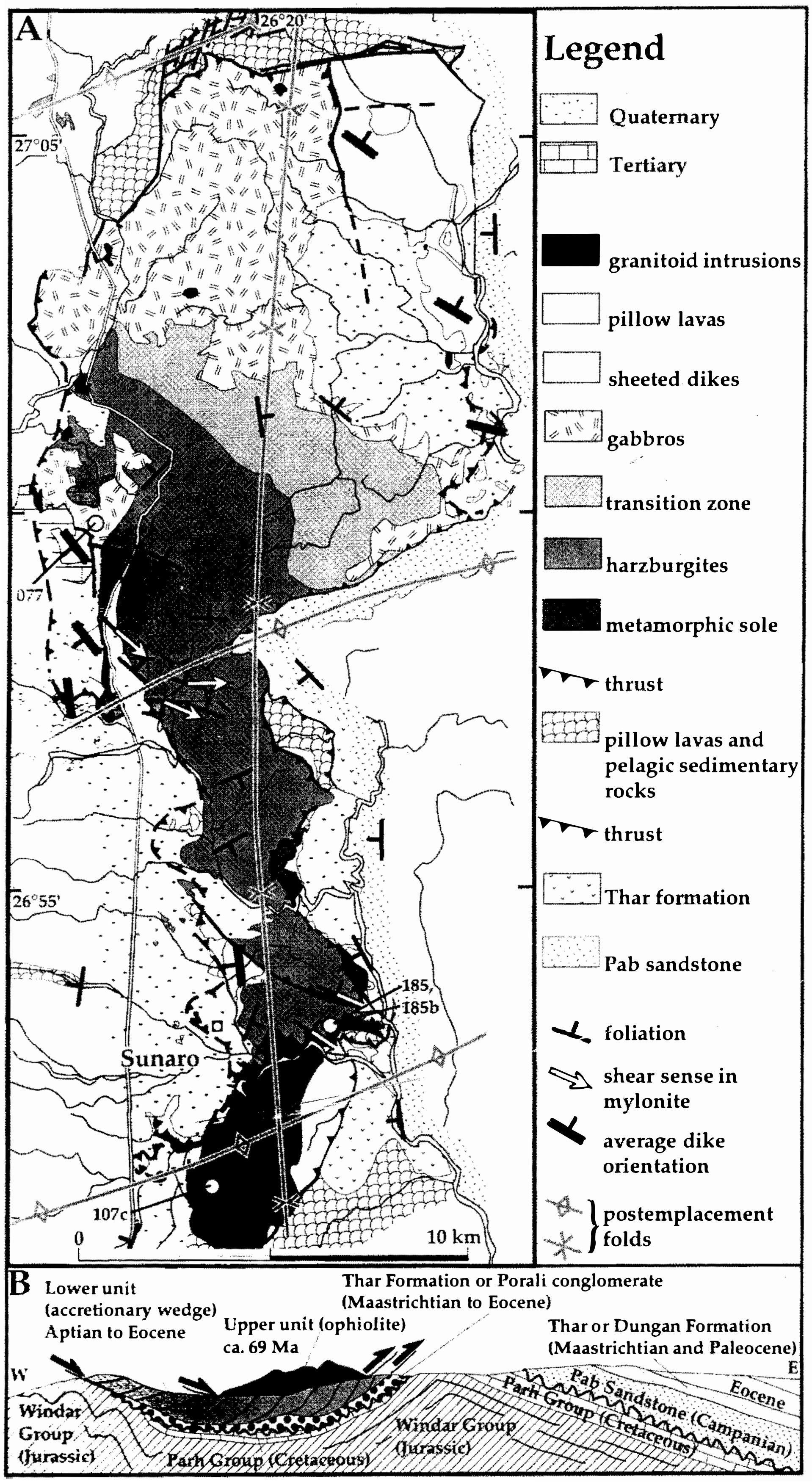

Figure 2. Geological map of Sunaro massif of the upper tectonic unit of Bela ophiolites, Pakistan (Gnos et al. 1998).

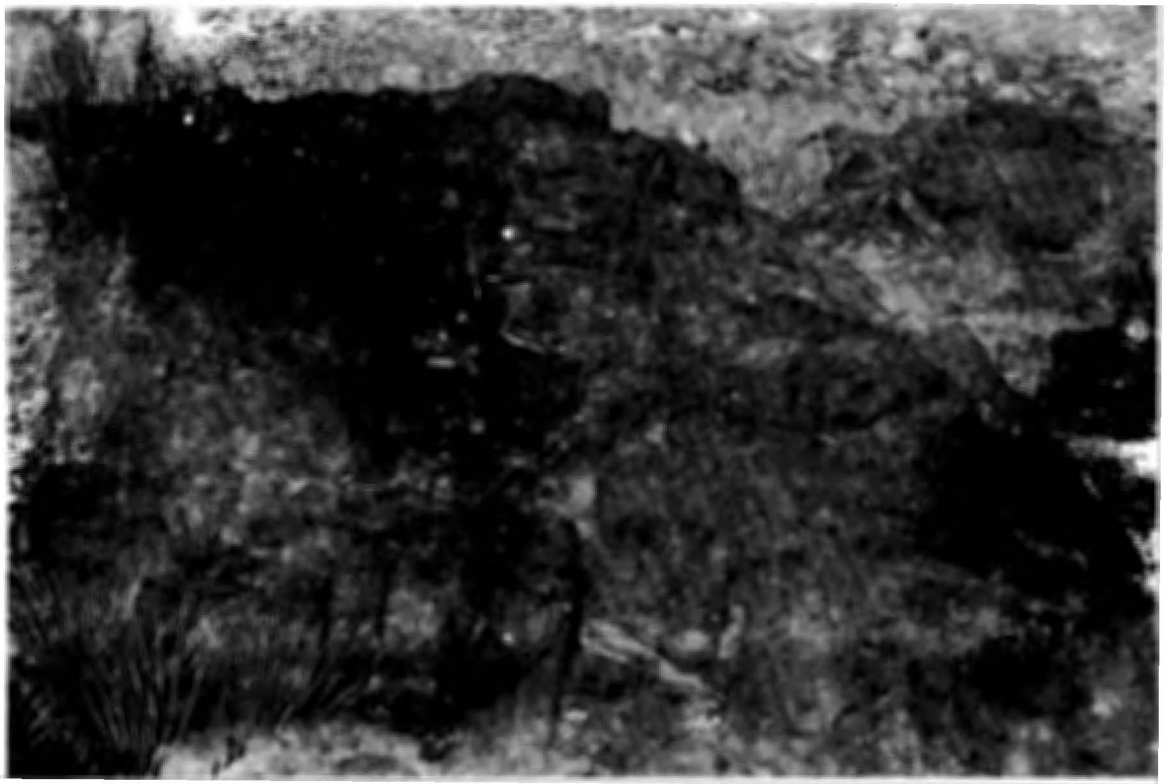

Figure 3. Photograph showing sheeted dikes boundaries of the individual dykes which are clearly visible (Khazeni area).

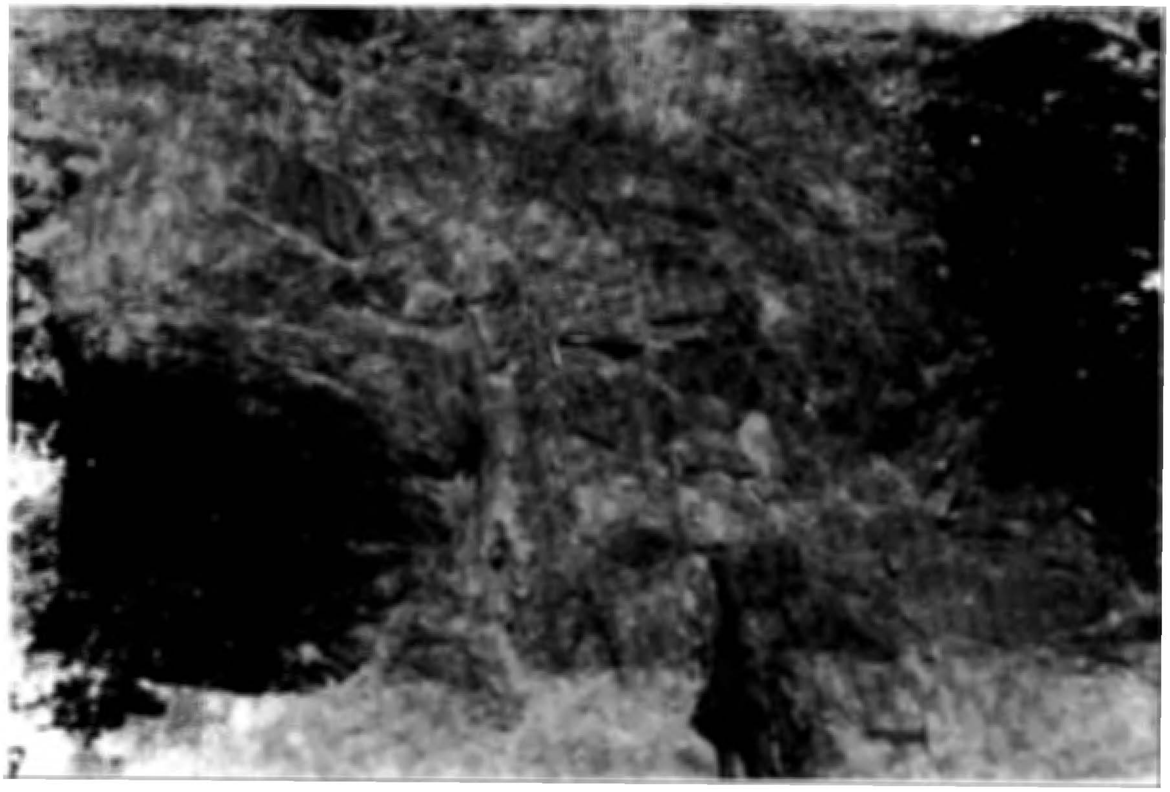

Figure 4. Photograph showing close-up view of the sheeted dikes. Note the thicknesses of the individual dykes are variable (hammer for scale).

Figure 5. Photograph showing contact between dykes and isotropic gabbro. Note the screens of sheeted dikes in the gabbro.

Figure 6. Photograph showing epidote vein in Sheeted dike complex in Khazni area.

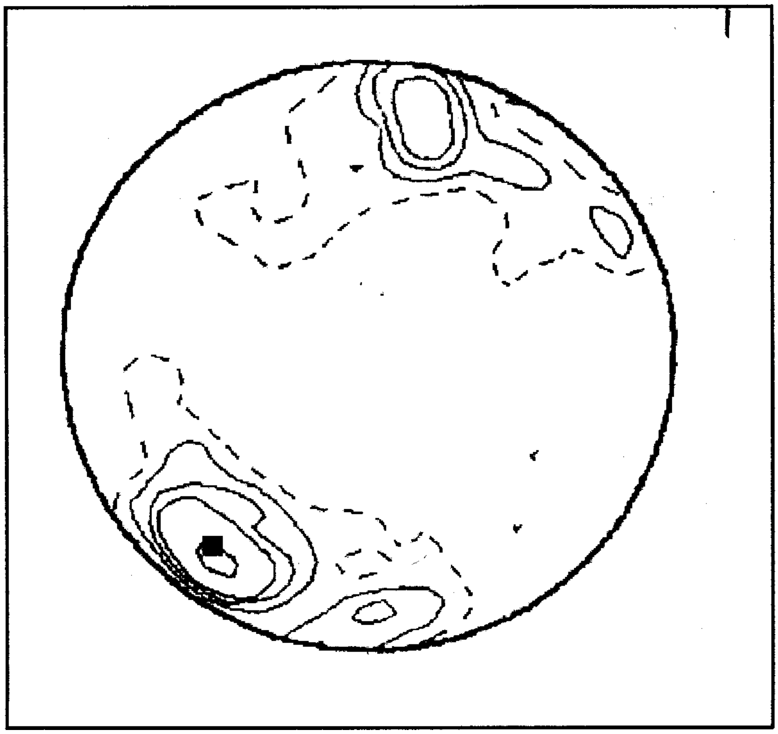

Figure 7. The stereo grams of lower hemisphere projections of poles of the dykes from sheeted dyke complex (244 measurements).

strengthens this idea that it has been generated in fast spreading ridge environment.

CONCLUSIONS

The trend of most of the dykes in Bela ophiolites is N 130°-140° with the dominant dip direction towards east and west (Fig. 3), which marks the orientation of the paleo-ridge. Vertical trend of the dikes possibly suggest a role for fluid pressure and forceful injection of dyke material, causing the rocks to fracture perpendicular to minimum compressive stress. The sheeted dyke complex is composite with respect to both its intrusive and sea floor hydrothermal alteration history. These dykes have been developed due to the hydrothermal circulation, as indicated by change of pyroxene to amphibole which take place at 600-700°C (Nicolas 1989). The well-developed sheeted dyke complex indicates the crustal section of the upper tectonic unit formed in fast spreading ridge environment.

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PLATINUM-GROUP MINERALS ASSEMBLAGES IN CHROMITES FROM THE MUSLIM BAGH OPHIOLITE, BALOCHISTAN, PAKISTAN

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ABSTRACT

Ru-Os-Ir-bearing minerals have been located in chromites in the Muslim Bagh ophiolite complex. The most common mineral is laurite $(Ru,Os,Ir)S_2$. An irasite was located as part of a composite with laurite. One mottled Ru-oxide was identified in silicate interstitial to the chromite grains. This paper documents, for the first time, the presence of discrete platinum-group minerals (PGM) in the Muslim Bagh ophiolite, following the report of occurrence of Ir and Os in 1996 by Nakagawa et al . Fifteen chromite-rich samples were studied using an SEM to locate and analyse the PGM. The samples came from both the Jang Tor Ghar and Saplai Tor Ghar blocks of the ophiolite. PGM have been found in both sample sets. PGM enclosed in chromite grains are often euhedral and sometimes associated with silicate inclusions in chromites. PGM in contact with interstitial silicates are often subhedral or rounded and may be mottled and composite indicating that they have been affected by alteration.

INTRODUCTION

Ophiolites are important relics of oceanic crust (Coleman 1977) and a study of them (Nicolas 1989) shows the 3 dimensional structure of the crust but they have also undergone deformation and alteration during emplacement onto continental crust. Ophiolites may contain economic deposits of chromite which may be enriched in all six of the platinum-group elements (PGE) (Crocket 1979, Leblanc 1991, Prichard et al. 1996, Pedersen et al. 1993, Auge 1985, Corrivaux and LaFlamme 1990, Edwards 1990, Ohnenstetter et al. 1991). It is well known that Os, Ir, and Ru-bearing PGM are hosted by podiform chromitites (Ahmed and Bevan 1981, Ahmed and Hall 1982, Stockman and Hlava 1984 ,Talkington et al. 1983, Auge 1986, Legendre and Auge 1986, Prichard et al. 1981, Prichard et al. 1994, Constantinides et al. 1980, Arai et al. 1999, Ahmad and Arai 2002). It is the aim of this study to record the presence of Os-Ir- and Ru-bearing PGM in the Muslim Bagh ophiolite complex.

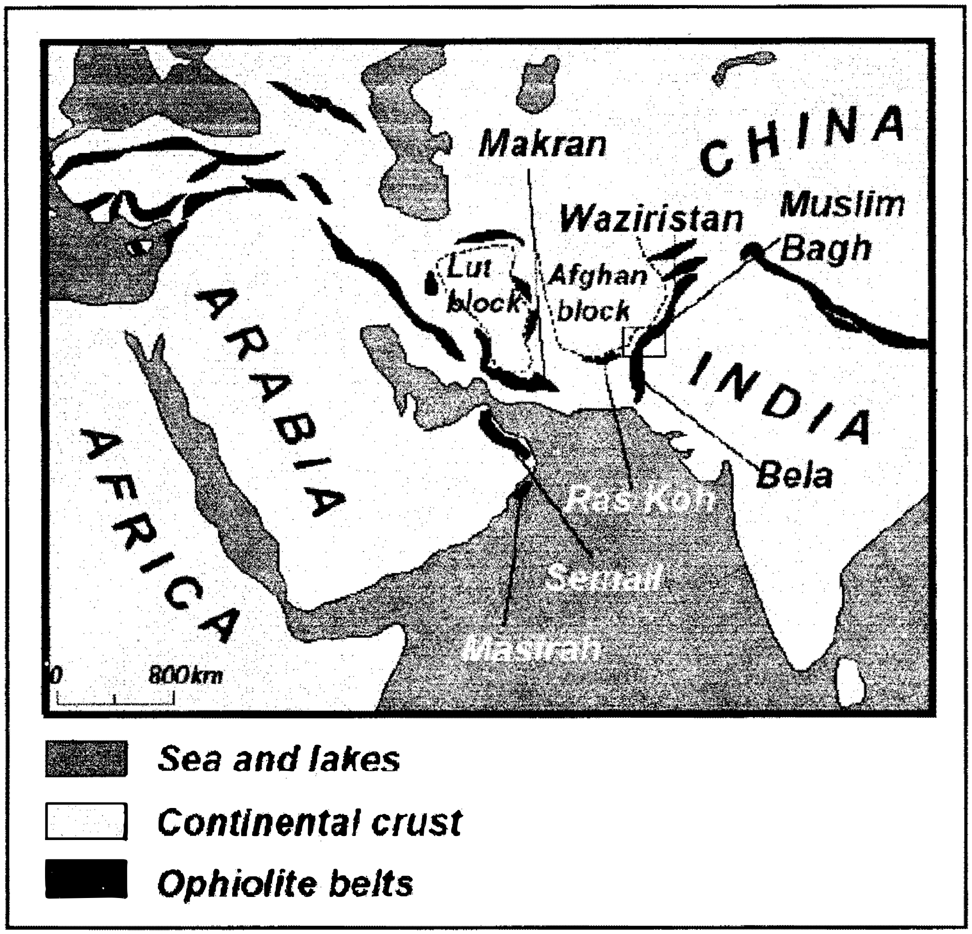


Figure 1. Overview map of the alpine suture zones between the Afro- Arabian, Indo- Pakistani and Eurasian plates (map based on Gansser 1964). The boundaries between continental blocks are underlined by ophiolite belts.

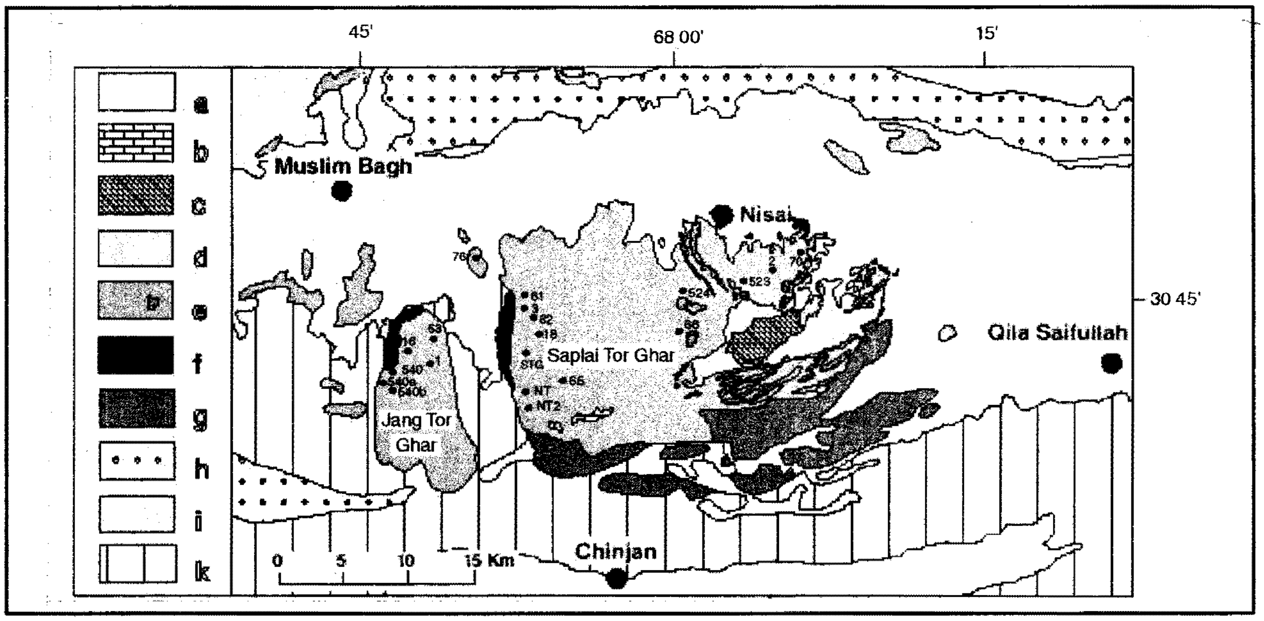


Figure 2. Geological overview map of the Muslim Bagh ophiolite showing the locations of the samples and the lithologic sequence of the two blocks. a = Quartemary; b = Tertiary; c = sheeted dyke complex; d = gabbros; e = mantle sequence with pyroxenite-gabbro intrusions; f = subophiolitic metamorphic rocks; g = melange with serpentinite matrix; h = molasse; i = flysch; k= Mesozoic carbonates (after Mahmood et al. 1995)

GEOLOGICAL SETTING

The Muslim Bagh ophiolite complex is located in the upper Zhob valley NE of Quetta and is part of the Bela-Muslim Bagh Waziristan western ophiolite belt in Pakistan (Fig. 1). This belt marks the boundary between the Indo-Pakistan and Afghan plates and the Muslim Bagh ophiolite complex is one of the well-exposed ophiolite in this belt. It includes two main blocks named the Jang Tor Ghar and Saplai Tor Ghar (Fig. 2). The eastern Saplai Tor Ghar massif consists of a nearly complete ophiolite sequence with the extrusive and sedimentary units missing. The ophiolite complex has been studied by many workers (Vredenburge 1901, Hunting Survey Corporation 1960, Bilgrami 1964, Ahmed and Chaudhry 1969, Ahmed and Abbas 1979, Shah 1974, Munir and Ahmed 1985, Otsuki et al. 1989, Sawad et al. 1992, Siddiqui et al. 1994 and Mahmood et al. 1995). Interest in the detailed mapping and geological interpretation of the area arose from its economic potential for high grade chromite ore with chromite mining having taken place in the area since 1901 (Vredenburg 1901). The reported compositions of the chromite are all of high Cr (Bilgrami 1963, 1968 and 1969, Ahmad 1975, and Ahmed 1986) but this previous work was based on analyses of separated chromite only. The first PGE records were made by Page et al. (1979) who presented data on 30 whole-rock samples of ultramafic lithologies with values ranging from 3 to 375 ppb of total PGE and they declared these ophiolites uneconomic for the PGE extraction. Hoshino and Siddiqui (1993) described a minor occurrence of Ir and Os in chromitite and Nakagawa et al. (1996) also reported Ir and Os hosted in chromitite from the Saplai Tor Ghar massif, but no PGM have been reported yet. In this study we have sampled 15 operating chromite mines (Fig. 2). There are numerous chromitite pods in dunites, which are strongly serpentinised. Fresh dunite and harzburgite are exposed uniquely in the basal parts of both massifs.

METHODS

Chromitites were analysed on a Cameca SX-50 microprobe at the University of Bern, Switzerland, using natural and synthetic silicate and oxide mineral standards, wavelength dispersive spectrometers and beam currents of 15 KV and 20 nA. Counting times were 20-30 seconds on element peaks and backgrounds. Data were reduced using the PAP procedure. PGM were located by one author (KM) during analysis of chromites on the LEO 360 SEM at Cardiff University. This led to a systematic survey for more PGM. Due to the small size of the PGM the use of the four quadrant back scattered detector on the SEM to locate the PGM was much more efficient than using a conventional optical microscope. PGM were located using a magnification of x 50. Analyses were obtained using an Oxford Instruments INCA EDX system. Operating conditions consisted of an EHT of 20 KV, a probe current of 1nA and a working distance of 25 mm. Cobalt standards were frequently analysed during the analysis to check for instrument drift. Pure standards for PGE, Co, Ni, Cu and Cr were used, supplied by Microanalysis Consultants (UK).

RESULTS

The chromitites have the following ranges of composition, Cr_2O_3, 53-62 wt % ; Al_2O_3, 9-16 wt % and MgO, 12-16 wt% (Table 2). They have a restricted range of $Mg/(Mg+Fe^{2+}+Mn)$ of 0.6-0.8. All 15 samples have yielded PGM with up to 10 PGM grains Ahmed and Hall 1981, in one section which has an area of 1-2 cm^2. The chromitites studied have different textures varying from massive to disseminated with chromite grain sizes of up to 0.5 cm. Chromite grains are both rounded and deformed and pull-apart texture is common with serpentinised veins crossing the chromite.

The PGM are generally enclosed in chromite but may be associated with silicate inclusions or be located inside cracks in the chromite. Also they may be on the edge of the chromite grains or more rarely be surrounded by silicate interstitial to the chromite grains. Where enclosed in chromite they often have extremely good euhedral shapes and appear homogeneous whereas where totally or partially surrounded by silicates they are often less euhedral and more rounded in shape and may have a mottled appearance. They are of a fairly uniform size with most grains being 3-4 microns in diameter with a few grains being up to 6 microns in diameter. The textures of the PGM are shown in Plates 1 (A-H) and 2 (I-N) in which the PGM images have been arranged in order with euhedral PGM enclosed by chromite first followed by progressively more subhedral to rounded PGM associated with more and more silicate towards the end.

Table 1. Selected SEM analysis of PGM in chromites from Muslim Bagh ophiolites. The last mathematical number of every sample corresponds to a specific point of analyses in a particular grain.

Sample wt%	C540AL4	C16L3	C63L1	C61L1	C524L3	CSTGL1b	CSTGL1b	CSTGL1b	CSTGL1b	CSTGL1d	CSTGL1d
Cr	2.98	1.71	1.68	1.68	2.07	2.17	2.17	2.55	2.55	1.75	1.75
Fe	b.d.	0.98	0.69	0.69	0.62	0.67	0.67	0.83	0.83	0.59	0.59
Ni	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ru	38.25	34.81	38.50	38.92	35.36	12.06	12.21	5.89	5.96	41.12	41.58
Rh	b.d.	b.d.	b.d.	b.d.	1.55	3.44	3.44	3.29	3.29	0.48	0.48
Pd	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Os	13.47	17.36	12.51	12.52	14.90	3.37	3.37	b.d.	b.d.	10.11	10.11
Ir	11.58	12.72	11.31	11.31	11.68	36.55	36.54	45.50	45.50	11.06	11.06
Pt	b.d.	b.d.	b.d.	b.d.	b.d.	3.14	3.13	2.87	2.87	b.d.	b.d.
S	33.68	33.21	34.40	34.37	33.12	17.73	17.72	14.98	14.98	32.98	32.95
As	b.d.	b.d.	b.d.	b.d.	b.d.	19.40	19.41	23.02	23.03	1.26	1.26
Total	99.96	100.79	99.09	99.49	99.30	98.51	98.65	98.94	99.01	99.34	99.77
Normalized to 2 (S+As) per formula unit											
Cr	0.109	0.063	0.060	0.060	0.077	0.103	0.103	0.127	0.127	0.064	0.064
Fe	b.d.	0.034	0.023	0.023	0.021	0.030	0.030	0.038	0.038	0.020	0.020
Ni	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ru	0.720	0.665	0.710	0.718	0.677	0.294	0.298	0.150	0.152	0.778	0.788
Rh	b.d.	b.d.	b.d.	b.d.	0.029	0.082	0.082	0.083	0.083	0.009	0.009
Pd	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Os	0.135	0.176	0.123	0.123	0.152	0.044	0.044	b.d.	b.d.	0.102	0.102
Ir	0.115	0.128	0.110	0.110	0.118	0.468	0.468	0.611	0.611	0.110	0.110
Pt	b.d.	b.d.	b.d.	b.d.	b.d.	0.040	0.040	0.038	0.038	b.d.	b.d.
S	2.000	2.000	2.000	2.000	2.000	1.362	1.362	1.207	1.206	1.968	1.968
As	b.d.	b.d.	b.d.	b.d.	b.d.	0.638	0.638	0.793	0.794	0.032	0.032
Endmembers											
$Ru(S.As)_2$ (laurite)	0.743	0.686	0.754	0.755	0.716	0.365	0.368	0.198	0.199	0.786	0.788
$Ir(S.As)_2$	0.118	0.132	0.116	0.115	0.124	0.581	0.578	0.802	0.801	0.111	0.110
$Os(S.as)_2$ (erlichmanite)	0.139	0.182	0.130	0.129	0.160	0.054	0.054	b.d.	b.d.	0.103	0.102

b.d.= below detection

Table 2. Representative microprobe analyses of chromites from Muslim Bagh Ophiolites.

Sample	CSTG	CNT	C1	C63	C16	C540A	C524	C540	CNT2	C61	C70	C76	C523	C540B
SiO_2	0.05	0.02	0.02	b.d.	0.03	0.09	0.06	0.01	0.04	0.01	0.04	0.05	0.01	b.d.
TiO_2	0.22	0.21	0.21	0.18	0.27	0.19	0.22	0.17	0.16	0.17	0.27	0.06	0.29	0.23
Al_2O_3	13.82	9.37	11.49	11.54	18.94	11.39	11.63	11.16	10.67	9.86	10.45	14.70	9.59	10.64
Cr_2O_3	57.45	61.55	59.05	59.96	47.93	59.42	59.00	59.45	59.92	60.76	59.75	58.14	59.08	60.19
Fe_2O_3*	0.98	4.02	2.73	4.13	5.20	2.34	3.28	3.62	3.29	3.82	2.03	0.30	3.47	3.75
Fe[illegible]	16.06	10.14	12.51	10.27	14.80	13.86	12.80	10.87	12.56	12.61	14.54	13.88	20.11	11.03
MnO	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
NiO	0.19	0.20	0.21	0.26	0.15	0.06	0.12	0.15	0.07	0.13	0.14	0.06	0.01	0.19
ZnO	0.02	b.d.	0.12	0.05	0.06	0.02	0.05	0.01	0.02	0.09	0.01	b.d.	0.03	0.04
MgO	12.11	15.48	13.94	15.75	13.41	13.34	14.09	15.09	14.06	13.97	12.57	13.61	9.35	15.03
CaO	b.d.	b.d.	b.d.	0.03	b.d.	0.01	b.d.	b.d.	0.01	0.01	b.d.	0.02	b.d.	b.d.
Total	100.89	100.99	100.27	102.17	100.78	100.72	101.26	100.53	100.80	101.43	99.80	100.82	101.96	101.11
Si	0.002	0.001	0.001	b.d.	0.001	0.003	0.002	b.d.	0.001	b.d.	0.001	0.002	0.001	b.d.
Ti	0.005	0.005	0.005	0.004	0.006	0.005	0.005	0.004	0.004	0.004	0.007	0.001	0.007	0.005
Al	0.518	0.350	0.432	0.423	0.691	0.429	0.433	0.417	0.401	0.370	0.400	0.544	0.370	0.396
Cr	1.445	1.543	1.491	1.473	1.173	1.500	1.475	1.489	1.510	1.530	1.535	1.443	1.529	1.504
Fe^{3+}	0.024	0.096	0.066	0.097	0.121	0.056	0.078	0.086	0.079	0.092	0.050	0.007	0.085	0.089
Fe^{2+}	0.427	0.269	0.334	0.267	0.383	0.370	0.339	0.288	0.335	0.336	0.395	0.364	0.551	0.292
Mn	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ni	0.005	0.005	0.005	0.006	0.004	0.002	0.003	0.004	0.002	0.003	0.004	0.001	b.d.	0.005
Zn	b.d.	b.d.	0.003	0.001	0.001	b.d.	0.001	b.d.	b.d.	0.002	b.d.	b.d.	0.001	0.001
Mg	0.574	0.732	0.663	0.729	0.619	0.635	0.664	0.712	0.668	0.663	0.609	0.637	0.456	0.708
Ca	b.d.	b.d.	b.d.	0.001	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	0.001	b.d.	b.d.
$MgAl_2O_4$	0.150	0.129	0.146	0.156	0.216	0.137	0.145	0.150	0.135	0.124	0.123	0.174	0.085	0.142
$FeAl_2O_4$	0.109	0.046	0.071	0.055	0.130	0.078	0.072	0.059	0.066	0.061	0.077	0.099	0.100	0.056
$MnAl_2O_4$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$MgFe_2O_4$	0.007	0.035	0.022	0.036	0.038	0.018	0.026	0.031	0.027	0.031	0.015	0.002	0.020	0.032
$FeFe_2O_4$	0.005	0.013	0.011	0.013	0.023	0.010	0.013	0.012	0.013	0.015	0.010	0.001	0.023	0.013
$MnFe_2O_4$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$MgCr_2O_4$	0.419	0.570	0.502	0.544	0.367	0.480	0.495	0.534	0.508	0.513	0.472	0.461	0.352	0.539
$FeCr_2O_4$	0.305	0.202	0.245	0.193	0.220	0.273	0.244	0.210	0.248	0.253	0.296	0.262	0.413	0.214
$MnCr_2O_4$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe_2TiO_4	0.005	0.005	0.005	0.004	0.006	0.005	0.005	0.004	0.004	0.004	0.007	0.001	0.007	0.005
Zn-Spine	0.000	0.000	0.003	0.001	0.001	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.001	0.001

Normalized to 3 cations and 6 charges per formula unit
b.d. = below detection
* = calculated by stoichiometry

The PGM are predominantly laurite (Ru, Os, Ir)S2 and these laurites contain moderately high Os and Ir contents of over 10% of each. Typical analyses are given in Table 1. One composite grain (Plate 2, L) consists of irarsite (IrAsS) and laurite (analyses CSTGL1b and 1d Table 1). The composite grain is small (approximately 5 microns) and the analyses given include a contribution of elements form the adjacent PGM so the irarsite contains a Ru component and the laurite analysis contains an As component. A rounded mottled PGM surrounded by silicate interstitial to the chromite grains gave an analysis of a Ru-oxide with the brighter mottles displayed in the back scattered image being richer in Ru than in the darker mottles (Plate 2, M and N).

DISCUSSION

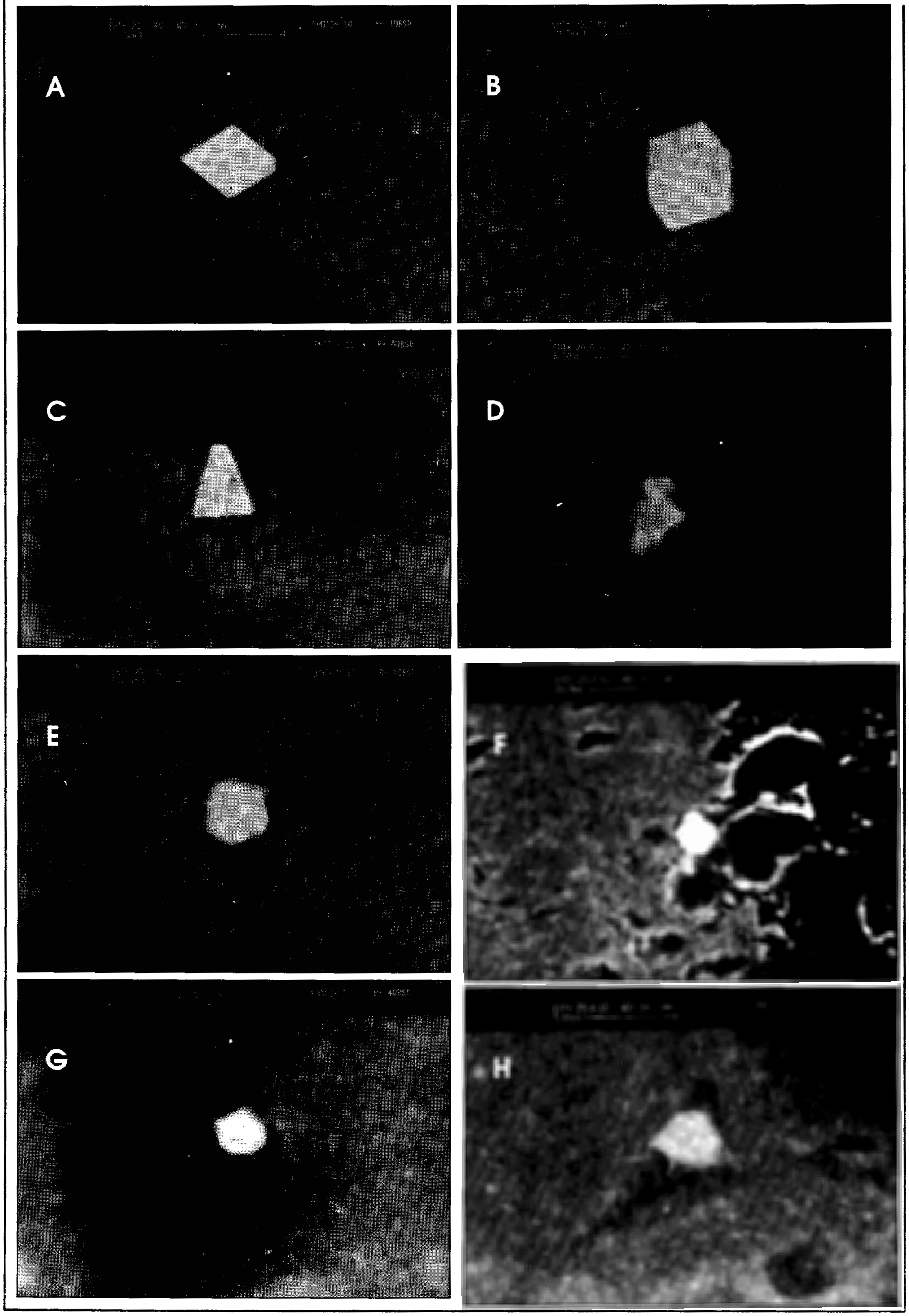
Euhedral laurites are commonly described from podiform chromitites (eg. Auge 1986, Constantinides et al. 1980, Legendre and Auge 1986, Prichard et al. 1986, Tarkian and Prichard 1987, and Talkington et al. 1983). They are thought to originate magmatically and because they are very refractory and crystallise from a magma early in a fractionation sequence. Laurites are often associated with chromite which is itself a refractory mineral. PGM are associated with high degrees of melting of the mantle (Keays 1995) and laurites occur in chromites not only in ophiolite complexes but also in layered complexes such as with the chromitites in the Bushveld complex (Von Gruenewaldt et al. 1986 and Lee 1996).

It has been debated whether the laurites crystallise directly form a magma or exsolve from the chromite structure. Gijbels et al. (1974), Agiorgitis and Wolf (1978), Crocket (1979) and Mitchell and Keays (1981) suggested that the PGE form solid solution in the spinel structure. Gijbels et al. (1974) thought that the PGM were produced by expulsion of the PGE from structural sites in spinel during subsolidus re-equilibration. Alternatively Johan and Lebel (1978), Constantinides et al. (1980), Prichard et al. (1981) considered that the laurites were entrapped in the chromite during crystallisation. The presence of Ru-bearing PGM in the silicates interstitial to the chromite grains in the Muslim Bagh ophiolites, described in this paper, suggests that these PGM at least were not expelled from the chromite structure.

During alteration and serpentinisation PGE may be altered and their crystal shape often becomes subhedral rather than euhedral. Prichard et al. (1986) described the change in shape of laurites as they were altered by serpentinisation. Euhedral laurites are enclosed in chromite where they are protected from the effects of serpentinisation and rounded irregular shaped laurites occur on the edges of chromite grains where they have been exposed to serpentinisation. This appears to be the case for the laurites in the Muslim Bagh ophiolite, described in this paper. They display a clear sequence with euhedral unaltered laurites enclosed in chromite and subhedral to rounded laurites where they are situated in cracks or on the edge of chromite grains.

Subhedral laurites situated in contact with altered minerals tend to have different compositions to those enclosed in chromite. McEluff and Stumpfl (1990) suggested that PGM enclosed in secondary minerals such as serpentine or by chromite altered to "ferritchromit" or magnetite are likely to have a secondary composition and PGM in cracks or late cross cutting veins in chromite are also likely to be altered (Nixon et al. 1990). Stockman and Hlava (1984) described a loss of sulphur from laurites during alteration. Euhedral unaltered laurites have homogenous compositions and are often Os-, Ir-bearing whereas altered laurites are generally Os- and Ir-poor. Partial alteration may occur leaving

Plate 1. *(facing page)* **A**; Euhedral laurite enclosed in chromite, sample no. 524 L3 (Analysis 4 Table 1), **B**; Euhedral laurite enclosed in chromite and adjacent to a silicate inclusion, sample no. C- 63B1 (Analysis 3 Table 1), **C**; Euhedral laurite enclosed in chromite and adjacent to a silicate inclusion, sample no 524L2, **D**; Angular laurite enclosed in chromite and adjacent to a silicate inclusion, sample no. C-16-63A1, **E**; Subhedral laurite enclosed in chromite and adjacent to a silicate inclusion, sample no. 540L4 (Analysis 1 Table 1), **F**; Subhedral laurite enclosed in chromite and adjacent to a silicate inclusion, sample no. C16L3 (Analysis 2 Table 1), **G**; Subhedral laurite enclosed in a silicate inclusion in chromite, sample no. C76L2, **H**; Subhedral and angular laurite enclosed in an angular silicate inclusion in chromite, sample no. NT 2.


A
B
C
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E
F
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H

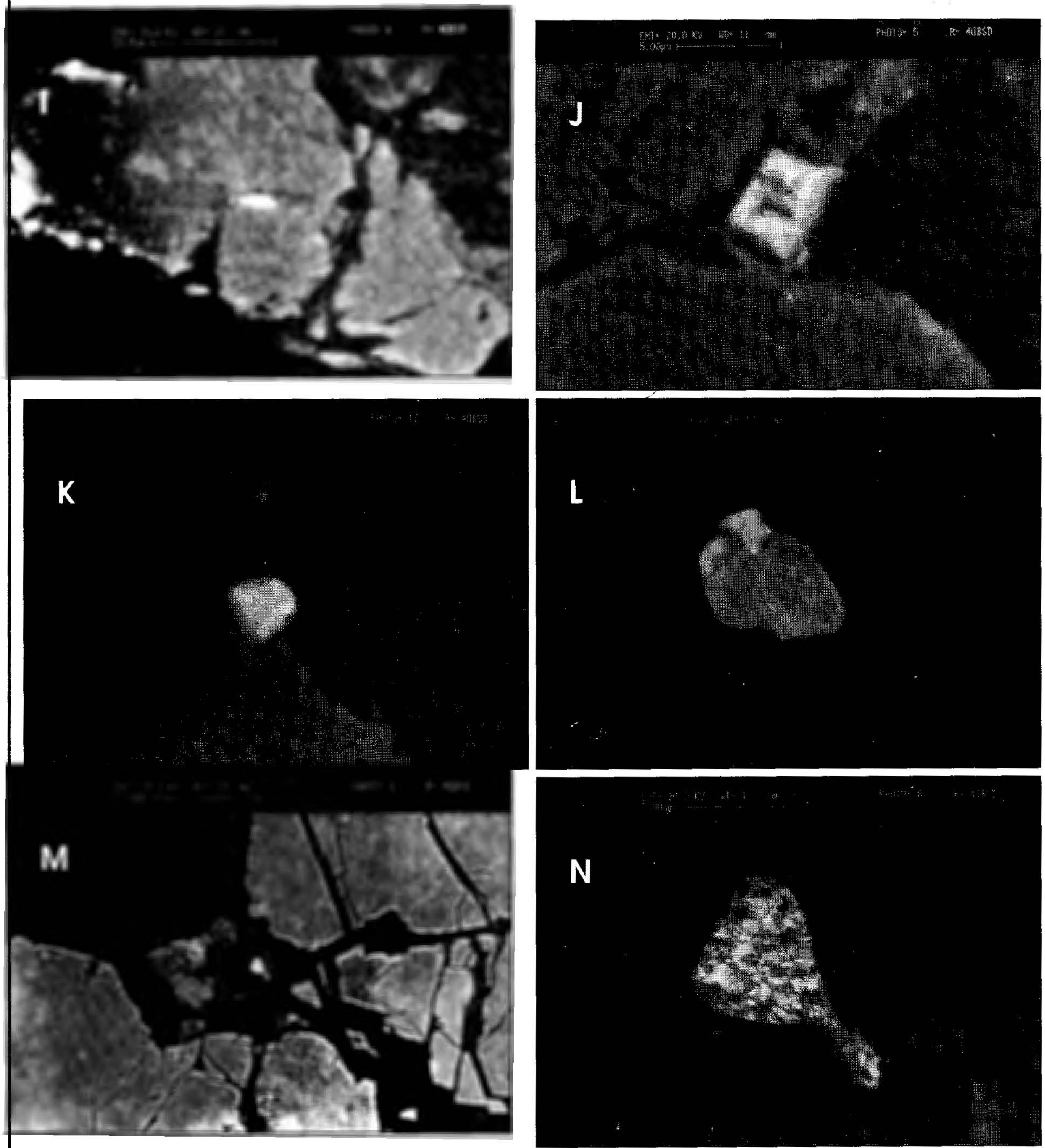

Plate 2. I; Elongate and subhedral laurite enclosed in a crack in chromite, sample no. C-16L6, **J**; Euhedral PGM which is mottled and cracked on the edge of two chromite grains, sample no. C-63B2, **K**; Subhedral laurite on the edge of a chromite grain, sample no. NTL6, **L**; Subrounded composite grain of laurite (grey) and irarsite (pale grey) enclosed in chromite (dark grey) and situated on a crack, sample no. STG1, (Analyses 5 and 6 Table 1), **M**; Rounded / spindle shaped PGM (centre) situated in silicate (dark grey) interstitial to chromite grains (pale grey), **N**; Close up of PGM shown in M showing the mottled texture, sample no. 540.

laurites with a mottled texture and variable composition (Tarkian and Prichard 1987). The altered laurites in contact with serpentine may be associated with other PGM which are As-bearing suggesting that the As has been introduced during serpentinisation (Prichard et al. 1994). Many of the laurites appear to have been altered in situ (Prichard and Tarkian 1988). The analyses of the Muslim Bagh laurites (Table 1) are mainly from euhedral PGM as these were easier to analyse due to their homogeneous nature. They are Os-, Ir–rich which is typical of laurites enclosed in chromite. The composite PGM consisting of laurite and irarsite is located on a crack and may be an altered laurite that has been affected by the introduction of As along the crack. The Os and Ir content of this laurite is slightly lower than in the other euhedral laurites but the difference is slight.

The presence of a rounded Ru-oxide in the interstitial silicate matrix to the chromite suggests that this PGM has been altered. It may have started as a laurite which has been oxidised during alteration. The occurrence of PGM oxides is being increasingly reported (Auge and Legendre 1994, Oberthur et al. 2002 and Moreno et al. 1999) and is interpreted as a late stage alteration possibly during weathering (Prichard et al. 1994) and these PGM tend to occur in altered silicates rather than enclosed in chromite where PGM are protected from such alteration.

CONCLUSIONS

Laurites are the most abundant PGM located in this study of PGM in the podiform chromitites of the Muslim Bagh ophiolite complex. Most laurites are less than 5 microns in size and are enclosed in chromite. However some laurites occur on the edges of chromite grains or along cracks in the grains and these show signs of alteration with loss of their euhedral shape. The one composite PGM includes a laurite and irarsite and is located along a crack and extreme alteration has produced a Ru-oxide.

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CHARACTERIZATION OF FLUVIAL DEPOSITS FOR ENGINEERING PURPOSES - A REVIEW

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INTRODUCTION

Unconsolidated to semi-consolidated Quaternary fluvial deposits are major sources of sand and gravel for use in many industries including, construction, agriculture, water supply, medicine, glass, tiles, and many others. The deposits from different areas may be comparable in texture and appearance. Sand and gravel deposits are products of a coarse-grained alluvial system traditionally believed to be braided streams (Billi and others, 1987).

Fluvial deposits are mostly mixtures of sand and gravel which is defined as continuously graded unconsolidated material present on the earth's surface as a result of the natural disintegration of rocks. These unconsolidated (or semi-consolidated) fluvial deposits are routinely used in construction of roads, dams, bridges, ports, harbours, buildings, etc. Thus they are generally referred to as construction material. The fluvial deposits are generally composed of sand and gravel. Both sand and gravel are composed predominantly of the mineral quartz, although gravel may also consist of various resistant rock types for example limestone, sandstone, quartzite, schist, granite granodiorite, basalt etc. Sand and gravel usually occur together, but in a wide variety of types and size classifications. Sand-sized material ranges from 0.0625 mm to 2 mm, whereas gravel is defined as ranging from 2 mm to 256 mm.

In most of the countries, certain Government departments set specific standards/ codes relating to the performance of construction materials, specially for sand and gravel used in civil work projects. Use of specific deposits of sand and/or gravel depends on the performance of these materials in standardized engineering tests, including, but not limited to, size distribution, abrasion resistance, grain shape (roundness), and percentage of admixed fines (silt or clay). Unfortunately no such codes/standards have been developed in Pakistan.

Deposits of sand and gravel are widely distributed in Pakistan specially in the mountainous areas. Major deposits are present as sedimentary units, on talus slopes, and as alluvial deposits in the flood plains, beds, and terraces of rivers and streams. Most of these unconsolidated deposits may be mined from open pits. Certain areas of the Pakistan are particularly notable for the abundance of these resource materials e.g. almost all the areas of the province of Balochistan, along the western boundary of Sindh and Punjab, and most of the areas of NWFP and Kashmir. Extensive Quaternary alluvial deposits of sand and gravel are found in the major river systems of Pakistan.

Engineering geologists, hydrogeologists, and geotechnical engineers routinely deal with the fluvial deposits as part of their professional responsibility. This paper provides basic information about the sedimentologic characters of these fluvial deposits including composition, texture, and depositional environment. The objective of the paper is to provide a scheme to field workers so that they can properly classify and characterize fluvial deposits.

OVERVIEW OF COARSE-GRAINED FLUVIAL SYSTEMS

Galay and others (1995, after Sutek Service Ltd. and Kellerhals Engineering Service Ltd. 1989) suggested that voluminous supplies of gravel produce streams with at least three channel patterns−braided, anastomosed, and wandering. As will be described later in this paper, these are not the only possible channel patterns. All rivers with high gravel content, no matter the channel style, are more likely to have greater lateral instability, valley slope, and high bed-load to total-load ratios (Galay and others 1995). Each of the channel patterns has different geomorphology. For example, islands are largely absent in braided rivers. In anastomosed rivers, islands at high flow are likely to be split or anastomosed as well. Bar development in braided rivers is mid-channel and diamond shaped. In anastomosed and wandering rivers, bars are likely diagonal, point, or midchannel. Lateral activity can be irregular in wandering and anastomosed rivers but can produce avulsion in all three types (Galay and others 1995). How these differences in fluvial styles effect (or reflect) sand and gravel characteristics related to aggregate uses is unknown.

Billi and others (1987) note that numerous researchers have found that coarse grained fluvial deposits can also be deposited by meandering rivers or low-sinuosity (irregularly sinuous) rivers such as those predominantly encountered in modern systems. Billi and others (1987) also show how gravel fabric and cross-stratification can be used to interpret deposits associated with low-sinuosity rivers. How this fabric and cross stratification is related to sand and gravel characterization in aggregate is unknown.

As noted previously, coarse-grained fluvial systems may develop where glaciation has occurred in the watershed. Desloges and Church (1987) note that glacial processes are less effective than fluvial processes in mixing sediments from different sources. Again, how clearly this will be reflected in sand and gravel characteristics important to use as aggregate is unknown. Gravels eroded from glacial moraines can be expected to have a larger portion of cobbles and boulders (Bliss and Bolm 2000). These can in places be crushed to augment grain sizes found to be deficient in the sand and gravel deposits.

DESCRIPTION OF FLUVIAL DEPOSITS

Finding a way to consistently describe fluvial deposits has been the subject of considerable interest by sedimentologists, geomorphologists and others. Miall (1996) has taken considerable effort in developing a consistent vocabulary using standardized architectural elements as well as standardized lithofacies. Although the presence of a system is important, ease of use is equally important. The overview that follows examines a part of the system developed by Miall (1996). Note that gravel is abbreviated as "GVL," sand as "SND" and silt as "SLT" in parts of this overview. How the classification system will fit into the assessment of sand and gravel to be presented in subsequent reports is undetermined.

Architectural elements, as used by Miall (1996), are distinct depositional units with recognizable bounding surfaces. These elements are strictly descriptive, not genetic. A sedimentary lithofacies is a body of sediments or sedimentary rock that is genetically related and commonly contrasted with adjacent bodies of sediment. Many sedimentary lithofacies can be products of different depositional environments. Interpretation of the lithofacies together and within the regional geologic context is necessary to make genetic assignments. Lithofacies, as used here, are characteristics that allow a larger sedimentary unit to be subdivided in a way that reflects characteristics that should be important to sand and gravel deposit definition. One can expect that a genetic explanation may not be possible everywhere and that sand and gravel models must be sufficiently "descriptive" to allow recognition where a genetic explanation is not possible.

Lithofacies

Fluvial deposits are dominated by clastic material. The simplest classification is a three component one--using gravel, sand, and fine-grained materials. Fine-grained components can include mud, silt, and very fine-grained sand. Some lithofacies (not considered here) also contain organic matter that is an undesirable contaminant for aggregate applications. Table 1 presents a list of 20 lithofacies classes (modified after Miall 1996) with associated names,

Table 1. Lithofacies classification (modified after Miall 1996) [GVL=gravel; SND=sand; SLT=silt.]

Litho-facies No.	Litho-facies Name	Description	Structure	Genetics
1	Gmm	GVL, matrix supported, mass	Weak grading	Plastic debris flow, high strength & viscous
2	Gmg	GVL, matrix supported	Inverse to normal grading	Pseudoplastic debris flow, low strength, viscous
3	Gci	GVL, clast supported	Inverse grading	Clast-rich debris flow (high strength) or pseudoplastic debris flow (low strength)
4	Gcm	GVL, clast supported, mass	None commonly seen	Pseudoplastic debris flow (inertial bedload, turbulent flow)
5	Gh	GVL, clast supported, crudely bedded	Horizontal bedding, imbricated	Longitudinal bedforms, lag deposits, sieve deposits
6	Gt	GVL, stratified	Trough cross-beds	Minor channel fills
7	Gp	GVL, stratified	Planar cross-beds	Transverse bedforms, deltaic growths from older bar remnants
8	St	SND, fine to very coarse, may be pebbly	Solitary or grouped trough cross-beds	Sinuous-crested and linguoid (3-D) dunes
9	Sp	SND, fine to very coarse, may be pebbly	Solitary or grouped planar cross-beds	Transverse and linguoid (2-D) dunes
10	Sr	SND, very fine to coarse	Ripple, cross laminated	Ripples (lower flow regime)
11	Sh	SND, very fine to coarse, may be pebbly	Horizontal lamination	Plane-bed flow (critical flow)
12	Sl	SND, very fine to coarse, may be pebbly	low-angle (<15°) cross-beds	Scour fills, humpback or washed-out dunes, antidunes
13	Ss	SND, very fine to coarse, may be pebbly	Broad, shallow scours	Scour fill
14	Sm	SND, fine to coarse	Massive, or faint lamination	Sediment-gravity flow deposits
15	Fl	SND, SLT, mud	Fine lamination, very small ripples	Overbank, abandoned channel, or waning flood deposits
16	Fsm	SLT, mud	Massive	Back swamp or abandoned channel deposits
17	Fm	Mud, SLT	Massive, desiccation cracks	Overbank, abandoned channel, or drape deposits
18	Fr	Mud, SLT	Massive, desiccation cracks	Root bed, incipient soil
19	C	Coal, carbonaceous mud	Plant, mud films	Vegetated swamp deposits
20	P	Paleosol, carbonate (calcite, siderite)	Pedogenic features, nodules, filaments	Soil with chemical precipitation

ARCHITECTURAL ELEMENTS

Class	Description
CH	Stream channels
GB	Gravel bars & bedforms
HO	Hollow deposits
SG	Sediment gravity-flow deposits
SB	Sandy bedforms
DA	Downstream accretion macrofonns
LA	Lateral accretion deposits
LS	Laminated sand sheets
FF	Overbank fines

Table 2. List of architectural elements after Miall (1996).

descriptions, structures, and genesis. The classes are arranged from coarser grain sizes in the lower numbers through finer grain sizes in the higher numbers. Most gravel (as well as boulders and cobbles) found in sand and gravel deposits will be from lithofacies 1-7. However, lithofacies 1 and 2 are matrix supported, so one may expect considerable sand and fine-grained material as well. Minor amounts of gravel are likely in lithofacies 8-9 and 11-13. The gravels are suspected to be present in these lithofacies based on the identification of "pebbly" in the description of Table 1. Sand is dominant in lithofacies 8-15 but will likely be encountered in all lithofacies listed in Table 1 albeit in minor amounts in lithofacies 16-20 and perhaps in lithofacies 1-7. Sources of undesirable fine-grained material (less than 0.074 mm) are likely found in small amounts in lithofacies 1-7 and likely in greater amounts in some of the sand dominated lithofacies 8-14. Fine-grained materials dominate lithofacies 16-19, and they should be avoided where encountered with sand and gravel deposits. Lithofacies 19 and 20 consist of vegetated swamp materials and soil horizons with chemical precipitates, respectively, both of which are undesirable in aggregate sources.

Architectural Elements

Miall (1996) develops a basic set of eight architectural elements that can be found in various combinations in fluvial system channels (Table 2). One additional element, floodplain fines (FF), is also considered here as it is one of the elements of overbank environment that may be found in abandoned channels (Miall 1996). The elements are the channel, gravel bars and bedforms, hollow deposits, sediment gravity-flow deposits, sandy bedforms, downstream-accretion macroforms, lateral accretion deposits, and laminated sand sheets. Each architectural element will be discussed in turn. Each element can consist of one or more lithofacies as given in Table 1. If these elements are sufficiently large they can be readily identified on low-level aerial photographs of modern rivers. One or more of these elements may be encountered in sand and gravel deposits suitable for aggregate. Relationships between elements can be complex, reflecting multiple truncations of one or more previous deposits and the overprinting of one or more new ones. The discussion that follows is more extensive for those architectural elements that are more likely to be potential sources of suitable sand and gravel. A summary of architectural elements and lithofacies is given in Table 3. Architectural elements can also be classified according to their potential for being a suitable source of sand and gravel based on the descriptions provided by Miall (1996). This is also reviewed in the text below. Table 3 provides a first hand information about the "likelihood of suitability" of sand and gravel deposits belonging to various lithofacies for use in construction aggregate.

Architectural elements likely to have gravel

Stream channels are the most common elements found in fluvial systems (identified as element **CH** by Miall, 1996). All lithofacies assemblages are possible in any combination in channels (Miall, 1996, Table 4.3). Sediment body types included fingers, lenses, or sheets with concave-up erosional bases where both scale and shape are highly variable. Channel-fill elements can be separated from other elements (in cross-section perpendicular to paleo-flow) by sloping channel margins. Channels are commonly multistoried with each story bounded by an erosional surface (Miall 1996). The angles of channel margins can in places indicate channel width; steep to vertical margins indicate narrow channels as compared to gentler margins that indicate a wider channels. Sheet-like channels commonly have nearly imperceptible margins (Miall 1996). Channel deposits typically gave grain sizes that fine upward where channels are filled by simple vertical aggradation as a result of progressive abandonment or flash floods (Miall, 1996). Miall (1996) notes that, "most coarse (gravel, sand) deposits in fluvial systems are deposited in channels." Channels are promising as a source of sand and gravel for use as aggregate.

Gravel bars and bedforms (element **GB**), by their very definition, constitute a promising source of sand and gravel for construction aggregate given adequate thickness, volume, etc. Three closely related gravel lithofacies (Hein and Walker, 1977 as cited by Miall 1996) are: bedded and imbricated (Gh), planar cross-bedded (Gp), and trough cross-bedded (Gt). These are three types of mesoforms found in gravel bars and bedforms (Miall, 1996). This element, GB, is important in gravel-dominated, braided rivers where transport occurs as random pulses of several hours duration resulting in bar erosion and channel evulsion (Miall 1996). Gravel may initially occur as thin layers, perhaps no more than a few clasts thick, which grow upward downstream to form thick horizontally stratified sheets up to about 1 m thick..

Table 3. Sedimentary sources of sand and gravel aggregate based on descriptions of architectural element (table 2) and lithofacies (assigned by number) (Miall1996). [No. is the lithofacies class number (see text). Assignments of "likelihood of suitability" (symbol code describe below table) is a subjective assignment using the anticipated lithologies associated with each lithofacies class and architectural element combination with the expectation that it will contain a substantial proportion of sand and gravel that may meet minimum geotechnical specifications for use in construction aggregate.]

No.	CLASS	GRAIN SIZE	ARCHITECTURAL ELEMENTS								
			CH	GB	HO	SG	SB	DA	LA	LS	FF
1	Gmm	GVL, matrix supported, mass	●			▲			▲		
2	Gmg	GVL, matrix supported	●			▲			▲		
3	Gci	GVL, clast supported	●			■					
4	Gcm	GVL, clast supported, mass	●			■					
5	Gh	GVL, clastsupporte, crudely bedded	●	●	●						
6	Gt	GVL, stratified	●	●	●				▲		
7	Gp	GVL, stratified	●	●					▲		
8	St	SND, fine to very coarse, may be pebbly	▲		▲		▲	▲	▲		
9	Sp	SND, fine to very coarse, may be pebbly	▲				▲	▲	▲	▲	
10	Sr	SND, very fine to coarse	▮				▮	▮	▮	▮	
11	Sh	SND, very fine to coarse, may be pebbly	▲		▲		▮	▮	▮	▮	
12	Sl	SND, very fine to coarse, may be pebbly	▲		▲		▮	▮	▮	▮	
13	Ss	SND, very fine to coarse, may be pebbly	▲				▮	▮	▮		
14	Sm	SND, fine to coarse	▮								
15	Fl	SND, SLT, mud	▮								▮
16	Fsm	SLT, mud	▮								
17	Fm	Mud, SLT	▮								▮
18	Fr	Mud, SLT	▮								
19	C	Coal, carbonaceous mud	◆								
20	P	Paleosol, carbonate (calcite, siderite)	◆			◆					

Explanation

Likelihood of Suitability for Aggregate Construction

● High
■ Moderate
▲ Low
▮ Too fine for construction aggregate
◆ Organic and other contaminants unsuitable for construction aggregate

Hollow deposits (element **HO**) are described by Miall (1996) as being trough shaped indentations in the stream bed, probably the product of deep scouring where channels converge, and can be up to six times as deep as the channels with which they are associated (Cowan 1991, as cited by Miall 1996). They are encountered in gravel braided and sand braided systems (Miall 1996) and may be present in deposits left by some of the major rivers originating from Himalayas and flowing into Pakistan. Siegenthaler and Huggenberger (1993, as cited by Miall 1996) report hollow-like structures in Pleistocene gravels in Switzerland. In braided systems, the scouring can be three times the mean channel depth and tends to occur upstream from large emergent bars (Cant and Walker 1976). In the Morrison Formation (of New Mexico USA), Cowan (1991) reports that hollows are 20 m deep and 250 m wide with an upper surface that is concave-up with fourth-order surfaces and basal surfaces dipping as much as 26°. Deposits are not cylindrical in shape as expected in channel deposits but scoop-shaped (Miall 1996). Because hollows develop below the channel base, chances of preservation are improved (Miall 1996). Lithofacies present in the Morrison Formation (Cowan 1991) include only Sh (horizontal laminated fine to very coarse to pebbly sand) and Sl (low-angle cross bedded sand). However, Miall (1996, Table 4.3) also suggests that the number of possible lithofacies assemblages found in hollows is far greater including Gh (clast-supported, crudely bedded gravels), Gt (stratified gravels), and St (solitary or grouped crossbeds of fine to very coarse to pebbly sand).

Sediment gravity-flow deposits (element **SG**) may contain considerable sand and gravel but may be an unlikely source of sand and gravel suitable for aggregate. Sand and gravel deposits with 15 percent or more silt, possible characteristic of gravity-flow deposits, commonly are not worked. Contamination of flow deposits with organic debris may also be a problem. Lithofacies located in flow deposits include both matrix-supported and clast-supported. Beds are commonly between 0.5 to 3 m thick, where flows can be up to 20 m wide and several kilometers in length downstream (Miall 1996). Multiple pulses may stack flow deposits, resulting in a composite thickness of several meters. Flow deposits have lower edges that are irregular where deposition occurs passively on existing surfaces of all types. Texture is disorganized and commonly distinctive.

Lithofacies commonly found in flow deposits are either matrix-supported with weak grading or inverse to normal grading (lithofacies Gmm, Gmg), or clast-supported with inverse to no grading (lithofacies Gci, Gcm). Matrix supported lithofacies are rich in fines and are the product of plastic to pseudoplastic debris flows, although clastic supported lithofacies are only produced by pseudoplastic debris flows (Miall 1996). Clast supported lithofacies are more likely to be possible sources of sand and gravel for aggregate.

Architectural elements not likely to have gravel

The following elements may contain sand but are not likely to have much gravel. Although many of these architectural elements may be a source of fine aggregate, the primary objective of the study is recognizing sources of sand and gravel. These are given briefly below for the sake of completeness.

Sandy bedforms (element **SB**) are identified by Miall (1996, Table 4.3) as having six principal lithofacies assemblages. They are St, Sp, Sh, Sl, Sr, and Ss (Table 1). Pebbles (some of which are sufficiently large to be considered GVL) may be present in lithofacies St and Sp.

Downstream-accretion macroforms (element **DA**) are described by Miall (1996, Table 4.3) has having six principal lithofacies assemblages. They are St, Sp, Sh, Sl, Sr, and Ss (Table 1). Pebbles (some of which are sufficiently large to be considered GVL) may be present in lithofacies St and Sp.

Lateral accretion deposits (element **LA**) are described by Miall (1996 Table 4.3) as having six principal lithofacies assemblages. They are St, Sp, Sh, Sl, Sr, and Ss (Table 1). These same lithofacies are found in downstream-accretion macroforms noted above. Pebbles (some of which are sufficiently large to be considered GVL) may be present in lithofacies St and Sp. Less commonly found in this element are lithofacies Gm, Gt and Gp that also contain GVL.

Laminated sand sheets (element **LS**) as described by Miall (1996, Table 4.3) consist of lithofacies Sh and Sl (Table 1). Minor Sp and Sr may also be found. Only Sp may contain material sufficiently large in grain size to be identified as GVL.

Overbank fines (element **FF**) as described by Miall (1996) consist of lithofacies Fm and Fl (Table 1). The element is commonly interbedded with element SB and is prevalent in abandoned channels.

ROLE OF ARCHITECTURAL ELEMENTS AND LITHOFACIES IN AGGREGATE ASSESSMENT

Can the application of architectural elements and lithofacies to the analysis of fluvial deposits provide insight into sand and gravel resources in deposits formed from braided rivers? Sources of sand and gravel are located in many elements. Some elements are dominated by gravel- and sand-rich lithofacies, but these elements can also contain lithofacies rich in undesirable fines. Lithofacies are classified using grain size (gravel, sand, silt) and, by definition, are useful to resource assessment. Can lithofacies and architectural elements be used to make better estimates of sand and gravel?

For a long time, braided rivers were thought to have random depositional patterns lacking cyclical patterns of any sort. However, work by Miall (1973) and Cant and Walker (1976) found that some deposits formed by braided rivers do exhibit cyclical patterns that can be recognized when using statistical techniques of Markov chain analysis of the bedding sequence. In fact, Cant and Walker (1976) initially developed the concept of lithofacies to allow surface designation for use in Markov analysis. Miall (1977) developed a four-lithofacies model for braided rivers that are cyclical. Both architectural elements and lithofacies are potentially useful in sand and gravel assessment but require the recognition of and reporting on sedimentary features used by the classification system as observed in pits and elsewhere. It is possible that quantitative relationships between geomechanical characteristics (Los Angeles Abrasion test, sand equivalency test and others) and lithofacies, and perhaps even architectural elements, are present, but these have yet to be demonstrated.

LIKELIHOOD OF SUITABILITY FOR AGGREGATE CONSTRUCTION

Based on the character criteria described for the various types of lithofacies (Table 1) and architectural elements (Table 2), it is evident that certain types have a higher likelihood than others to contain a substantial proportion of sand and gravel that may meet minimum geotechnical specifications for use in construction aggregate. Some other types, such as swamp deposits, are known to be unsuitable for such applications. Based on these criteria, a simple classification matrix, shown in Table 3, is used to assign each lithofacies type associated with certain architectural elements a "likelihood of suitability" that it will meet the minimum construction aggregate specifications. This classification matrix is based strictly on hypothetical physical and chemical characteristics for a range of sedimentary structures that may occur in alluvial deposits. It is not based on data collected from any specific area. However, the classification matrix may serve as a useful screening tool when investigators, land planners, or others seek to identify sedimentary features as potential exploration targets for high quality construction aggregate and by hydrogeologists when developing the lithologic log during drilling.

SELECTION OF AGGREGATE FROM THE SOURCE

The quality of concrete construction is considerably influenced by properties of aggregate used for concrete preparation for example chemical and mineralogical composition, petrophysical classification, specific gravity, hardness strength, physical and chemical stability, pore water pressure, porosity and permeability. These properties of an aggregate particle entirely depend upon the parent/source rock.

American Society of Testing of Material (ASTM), British Standard Specifications (B.S.) and American Association of State Highway Transportation Officials (AASHTO) designed and developed standard specifications and testing procedure for selection of aggregate for civil engineering construction works. These specifications and procedures are widely accepted and are in use all over the World including Pakistan.

Streams and their flood plain in mountainous areas are the principal sources of gravel. A good quality natural aggregate must have higher specific gravity, low porosity and least permeability. the aggregate of such properties are widely available in Pakistan, specially in Balochistan. Some of the notable deposits of good quality natural aggregates in Balochistan may be found in the valleys of Bolan River, Hangol River, Kech-Dasht River, Rakhshan River, Porali River, Hub River, Zhob River, Mula River, Baddo River, Bheji River, Kulachi-Gaj River and Pishin Lora. Beside these major sources of sand and gravel deposits, comparatively smaller deposits are widely scattered all over the mountainous areas of Balochistan, NWFP, northern and western Punjab, AJK and western Sindh in smaller streams, alluvial plains and piedmont areas.

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PETROLOGIC AND GEOCHEMICAL EVOLUTION OF THE SHEETED DYKES IN WAZIRISTAN OPHIOLITE, NW PAKISTAN

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ABSTRACT

The Waziristan Ophiolite is located in the suture zone between the Indian plate to the east and Afghan block to the west. It is highly dismembered and divisible into three main sheets or nappes which, from east to west, are: the Vezhda Sar nappe, entirely comprised of pillow basalts; the Boya nappe, made up of ophiolitic melange with an intact section in its basal part; and the Datta Khel nappe, consisting mainly of sheeted dykes with small proportions of other components. Faunal evidence suggests that the ophiolite is Tithonian-Valanginian in age. It was thrust over the Mesozoic shelf-slope sediments of the Indian plate to the east during the Paleocene and is unconformably overlain by sedimentary rocks of Early to Middle Eocene age to the west. Beside the sheeted dykes, which are best exposed in the hanging wall of the Datta Khel Thrust ENE of Datta Khel, the ophiolite also contains isolated dykes. These are mafic to intermediate in composition and contain high Na_2O contents, and have high FeO^t/MgO and LILLE/HFSE ratios, and low TiO_2 (< 0.1 wt. %) and K_2O contents. Non-depletion of Nb and high LILE/HFSE ratio negate, respectively, an island-arc or mid-ocean ridge settings for these dykes. Enrichment in the LILE suggests involvement of crustal components driven by fluids in a subduction zone. Several geochemical parameters suggest that the Waziristan dykes have transitional characteristics between mid-ocean ridge basalt and island-arc tholeiite. It is therefore proposed that the Waziristan dykes may have originated in a back-arc basin tectonic set-up.

INTRODUCTION

The sheeted dyke unit is an important component of most ophiolite suites. It occupies a specific horizon in the crustal sequence, directly below the pillow basalts (layer-2) and above the isotropic gabbros (layer 3) (Penrose Conf. 1972, Coleman 1977). The presence of sheeted dykes in ophiolite suites was taken as being indicative of their formation in a sea-floor spreading setting. Some ophiolites show petrologic and geochemical similarities with crust generated at mid-ocean ridges (MOR). They include the large, relatively intact Tethyan ophiolites, such as Troodos in Cyprus, Semail in Oman, Muslim Bagh in Pakistan, as well as those at Zambales (Philippines), California (USA),

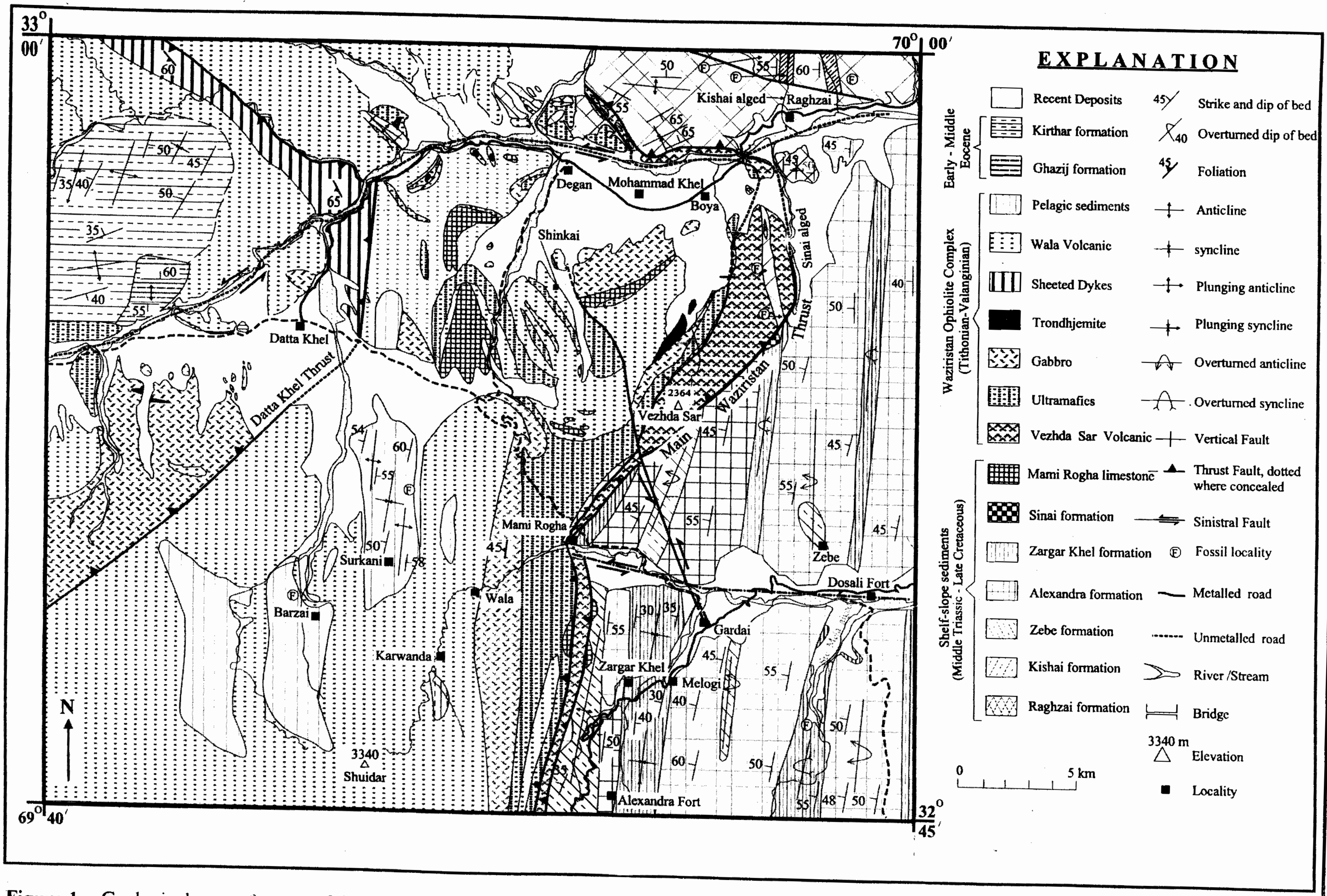

Figure 1. Geological map of a part of the Waziristan Ophiolite, North Waziristan, NW Pakistan.

Kamray (Norway) and Newfoundland (Canada) (Alt et al. 1998, Yumul 1996). The Waziristan Ophiolite (WO) is one of the fragmented Tethyan ophiolites, widely considered to have formed in back-arc basin settings and different from those formed at mid-ocean ridges (Khan et al. 2001a). The composition of the ophiolitic rocks formed in a back-arc basin setting are characterized by a higher concentration of large-ion lithophile elements (LILE), non-depletion of Nb, low-Ti content and highly differentiated nature (basalt to rhyolite), as compared to mid-ocean ridge basalts (Saunders & Tarney 1979, Pearce et al. 1984 Harper et al. 1988, Schiffman & Fridleifsson 1991, Bloomer et al. 1995, Yumul 1994, 1996, Alt et al. 1998, Leat et al. 2000).

Sheeted dykes yield important geochemical information about the origin and tectonic setting of the magmas responsible for ophiolites formation. Firstly, their origin is directly related to important tectonic processes such as sea-floor spreading. Secondly, sheeted dykes often serve as magma conduits between the underlying magma chamber and the overlying pillow basalts. The geochemistry of the sheeted dykes is often more reliable than that of gabbros and basalts from the same ophiolite suite (Pearce et al. 1984, Nicolas 1989, Leat et al. 2000, Rolland et al. 2000). The geochemistry of gabbros depends upon the relative proportion of cumulus minerals rather than the magma from which these rocks are crystallized. The basalts, particularly the pillow basalts, are often subjected to reaction with seawater and hydrothermal alteration.

This paper provides petrographic and geochemistry data of the sheeted as well as isolated dykes from the Waziristan Ophiolite. These data suggest a back-arc basin affinity for the ophiolite.

REGIONAL GEOLOGY

Ophiolites in Pakistan can be divided into those occurring along the Indus Suture Zone and those along the western margin of the Indian Plate. The latter (Waziristan, Zhob, Muslim Bagh, and Bela ophiolites in Pakistan and the Khost Ophiolite in eastern Afghanistan) are grouped into the western ophiolite belt. Ophiolites and mafic-ultramafic complexes exposed along the Indus Suture Zone (Malakand, Shangla, Dras ophilites and Jijal, Sapat igneous complexes) have been grouped into the northern ophiolite belt (Gnos et al. 1997, Khan et al. 1998a, 1998b, Khan 2000).

From west to east, the region comprises of the Afghanistan-Kabul blocks, the Katawaz Basin, the ophiolite belt (including Kabul, Khost, Waziristan, Zhob, Muslim Bagh, Bela ophiolites), and the Indian plate (comprising Mesozoic shelf-slope sediments of the Axial Belt, Sulaiman and Kirthar ranges, Sofed Koh fold belt, and the mollase deposits in the foredeeps of the Sulaiman and Kirthar ranges), respectively (Tapponnier et al. 1981, Treloar & Izzat 1993, Khan 1999, 2000). The continental blocks (Afghanistan-Kabul-India) are presently welded to each other by a network of sutures, which are defined by the ophiolite outcrops. The WO is located near the western terminus of the Himalayan orogen and is presently sandwiched between the Afghanistan and Kabul blocks to the west and the Indian Plate to the east. The WO is dismembered, but contains all the segments of an ideal ophiolite suite. However, an intact section occurs at Mami Rogha, where ultramafic rocks are overlain by isotropic gabbros and pillow basalts capped by pelagic sediments. The ophiolite, and the Indian Plate sediments, are intensively deformed by folding, faulting and, in places, fracturing and brecciation.

The ophiolite is thrust eastwards onto, rather than beneath, the Indian Plate sedimentary rocks as documented by Robinson et al. (2000). Regionally, the Main Waziristan Thrust (MWT) trends north to south and dips westwards, clearly indicating overthrusting of the ophiolite onto the shelf-slope sediments of the Indian Plate. Local changes in the trend of the MWT (from N-S to E-W) and dip (from W to N) occur north of Boya-Mohammad Khel. These changes have been affected by later east-west trending strike-slip faults. Thus these local changes in the trend and dip of the MWT or overlying of the shelf-slope sediments on the ophiolite are not to be taken as evidence of under thrusting of the ophiolite under the Indian Plate sediments. Field evidences, for example the intact ophiolite section (base towards the east and top towards west), the westward dip of the MWT, and deposition of Tertiary sediments on top of the ophiolite to the west, clearly support overthrusting of the ophiolite onto the shelf-slope sediments of the Indian Plate to the east.

LOCAL GEOLOGY

The study area lies at the western terminus of the Himalayan orogen and can broadly be divided into two main tectonic blocks: i) Waziristan Ophiolite to the west, and ii) shelf-slope sediments to the east (Fig. 1). The shelf-slope sediments, comprising of limestone, shale, sandstone and siltstone of Middle Triassic to Late Cretaceous age, are overthrust by the ophiolite.

The WO is one of a series of ophiolites exposed along the western margin of the Indian Plate. It extends westward into eastern Afghanistan, where it has been named the Khost Ophiolite (Cassaignaeu 1979). The WO is strongly dismembered and contains all the segments of an ideal ophiolite suite. It is internally divisible into three thrust sheets or nappes. These nappes, from east to west, or lower to upper, are: the Vezhda Sar nappe, which forms the eastern edge of the WO and is thrust over the shelf-slope sediments of the Indian plate. It is entirely composed of pillow basalts. Pelagic sediments and other ophiolitic components have not been identified, although exotic blocks of ultramafic rocks are found in the pillow basalts. Several mappable exotic blocks of the shelf-slope sediments occur within the pillow basalts.

The Boya nappe forms the central part of the WO, which is strongly dismembered, giving the appearance of a typical melange. Here the ultramafic and gabbroic rocks are irregularly distributed as fault-bounded blocks within a larger mass of the pillow basalt. However, an intact ophiolite section occurs in the basal part of the nappe at Mami Rogha (Fig. 2). This sequence is composed of ultramafic rocks at the base, followed upwards by isotropic gabbros, and pillow basalts capped by pelagic sediments. These sediments occur as isolated bodies, intercalated within, and overlying, the pillow basalts. The section is devoid of layered gabbros and sheeted dykes. Trondhjemite intrusions occur as small lensoid bodies and veins, mostly in the ultramafic and rarely in the gabbroic rocks.

The Datta Khel nappe forms the westernmost part of the WO. Its base, exposed WSW of Datta Khel is marked by a sequence of layered gabbroic rocks. ENE of Datta Khel, the basal part of the nappe cuts upsection, and exposes only a sheeted dyke complex. Small tectonic blocks of ultramafic rocks, which are otherwise missing from the basal part of the nappe (probably due to a higher level of propagation of the Datta Khel Thrust), are exposed only along the Tochi River, west of Datta Khel. In this nappe, the pelagic sediments are missing and trondhjemite intrudes the gabbros. The pelagic sediments contain radiolarian fauna (Tithonian-Valanginian) indicating a Late Jurassic or older age for the WO (Khan 1995, 1999, 2000, Khan et al. 1998a, 1998b). The Waziristan Ophiolite contains tectonic blocks of Mami Rogha limestone (Parh Group) of Late Cretaceous (Campanian) age, and is thrust over Maastrichtian green shale (Beck et al. 1996), indicating post-Maastrichtian, most probably Paleocene, emplacement of the ophiolite. That a sequence of rocks of the Early Eocene Ghazij Formation and the Early to Middle Eocene Kirthar Formation age, unconformably overly the ophiolite lends support to a Paleocene age of emplacement.

FIELD FEATURES AND PETROGRAPHY

The WO contains dyke swarms as well as individual dykes. Both types display sharp intrusive contacts with the basaltic rocks and are characterized by chilled margins. The sheeted dykes trend north-south and usually have high dips. They range from a few centimetres to about five metres in width and may laterally extend for hundreds of metres. The sheeted dyke unit is well-exposed in the basal part of the Datta Khel nappe, ENE of Datta Khel village. These dykes intrude the pillow basalts of the Datta Khel nappe. Individual dolerite dykes are sporadically distributed irregularly oriented and intrude all the ophiolitic rock types except the pillow basalts of the Vezhda Sar nappe. These dykes also cross-cut the sheeted dykes and are thus younger than them.

The dykes are fine- to medium-grained, with ophitic to subophitic textures. They are composed of plagioclase, clinopyroxene, hornblende and magnetite. Plagioclase (45 to 60 modal %) occurs as laths in pyroxene and hornblende and as inclusions within the diopsidic-augite oikocrysts. The plagioclase is partly to completely altered to sericite, calcite, and epidote. Quartz grains, developed during decomposition of plagioclase, are identified in most dyke samples.

The clinopyroxene is diopsidic-augite (but locally augite), making 10 to 15 modal % of the dykes, and is partly to completely altered to amphibole and magnetite. Amphibole forms up to 15 modal % and can be divided into two generations. Primary (igneous) amphibole is brownish in colour and pleochroic. In contrast, the secondary amphibole is bluish-green and ranges from equant grains to slender (uralitic) fibres. The former (primary) may be common hornblende and the secondary actinolite and or tremolite. The hornblende (reaching up to 20 modal%) is commonly altered to chlorite, but in places

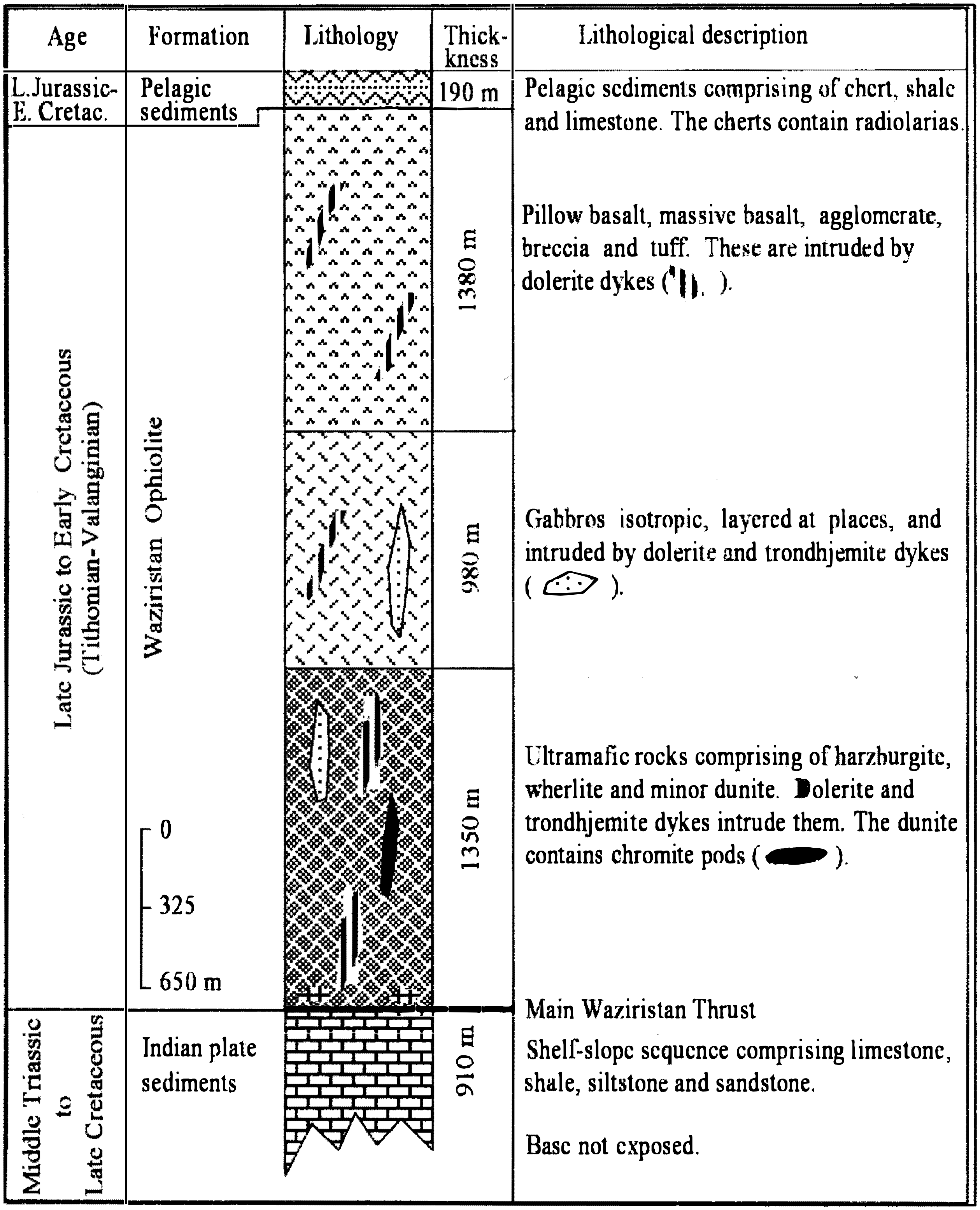

Figure 2. Schematic litho-stratigraphic column of the Waziristan ophiolite exposed at Mami Rogha. The dykes are not according to scale.

Table-1 Major and trace element data (wt. % and ppm) for the Waziristan dykes.

Samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum	Nb	Zr	Y	Sr	Rb	Zn	Ni	Cr	V	Ba	Cu	Co	Sc	Ga	Ce	Nd	Zr/Y	Y/Nb
WD 1	52.71	0.99	15.34	11.95	0.196	4.24	6.6	3.74	1.24	0.098	2.71	99.81	5	76	20	133	28	75	14	138	354	399	54	42	bdl	14	6	15	3.80	4.00
WD 2	54.17	0.845	15.27	10.95	0.178	4.86	6.38	3.13	1.24	0.099	2.90	100.02	6	76	21	246	23	69	17	43	340	356	125	39	bdl	14	1	2	3.62	3.50
WD 3	55.48	0.912	15.22	11.09	0.174	3.36	5.96	4.22	0.61	0.117	2.86	100.00	6	63	20	91	11	83	8	6	339	177	170	34	bdl	16	19	15	3.15	3.33
WD 4	55.18	0.953	14.91	11.4	0.177	4.28	6.25	3.61	1.03	0.104	2.12	100.01	5	59	21	263	27	77	16	19	362	477	100	45	bdl	12	20	19	2.81	4.20
WD 5	54.73	0.977	14.97	11.88	0.19	3.77	6.52	3.95	0.94	0.122	1.97	100.02	6	62	21	164	17	79	12	17	363	257	115	36	bdl	16	48	19	2.95	3.50
WD 6	55.38	0.92	15.35	11.16	0.177	3.55	7.46	3.11	0.58	0.121	2.19	100.00	7	67	20	202	13	84	10	13	301	278	110	39	bdl	14	18	17	3.35	2.86
WD 7	53.16	0.988	15.54	11.64	0.176	4.69	6.71	3.71	1.05	0.194	2.14	100.00	5	66	20	210	23	86	16	9	364	226	162	39	bdl	17	35	15	3.30	4.00
WD 49	52.31	0.919	15.36	11.79	0.195	5.06	8.23	3.33	0.63	0.095	2.08	100.00	4	53	22	190	14	76	19	13	445	194	34	38	38	17	bdl	6	2.41	5.50
WD 58	53.08	1.117	15.39	11.01	0.167	4.21	7.26	4.18	0.49	0.219	2.88	100.00	4	87	35	221	13	59	14	4	235	101	115	37	24	18	bdl	7	2.49	8.75
WD 59	51.75	1.308	16.21	11.26	0.144	3.64	7.58	3.74	0.59	0.163	3.62	100.01	3	85	30	311	11	46	7	bdl	311	127	35	34	28	19	bdl	7	2.83	10.00
WD 60	51.41	1.259	14.58	11.81	0.173	4.47	8.09	3.15	0.68	0.161	4.21	99.99	3	81	31	329	14	52	16	15	367	111	144	36	23	18	bdl	8	2.61	10.33
WD 71	53.84	0.968	15.25	11.27	0.186	4.14	7.03	4.00	1.13	0.133	2.05	100.00	6	67	25	222	25	82	11	9	412	354	21	34	31	17	bdl	bdl	2.68	4.17
WD 80	52.04	0.742	15.34	10.69	0.191	5.97	8.26	3.64	0.8	0.087	2.24	100.00	4	46	20	181	18	78	22	12	386	177	118	42	35	15	bdl	2	2.30	5.00
WD 92	56.21	1.017	14.54	11.67	0.186	3.28	5.77	4.25	1.12	0.149	1.82	100.01	6	80	29	222	29	105	7	4	372	256	169	29	28	17	3	12	2.76	4.83
WD 96	54.64	0.98	15.18	11.72	0.91	3.32	6.55	4.66	0.18	0.157	2.43	100.73	6	65	24	195	6	78	5	3	476	227	145	34	34	19	bdl	9	2.71	4.00
WD 99	52.51	1.082	15.85	11.74	0.206	3.85	5.39	5.66	0.25	0.451	3.00	99.99	6	70	28	228	7	93	4	1	306	66	21	30	22	21	bdl	9	2.50	4.67
WD 109	53.75	0.895	15.65	10.69	0.163	4.47	6.13	5.80	0.56	0.116	1.79	100.01	5	64	25	142	13	58	14	16	360	93	8	33	33	18	bdl	6	2.56	5.00
WD 157	55.72	0.931	15.01	11.41	0.175	3.46	6.37	3.88	1.04	0.138	1.87	100.00	6	69	28	185	24	86	10	15	415	538	167	30	34	14	72	27	2.46	4.67
WD 160	53.99	0.805	14.48	11.26	0.178	5.32	7.31	4.77	0.23	0.088	1.58	100.01	4	45	21	95	7	84	20	33	428	69	120	34	50	10	71	27	2.14	5.25
WD 184	53.95	0.864	15.22	11.5	0.205	4.44	6.83	4.17	0.79	0.11	1.91	99.99	5	62	25	250	21	85	14	11	391	253	149	33	41	14	94	31	2.48	5.00
WD 185	54.54	0.903	14.8	10.75	0.169	3.79	6.78	4.41	1.09	0.125	2.65	100.01	6	75	27	243	16	79	10	11	396	177	46	32	40	18	97	32	2.78	4.50
WD 191	53.79	0.894	15.31	11.53	0.18	4.47	6.59	4.68	0.96	0.112	1.50	100.02	5	73	25	460	24	96	12	3	483	510	166	32	44	15	71	29	2.92	5.00
WD 19	55.94	1.22	15.07	10.86	0.155	2.7	6.31	3.78	0.53	0.231	3.21	100.01	4	114	42	140	17	46	bdl	1	145	53	15	29	24	20	bdl	8	2.71	10.50
WSD 25	54.89	1.563	14.34	12.02	0.162	3.46	5.93	5.02	0.23	0.18	2.22	100.02	3	101	37	138	6	65	3	3	316	61	25	34	25	19	3	11	2.73	12.33
WD 26A	54.06	1.324	15.02	11.32	0.166	2.84	6.89	4.39	0.27	0.187	3.53	100.00	4	92	36	46	9	65	2	7	246	14	161	30	22	19	bdl	3	2.56	9.00
WD 26B	54.54	1.286	15.12	10.91	0.165	2.62	6.31	4.11	0.67	0.2	4.07	100.00	4	116	39	421	36	46	2	3	179	114	9	27	27	19	bdl	9	2.97	9.75
WD 27	53.43	1.254	15.06	11.69	0.177	3.48	6.94	3.61	0.46	0.159	3.74	100.00	4	94	34	219	11	58	4	4	321	64	177	31	28	19	bdl	9	2.76	8.50

Key: WD = Waziristan dykes; total iron as Fe_2O_3; LOI = loss on ignition; Mg # = 100xMg/(Mg+Fe^{2+}); bdl = below detection limits.

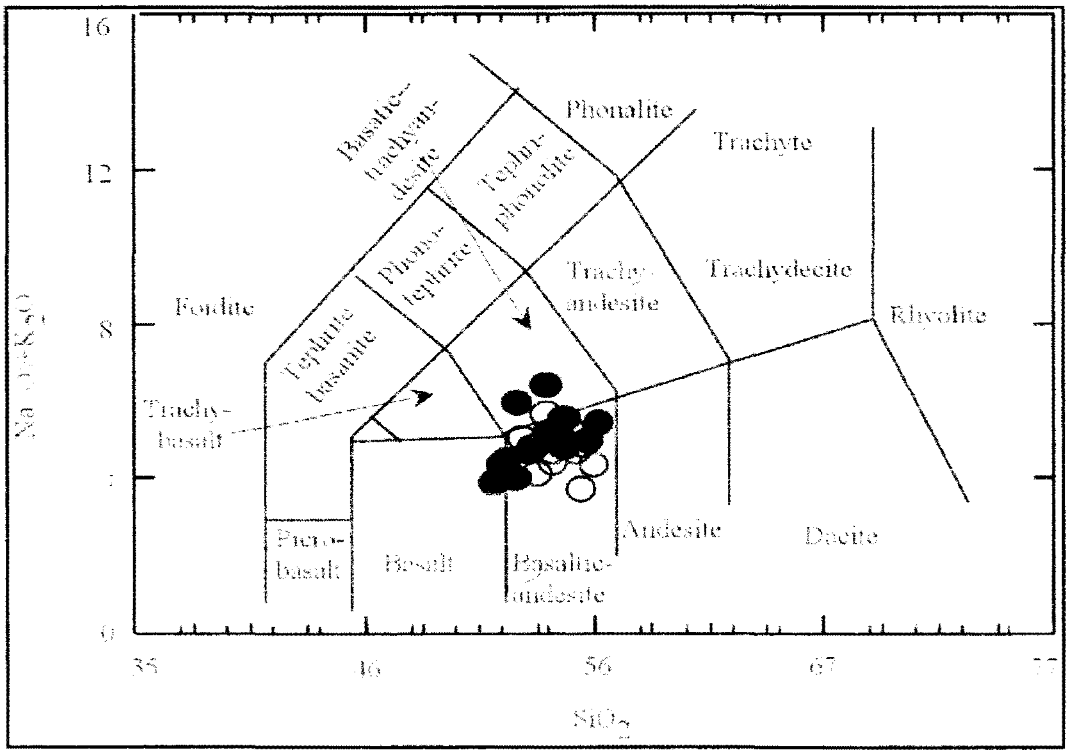

Figure 3. Silica-alkalis plot for the classification of Waziristan dykes (fields are after Le Bas et al. 1989). Open circles = sheeted dykes and filled circles = isolated dykes.

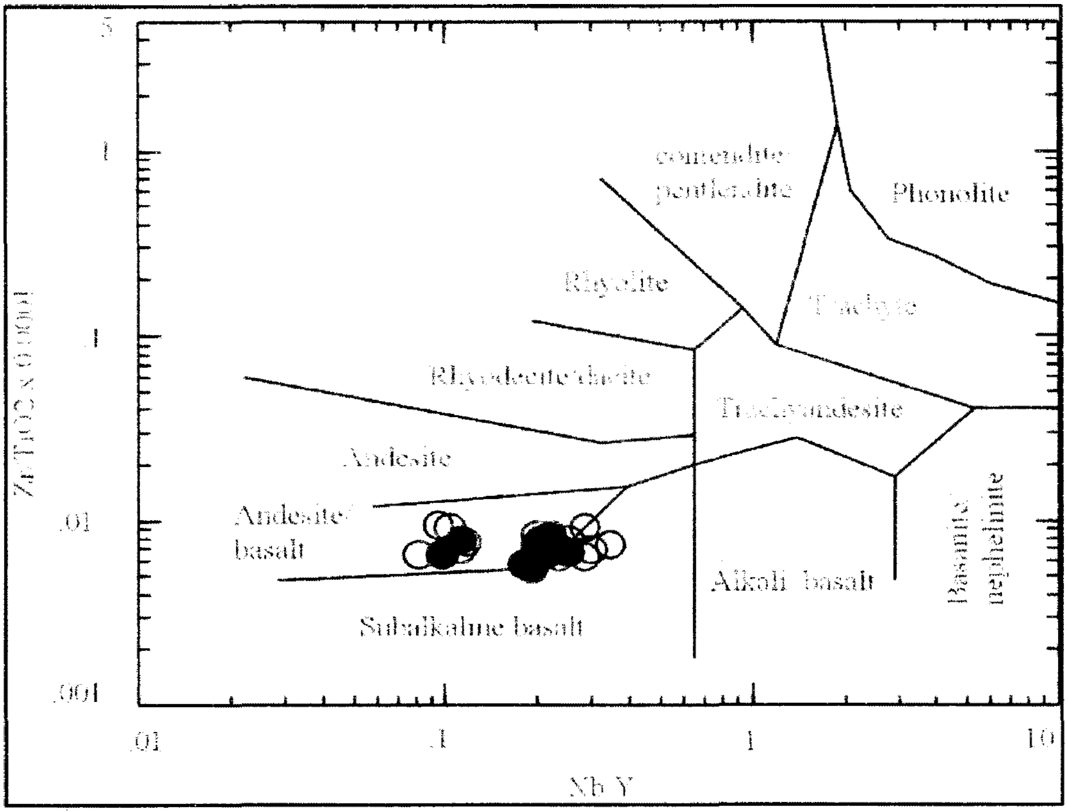

Figure 4. Nb/Y -Za/TiO$_2$ plot for the classification of Waziristan dykes (fields after Winchester and Floyd 1979). Symbols are same as in Fig. 3.

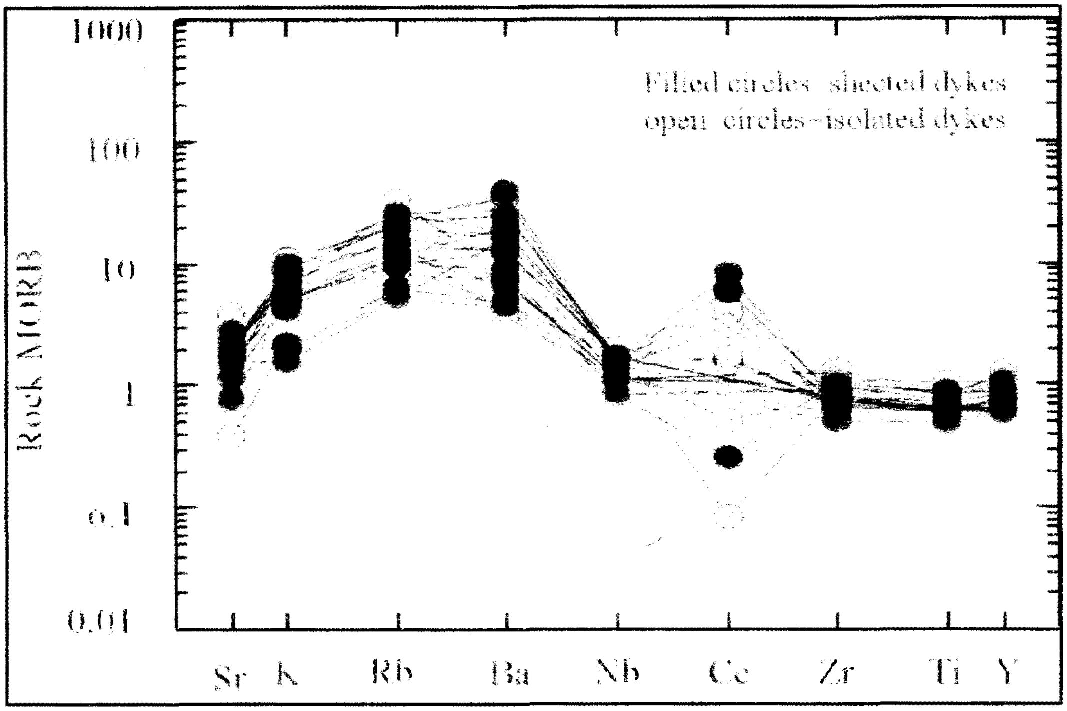

Figure 5. N. MORB normalized spidergram for the Waziristan dykes (after Pearce 1983).

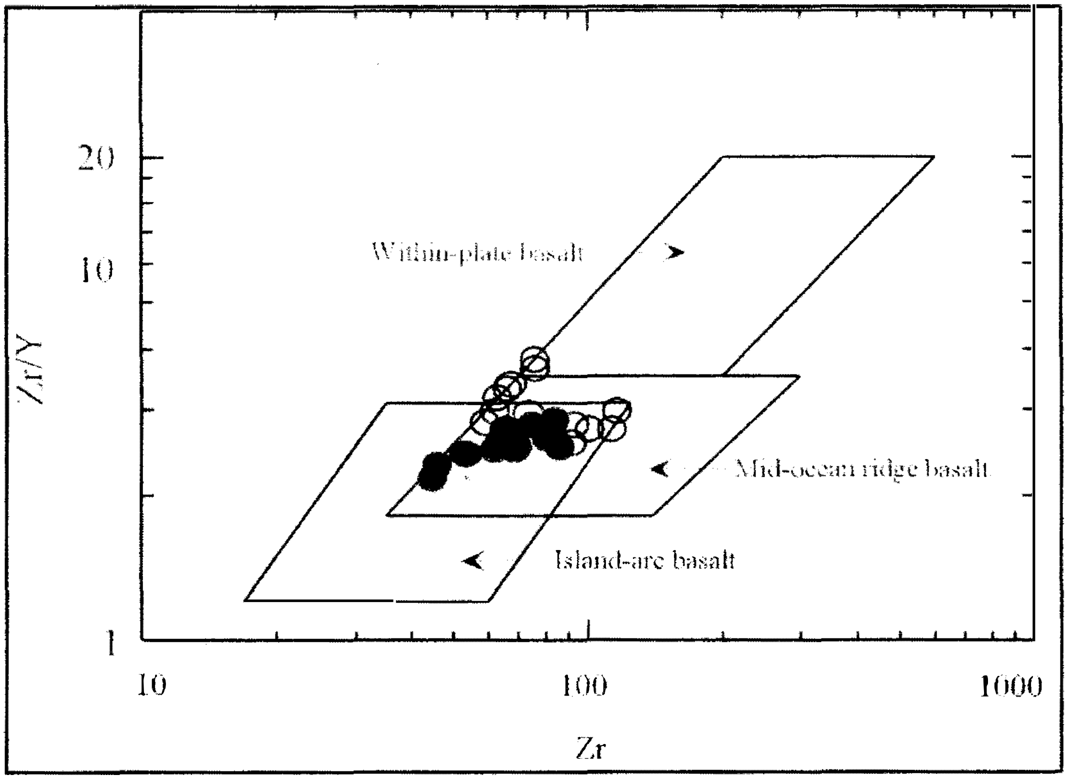

Figure 6. Zr vs Zr/Y plot for the Waziristan dykes (fields are after Pearce and Norry 1979). Symbols are same as in Fig. 3.

is replaced by biotite.

Opaque minerals include magnetite, hematite, ilmenite and leucoxene as oxides, and pyrite and chalcopyrite as sulphides. Oxides are present in almost all of the dyke samples and forms up to 10 modal %, whereas sulphides are present only in trace. Skeletal and anhedral magnetite grains identified in and around the clinopyroxene grains appear to be probably formed due to decomposition of clinopyroxene. Hematite and magnetite grains also form by alteration of pyrite and chalcopyrite. The secondary mineral assemblage (calcite, epidote, chlorite, amphibole and quartz) suggests that the dykes have been subjected to metamorphism under greenschist facies conditions.

GEOCHEMISTRY

Twenty-seven samples of the sheeted dyke swarm and isolated dykes were analysed using a Regaku X-Ray Fluorescence spectrometer (WD/XRF 3370) in the National Geoscience Research Centre, Geological Survey of Pakistan, Islamabad, Pakistan. The major element compositions were determined using glass beads formed by mixing powder with lithium tetraborate in the ratio 1:4 ratio. Total sample dissolution was achieved by melting at 1100 °C. The trace elements were determined on pellets pressed at 20 tons.

Representative analyses are given in Table 1. The dykes range in composition from basic to intermediate. They are soda-rich, potash-deficient and tholeiitic. They also have rather high Fe_2O_3, FeO^t /MgO ratios and low TiO_2 (mostly < 1.0 wt. %). Using the alkalis versus SiO_2 classification scheme of Le Bas et al. (1986), most of the dyke are basaltic-andesite in composition, and three basaltic-trachy andesites (Fig. 3). On the Zr/Ti versus Nb/Y plot of Winchester and Floyd (1977), most of the analyses plot in the andesite-basalt field, but some plot within or along the border of the field of subalkaline basalts (Fig. 4). None of the samples are classified as alkalic-basalt or trachyte, suggesting that the alkalis (Na_2O+K_2O) have been remobilized in these rocks and thus, cannot be used as a reliable petrogenetic tool. Instead, the high-field strength elements (HFSE), which are resistant to alteration, are used to specify the petrogenetic and tectonic configuration of the dykes.

The data set of the Waziristan dykes is plotted on the N-MORB-normalized spider diagram (Fig. 5) of Pearce (1983). In this plot, the dykes depict almost similar and nearly flat geochemical patterns with slight enrichment in the LILE. The higher LILE/HFSE ratios in the dykes result in prominent spikes at Rb and Ba. The higher LILE/HFSE ratios in these rocks might be due to involvement of crustal components within the subduction zone by fluids (Pearce et al. 1984, Yumul & Balce 1994, Yumul 1996). However, it is important to note that a strong negative Nb anomaly, which is characteristic of island-arc type rock suites, is not found in these dykes.

The dykes apparently share the characteristics of island-arc tholeiites (IAT) and mid-ocean ridge basalts (MORB). Use of discrimination diagrams based on high-field strength elements (Zr/Y versus Zr and TiO_2 versus Zr) demonstrates this as the analysed dykes plot essentially in the overlapping fields of the two basalt groups (Figs. 6 & 7).

Shervais (1982) used V and Ti as effective discriminates between basalts of various tectonic settings. The Waziristan dykes plot well within the back-arc basin field (Fig. 8).

DISCUSSION AND CONCLUSIONS

The basaltic-andesite to andesite composition of the dykes, with transitional characters between N. MORB and IAT, negates a typical mid-ocean ridge origin for the WO. This raises the possibility that the dykes may have originated in a marginal basin. A fore-arc origin for the ophiolite cannot be advocated due to the absence of rocks typical of fore-arcs, particularly boninites, which are common in active fore-arcs of the present day, for example, Mariana (Saunders & Tarney 1984, Alt et al. 1998). The enrichment of the LILE over the HFSE and the non-depletion of Nb in these dykes suggest involvement of crustal components along a subduction zone added to the overlying mantle by rising fluids (Fig. 5).

It is concluded that the Waziristan dykes probably formed in a back-arc basin or supra-subduction zone setting. That the majority of rocks have a N. MORB character and are intercalated with rocks of a transitional character between N. MORB and IAT, favours this setting. Rocks in such settings are produced by processes similar to those at mid-ocean ridges. However, partial melting of the mantle slab overlying the trench in high P_{H2} results in the eruption of basalts with a subduction-related signature. It is therefore expected that the rocks in

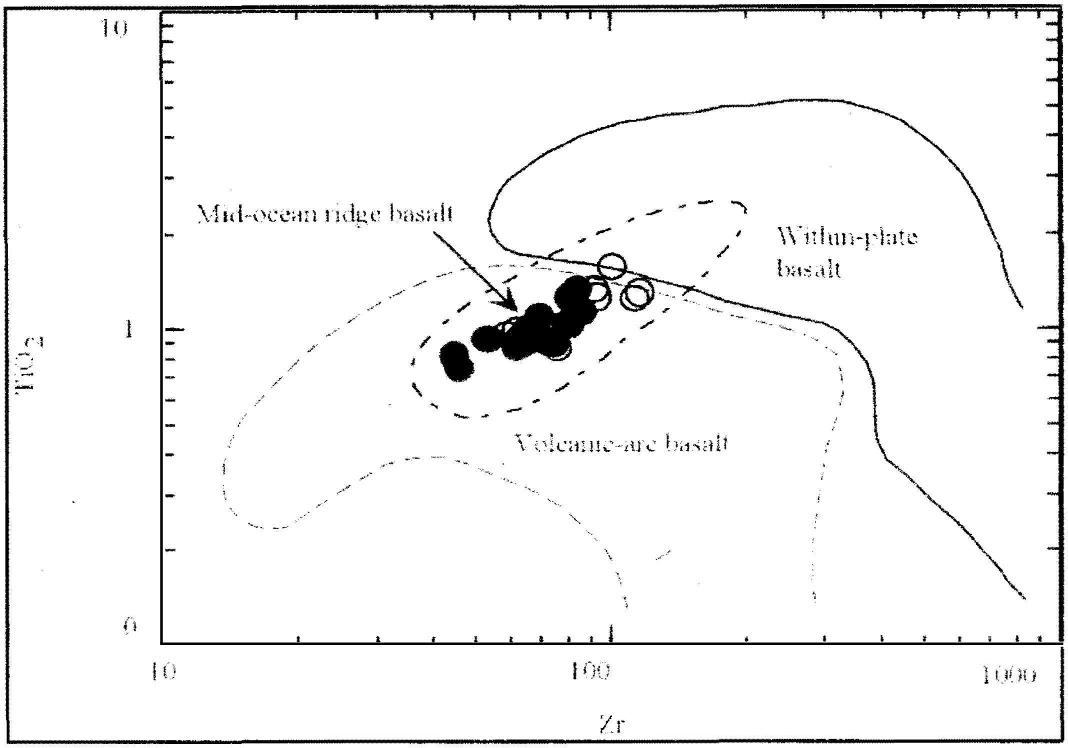

Figure 7. Zr vs. TiO_2 plot for Waziristan dykes (fields are after Pearce et al. 1979). Symbols are same as in Fig. 3)

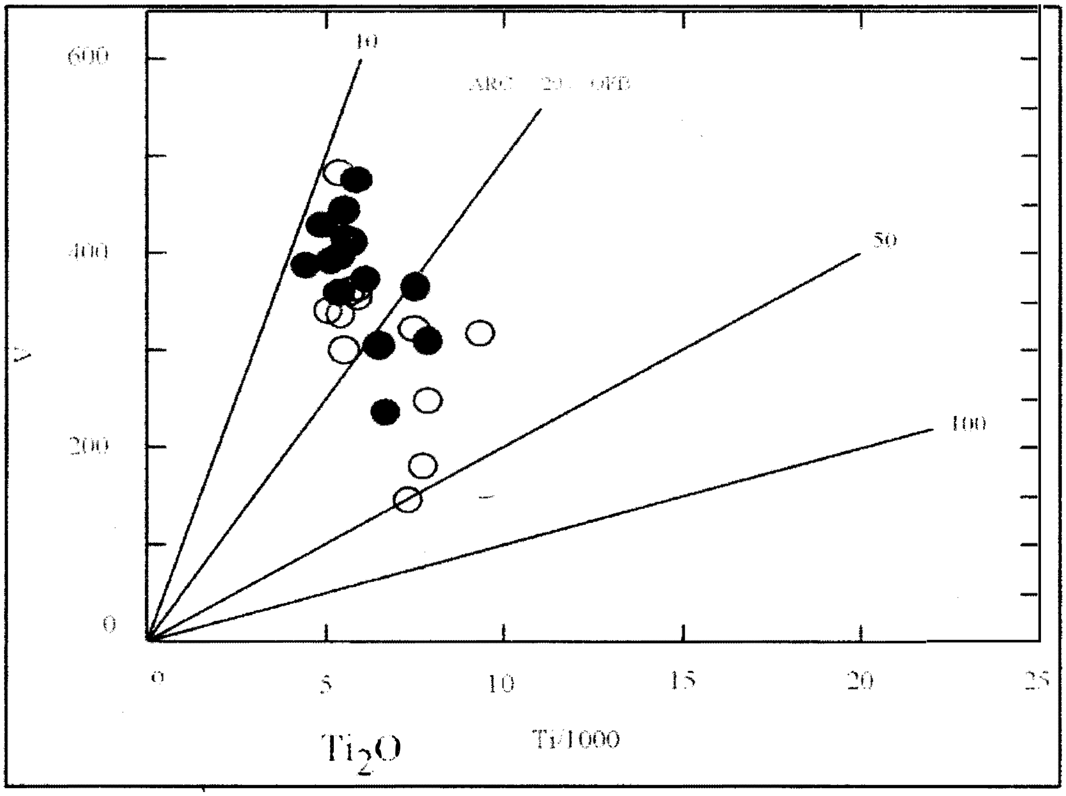

Figure 8. Ti vs. V diagram for the Waziristan dykes (fields are after Shervais 1982) Symbols are same as in Fig. 3.

marginal back-arc basins settings will include rocks with true N. MORB as well as subduction-related characteristics.

The dykes from the Waziristan Ophiolite are thus interpreted to have formed in a back-arc basin or supra-subduction zone setting (Pearce et al. 1984, Tatsumi 1986, Jones et al. 1991, Yumul & Balce 1994, Yumul 1996, Benolt et al. 1999, Chandra et al. 1999). The back-arc basin or supra-subduction zone setting is supported by some chemical characteristics of the sheeted and isolated dykes. These include 1) the transitional chemistry from MORB to island-arc rocks, 2) the V-Ti relations, 3) the enrichment in LILE (such as Ba, Rb) and depletion in HFSE (such as Zr or Ti), and low negative Nb anomaly.

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GEOLOGY, GEOCHEMISTRY AND TECTONIC SETTING OF DOLERITIC SILLS OF QILA-SAIFULLAH DISTRICT, BALOCHISTAN, PAKISTAN

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ABSTRACT

The well exposed doleritic sills at Zahir Tash the Southeastern part of Qila Saifullah District, Balochistan intruded in lower Jurassic sediments. The doleritic sills contain plagioclase, titaniferous augite and olivine, whereas apatite, magnetite and ilmenite occur as accessory minerals. These sills are predominantly alkali and Fe-tholeiites. The geochemistry and field observations suggest that these doleritic sills and the volcanic rocks of Babai (Kach) and Chinjan were formed simultaneously during Reunion hotspot magmatism. The upward movement of magma, have been intruded into the lower Jurassic sediments forming doleritic sills, whereas the rest of the magma was probably erupted as Babai and Chinjan volcanic rocks. These sills are interpreted to have been formed due to the northward movement of Indo-Pakistani plate over the active Reunion hotspot. These doleritic sills and volcanic rocks formed slightly earlier than those of the Deccan Traps. This suggests that they represent the earliest magmas generated off the rising Reunion hotspot plume, which would have been below the western Indian continental margin before the main pulse of Deccan volcanism. Therefore, the doleritic sills and Babai (Kach)-Chinjan volcanic rocks probably are the northern most and oldest of the Reunion hotspot Trail. This interpretation is in agreement with the previous interpretation according to which the hotspot had later formed the Deccan Traps and then Maldives Laccadive Ridge, Mauritius Island and finally the active Reunion hotspot

INTRODUCTION

The doleritic sills of southeastern part of Qila-Saifullah (Zahir Tash) intruded the lower Jurassic sediments (Fig.1). Previously these sills were not studied from genetic point of view. However, Ahmed (1991) studied doleritic sills exposed in Spangar peak Garkai area of Pishin District. They intruded the lower-most Jurassic sediments. On the basis of geochemistry, Ahmed (1991) proposed that they are hot spot related mildly alkaline basaltic rocks that were originated during the break-up or rifting of the

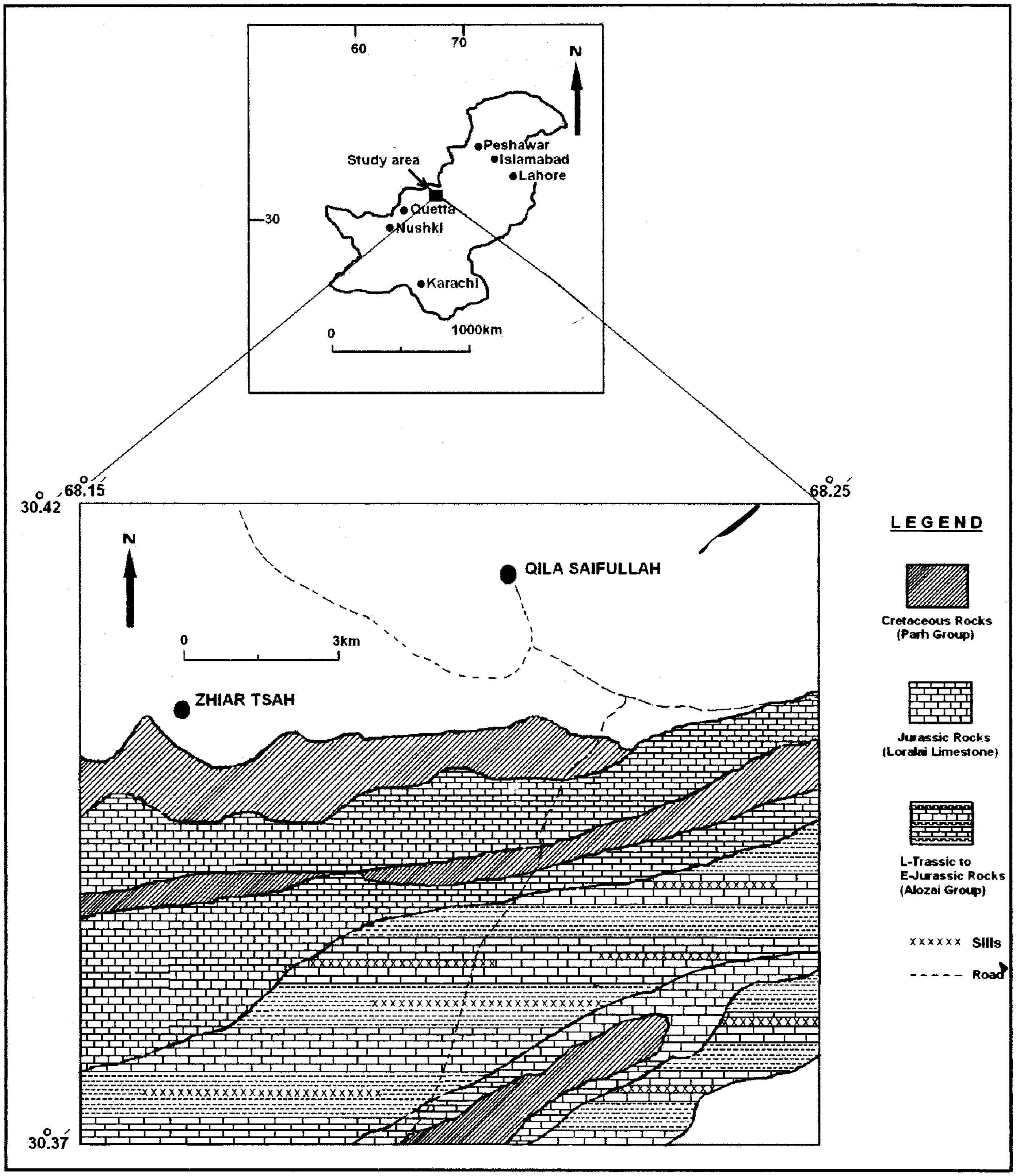

Figure 1. Geological map of the Zahir Tash, Qila-Saifullah District.

Indian plate from Gondwanaland. Such type of sills are also present beneath Muslim Bagh ophiolites (e.g. in the Nuda Taki area). Here they are present in the East and West of Muslim Bagh ophiolites, intruding the Jurassic Alozai Group. However, these sills are not present in the main body of Muslim Bagh ophiolites, melange or the metamorphic sole rocks, which indicates that they were intruded into the Indian continental sediments, before the emplacement of Muslim Bagh ophiolites. The Present study is based on geological mapping, petrography, geochemistry and field observations of Zahir Tash sills to determine the relationship with those of Babai-Chinjan Volcanic rocks and to determine the petrogenetic origin of these sills. The relationship of these sills and the Babai-Chinjan Volcanic with the Reunion hot spot has also been discussed.

FIELD OBSERVATIONS

The sills of southeastern part of Qila- Saifullah varies in thickness from 1 m to 24 m (Plate 1), and have chilled margins. The middle part of sills have coarse-grained equigranular texture. They are light gray to brownish or greenish gray on fresh surfaces. The doleritic sills trend N 80° E. They run parallel to each other and extend several kilometers laterally (Plate 2). At places, they have been structurally deformed and broken (Plate 3). In Muslim Bagh region, they may be hidden beneath the thick sequence of Muslim ophiolites.

MINERAL COMPOSITION

The doleritic sills commonly have ophitic texture. The phenocrysts of titaniferous augite, olivine plagioclase and magnetite are common, whereas the ground mass consists of augite, olivine, plagioclase, magnetite and ilmenite. Many of the samples consists of intergrown plagioclase, augite, magnetite, and rarely olivine and hornblende. Ilmenite and apatite are present as accessory minerals The textural and compositional characteristics of major rock forming minerals i.e. plagioclase, pyroxene and olivine are described below.

Plagioclase: They are intermediate, ranging in composition from $An_{55}Ab_{45}$ to $An_{85}Ab_{15}$, and are present as phenocrysts, whereas in some samples it shows zoning (An_{55-80} at cores to An_{30-40} at rims). The plagioclase forms 54% to 62% of the whole rock. Some grains have been altered to carbonates, zoisite (p-4) and epidote.

Pyroxene: Titaniferous aluminous pyroxenes ($TiO_{0.03-0.16}$ $AL_{0.09-0.45}$) are present both as phenocrysts and as the ground mass. The phenocrysts are strongly zoned with purplish brown rims. Augite is also present in these rocks. Large phenocrysts of titaniferous augite are altered into chlorite and serpentine (Plate 5).

Olivine: The characteristics of olivines are different in the studied samples. In alkaline rocks, it consists of medium-sized phenocrysts and are often strongly zoned with more iron-rich rims. Whereas, in tholeiitic sills it consists of commonly zoned phenocrysts of comparatively larger size that show reaction rims of orthopyroxene. Some olivine grains have been altered to serpentine and iddingsite.

WHOLE ROCK CHEMISTRY

Six samples were analyzed for major oxides using ED-XRF-NES-500, Horipa, at the Geoscience Laboratories, Islamabad. (Table 1). The data were plotted on SiO_2 versus Na_2O+K_2O (alkali) diagram (Fig. 2a) of Le Base, (1987) for rock classification which revealed that four samples trachybasalt and two are basalt. The alkali vs. silica plot of Schwarzar and Rogers (1974) indicate that the four samples were originated from mildly alkaline magma whereas the remaining two samples belong to tholeiitic magma (Fig. 2b). When plotted in SiO_2 versus FeO/MgO (after Miyashiro, 1974) all the samples plot in the field of tholeiite basalt (Fig.3). When plotted on the triangular tectono-discrimination diagram (Fig.4) involving TiO_2-MnO-P_2O_5 (after Mullen 1983), three fall in the field of oceanic island basalt (OIB), two plot in the field of transition between OIB and calc-alkaline basalt (CAB) and one fall in the field of CAB. With reference to the classification of magma series most of these samples plot either in the field of alkaline series or in tholeiitic series. Fe- tholeiite and alkaline basalt rocks are characteristic of hot spot (McCormick 1985, Khan 1994, Gnos et al. 1998, Courtillot et al. 1986, Bonneville et al. 1988, and Khan et al. 1998). The major elements chemistry of the doleritic sills show that they are related to hot spot, and have more or less similar composition as those of Babai volcanic rocks of Kach and volcanic rocks of Chinjan. (Khan, W. et al. 1999). The absence of calc-alkaline rocks in Parh related volcanics

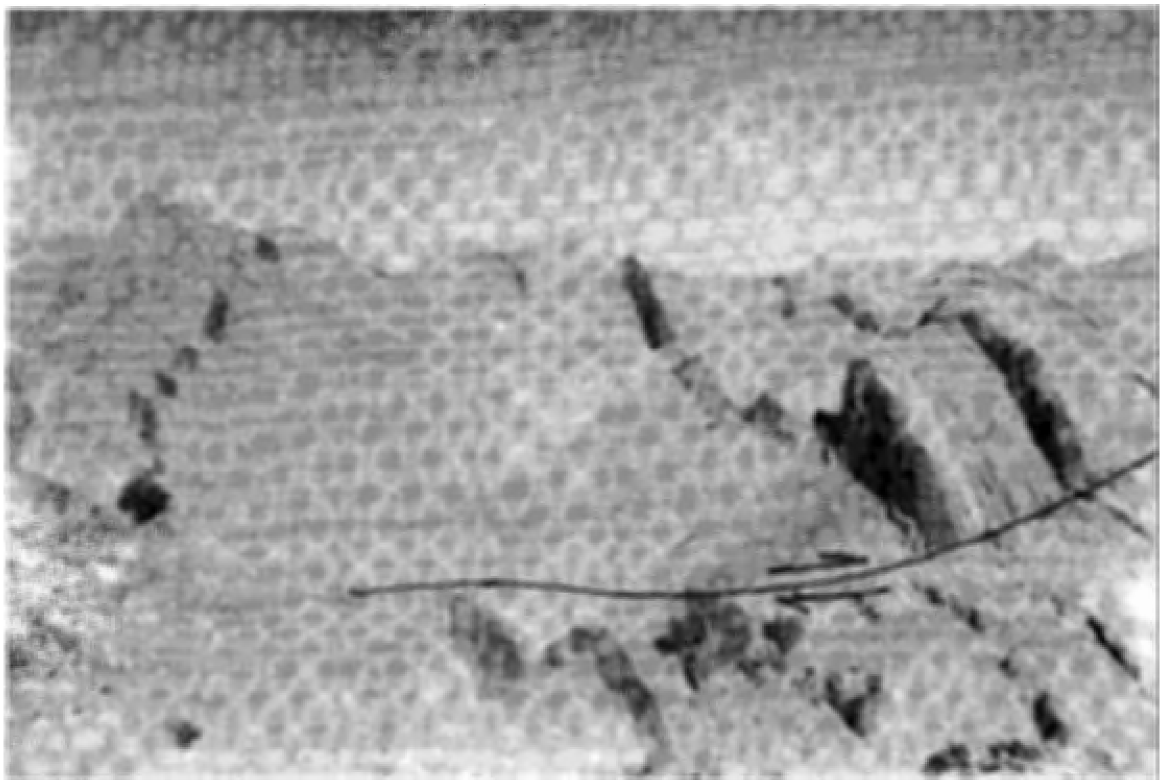

Plate 1. Photograph showing doleritic sill of Southeastren part of Qila Saifullah intruded in the Lower Jurassic sediments.

Plate 2. Photograph showing doleritic sills running parallel to each other.

Plate 3. Photograph showing structurally deformed doleritic sills.

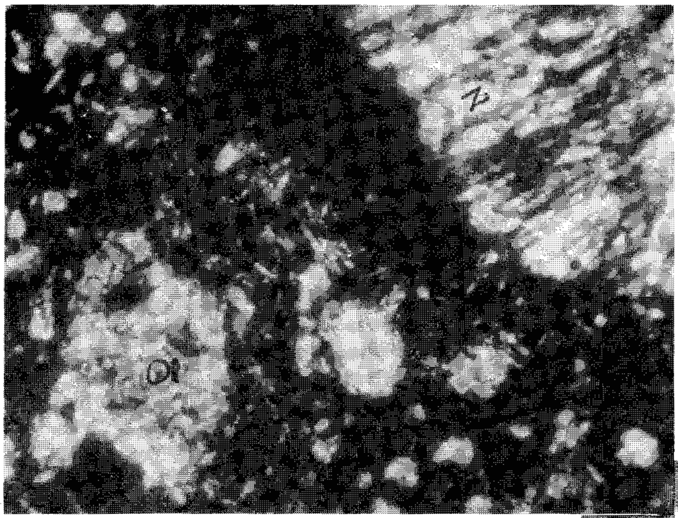

Plate 4. Photograph showing plagioclase alteration into zoisite (Z).

Plate 5. Photograph showing pyroxene alteration into Chlorite and Serpentine.

Table-1 Results of the geochemical analysis of doleritic sills of southeastern Qila Saifullah.

Sample	S - 1	S - 2	S - 3	S - 4	S - 5	S – 6
SiO_2	50.11	51.50	50.00	50.04	50.90	49.72
TiO_2	2.38	1.57	2.05	2.28	2.73	1.53
Al_2O_3	14.47	15.75	13.85	16.15	13.14	16.05
FeO^{total}	10.92	11.34	11.54	9.98	11.59	10.54
MnO	0.52	0.26	0.26	0.21	0.15	0.25
MgO	6.46	4.72	6.67	7.74	7.57	6.62
CaO	8.00	7.09	8.77	7.74	8.45	7.13
Na_2O	4.60	4.62	4.62	3.61	3.92	4.58
K_2O	1.05	1.57	1.54	0.57	0.31	2.04
P_2O_5	1.50	1.57	0.72	1.39	1.24	1.53
Total	100.01	101.99	103.02	103.71	105.00	105.99
%AN	28.78	31.03	28.88	46.14	34.38	33.28
Quartz	0.00	0.00	0.00	1.42	1.65	0.00
Orthoclase	6.20	9.28	9.06	3.34	1.82	12.01
Albite	38.75	38.97	30.73	30.43	32.99	34.36
Anorthite	15.66	17.53	12.48	26.07	17.29	17.14
Nepheline	0.00	0.00	4.43	0.00	0.00	2.34
Diopside	11.40	5.99	21.29	2.47	13.16	6.66
Hypersthene	5.27	9.94	0.00	22.23	18.91	0.00
Olivine	9.10	7.13	11.29	0.00	0.00	16.66
Magnetite	5.67	4.55	5.19	5.96	6.17	4.42
Ilmenite	4.50	2.98	3.88	4.88	5.16	2.89
Apatite	3.46	3.64	1.66	3.21	2.85	3.53
FeO	10.57	10.80	11.25	9.67	11.25	10.35
Mg	51.32	42.63	50.75	58.04	53.82	52.84

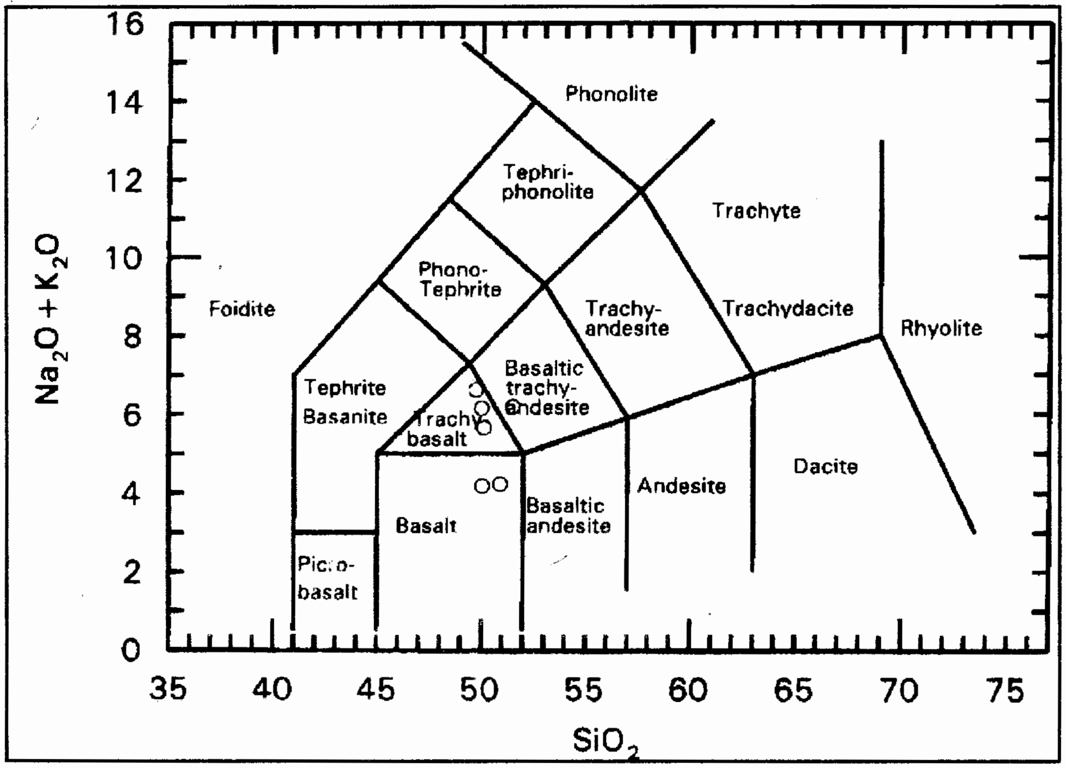

Figure 2a. Alkalis (Na_2O +K_2O) versus SiO_2 for the doleritic sills of southeastern Qila-Saifullah (after Le Base et al 1987)

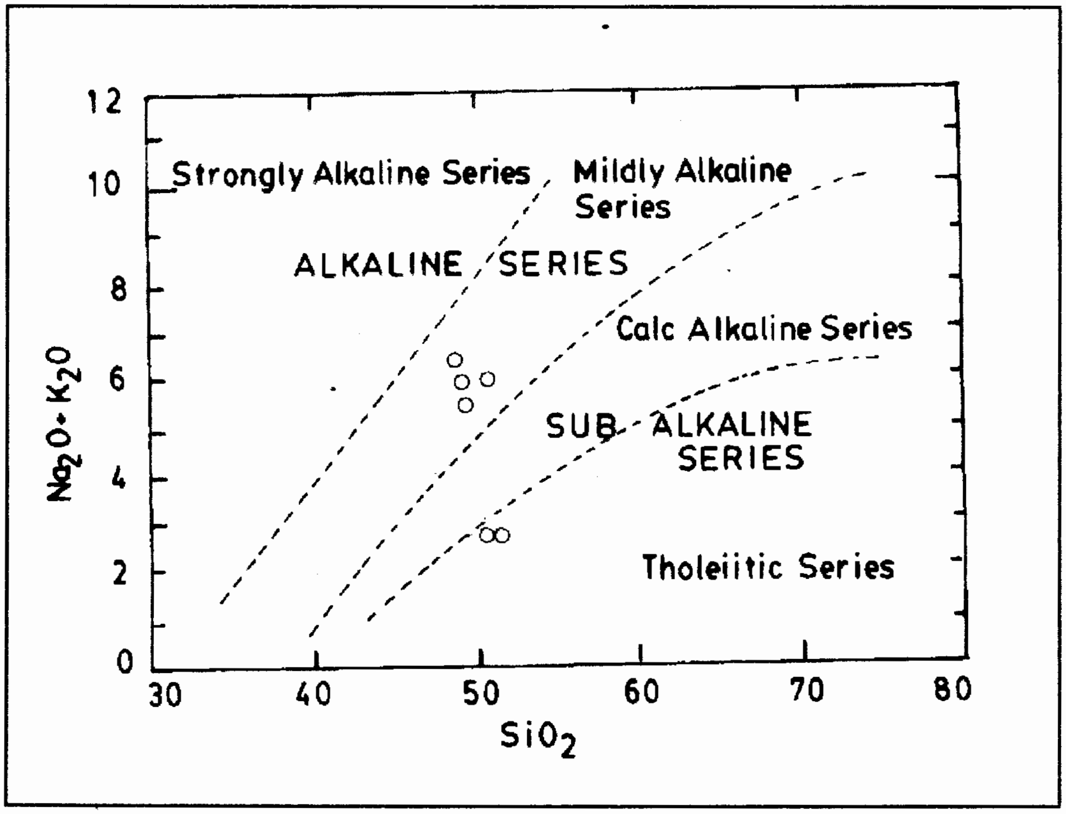

Figure 2b. Alkalis versus SiO_2 for the doleritic sills of southeastern Qila-Saifullah (after Schawarzer and Rogers, 1974).

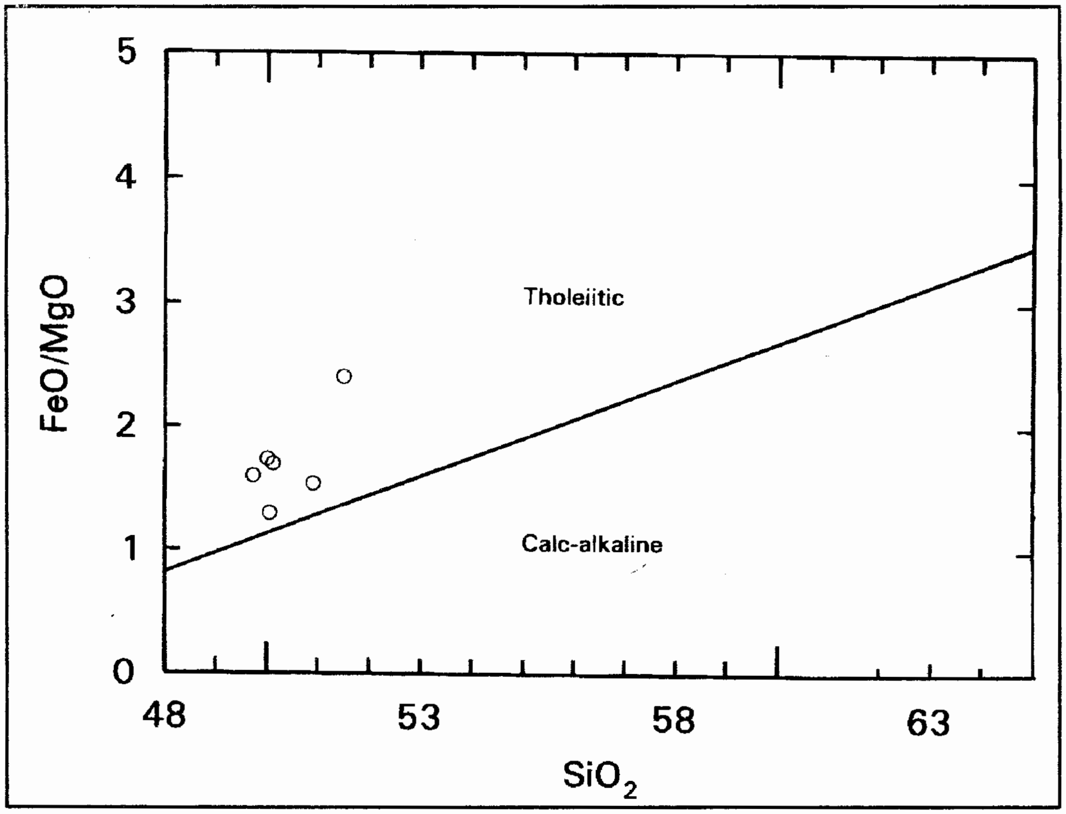

Figure 3. SiO_2 versus Fe/MgO plot for doleritic sills of southeastern Qila-Saifullah (after Miyashiro 1974).

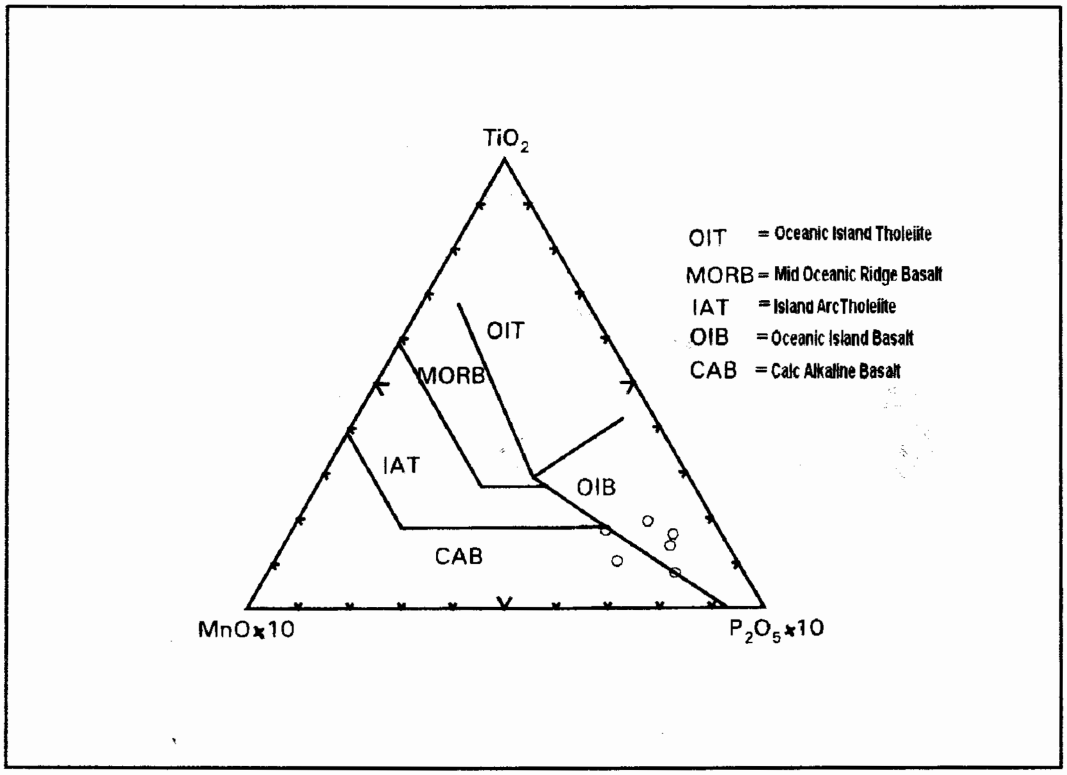

Figure 4. TiO_2 - MnO- P_2O_5 tectonomagmatic discrimination diagram of southeastern part of Qila- Saifullah (after Mullen 1983).

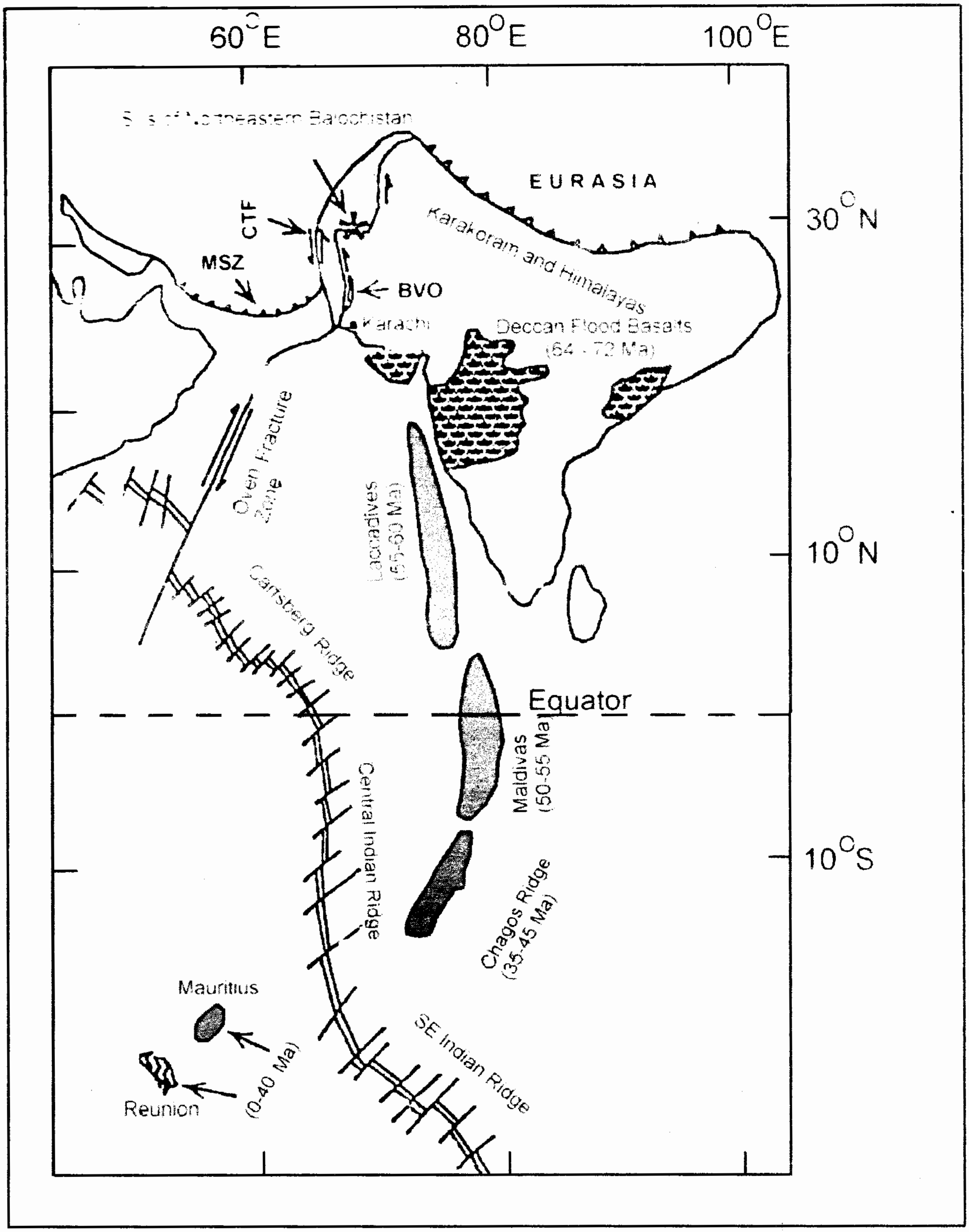

Figure 5. Regional map showing the major tectonic zones, continental flood basalt of the Deccan (India), location of the study area and present position of Reunion hot spot. CTF= Chaman Transform fault, MSZ= Makran subduction zone, BVO=Bela volcanics and affiliates (after Khan, W. et al. 1999).

(Khan, W. et al 1999) and in Babai volcanics of Kach-Chinjan areas (Khan, A. et al 1999) strongly suggest that these volcanics including the doleritic sills of Allozai Group were formed during hotspot magmatism.

DISCUSSION

Magmas originated in different tectonic environments have specific geochemical characteristics, so geochemical data of the igneous rocks can provide significant clues for the recognition of past tectonic environments (Wilson 1991). However, the geochemical recognition of some magma is more complex, when they share characteristics of two or more tectonic settings.

The field characteristics and relationship of the studied sills to surrounding rocks and their similarity of composition to those of Babai and Chinjan volcanic rocks indicate their origin during hotspot magmatism. McCormick (1985), and Khan (1994) proposed that the volcanic rocks of Babai and Chinjan are related to Reunion hot spot presently under Reunion Island in the Indian ocean. The Reunion plume head at the base of the Indo-Pakistan continental lithosphere has been proposed as a most probable source for the generation of the Deccan Traps of India (Duncan and Hargraves 1990, Valdamme and Courtillot et al. 1990, Duncan 1990). Continued movement of Indian plate over this hot spot generated the Chagos-Ridge and Maldives Laccadive Ridge (Fig.6; Duncan 1990). With a few exceptions, the age of the volcanic rocks decrease linearly from the Deccan Traps (64-72 Ma) to Reunion Island (0.2 Ma) (Royer et al. 1991, Morgan 1981, Fleitout et al. 1989).

The Babai and Chinjan volcanic rocks (Khan [1994] named these volcanic rocks as the Parh group basalts) which lie along the northward projection of the Reunion hot spot trail north of the Deccan Traps (Fig.5), have been dated by Khan (1994), which yield ages of 65.7 to 75.9 Ma by the ^{39}Ar-Ar^{40} method. When the geochemistry and age of these volcanic rocks are considered along with the paleogeographic position of the Indo-Pakistani continent during Late Cretaceous time, it appears that the Babai and Chinjan volcanic rocks are related to the Reunion hot spot and may represent its earliest and northern-most magmatism. As far as the doleritic, sills are concerned. The field observations and geochemistry indicate that they may have been intruded at the same time, when Reunion hot spot formed the Babai and Chinjan volcanic rocks. In this context, it seems possibly that the ages of sills are same as those of Babai-Chinjan volcanic rocks i.e. 65.7 to 75.9 Ma.

CONCLUSION

The field observations and geochemistry indicate that the doleritic sills of Southeastern part of Qila- Saifullah are related to the Reunion hot spot. The doleritic sills formed the northern-most and oldest rocks of Reunion hot spot trail as Babai and Chinjan volcanic rocks. The sills are neither present in the Muslim Bagh ophiolites nor in the matamorphic sole rocks, which indicates that they have been generated before the emplacement of Muslim Bagh ophiolites. These doleritic sills, and Babai-Chinjan volcanic rocks were intruded into the Indian continental margin. After the intrusion these sills became part of the Indian plate and traveled thousands of km from its originated location to its present position.

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BENEFICIATION OF DILBAND IRON ORE (PART-1)

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ABSTRACT

Huge deposits of iron ore have recently been discovered in Dilband Area of District Mastung, Kalat Division, Balochistan. Investigations of beneficiation of the ore by floatation were carried out with a view to develop a process for up-gradation of the ore for its utilization in iron/steel making. The ore was characterized for its mineralogy and structure by chemical analysis and X-Ray diffraction (XRD) techniques which revealed that the ore primarily consists of α-Fe_2O_3 with quartz as major impurity phase. Other associated impurities as determined by XRD are Al_2O_3 and carbonates of Ca, Mg, Na and K.

The ore containing ~38% iron has been upgraded to a concentrate assaying 44% iron with a weight recovery of 78%. The floatation studies were carried out on particle size of -200# using starch as depressant. Other reagents used were: fuel oil, oleic acid (as collector) and polypropylene glycol (as froher) at pH of 11 in 35% pulp density.

INTRODUCTION

Research on the floatation of iron ore started in early 30's (e.g. Crabtree and Vincent 1962 and references therein) and it was mostly focused on ores containing gangue (Houot 1983). A host of researchers (Bunge and Pocrnich 1969, Jacobs et al 1978, Major 1974, Smith and Sougstad 1962, Dicks and Morrow 1978) later proposed a variety of approaches in the floatation techniques which resulted in two different methods of beneficiation of iron ore by floatation (Houot 1983); a) direct floatation of iron oxide and b) indirect or reverse floatation.

The direct floatation present in the ore utilizes a series of reagents such as petroleum sulphonates, fatty acids and hydroxamates as collectors to float the iron oxide in the ore while depressing all the gangue minerals (Crabtree and Vincent 1962). In the reverse floatation, on the other hand, froth containing the gangue minerals is produced using various collectors, most important of which are amines (Jacobs and Colombo 1981). Regardless of the method of floatation, it is an established fact that the slimes (particles finer than 10μ) generated during the grinding operation seriously hamper the floatation process (Jain 1987). The presence of slimes not only makes the process uneconomic by increasing the consumption of reagents, it also interferes with conditioning of the surfaces of the ore particles (Iwasaki 1985). Desliming of the ore prior to the floatation thus, becomes an unavoidable step in the beneficiation of the iron ores.

GEOLOGY AND HISTORY OF DILBAND IRON ORE DEPOSIT

The Kalat plateau which is comprised of almost flat-lying strata with an average height of 2000 metres is a unique physiographic feature of the area. Towards the northern edge of this plateau lies another feature of flattish topography with an average altitude of 1500 metres. This has been termed as Dilband plateau by the Geological Survey of Pakistan where 1-7 m thick ironstone bed is found to lie on top of the Jurassic Chiltan Limestone throughout the area. This ironstone bed was ignored in the past as being an uneconomic residual laterite bed marking the unconformity, which, of late, has gained immense importance. This is because recent investigations carried out by Geological Survey of Pakistan have proved that this iron mineralization is a potential economic ore deposit of the ironstone type.

The Dilband Plateau is underlain by the Jurassic, Cretaceous, and Tertiary stratigraphic sequences and the Quaternary deposits. It has been folded and faulted more than once The ironsone bed underlies the Cretaceous Parh Group. The area was mapped by the Hunting Survey Corporation (1960) on 1:253,440 scale. They mapped and described the ironstone bed as an unconformity surface between the Jurassic Chiltan Limestone and Cretaceous Sember Formation. About 10 years later, Geological Survey of Pakistan mapped the area on 1:50,000 scale in 1969-1970. But until then the idea of this ferruginous bed to be an economic iron ore deposit was not conceived. Balochistan Development Authority working in late 80s reported that it was large deposit of bauxite-a source of aluminum metal. However, later field studies and chemical assays carried out by G.S.P. at Geoscience Lab., Islamabad proved that no significant amount of alumina was present. Instead, they reported the presence of considerable amount of iron oxide. On the basis of the same field and laboratory information they have called this ferruginous bed "ironstone" (Abbas, et al., 1998).

This area can be reached from Mangochar, a small town with a population of ~7000 people, by means of a 70 km long truckable shingle road. The town of Mangochar is located on the main RCD Highway, approximately 100 km south of Quetta and 580 km north of Karachi. Since Dilband iron ore deposit is easily accessible, has simple mineralogy and good grade, large reserves and open cast mineability (Abbas et al. 1998) it can be developed as an indigenous resource to supply iron ore to the only steel mill of the country at Karachi. Exploitation of all other known iron ore deposits, such as those of Chichali, Langrial, Chilghazi, and Pachinkoh has been proved to be economically unfeasible because of one reason or the other. Thus, if Dilband iron ore deposit is developed, it is expected Pakistan would be able to save substantial amounts of foreign exchange in future which are spent for the purchase of iron ore from abroad for its steel mill.

This study has been carried out as a pilot project to beneficiate the iron ore from Dilband Ironstone Deposits and to recommend a feasible process of beneficiation for commercial purposes. The average sample of five ore samples from the area are used during this project and the results are reported here.

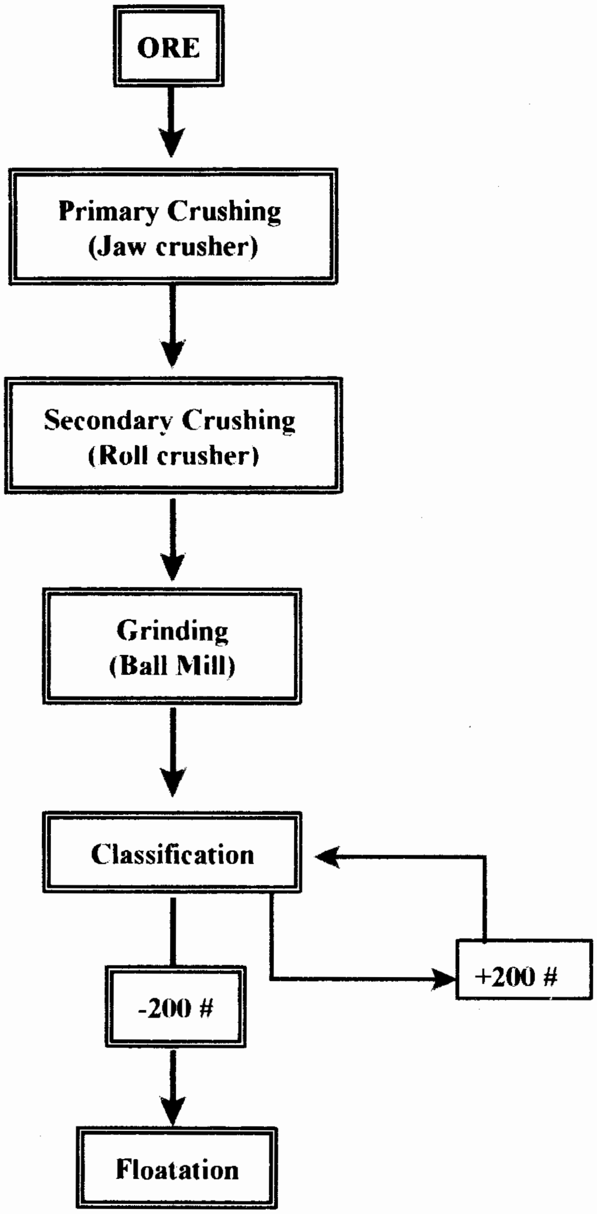
CHARACTERIZATION OF THE ORE

The chemical analysis of the as-received ore samples was carried out using standard gravimetric methods as well as atomic absorption spectrometry. Table-1 presents the results of average chemical

Table-1. Chemical analysis of Dilband Iron Ore. LOI; loss on Ignition.

Major Oxides	Fe_2O_3 + FeO	CaO	SiO_2	MgO	Al_2O_3	P_2O_5	Na_2O	K_2O	LoI	Total
Wt. Percent	57	7.79	18	2.45	3.13	0.1	0.23	0.11	7.86	96.67

FLOW CHART-1
SAMPLE PREPARATION



FLOW CHART-2
FLOATATION OF IRON ORE

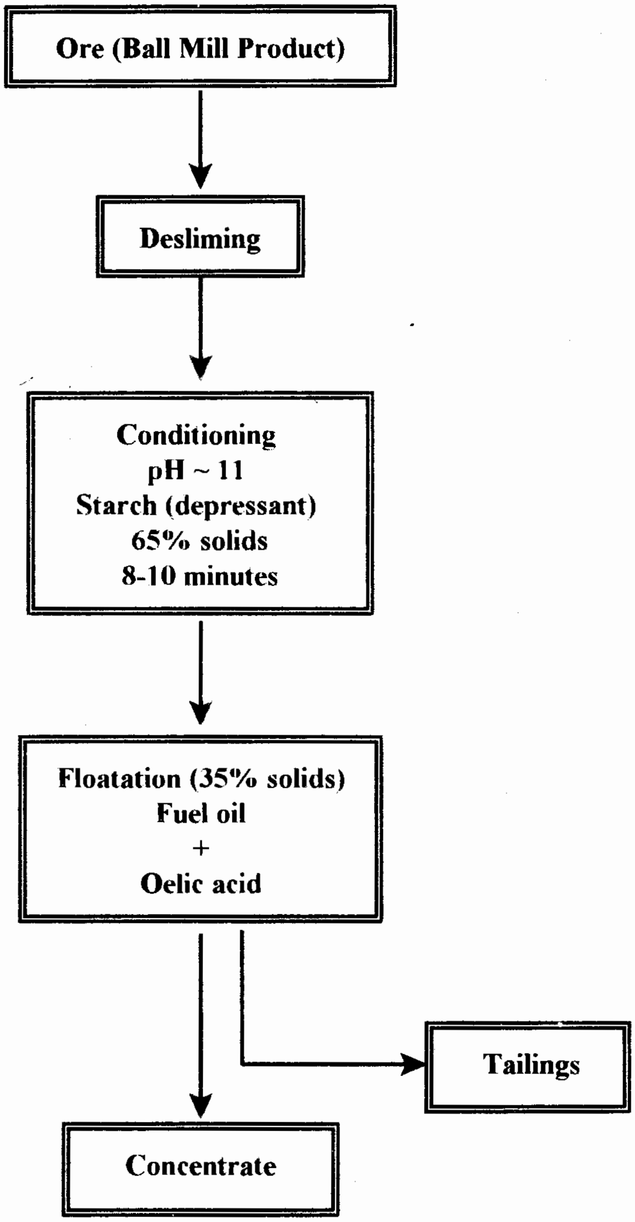


Table 2. Size analysis of Feed to the Ball Mill

Mesh Size	Weight (grams)	Weight %	Commulative Wt. % Retained	Commulative Wt. % Passing
+ 8 #	181.1	44.28	44.28	55.72
+15 #	78.2	19.12	63.40	36.60
+25 #	79.5	19.44	82.84	17.16
+60 #	51.7	12.64	95.48	4.52
+100 #	5.2	1.27	96.75	3.25
+150 #	3.1	0.75	97.50	2.50
+200 #	1.5	0.36	97.86	2.14
- 200 #	8.6	2.14	100	0.0

analysis of five samples from different location of the ore deposit. Previous workers (Kazmi and Abbas 2001, Abbas et al 1998), however, reported higher (35-48%) iron content from the Dilband iron ore deposit. X-ray diffraction was also carried out on powdered samples of the ore in a Debye-Sherrer camera of 11.46 cm diameter using Cr Kα radiation on a constant voltage X-ray generator having ratings of 35 kv and 15mA. The analysis of the powder photograph revealed that the sample mainly consisted of hematite (α-Fe_2O_3) with quartz (SiO_2) as major impurity base. Other associated impurities being Al_2O_3 and carbonates of Ca, Mg, Na, and K.

ORE PREPARATION

The preparation of the ore for floatation studies included primary crushing (in jaw crusher) followed by intermediate crushing by a roll crusher. The product of intermediate crushing was subjected to wet grinding in a ball mill for 40 minutes at 60% solids. The screen analysis of the ball mill feed is given in Table-2. The ball mill product was classified with a 200# screen. The oversize was re-ground in the ball mill until -200# size (Flow Chart No. 1). The ground ore was subjected to desliming using starch as depressant for iron oxide. After the desliming, the pulp density was subjected to 56% solids for subsequent floatation.

FLOATATION OF THE ORE

The success of the process of froth floatation, besides other factors depends upon the grind size. The purpose of optimization of grind size is to get the maximum separation of the gangue from the ore. During this investigation, the grind size of -200# was found adequate to liberate over 85% of the gangue minerals from the ore. Excessive grinding although resulted in better liberation but at the same time generated considerable proportions of slimes which resulted in the inhibition of floatation.

The other major factor in floatation of the ores is selection of collectors and pH. During current investigation, oelic acid (collector) yielded best results at a pH close to 11. Any deviation in the pH (on either side) had an adverse effect on the yield.

The reverse floatation was carried out in a Denver floatation machine using a 2 litre floatation cell. Conditioning of the pulp was done for 8-10 minutes with the addition of starch (140 gm/ton) fuel oil (90 gm/ton) and oelic acid (160 gm/ton) at a pH at a pH close to 11. After the conditioning, the pulp density was adjusted to ~35% solids followed by floatation at 100 rpm impeller speed. A small quantity of frother (polypropylene glycol) was also used to stabilize the froth. The froth thus, generated as well as the concentrate were dried in ovens and weighed. The floatation process adopted during this investigation is summarized in Flow Chart-2. The weigh recovery during floatation was 78%. The chemical analysis of the concentrate revealed that the iron content of the concentrate was 44% whereas, the froth mainly consisted of gangue minerals such as carbonates and silica.

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Short Communication

DISCOVERY OF A MISSING LINK IN WHALE'S EVOLUTION

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Paleontologists dream about discovering morphologic intermediates in the fossil records, such discoveries are rare and exciting when they occur. The discovery of *Rodhocetus balochistanensis*- a 47 million years old specie of Whale from the Eocene rocks of Balochistan is also exciting because it is among the oldest known archaeocetes (Primitive whales). Archaeocetes are best known from shallow marine sedimentary rocks of early to middle Eocene deposited in the eastern Tethys sea in what is now India and Pakistan. The newly discovered fossil (was found in October 2000) come from a transitional bed at the top of the Habib Rahi Formation and base of the Domanda Formation (Table 1) in Lakha Kach Syncline near Rakhni, (30°05'09"N Latitude and 69°47'39"E Longitude) District Barkhan, Balochistan, Pakistan.

Whales are marine mammals grouped in the order Cetacea. Most mammals live on land and the fossil record of early mammals is terrestrial. Thus it has long been reasonable to infer that the origin of whales involved an evolutionary transition from land to sea. Most Cetaceans lack hind limbs, but recovery of reduced tarsal bones in middle to late Eocene (37 Ma) archaeocetes. *Basilosaurus* and Dorudon from Egypt in 1989 raised hope that earlier archaeocetes might retain astralagus that could be compared with artiodactyls and Mesonychids. Ankle bones (Astragalus and Cuboid) are the most diagnostic elements of the Artiodactyl skeletons. Artiodactyla (Greek *artios*, even numbered, and *dactylos*, finger or toe) are named for the even number 2 or 4 of fingers and toes. *Rodhocetus balochistanensis* is the oldest whale having virtually complete hands and feet which were previously not found in the geological record. It has an astragalus and cuboid in the ankle with characteristics diagnostic of artiodactyla.

Molicular Biologists in 1952, by DNA and molecular sequencing studies, supported close relationship of whales to Antiodactyls. But due to the available fossil record most morphologists and Paleontologists favoured a mesonychid origin of whales. The present discovery resolves a long standing disagreement between Paleontologists and molecular Biologists and proves that whales evolved from early artiodactyls and suggests that hippos may be the closest living relatives of whales.

The present discovery of hands and feet in *Rodhocetus balohistanensis* invites functional explanations for their use in locomotion, and is expected to produce high interest in local and global scientific communities for opening up several new vistas of research like functional morphology, evolution and phylogeny of whales.

First report on the discovery of this missing link has already been published (Fig. 1) by Gingerich et al (2001). More interesting results are expected to come with further research. Geological Survey of Pakistan and the University of Michigan (USA) are working together on Whale research project for the last two decades under the supervision of Professor Philip D. Gingerich of Museum of Paleontology, University of Michigan (USA). The author of this report has been involved in the project since beginning and has the credit of locating these fossils in the field. He has also spent four months at the Museum of Paleontology, University of Michigan in early 2001 and participated in the identification of different pieces of the fossil.

Table 1. Stratigraphic position of the *Rodhocetus balochistanensis* found in the Eocene rocks of the northeastern Balochistan.

Age	Thickness (m)	Name of the Stratigraphic Unit	Lithology
EOCENE	280	Darazinda Formation	Shale with minor coquina beds
	20	Pir Koh Formation	Limestone, marl and shale
	210	Domanda Formation	Shale, gypsum and limestone
	Whale Fossil *(Rodhocetus balochistanensis)*		
	30	Habib Rahi Formation	Limestone and Shale
	60	Baska Formation	Shale, gypsum, limestone and siltstone
	250	Drug Formation	Limestone, shale and marl
	300	Toi Formation	Sandstone, shale and limestone
	500	Shaheed Ghat Formation	Shale with minor marl

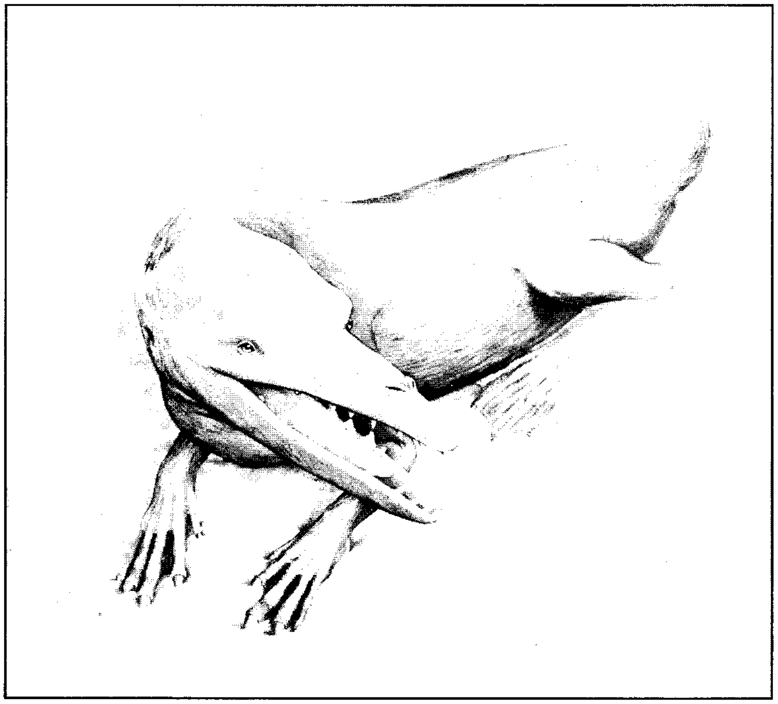

Figure 1. *Rodhocetus balochistanensis*. Age; 47 Ma old, estimated body weight; 450 kg, type locality; Lakha Kach Syncline near Rakhni, (30°05'09"N 69°47'39"E) District Barkhan, Balochistan, Pakistan. (Gingerich et al 2001).

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[1]GEOLOGY OF PART OF SOUTHWESTERN MAKRAN, PAKISTAN

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ABSTRACT

Southern Makran-a convergent margin between Arabian and Eurasian plates, is part of the Makran Accretionary Complex that has developed throughout the Cenozoic. The structural and stratigraphic history involves many phases of development. The dominant structural style in southwestern Makran is one of east-west trending, very long, narrow, asymmetric to overturned isoclinal anticlines separated by broader asymmetric synclines. Thrust and strike slip faults are common throughout the area mostly cutting the Pre-Pleistocene strata, whereas normal faults, though uncommon, are restricted to post-Pleistocene strata which shows effects of tensional forces, at least in certain parts of the subduction zone.

The deposition of Panjgur turbidites started in Middle Miocene on a vast deep sea fan which originated from the east. Sediments were supplied from uplands raised by the collision of Indian and Eurasian plates. Sediment transport was towards the west and sandstones found along an axial belt of nearly 400 km show little change in texture or bedding characteristics. Four packages of lithofacies have been identified in Panjgur turbidites namely thick bedded turbidite package, thin bedded turbidite package, chaotic mudstones package, and mudtone package. Thick bedded turbidites were deposited from flows of a higher sediment concentration (high density) by rapid suspension settling (T_a) and upper-flow-regime plane-bed traction (T_b), whereas thin bedded turbidites were deposited from flows of lower concentration (low density) by lower-flow regime traction (T_c and T_d) and suspension settling (T_e). The cahotic mudstone packages were deposited by cohesive slumps and debris flows that resulted from gravitational remobilization of

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previously deposited sediments and rocks. The mudstones packages are interpreted to have been deposited from mud-dominated, low density turbidity currents and from hemipelagic settling. These mudstone packages indicate relatively calm and deeper environment of deposition. These packages are repeated several times randomly and their thickness varies from place to place.

Very thin-bedded mudstone and fine grained sandstone with a low (<30%) percentage of sandstone is the most characteristic lithology of Late Miocene Parkini Mudstone. The sedimentological characters of the Parkini Mudstone indicate its deposition from low density turbidity currents in mid to upper slope environment. Early to Late Miocene Talar Formation is composed of sandstone, shale, mudstone, shelly limestone and minor channel conglomerates. Although there are number of idetifiable facies in the Talar Formation, only two lithofacies packages are dominat. They are Sandstone-Mudstone facies package and Sandstone facies package which are interpreted to have been deposited in outer shelf to near shore environment of the fluvial dominated delta front system. Detrital modes of limited samples of Talar Formation suggest derivation of sediments from mixed provenance of recycled orogen and arc. This interpretation is inconclusive because of smaller number of samples analyzed during present study.

During Early to Middle Pleistocene the Chatti Mudstone, which is dominantly composed of mudstone with minor interbeds of siltstone, fine grained sandstone, and marl, was deposited in outer shelf to inner shelf environment. During late Pliestocene the massive mudsones of Ormara Formation were deposited in inner self to near shore environment which was capped by near shore sandstone, conglomerate and coquina lag deposits of late Pliestocene Jiwani Formation.

Beautifully exposed active and extinct mud volcanoes along the Makran coast have been built by gas charged water escaping to the surface. Previously only active mud volcanoes were reported but this study, for the first time, reports the presence of a basin which is tentatively named as "Kappar Basin" located northeast of Gawadar. In "Kappar Basin" a large number(more than 200) of extinct mud volcanoes crop out. A thorough study of these extinct mud volcanoes, coupled with the active ones, may provide valuable information about the history of the location and development of week zones, e.g. fault planes, in the Makran Accretionary Complex.

The hydrocarbon potential of Makran is yet to be fully evaluated. Good reservoir/source assemblages and large structural features with good trapping conditions are present in the offshore, as well as onshore. Appropriate source material seems to be present and reasonable thermal maturation seems to have occurred. Convergent plate-margin geometry seems to have provided pathways for the migration of oil and gas. The petroleum prospects of the Makran region should, therefore, be not written-off following the failure of the so far negligible exploration efforts made in such a vast terrain. The recently reported presence of a thick gas-charged layer under the Makran continental margin promises further petroleum exploration activities in the area.

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[1]FACIES ANALYSIS OF CRETACEOUS PAB SANDSTONE, KIRTHER FOLDBELT, PAKISTAN

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ABSTRACT

The Pab Formation, well exposed in the N-S trending Kirther Fold-belt of western Pakistan, is 150-250m thick and dominated by medium to thick-bedded quartzose sandstones with subordinate argillites and marls, all deposited on the western continental margin of the Indian Plate during the late Cretaceous (Maastrichtian). Seven detailed sedimentologic logs, measured along a strike-wise extent of some 290 km, provide data for facies analysis, dispersal patterns and process/environmental interpretations.

Eight main facies, grouped into four facies associations, have been distinguished: Facies 1 (graded sandstones) was deposited by turbidity flows; Facies 2 (argillites with sandstone interbeds) was formed by a combination of hemipelagic processes and turbidity flows; Facies 3 (massive sandstones) was deposited either by dumping from dense suspensions or by freezing of highly concentrated traction flows, with subsequent minor wave reworking in a few cases; Facies 4 (bioturbated sandstones) probably was created by episodic supply of the sands in dense suspensions and subsequent pervasive burrowing by a variety of organisms; Facies 5 (hummocky sandstones) results from both transport and reworking by high energy storms and oscillatory waves or, rarely, from remolding of the tops of turbidites by high-energy, unidirectional, 'clear-water' flows; Facies 6 (parallel- to cross-laminated sandstones) is the product of upper plane-bed tractional flows with high rates of bedload transport; Facies 7 (cross-bedded sandstones) also attests to strong tractional flows; Facies 8 (slumped units) is associated with sandstone dykes and sills: the slumping and remobilization are attributed to local slope-failure.

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The four facies associations comprise: (a) Shoreface Association – dominated by facies 7, with subordinate facies 6, 5 and 4 and formed in an inner shelf or delta-fed ramp setting; (b) Shelfal Delta Lobe Association"– characterised by facies 3, with subordinate facies 4, 5, 2, 1 and 8 and deposited below fair-weather wave base in mid- shelf or ramp areas; (c) Deeper Shelf or Ramp Association – mainly comprising facies 3, accompanied by facies 2 and 5, and effectively a distal equivalent of the Shelfal Lobe Association; (d) Submarine Fan Lobe Association – almost exclusively made up of facies 1 and attributed to relatively deep water settings. The vertical and lateral distribution of facies reveals overall upwards-shallowing in the Pab Formation and also demonstrates that two different depositional systems were operating in the southern and northern parts of the study areas. Submarine fan lobe deposits formed in the south while shallow marine sands were being deposited in the north, where the evolution of sediment-gravity flows proceeds from east to west, following a broadly down-slope pattern consecutively from facies 7 (cross-bedded sandstone) to facies 1 (graded sandstone). Paleoflow in the northern system was predominantly to the W and NW and sandstone petrography suggests supply from the uplifting Indian basement to the east, feeding a broad, west sloping shelf or clastic ramp, probably delta –fed and characterised by Mutti-type 'shelf-lobes'.

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[1]STRATIGRAPHY ALONG THE K-T BOUNDARY, WESTERN SULAIMAN FOLD BELT, PAKISTAN

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ABSTRACT

The stratigraphy along the K-T Boundary (upper Cretaceous to Paleocene) of the western Sulaiman Fold Belt, that is mostly exposed in Balochistan, has been studied. The field and limited laboratory studies indicate that the sedimentation in the Middle Indus Basin (which is part of the Sulaiman Fold Belt) began during the Triassic. The Cretaceous sequence in the basin comprises two shallowing upward sequences. The Parh Limestone cap the first shallowing upward sequence. The formation was deposited during Turonian to Early Campanian and predominantly consists of limestone that was deposited in an outer shelf to deeper water setting. The Campanian to Maastrichtian Mughal Kot Formation represents the lowest unit of the upper sequence. The formation consists of argillaceous limestone, calcareous claystone with locally abundant sandstone intercalations. The deposition of Mughal Kot formation initiated by the development of a deep water basin whose depo-center lies in the eastern part of the fold belt. The formation shallows upward and is represented by inner shelf facies of the Fort Munroo Formation in the upper part. The Maastrichtian Pab Formation represents the final regressive phase of the Cretaceous sequence. The formation, to the east, consist predominantly of the sandstone with subordinate intercalations of siltstone, shale, conglomerate and pebble sandstone. The western part consists essentially of sandstone, but the percentages of claystone and conglomerate are much higher. The formation was mainly deposited in a marginal marine setting with intermittent interruptions by fluvial deposits. The Paleocene exhibit highly variable lateral facies. The Paleocene Dungan Formation is developed in the western part and consists of dominantly limestone. It was

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mainly deposited in shelf setting; slope, reef and high energy deposits occur locally.

Thin section study of the Parh Limestone Formation suggests that micrite and pelagic foraminifera are the predominant constituent of the limestone. The rock is classified as mudstone to packstone. *Globotruncana* is the most abundant fauna. The limestone exclusively comprises calcite mineral. The diagenetic processes include neomorphism and intra skeletal cavity cementation. The formation lack porosity. The petrographic characteristic of the Dungan Limestone include the occurrence of pelagic and benthic fauna, calcareous cement, micritic, and packstone to wackstone texture. The benthic and pelagic fauna dominantly comprises Nummulites, Discocyclinids, Alveolina, Miliolids and globorotalia.

The nature of the K-T boundary in the Sulaiman Fold Belt is different than those reported from other parts of the World, as this boundary may not be as prominent in the field as envisaged. In most cases this boundary is either covered under alluvium/scree or is not exposed at the surface. Spera Ragha and Chapper Rift valley are the two promising sites where the K-T boundary may be located provided that more detailed palaeontological, geochemical and radiometric studies are carried out.

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[1]GEOCHEMISTRY AND DIAGENESIS OF CRETACEOUS SEMBAR FORMATION, PART OF WESTERN SULAIMAN FOLD BELT, PAKISTAN

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ABSTRACT

The Early Cretaceous (to Lower Jurassic) Sembar Formation of the the Western Sulaiman Fold Belt, Pakistan, has long been considered as one of the possible source rocks for the hydrocarbon reservoirs of the Upper Indus Basin. Considering its importance as a possible source rock, the shales of the Sembar Formation have been studied for the purpose of understanding and exploring the geochemical signatures of these sediments.

The chemical and mineralogical studies of the shales from four locations, revealed that on average the shales are composed of 42.5±7.40 wt% SiO_2, 15.52±3.1 wt% Al_2O_3, 0.67±0.13 wt% TiO_2, 10.40±5.34 wt% CaO, 2.03±1.05 wt% MgO, 2.86±0.64 wt% K_2O, 0.46±0.14 wt% Na_2O, 1.39±0.77 wt% FeO, 2.02±0.67 wt% Fe_2O_3 and 0.13±0.04 wt% P_2O_5. These shales also contains 194ppm Mn, 65ppm Ni, 39ppm Cu, 84ppm Zn, 343ppm Sr, 275ppm Ba, 23ppm Pb, 100ppm Cr, 155ppm Rb, 25ppm Y, 130ppm Zr, 15ppm Nb, and 147ppm V as average amounts of trace elements. The chemical analysis also revealed that in these sediments the average calcite content is 19.66 wt%, the average quartz content is 15.60 wt%, average pyrite content is 2.6wt%, average organic carbon is 3.31 wt %, average organic sulphur is 0.15 wt %, and average inorganic sulphur is 1.40 wt %.

The analysis of the geochemical data indicate that the Sembar shale is

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[1] *Abstract of the dissertation submitted by M.Z. Kakar for the degree of Master of Philosophy (University of Balochistan) under the research supervision of M.A. Farooqui.*

comparatively less siliceous in the north i.e. in Mekhtar and Loralai areas as compared to Murree Brewry and Gawani Nala areas (near Quetta) in the south. The quartz and clay minerals have positive correlation with eachother. Higher calcite/(Qtz+Clay) ratio in the Murree Brewry and Gawani Nala samples indicate significant biogenic activities in these areas during the deposition of the Sembar Formation. There is a positive generally linear correlation between CaO and CO_2, and between CO_2 and CaO+MgO, but on the other hand Calcite and Quartz+Clay has a negative correlation. Based on the values of the degree of pyritization it appears that most of the shales of the Sembar Formation were deposited in an aerobic water conditions in normal marine environment.

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ANNUAL REPORT
(Jan. to Dec. 2002)

NATIONAL CENTRE OF EXCELLENCE IN MINERALOGY, QUETTA

ACADEMIC STAFF

Director

Dr. Akhtar Mohammad Kassi, Professor of Geology, University of Balochistan continued working as Acting Director, C.E.M. until September 2002. After receiving Fulbright Postdoc Fellowship, he proceeded to Muncie, (Indianan, U.S.A.) and Dr. Adbul Salam Khan took over the acting charge of the Director. The appointment of a permanent Director (by the Federal Government) is still awaited.

Professors	Specialization	Date of Joining C.E.M.
Abdul Salam Khan	Sedimentology, Ph.D. (U.K.)	01-Jan-1998

Associate Professors

1.	Jawed Ahmad	Clay Mineralogy, M.Phil. (Univ. of Balochistan)	01-Apr-1980
2.	Khalid Mahmood	Ophiolites, Ph.D. (France)	05-Nov-1989
3.	Muhammad Ahmed Farooqui	Sedimentary Geology and Tectonics, Ph.D. (U.S.A.)	05-Nov-1989

Dr. Shamim Ahmed Siddiqui, Associate Professor, left C.E.M. in early 2002, and joined Karachi University as Professor of Geology. Similarly Dr. Mehrab Khan, Assistant Professor, also left C.E.M. in May 2002 and joined the Geology Department, Balochistan University as Associate Professor.

ADMINISTRATIVE/TECHNICAL STAFF

	Name	Designation	Date of joining C.E.M.
1.	Mirza Manzoor Ahmad	Accounts Officer	07-May-1980
2.	Syed Shahabuddin	Administrative Officer	28-May-1977
3.	Khushnood Ahmad Siddiqui	Senior Technician	13-Jul-1976
4.	Abdul Ghafoor	Assistant Librarian	02-May-1985
5.	Lal Mohammad	Superintendent	12-May-1973
6.	Hussainuddin	Photographer	16-Jun-1981
7.	Ghalib Shaheen	Stenographer	17-Jul-1985

	Name	Designation	Date of joining C.E.M.
8.	Ahmad Khan Mangi	Draughtsman	01-Jul-1981
9.	Musa Khan	Laboratory Supervisor	20-Aug-1977
10.	Sher Hassan	Store Keeper	22-Aug-1977
11.	Mohammad Anwar	Assistant	18-Sep-1973
12.	Juma Khan	Assistant	12-Jun-1985
13.	Ikram Ali	Laboratory Assistant	13-Sep-2000
14.	Hameedullah	Laboratory Assistant	09-Dec-2000
15.	Abdul Malik	Senior Clerk	28-Apr-1987
16.	Manzoor Ahmad	Junior Clerk	26-Apr-1995
17.	Mohammad Tariq	Junior Clerk	09-Dec-2000
18.	Ali Mohammad	Driver	17-Jul-1984
19.	Saleh Mohammad	Driver	18-Aug-1990
20.	Ghulam Rasool	Junior Mechanic	20-Aug-1977
21.	Mohammad Rafiq	Peon *(Naib Qasid)*	12-Oct-1978
22.	Sikandar Khan	Peon *(Naib Qasid)*	30-Apr-1976
23.	Atta Mohammad	Peon *(Naib Qasid)*	25-Mar-1986
24.	Shabbir Ahmed	Peon *(Naib Qasid)*	01-Aug-1998
25.	Abdul Salam	Peon *(Naib Qasid)*	12-Dec-2000
26.	Mohammad Din	Peon *(Naib Qasid)*	12-Dec-2000
27.	Murad Baksh	Peon *(Naib Qasid)*	15-Nov-2000
28.	Abdul Wadood	Watchman *(Chowkidar)*	26-Jan-1992
29.	Amir Bakhsh	Watchman *(Chowkidar)*	11-Sep-2000
30.	Nazir Masih	Janitor	01-Apr-1977
31.	Muhammad Basharat	Loader	04-Sept-2002

ACADEMIC/RESEARCH ACTIVITIES

During the year 2002 the following M.Phil. students completed their thesis work:

	Student	Supervisor	Co-Supervisor	Thesis Title	Status
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.	Successfully defended the thesis. Degree has been awarded.
2	Khawar Sohail	Abdul Salam Khan	Muhammad Ahmed Farooqui	Petrology, sedimentology and diagenesis of Miocene-Pliocene Hinglaj Formation, District Khuzdar and Bela Balochistan.	Successfully defended the thesis. Degree has been awarded
3	Mohammad Sarwar	Akhtar M. Kassi	Abdul Salam Khan	Geology of the area west of Spera Ragha, District Ziarat, Balochistan.	Successfully defended the thesis. Degree has been awarded
4	Muhammad Umar	Abdul Salam Khan	Akhtar M. Kassi	Sedimentological studies of Upper Cretaceous Pab Sandstone, Kirther Fold Belt Balochistan.	Successfully defended the thesis. Degree has been awarded
5.	Mohammad Zahir Kakar	Muhammad Ahmed Farooqui	Din Mohammad Kakar	Depositional environment and Diagenesis of Lr. Cretaceous Sembar Fm. Balochistan.	Thesis approved. Waiting for final oral Exams.

	Student	Supervisor	Co-Supervisor	Thesis Title	Status
6.	Syed Ashrafuddin	Muhammad Ahmed Farooqui	Mehrab Khan	Study of K-T Boundary in the western Sulaiman Foldbelt, Pakistan.	Thesis approved. Waiting for final oral Exams.
7.	Arif Ali	Jawed Ahmad	Mobasher Aftab	Assessment of groundwater budget of Mangocher Valley, Balochistan.	Thesis submitted. Waiting for evaluation and defense
8.	Abdul Razique	Shamim Ahmed Siddiqi	--	Copper mineralization in Chaghi metal-logenic province, Balochistan.	Thesis submitted. Waiting for evaluation and final oral Exams.

By the end of December 2002, the C.E.M had the following Ph.D. and M.Phil. students working on various aspects of the geology;

	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 Khan	Jawed Ahmad	Petrography and depositional environment of Ghazij Formation (Eocene) Balochistan.
			M. PHIL. PROJECTS	
1.	Mohammad Rahim Jan	Muhammad Ahmed Farooqui	--	Geology and mineral resources of part of Makran Coast, Balochistan.
2.	Muhammad Ishaq	Mehrab Khan	Khalid Mehmood	Metamorphic rocks associated with Muslim Bagh Ophiolites, Balochistan.
3.	Mushtaq Ahmad Pathan	Khalid Mehmood	Mehrab Khan	Origin and mode of occurrence of chromites in the mantle section of Muslim Bagh Ophiolites..
4.	Razzak Abdul Manan	Abdul Salam Khan	Akhtar M. Kassi	Iron ore deposits of Dilband area, Kalat.
5.	Shah Maqsood Ahmed	Khalid Mehmood	Mehrab Khan	The nature and structural studies of mafic intrusion in the Mantle section of Splai Tor Ghar Ophiolites of Muslimbagh, Pakistan.
6.	Aimal Khan	Akhtar M. Kassi	Abdul Salam Khan	Sedimentology and Petrology of the Oligocene Panjgoor Formation, southwest Makran, Pakistan.
7.	Muhammad Afzal	Abdul Salam Khan	Akhtar M. Kassi	Sedimentology of Upper Cretaceous Moghal Kot Formation, Sulaiman foldbelt, Balochistan, Pakistan.
8.	Hassan Shaheed	Mr. Jawed Ahmed	Abdul Salam Khan	Studies of Bauxite and Laterite as economically exploitable mineral, existing in the vicinity (east to west) from Chauteer-Ziarat and Umai areas of Ziarat District Balochistan, Pakistan.

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 M. Kassi	A. Salam Khan, M. A. Farooqui and Din Mohammad Kakar	UGC
4	Metamorphic rocks associated with ophiolites	Mehrab Khan	Khalid Mahmood	UGC
5	Geology of the Cretaceous-Paleocene succession, Sulaiman Thrust Belt, Pakistan	Akhtar M. Kassi	A. Salam Khan, M.A. Farooqui	UGC
6	Petrology and sedimentology of coal bearing Ghazij Formation, Balochistan	Abdul Salam Khan	Jawed Ahmed	UGC

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

M.A. Farooqui returned from Utah State University, Logan, (USA) in July 2002 after availing the Fulbright Grant for postdoctoral research. His research project was about the inorganic geochemical aspects of Miocene Diz Formation, Makran and their relationship with hydrocarbon potential of fine grained clastic rocks of Makran Accretionary Prism.

After staying one year at University of Cradiff, U.K. Khalid Mahmood also returned in October 2002. He availed the postdoctoral Fellowship by the Commonwealth Organization (Association of Commonwealth Universities) for the year 2001-2002 and studied the geochemistry and structural features of Muslimbagh ophiolites.

Akhtar Muhammad Kassi, proceeded to U.S.A. (Muncie, Indiana) in October 2002 after receiving Fulbright Postdoctoral Research Grant for the year 2002-2003. He has planned to carry out research on sedimentology and geochemistry of the Panjgoor Formation, Makran, during this fellowship.

Compiled by M.A. Farooqui

INSTRUCTIONS FOR AUTHORS

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