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On the Cover Close up view of the layered gabbro from Bela Ophiolite, west of Ornach Cross, District Khuzdar. Layering is characterised by alternating plagioclase rich, and pyroxene-olivine rich with sharp boundaries that range from one to ten cm. *Photo courtesy of Mehrab Khan and Khalid Mahmood.*

Address for correspondence	Editor, *Acta Mineralogica Pakistanica*, Centre of Excellence in Mineralogy, University of Balochistan, Quetta. Pakistan. Phone No. (081) 9211323, Fax No. (081) 9211285 cem@minerals.qta.sdnpk.undp.org cem@uob.qta.sdnpk.undp.org
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LITHOSTRATIGRAPHY OF THE CRETACEOUS - PALEOCENE SUCCESSION IN QUETTA REGION, PAKISTAN

AKHTAR MUHAMMAD KASSI[1], DIN MUHAMMAD KAKER[1], ABDUL SALAM KHAN[2], MUHAMMAD UMAR[1] AND ABDUL TAWAB KHAN[1]

[1] Department of Geology, University of Balochistan, Quetta Pakistan
[2] Centre of Excellence in Mineralogy, University of Balochistan, Quetta Pakistan

ABSTRACT

The Upper Cretaceous succession is highly variable, laterally and vertically, in northeast Balochistan. In Quetta region six distinct lithostratigraphic units and four disconformities are present between the Jurassic Chiltan Limestone and Paleocene Dungan Formation. These lithostratigraphic units include the Sembar Formation, Goru Formation, Parh Limestone, Hanna Lake limestone, Fort Munro Formation and Pab Sandstone. The Hanna Lake limestone, which is the lateral equivalent of the Mughal Kot and Bibai Formations, is recognized and named as a distinct lithostratigraphic unit for the first time in Quetta region. It is a dull brownish grey and thick bedded limestone bounded disconformably by the underlying Parh Limestone and overlying Fort Munro Formation. The Pab Sandstone, which has not been recognized before in Quetta region, is present and overlies disconformably the Fort Munro Formation in the Zharai and Hanna Lake sections. However, it is missing in the Marree Brewery and Gwani Nala sections.

INTRODUCTION

The Quetta area lies at the junction of the Kirther and Sulaiman ranges (Fig. 1). The area has been studied by the Hunting Survey Corporation (1960) as part of their reconnaissance study of West Pakistan. Later, the area was visited by various workers (Allemann 1979, Aubry et al. 1991, Mohsin et al. 1991, Kakar and Kassi 1997) and geology students of various universities. Most of them, except Allemann (1979) and Aubry et al. (1991), have studied the area without contributing to the lithostratigraphy or biostratigraphy of the area and seem to have accepted lithostratigraphic units of the Hunting Survey Corporation (1960). During our visit to the Zharai, Hanna Lake and Marree Brewery sections we discovered two lithostratigraphic units and disconformities within the Late Cretaceous succession which had not been recognized by early workers.

The present paper describes and correlates the Late Cretaceous lithostratigraphy of the Quetta region and the newly recognized lithostratigrphic units and disconformities in Zharai, Hanna Lake and Marree Brewery sections of the Quetta and surrounding region.

LITHOSTRATIGRAPHY

The stratigraphic succession of Quetta region is exposed in Marree Brewery, Hanna Lake and Zharai sections. The succession includes various formations

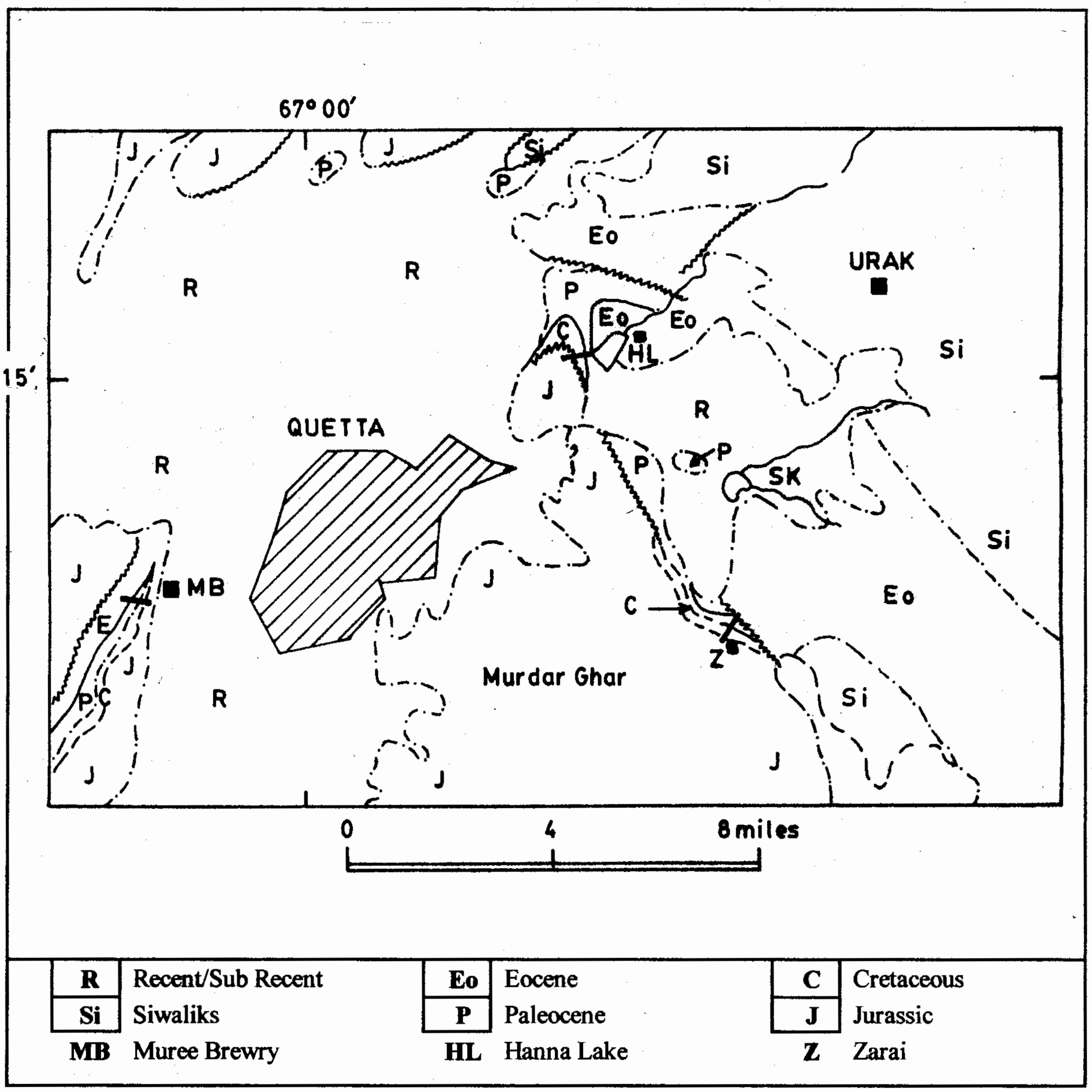


Figure 1. Location map of the studied areas and correlated sections.

ranging in age from Jurassic to Eocene (Table 1) which are the Jurassic Chiltan Limestone, Cretaceous Sembar Formation, Goru Formation, Parh Limestone, a limestone unit which has not been recognized and described before for which we propose the name Hanna Lake limestone, Fort Munro Formation, Pab Sandstone, Paleocene - Early Eocene Dungan Formation, Ghazij Formation and Eocene Kirther Formation. Beside these lithostratigraphic units four depositional breaks within the succession are present above the Jurassic Chiltan Limestone and below Paleocene-Early Eocene Dungan Formation (Table 1).

CHILTAN LIMESTONE

(MB1; Fig. 2, 5)

The Chiltan Limestone of Hunting Survey Corporation (1960), now considered (Kazmi, 1995) as the Loralai Limestone member of the Shirinab Formation of Williams (1959), comprises medium to very thick bedded, hard, brownish grey to dark grey, mostly very finely crystalline and rarely fossiliferous limestone. Its type section is located along Dara Manda south of Bostan (30° 22' 20" N; 69° 03' 39" E). Lower contact of the Chiltan Limestone is not exposed in Marree Brewery, Hanna Lake and Zharai sections (Fig. 1), however, it is seen to be transitional with the Spingwar Member of the Shirinab Formation (Kazmi 1995). Upper contact with the Sembar Formation in Marree Brewery is disconformable. It is considered Jurassic on the basis of ammonites found in the underlying Spingwar member of the Shirinab Formation (Fatmi 1977).

Table 1. The Upper Cretaceous stratigraphic succession around Quetta valley.

FORMATION	AGE	LITHOLOGICAL CHARACTERS
Dungan Formation	Paleocene to Early Eocene	Thin to medium bedded shale in lower part. Thick bedded, compact, nodular limestone in upper part.
Pab Sandstone*	Maestrichtian	White, cream and brownish grey, highly quartzose sandstone.
Disconformity		
Fort Munro Formation**	Maestrichtian	Dark grey, thin bedded, orbitoidal limestone.
Disconformity		
Hanna Lake limestone	Campanian to Early Maestrichtian	Dull, dark brownish grey, thick bedded, barely fossiliferous limestone.
Disconformity		
Parh Limestone	Barremian to Sentonian.	White, cream, biomicritic limestone.
Goru Formation	Lower Albian to Cenomanian	Biomicritic, reddish brown and pale green limestone and shale .
Sembar Formation	Late Jurassic to Early Cretaceous (Neocomian)	Dark brownish, greenish and pale green shale.
Disconformity		
Chiltan Limestone	Jurassic	Thick bedded, dark brownish grey limestone.

* Pab Sandstone present in Zharai and Hanna Lake sections, pinches laterally towards Marree Brewery section.
** A local depositional break occurs within the Dungan Formation in Hanna Lake section.

SEMBAR FORMATION
(MB2, MB3; Fig. 2, 5).

The Sembar Formation (Williams 1959) is the lower most unit of the Cretaceous succession in Kirther-Sulaiman region. In Marree Brewery section it consists dark brownish to greenish grey, glauconitic and gypsiferous shales including thin to medium bedded (10-20 cm), dark grey to black argillaceous limestone. Frequency of the limestone beds increases upwards. The formation is 122 meter thick in type section (Sembar Pass, 29° 55' 05" N; 68° 34' 48" E), however, it is only 17 meters thick in Marree Brewery section. Belemnites including *Hibolithes pistiloformis, H. subfusiformis* and *Duvalia sp.* are commonly present in the Sembar Formation (Williams 1959). In Marree Brewery section fish teeth were also found. The formation is transitionally and conformably overlain by the Goru Formation. It is mainly of Neocomian age, however, according to Fatmi (1977) it may extend to Late Jurassic.

GORU FORMATION
(MB4, HL4; Fig. 2, 3, 5)

The Goru Formation of Williams (1959) is composed of interbedded limestone, shale and siltstone. Frequency of the limestone beds increases upward. Limestone is porcelaineous, very finely crystalline (micritic), sub-lithographic, thin to medium bedded, reddish brown and light greenish grey. Shale is splintery and pale to olive green coloured. Its thickness in type section (Goru village, 27° 50' N; 66° 54' E) is 536 meters. At Marree Brewery section its thickness is estimated as 77 meters and at Hanna Lake section its base is not exposed. Elsewhere, in Kirther-Sulaiman Fold Belt it contains belemnites, but no belemnites were seen in Marree Brewery and Hanna Lake sections. However, the limestone is highly rich in planktonic foraminifera. Fritz and Khan (1967), Williams (1959) and Allemann (1979) have reported *Hedbergella sp., Ticinella, Rotalipora* and other fauna which suggest a lower Albian to Cenomanian age for the Goru Formation.

PARH LIMESTONE
(MB5, HL5, Z5; Fig. 2, 5)

The Parh Limestone of Williams (1959), is a laterally persistent rock succession exposed throughout the Sulaiman-Kirther Fold Belt. It is thin to medium bedded, light grey, white and cream coloured limestone with chert bands and nodules. Limestone is hard, lithographic, porcelaineous and breaks with characteristic conchoidal fracture. In

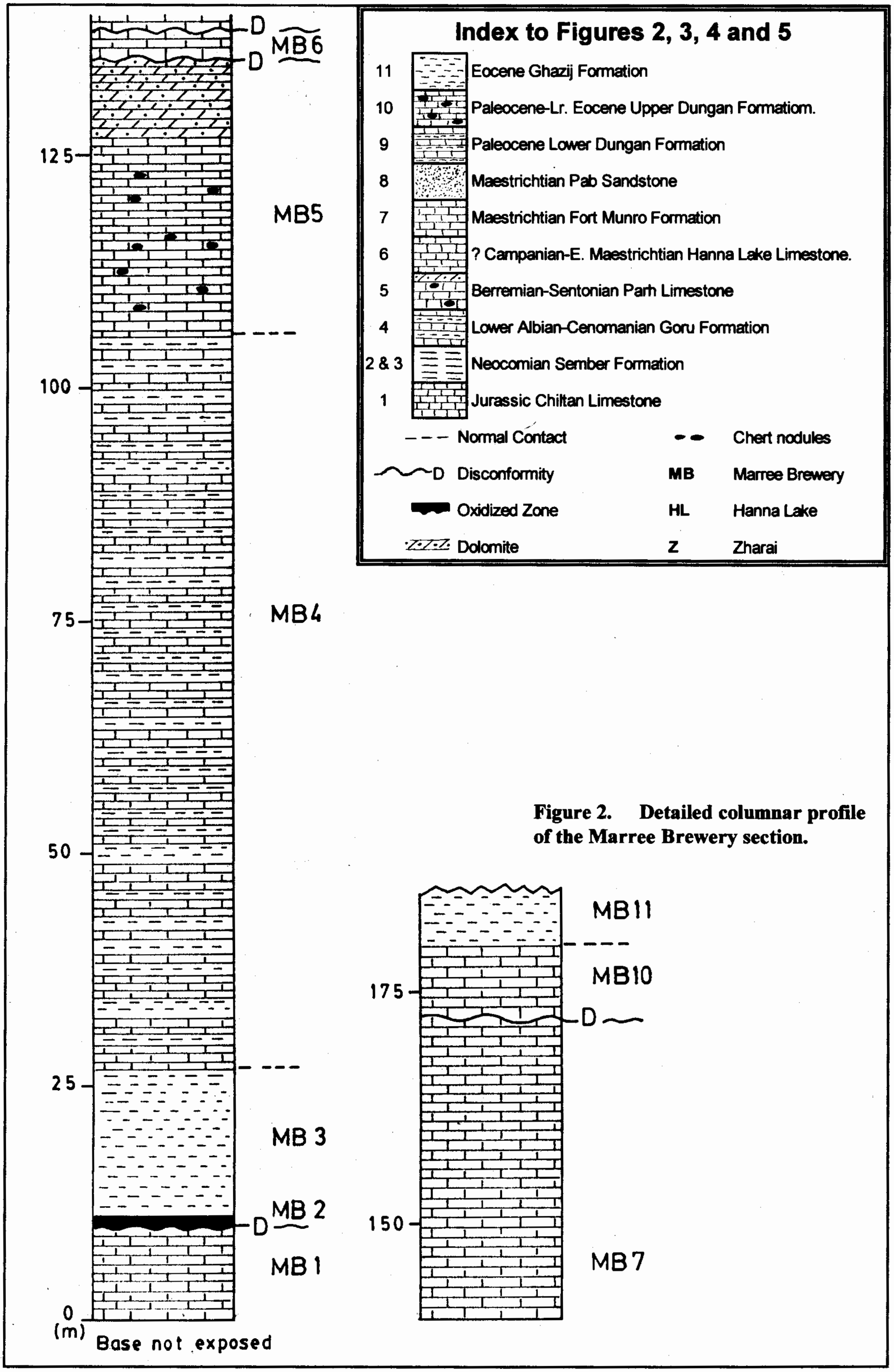


Figure 2. Detailed columnar profile of the Marree Brewery section.

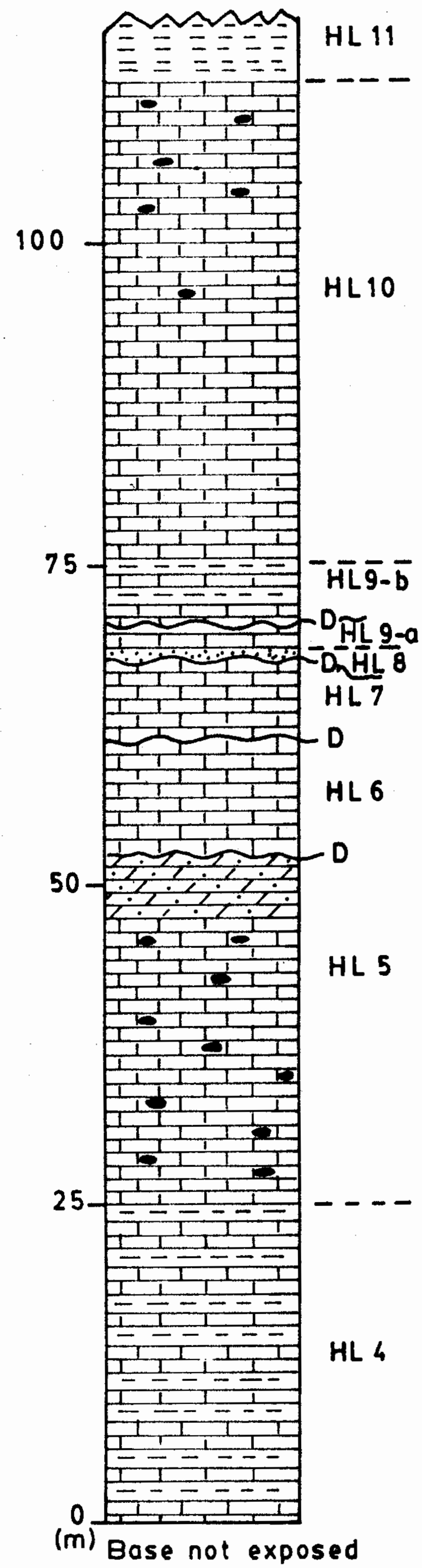


Figure 3. Detailed columnar profile of the Hanna Lake section.

Quetta region the upper part has been partially or completely dolomatized. Thickness of the Parh Limestone is 268 m in its type section at Parh range (26° 54' 45"N; 76° 54' 45"E). In Quetta region its thickness ranges between 20-30 m. The Parh Limestone in Marree Brewery, Hanna Lake, Zharai and surrounding areas has a conformable and transitional contact with the underlying Goru Formation and has a disconformable upper contact with the Hanna Lake limestone. The disconformity is marked by an oxidized, lateritic horizon lying on erosional surface on upper most horizon of the Parh Limestone. The Parh Limestone contains many species of globotruncana (Williams 1959, Fatmi 1977, Gigon 1962, Allemann 1979) and is considered Baramian to Campanian by Kazmi (1955), Sentonian by Williams (1959) and Late Coniacian-Sentonian by Allemann (1979).

HANNA LAKE LIMESTONE

(MB6, HL6, Z6; Fig. 2, 5)

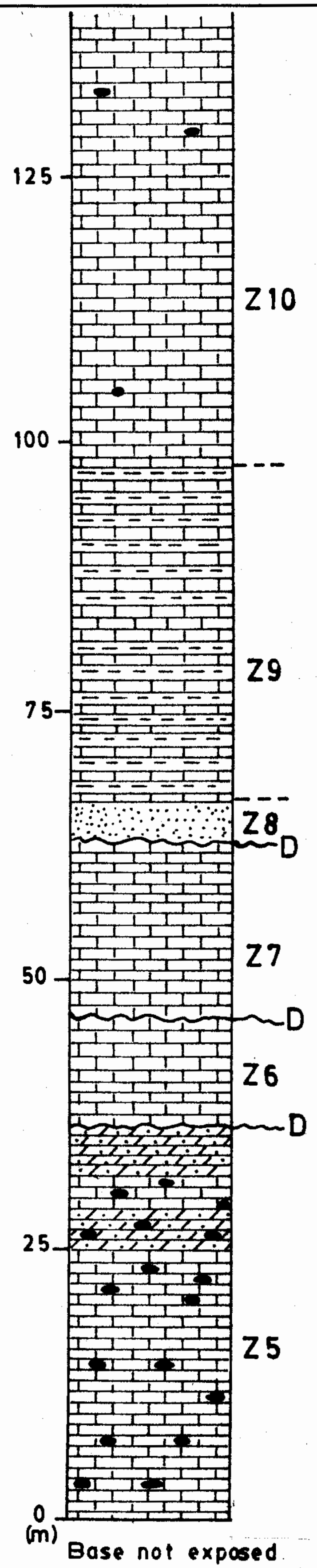
The Parh Limestone in Hanna Lake, Marree Brewery, Zharai, Bolan Pass and adjoining areas of Quetta District is overlain disconformably by a dull brownish grey, very finely crystalline (micritic), thick bedded limestone which is hard, compact and barely fossiliferous. Some parts contain very small sized foraminifera. In Marree Brewery section only a single (3 meters thick) bed is exposed. At Zharai section it is 10 meters and Hanna Lake section up to 13 meters thick.

Its upper contact with Fort Munro Formation is also disconformable. Its biostratigraphy has not been studied yet, however, because of its presence disconformably on top of the Parh Limestone and disconformably below the Fort Munro Formation, it is interpreted to be of Campanian to Early Maestrichtian.

FORT MUNRO FORMATION

(MB7, HL7, Z7; Fig. 2, 5)

The Fort Munro Formation comprises dark grey, dark brownish grey, hard, thick bedded and, in places, nodular limestone. Its type locality is in the western flank of Fort Munro Anticline (29° 57' 14"N; 70° 10' 30"E), where it is up to 248 metres thick. In Marree Brewery, Hanna Lake and Zharai sections its thickness ranges between 12-30 meters. In Hanna Lake and Zharai sections it is disconformably overlained by the Pab Sandstone, whereas, in Marree Brewery section by the Dungan Formation. The Fort Munro formation contains various species of orbitoids and is considered as Late Companian to Maestrichtian age by Fatmi (1977). However, in Marree Brewery section Allemann (1979) considers it as Late Maestrichtian.



PAB SANDSTONE

(HL, Z8; Fig. 3, 5)

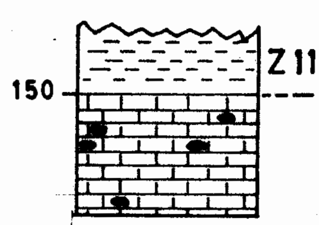
The Pab Sandstone (Williams 1959) is widely exposed in Kirther and Sulaiman region. Normally it rests conformably on the Fort Munro Formation, however, at Zharai, and Hanna Lake sections only 1-4 m thick sandstone lies disconformably on a highly oxidized and erosional surface of the Fort Munro Formation. It comprises a white and light brownish grey sandstone which is very fine grained, massive, well sorted and highly quartzose. Its type section is west of Wirhab Nai (25° 03' 12" N; 67° 00' 19" E) in the Pab Range where it is 490 m thick (Hunting Survey Corporation 1960). The formation is missing in Marree Brewery and Gwani Nala sections, but reappears in the Bolan Pass. In Zharai and Hanna Lake sections it is transitionally overlain by the Dungan Formation. On the basis of foraminifera the formation has been assigned Maestrichtian age (Williams 1959, Hunting Survey Corporation 1960).

DUNGAN FORMATION

(MB 10, Z 9-10, HL 9-10; Fig. 2, 5)

The Paleocene to Early Eocene Dungan Limestone of Hunting Survey Corporation (1960) is also widely exposed in Kirther-Sulaiman Fold Belt. In Zharai area (Fig. 4,5) it has well defined lower (Z9) and upper (Z10) parts. The lower part (30-40 m thick) comprises light brownish grey, nodular limestone interbedded with dark grey shale. Upper part is 50-60 m thick and contains hard, compact and thick bedded limestone. The formation is highly fossiliferous and rich in foraminifera, bivalves, cephalopods, gastropods and echinoderms. Dark

Figure 4. Detailed columnar profile of the Zharai section.



grey chert is also present. In Hanna Lake section lower part (HL 9a and HL 9b) is poorly developed and comprises 7m thick succession of thin to medium bedded (5-50 cm), nodular limestone. Lower part of the Dungan Formation in Hanna Lake section shows a depositional break which is represented by an oxidized erosional surface between HL9a and HL9b (Fig. 3). In Marree Brewery section lower part is completely missing and only 8 meters thick compact limestone of the upper part (MB 10; Fig. 2) is present which disconformably overlies the Fort Munro Formation.

Lower contact of the Dungan Formation in Marree Brewery is disconformable with the Fort Munro Formation, whereas, in Zharai and Hanna Lake sections it is transitional and conformable with the Pab Sandstone. Upper contact is conformable with the Ghazij Formation. The formation is of Paleocene age (Hunting Survey Corporation 1960, Fatmi 1977), however, because of the association of certain foraminifera Allemann (1979) suggests that lower part of the Paleocene is missing in the Marree Brewery section and the Dungan Formation represents the Cucmiformis zone i.e. the base of the Upper Paleocene. This notion also gets support form the absence of lower part of the Dungan Formation (Z9 and HL9; Fig. 3,4) at Marree Brewery and Hanna Lake sections.

CORRELATION

Figure 5 shows columnar profiles of the Marree Brewery, Hanna Lake and Zharai sections which have been plotted on reduced scale for the purpose of correlating the Upper Cretaceous succession in Quetta region. Various lithostratigraphic units of the Upper Cretaceous-Paleocene succession, including the newly proposed Hanna Lake limestone, are easily correlatable. The Pab Sandstone (Z8, HL8; Fig. 5) is present in Hanna Lake and Zharai sections but missing in the Marree Brewery section. Also the lower part of the Dungan Formation which is fully developed in the Zharai section (Z9; Fig. 4,5) and partly developed in the Hanna Lake section (HL9; Fig. 3, 5) is missing in the Marree Brewery section. Further more, thickness of upper part of the Dungan Formation (Z10, HL10; Fig. 3,5) has been greatly reduced in the Marree Brewery section (MB10; Fig. 2). This shows that upper part of the Upper Cretaceous (Pab Sandstone, Z8, HL8), lower part of the Paleocene Dungan Formation (Z9, HL9) and even some part of the upper Dungan Formation (Z10, HL10; Fig. 3, 5) is missing in the Marree Brewery section and represented by a major disconformity between the Fort Munro Formation (MB7) and upper part of the Dungan Formation (MB10; Fig. 2, 5).

DISCUSSION

Upper contact of the Chiltan Limestone with the Sembar Formation in Marree Brewery area is represented by a marked undulatory, brecciated and oxidised surface on uppermost bed of the Chiltan Limestone which represent clear disconformity. This undulatory surface is followed by a 2,4 m thick oxidation zone of yellowish brown lateritic shale possessing elliptical to rounded concretions. These concretions usually posses a nucleus of decayed organic matter surrounded by concentric rings of silty material accreted around the nucleus. This unconformity is not exposed in Hanna Lake and Zharai sections, however, similar concretions are present in the detritus of the streams in Zharai area. Elsewhere in Sulaiman Fold Belt karstic horizon is present below several meters thick laterite that is overlained by the Sembar Formation of the Parh Group.

At Marree Brewery section up to 50 cm thick, light grey and partially to completely dolomitized beds, are interbedded with Parh Limestone. Frequency of the dolomitized beds increases upward. At Zharai and Hanna Lake sections, 330-480 cm thick, partially to completely, dolomitized zones, which are light brownish grey to reddish brown and medium to thick bedded (15-60 cm), are present. In the field they may be mistaken by a medium grained, well rounded, massive and very well sorted sandstone. Some dolomitized horizons also contain chert nodules. Within the Zharai section up to 480 cm thick upper most part of the Parh Limestone has been dolomitized and also highly oxidized. The chert nodules, which are formed as secondary diagenetic process, have not been affected by the secondary dolomitization which suggests that dolomitization occurred at a later stage of diagenetic processes which has effected the limestone, however, leaving behind the chert nodules fairly in tact.

The Hanna Lake limestone has been recognised as a distinct lithostratigraphic unit for the first time. Although it is the lateral equivalent of the Mughal Kot (Williams 1959, Fatmi 1977) and Bibai Formations (Kazmi 1955), its characters does not resemble with any of these formations. The Mughal Kot Formation in Sulaiman Fold Belt comprises shale, mudstone, quartzose and arkosic sandstone and grey argillaceous limestone, whereas, the Bibai Formation in Kach-Ziarat area is composed of basaltic lava flows and volcaniclastic succession. However, the Hanna Lake limestone is 3-13 m thick limestone distinguishable on the basis of its lithological characters and stratigraphic position. This dull brownish grey limestone disconformably overlies the Parh Limestone and disconformably

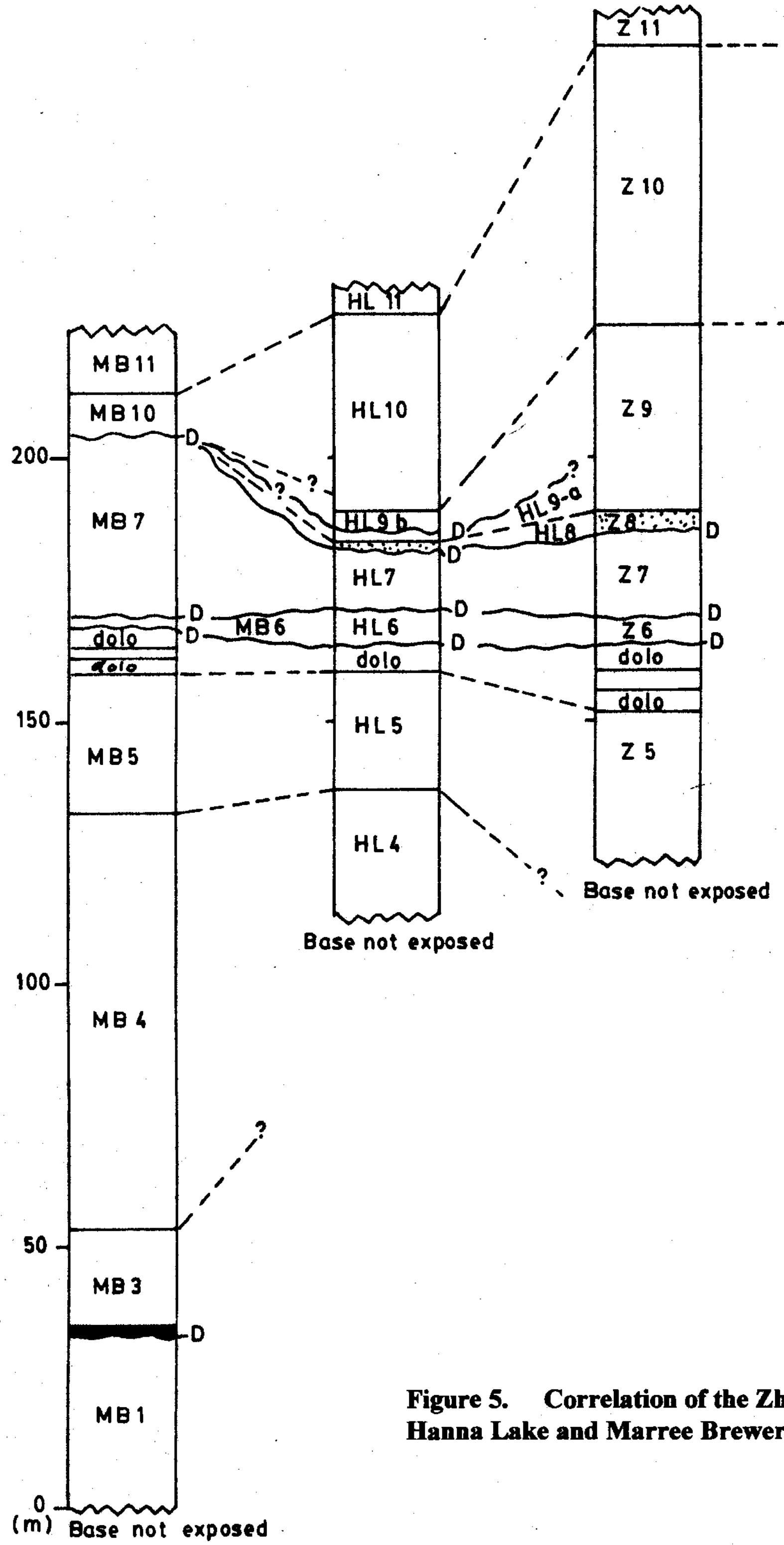


Figure 5. Correlation of the Zharai China, Hanna Lake and Marree Brewery section.

underlies the Fort Munro Formation. On the basis of its distinct lithological characters, stratigraphic position, disconformable upper and lower contacts and lateral continuity for several tens of kilometres, it may be designated as a separate lithostratigraphic unit (North American Stratigraphic Code 1983). Therefore, we name it the Hanna Lake limestone and propose Hanna Lake (30° 01' E; 67° 03' N) as its type locality. In Hanna Lake section the outcrop is easily accessible (at the back of the Hanna Lake Dam). Several other outcrops are exposed in Zharai (29° 06' E; 67° 06' N), Marree Brewery and in Bolan Pass near Dozan Railway Station.

Presence of the Pab Sandstone in Zharai and Hanna Lake section is worth mentioning because it has not been reported by early workers in this area, although it is only up to 4 m thick in Zharai and 1 m in the Hanna Lake section. It is missing in the Marree Brewery and Gwani Nala sections, however, reappears in Bolan Pass. The variation in the stratigraphy needs to be studied more in detail which would help reconstruct the paelogeoraphy of the area during late Createaceous-Early Paleocene.

CONCLUSIONS

1) The Cretaceous succession in Quetta region comprises six distinct lithostratigraphic units and four disconformities between the Jurassic Chiltan Limestone and Paleocene Dungan Formation.

2) The Hanna Lake Limestone is a dull brownish grey limestone, bounded by two disconformities, situated above the Parh Limestone and below the Fort Munro Formation. It has been distinguished as a separate lithostratigraphic unit for the first time. The formation is correlatable between the Marree Brewery, Hanna Lake and Zharai sections.

3) Although very thin (less than 4 m), the Pab Sandstone is present in Zharai and Hanna Lake sections, however, it is missing in the Marree and Gwani Nala sections.

4) Upper most part of the Upper Cretaceous (Pab Sandstone) and lower part of the Paleocene Dungan Formation, which are recognizable in Zharai and Hanna Lake sections, are missing in the Marree Brewery section and represented by a major disconformity between the Fort Munro Formation and Dungan Formation.

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LOWER CARBONIFEROUS DELTA PLAIN DEPOSITS AT COVE, SCOTLAND, U.K.

GHULAM NABI
Department of Geology, University of Balochistan, Quetta. Pakistan

ABSTRACT

The sequence at Cove in the Cockburnspath area of east Berwickshire (Southern Scotland) is characterized by fine-grained sedimentary rocks which grade upward to coarser clastic sedimentary rock. The sediments were deposited in the Oldhamstock Basin dominated by deltaic (fluvial) process. Body fossils are rare, but rootlets-penetrated and coal bearing facies are present in fine-grained units. The claystone-siltstone-sandstone units in this sequence were deposited in alluvial flood-plain, inter-distributary bay and delta-plain environments. Dolomitic cementstone in flood-plain claystones are interpreted to have formed in low salinity flood-plain lakes during early diagenesis. Complete bay filling allowed the establishment of palaeosols, either as seatearths with rootlets, or as siderite nodules within coals. Two marine flooding events resulted in the deposition of the fossil-rich Cove Marine Bands. Brachiopods, crinoids and bivalve remains are common in these siltstone-sandstone intervals.

INTRODUCTION

The fine-grained clastic rocks at Cove (Fig.1) can be divided into five lithofacies on the basis of lithology, texture, sedimentary structures and fossils. These are:- I) Claystone-siltstone-sandstone, II) Fossiliferous siltstone-sandstone, III) Palaeosol, IV) Dolomitic cementstone, V) Organic-rich claystone. Each lithofacies was deposited in a specific sub-environment of a delta.

LITHOFACIES-I
(Claystone-siltstone-sandstone)

This lithofacies (Plate 1a, b) is composed of (a) claystone-siltstone-thinly-bedded sandstone, (b) medium-bedded sandstone and (c) coal and siderite.

Sublithofacies-Ia (Claystone-siltstone-thin-bedded sandstone) Lithofacies Ia mostly consists of an upward transition from claystone to laminated and cross-laminated, siltstone and to fine-grained sandstone (Fig. 2). Usually this lithofacies is capped with medium-bedded sandstone. Sandstone beds are generally up to 0.2m thick.

The claystone is grey to dark grey, and contains coalified fossil plants, rootlets, and leaves such as *Cardiopeteris polymorpha*. Some of the plant fragments are pyritized. In places the claystone is more carbonaceous and is interbedded with coaly shale, whereas in other places, it is dominantly micaceous. The claystone is associated with thin coal and rooted horizons forming a cyclic sequence. Bioturbation is present in some beds and the burrows may have be infilled with sand from overlying beds. The only body fossils seen are broken shells of ostracods. Some beds contain gray oval-shaped nodules which weather red. These

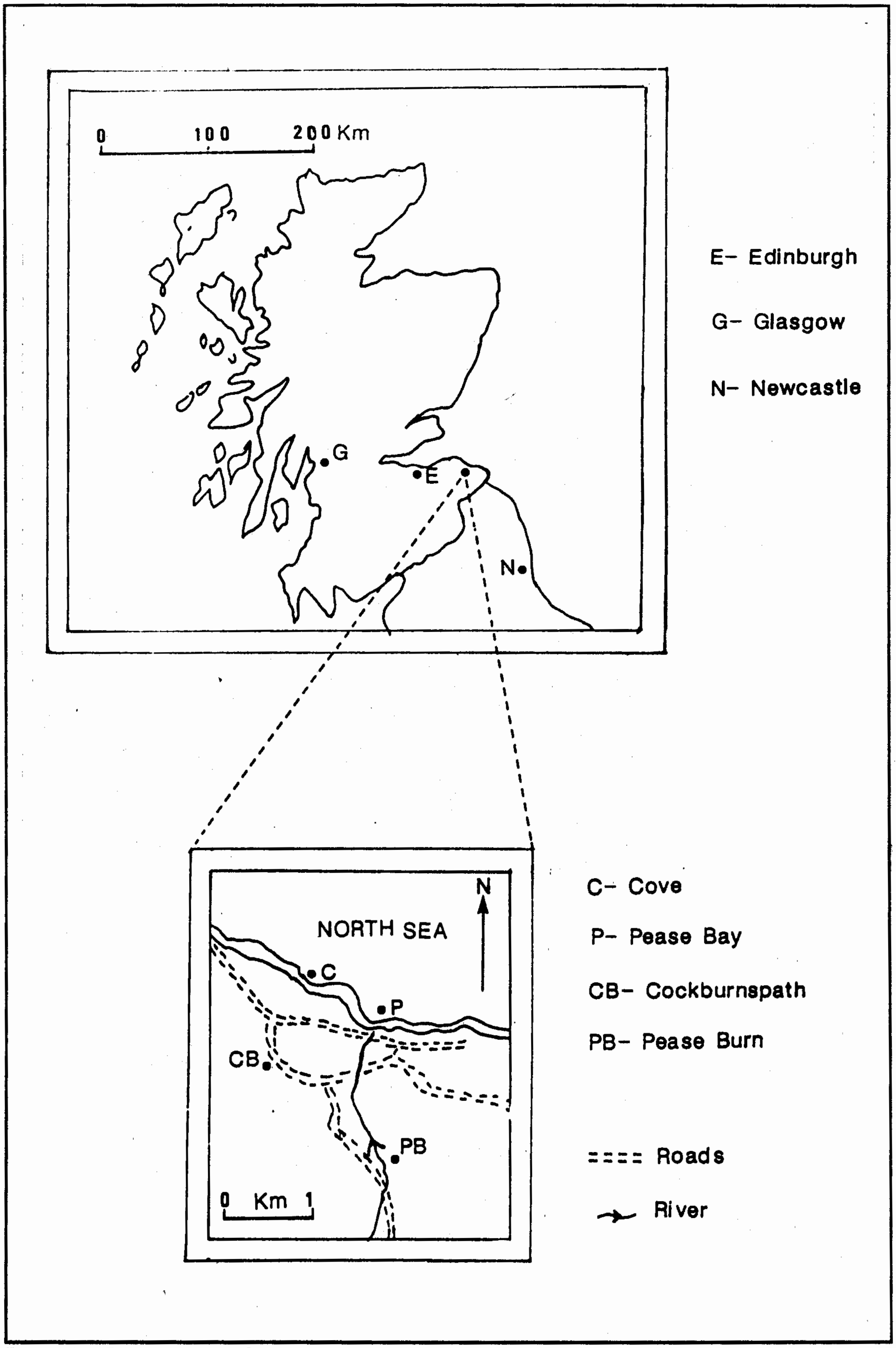

Figure 1. **Location map of the study area.**

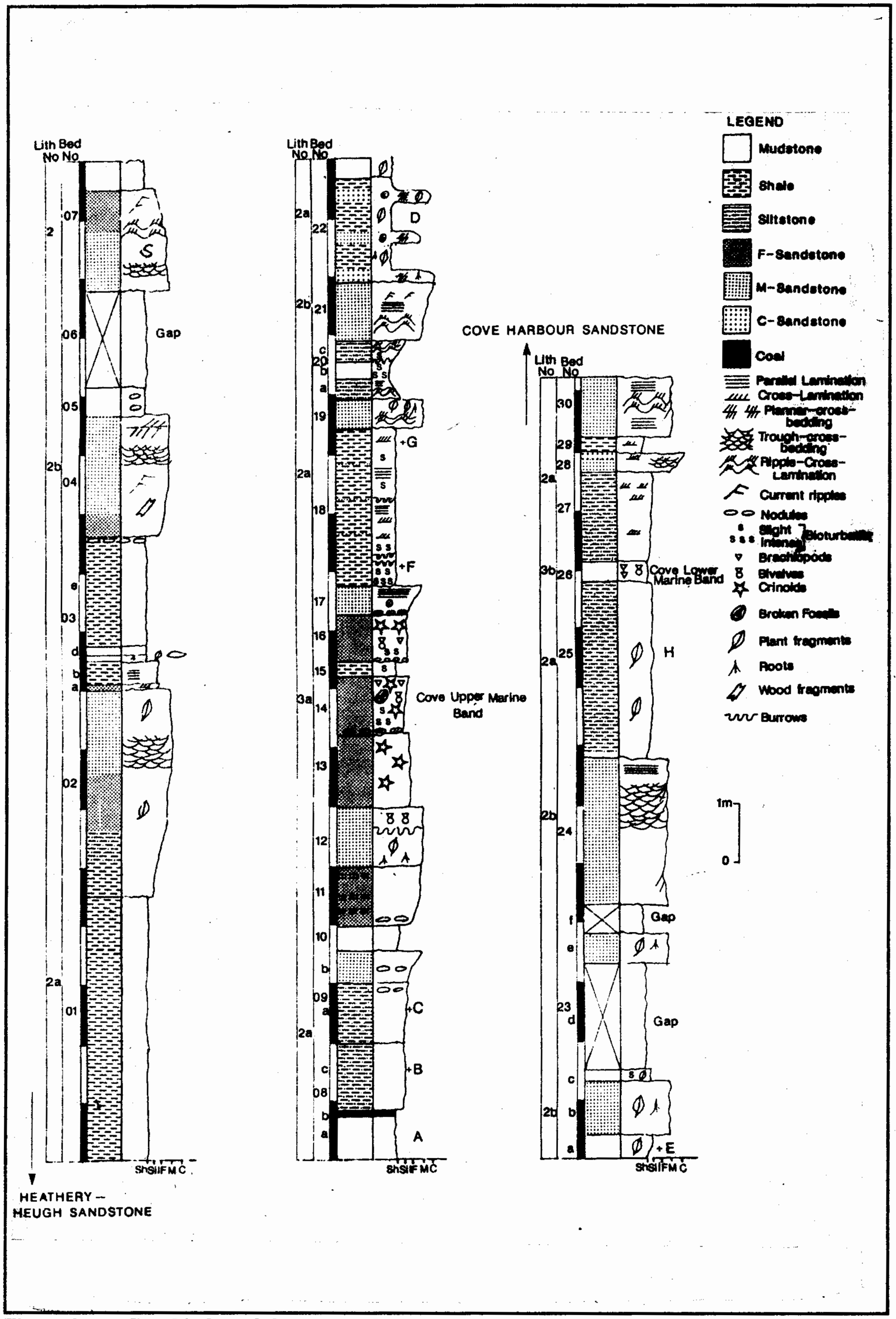

Figure 2. Graphic log of the strata of between Heathery Heugh Sandstone and Cove Harbour Sandstone lithofacies 2 & 4a (sublithofacies Ia, Ib, and lithofacies II.

nodules are approximately 10cm thick and 18cm long and are mainly composed of a sideritic groundmass with kaolinite veins. There is an upward gradational from claystone to siltstone. Clay minerals in the claystone are dominated by kaolinite and illite.

The siltstone is thinly-bedded, dark grey, carbonaceous and micaceous, with coalified plants and small-scale sedimentary structures such as parallel-lamination, ripple-cross-lamination, and bioturbation. Bedding contacts with the sandstone are generally sharp. In places, the carbonaceous siltstone is underlain by rooted palaeosols. Quartz grains are sub-rounded to rounded with a high sphericity, and mica flakes are usually concentrated in lamine. Some grains of mica are altered to chlorite. Whole carapaces and broken ostracod shells occur in places (Plate 2).

The thin-bedded sandstone is light-grey to yellowish-grey, fine-grained, and usually interbedded with claystone and siltstone. Bed range in thickness from 0.06m to 0.3m and lateral lensing out is common. Thin beds are structureless whereas thicker beds show parallel-lamination and current-ripple cross-lamination. In places, small scale-planar- and trough-crossbedding occurs with subordinate wave-ripple lamination. Roots, mud-cracks and bioturbation are also present. In a few places concretions, composed of hematite, occur on the upper surface of some beds. Quartz grains are usually rimmed by iron oxide and in places ferroan dolomitic display rhombic cleavage (Plate 3).

Interpretation Lithofacies Ia is interbeded with medium-bedded sandstone of lithofacies Ib. Lithofacies Ia is interpreted tom have been deposited as crevasse-splays in calm shallow interdistributary bays. Deposition was mostly by unconfined sheet flow, and suspension fall-out of fine-grained sediments occurred as bed load deposition waved. Breaching of distributary channel banks during flooding lead to the deposition of crevasse splays. Simultaneous with crevasse splay deposition, sediments were deposited by overbank flooding from minor distributary channels (Fielding 1984). The overbank flood sediment of minor distributary channels was deposited largely from turbulent suspensions by turbidite underflows and the sandstones are interpreted as minor crevasse splay deposits. The bay-fill strata indicate deposition through a combination of effluent-generated under-flow and intense suspension fall-out, alternating with periods of mud settling and bioturbation (Nemec et al., 1988). The occurrence of thin coals in this sequence probably indicates deposition on a lower delta-plain. Cross-laminated sandstones were deposited by repeated overbank flooding more proximal to the channel. Bioturbation of the top parts of the sandstones suggests abandonment before emergent conditions were established (Pulham 1989).

Sublithofacies -Ib (Medium-bedded sandstone)

These sandstones, commonly 1m to 2.50m thick, are invariably composed of sandstone beds 0.1m to 0.3m thick separated by dark grey carbonaceous claystone and siltstone partings and/or erosion surfaces. The sandstones are fine-grained, yellow to yellowish grey, and in some places, weather to a purple colour. They contain both planar- and trough-crossbedding. A few bedding surfaces show straight-crested, symmetrical ripple-marks. One bed has planar-lamination passing upward to ripple-crass-lamination and finally to interference and sinous-crested ripple-marks on the top surface. In some places internal erosion surfaces and small slump structures are present. Some beds contain plant fragments, coalified plant material, and iron sulphide concretions. Quartz grains are compacted and have quartz growth (Plate 4). K-feldspar grains are altered to kaolinite, while microcline grains have been diagenetically alterated to albite.

A cumulative grain size curve (Fig. 3) for one semi-consolidated sand bed of lithofacies Ib suggests that there is a dominantly a mixture of saltation and suspension deposits in the size population, which suggest a highly variable energy condition (Visher,1969). The sandstone is moderately sorted, symmetrical and leptokurtic (Fig. 4).

Interpretation These sandstones units have sharp bases and generally cap the claystones and siltstones of lithofacies Ia. The palaeocurrents and internal erosional surfaces show that these sandstones were deposited by highly erosive, unidirectional flows. They are interpreted to have been deposited in proximal confined or partly confined, crevasse channels. These channels were formed by breaching the main distributary channel banks during flooding causing erosion of the levee and adjacent flood basin sediments. These channels fed crevasse splays of lithofacies Ia, which were deposited in the interdistributary bays. Trough-crossbedding and planar-crossbedding were probably formed by migrating sinuous- and straight-crested dunes respectively (Myers and Bristow 1989). Ripple-cross-lamination and planar-laminations were formed during the falling stage of flood deposition and were produced by ripple migration (Graham 1983). Straight-crested ripples which occur on some sandstone bedding surfaces are interpreted as being

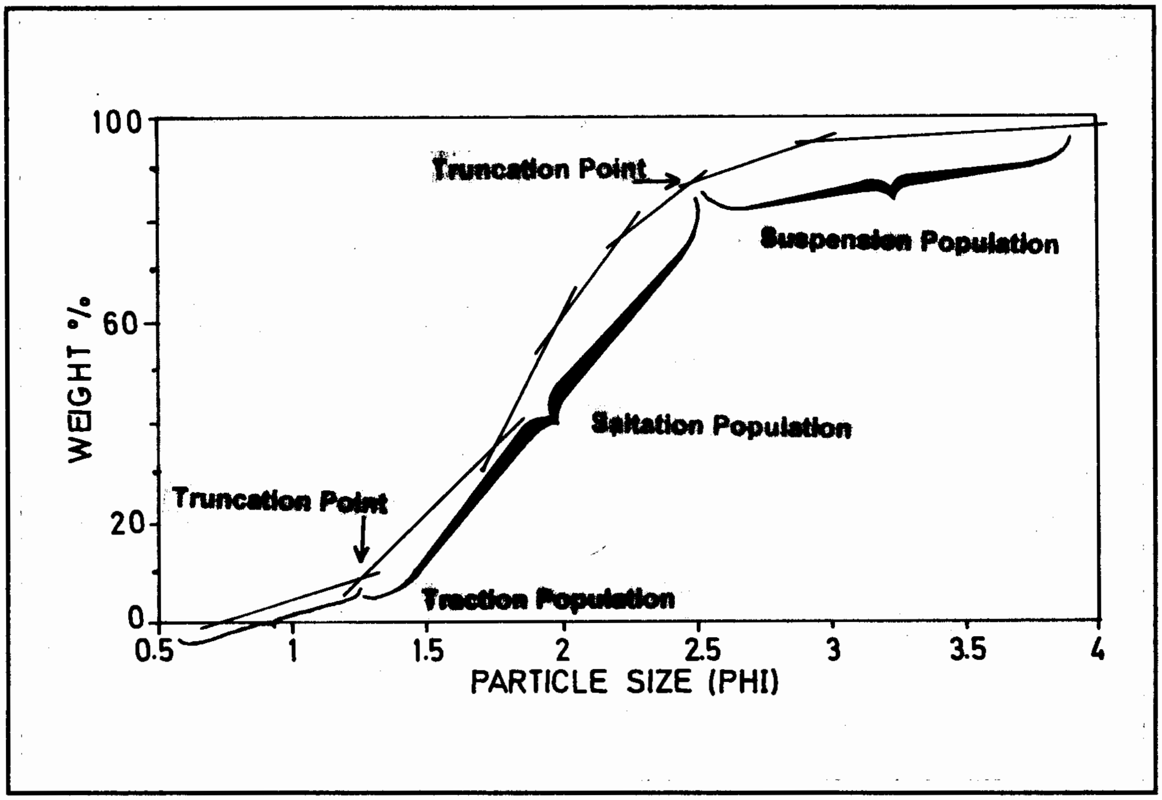

Figure 3. Grain size distribution cummulative curve showing the different populations in the sandstone of lithofacies I.

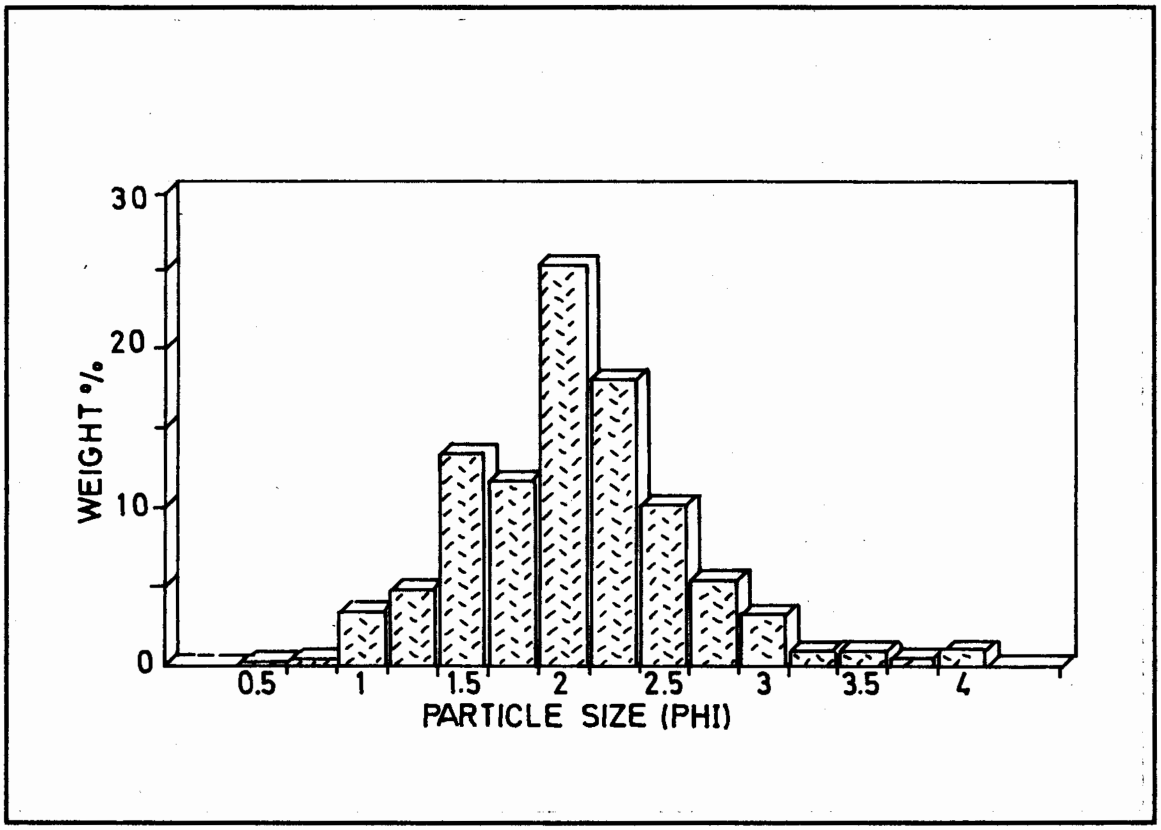

Figure 4. Histogram showing the particle size distribution in the sandstone of lithofacies I.

formed by wave activity indicating a consistent orientation of the waves (Guion 1984). Interference- and sinuous- crested ripples on one of the beds suggests deposition by currents on a flood-plain surface or in a lake, with intermittent flow (Pederson 1989). Slumping in some places probably occurred when the sediment was in a fluidized state and may have been initiated by simple gravitational adjustment of dune foresets.

SubLithofacies - Ic (Coal and Siderite)

Coal beds are interbedded with carbonaceous Claystone beds of lithofacies Ia (Fig. 5). The coal is poorly developed and ranges in thickness from a few centimetres to as much as 20 centimetres. Some seams weather to a yellow colour owing the sulphur content. In some places coal is interbedded with kaolinitic claystone and in other places sandstone with palaeosol textures underlies the coal (Plate Ib).

Interpretation The vertical distributation of this lithofacies interbedded with lithofacies Ia suggests deposition in swamps, furthest from fluvial channels. The swamps developed by prolific growth of hydrophytic vegetation on submerged abandoned surfaces of interdistributary bay infills. Swamp vegetation acted as a sediment filter allowing only occasional thin layers of clastic sediments to settle in the swamp. Sulphur probably originated from the decay of diagenetic iron-pyrites indicating that the sulphur was originally available from organic matter, or from seawater. Rootlets in strata below the coals indicates that the plants were grew in place and that the coals are therefore, at least in part, autochthonous. Lateral thinning of the coals and their silty nature suggests that optional condition for peat growth was never attained.

Sideritic ironstones form impersistent layers near the top of claystones in lithofacies Ia. These are 0.2m to 0.35m thick, red in colour, usually nodular, and consists of a fine-grained mosaic of rhombic-shabed carbonate crystals. Grain-size ranges from 0.1 to 0.15mm (Plate 5). Some grains have a concentric structure (pseudo-oolites) and are partially altered to yellow to greenish brown chamosite.

Siderite is more common in non-marine sediment whereas pyrite is more abundant in marine sediment. Siderite probably represents early diagentic growth of iron carbonates ($FeCO_3$) under strongly reducing swamp conditions. Siderite is frequently associated with carbonaceous sequences and it precipitates prefoentially to pyrite during early diagenesis, when sulphate ions in the pore fluid are sufficiently low, either reduced by sulphate-reducing bacteria, or low in dissolved sulphate initially (i.e. freshwater) (Fuchtbauer 1983). The ferric oxide hydrosols in river waters would be reduced to the ferrous state and removal of CO_2 by photosynthesis of plants would dissociate the bicarbonate ions to cause the direct precipitation of $FeCO_3$, potentially explaining the association between siderite and coal. Mudstones are equally iron rich and when buried with organic detritus then the combined effect of iron reduction and organic degradation by microbial processes could cause siderite to form (Curtis & Coleman, 1986) such as:

$$7CH_2O + 2Fe_2O_3 \rightarrow 3CH_4 + 4FeCO_3 + H_2O$$

Under reducing conditions, ferric compounds are unstable and are likely to be reduced to Fe^{+2}. Reduction of iron needs an equivalent oxidation of organic matter, therefore, both ferrous iron and carbon dioxide are produced. Therefore, the early formed siderite grew mainly from iron hydro-oxide and organic carbon oxidized in fermentation reactions to produce CO_2 and siderite. The siderite layers probably grew from porewater where conditions of carbonate supersaturation were maintained. Hence, soon after burial, diagenetic precipitation of carbonate commenced in thin stratiform sheets.

LITHOFACIES II
(Fossiliferous Siltstone-sandstone)

This lithofacies is represented by the Cove Lower Marine Band and Cove Upper Marine Band (Greig, 1988).

Sublithofacies - IIa (Cove Lower Marine Band)

This marine band, 4.5m thick, is mainly composed of fine-grained, well-cemented, grey sandstone beds which weather dark red to yellow. In some places interbedded siltstone occurs. Sandstone beds do not show clear sedimentary structures probably as a result of generally intence bioturbation which diminishes out upwards. The beds are contain plant material and are characterized by the presence of abundant brachiopods (*Punctosprifer, Productus redesdalensis* and *Buxtonia scabricula)* (Wilson, 1989), gastropods, crinoid ossicles are common throughout, usually on bedding surfaces. Some beds contain abundant pyrite in frambodial form (Plate 6) and as pyritized bivalve and ostracod shells (Plate 7). A 30cm-thick silty and sandy nodular band occurs at the base of the marine band. Ferroan dolomite accounts for 30-35% of the rock volume and is the main cementing material (Plate 8)

Interpretation Lithofacies IIa is interbedded with the Lithofacies Ia and Ib. The presence of a restricted marine fauna implies that the open sea

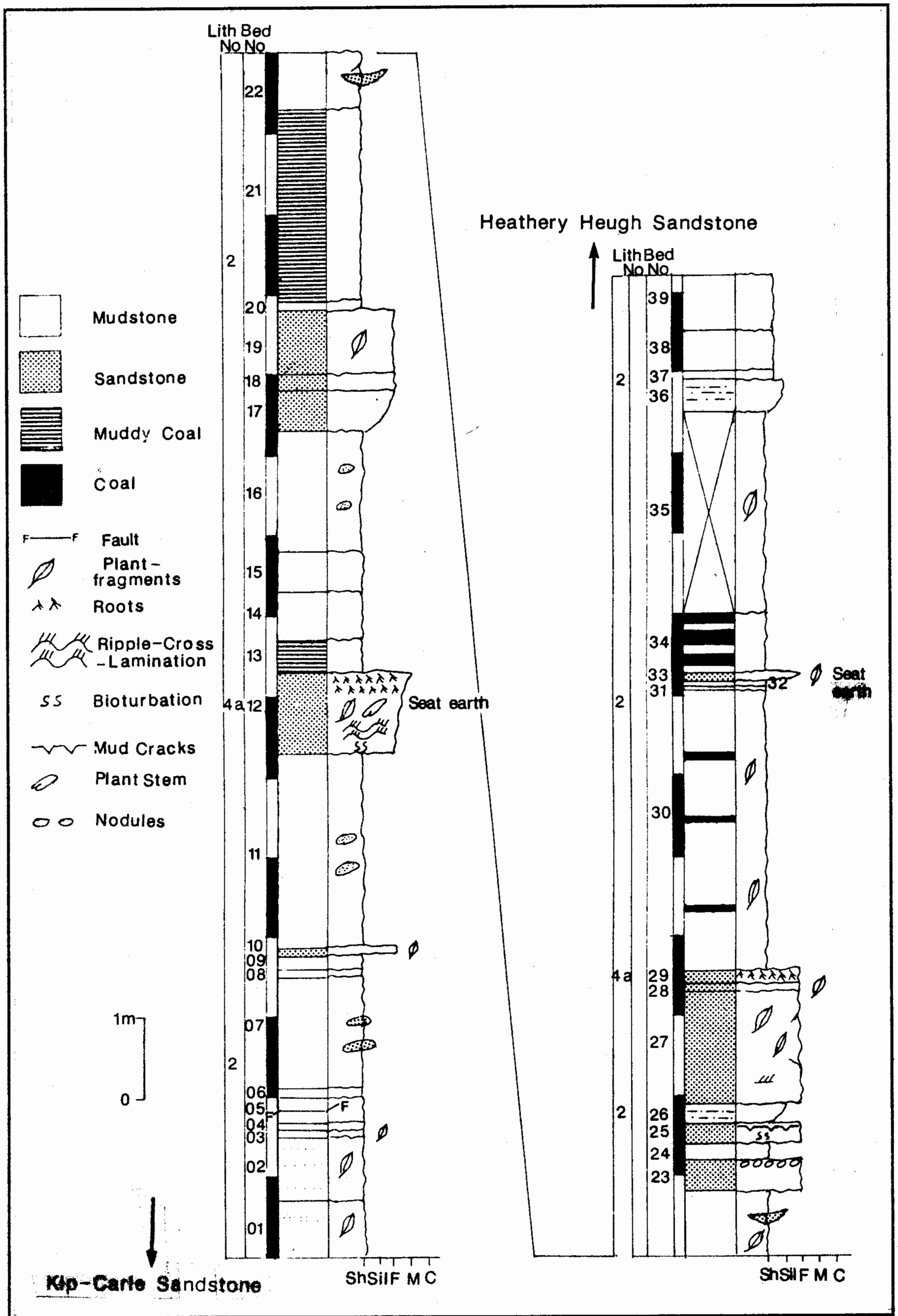

Figure 5. Graphic log of the carbonaceous beds between Kip-Carle Sandstone and Heathery Heugh Sandstone lithofacies 2 & 4a (sub-lithofacies Ia, Ic, and lithofacies III).

was not far away (to the east). Grain- size, sorting, and bioturbation are consistent with a shore-face environment (Plint, 1983). Deposition of the sand was probably a direct response to rising sea-level with weak wave and current reworking of underlying fluvial-derived sand. The lack of wave-ripples and crossbedding could suggest a rapid transition into relatively deep water (Flint et al., 1986), although it is perhaps more likely that these primary sedimentary structures were obscured by intense bioturbation.

Sublithofacies - IIb (Cove Upper Marine Band)

This marine band, 0.35m thick, is mainly composed of soft, dark grey, micaceous, silty-mudstone yielding brachiopods such as *Punctospirifer scabricosta*, *Gigantoproductus* , and *Spirifer duplicicosta* and the bivalves *Pteronites angustatus* and *Streblopteria redesdalensis* (Wilson, 1989). Pyrite concretions are the only other noticeable feature.

Interpretation This lithofacies is interbedded with Lithofacies Ia and Ib. The sediment was probably deposited slowly from suspension in low energy marine environment. The lack of sedimentary structures might be taken to imply deposition below normal wave base (Plint, 1983) however, bioturbation may have obscured primary sedimentary structures. The fauna in this marine band is considered to reflect slow deposition rates during a transgression.

LITHOFACIES III
(Palaeosol)

This Lithofacies is basically a light greysandstone, 1.25m thick, and yellowish-grey when weathered. It is fined-grained at the top and medium-grained at the base. The upper 40 cm is intensively rooted in some places (Plate 9) and also contains *Stigmaria* impressions. In the lower portion, some beds are ripple-cross-laminated and bioturbated. Iron minerals are also present.

Interpretation Lithofacies III is overlain by the various thickness of coal of Lithofacies Ic. The character of Lithofacies III is similar to the definition of a ganister as stated by Percival (1983): a ganister is a very fine to medium-grained quartz arenite cemented by silica, occurs commonly as a seatearth below a coal seam and often contains abundant carbonaceous traces or rootlets". *Stigmaria* and associated fossil rootlets provide evidence for emergence and colonization by plants. Thin coal at the top of the palaeosol indicates the accumulation of plant debris during a subsequent phase of water-logging (Percival, 1986). Absence of sedimentary structures in the upper part was probably the result of bioturbation caused by rootlets and soil organisms. The presence of siderite suggests that the soils were leached first and subjected to segration of iron under the influence of permanent ground water and plant roots.

LITHOFACIES IV
(Dolomitic Cementstone)

It is a one metre thick, white calcareous, very fine-grained cementstone intercalated with greenish-grey, sandy mudstone. Mostly it is brecciated owing to the movement of the Cove Fault. The breccia is mainly composed of flat, angular clasts of cementstone ranging in size up to 70mm long and 30mm thick. Well developed crystals of dolomite (late- diagenetic cements) line some of the cavities between breccia fragments.

Interpretation The cementstone is associated with siltstones of floodplain origin and capped by channel sandstones. The composition of the cementstone indicates deposition of primary carbonate by precipitation in shallow water, probably a floodplain lake. The lakes probably periodically dried out resulting in exposure of the cementstone. During further reduction of the water body dolomitization have occurred. The lack of evaporite minerals suggest that the water was not highly saline supporting the idea of deposition in a flood plain lake. Dolomitization of the cementstone was probably caused by microbially-mediated, early diagenesis.

LITHOFACIES V
(Organic-rich Claystone)

This lithofacies is well exposed north of Cove Harbour. It is 30cm thick, fissile, dark grey to black with a light brown, oily sheen, weathering bright red at the top. High organic content imports a dark colour. It contains abundant pyritized plant leaves, stems and fragments. Current generated sedimentary structures are absent.

Interpretation This black organic rich claystone passes upward to mudstone. The high content of very fine-grained organic matter indicates an extremely low rate of sedimentation. Abundant pyritized plants and the absence of a bottom-living fauna indicates an anoxic environment of deposition (Fielding, 1984). Therefore, this lithofacies is interpreted as an organic ooze accumulated in a shallow lake (Boggs, 1987). The location of this lake immediately above the Cove Harbour Sandstone may have been controlled by subsidence of the channel sandstone. Fine-grained clastic sediment and plant detritus were deposited very slowly from suspension in a static water column. Strongly reducing bottom condition were inimical to bottom living animals and the sediments were undisturbed by bioturbation.

CONCLUSIONS

The mudstones, shales, coal and thinner-bedded or finer-grained sandstones show characteristics of deposition in interdistributary bay and delta plain environments. During floods excess discharge initiated crevassing of the distributary channel and sediments splayed over from banks with fine grained suspended sediments, forming parallel laminated and current rippled. Pauses to sedimentation may have allowed these deposits to became vegetated producing coal.

Minor distributary channels probably formed by the crevassing of major distributaries and transported coarse sediments into the intervening interdistributary bays. The rhythmic interbedding of coarser and finer deposits suggests alternation of high and low stage conditions, consistent with a seasonal (tropical) climate with eoisodic precipitation and run off. The delta plains were characterized by rapidly shifting fluvial channels with shallow lagoons or lakes between channels. These condition were in the Cove Oil Shale which accumulated in a small depression perhaps caused by subsidence of the underlying Cover Harbour Sandstone.

From their lithological character and the presence of seat earths, coal seams are interpreted as largely autochthonous organic deposits of peat swamps. As the proximal parts of the crevasse-delta built up close to the water surface, hydrophytic swamp vegetation became established, eventually blanketing the former lake surface following infilling and final abandonment. Layers of sideritic ironstone probably represent early diagenetic growth of iron carbonate under strongly reducing conditions.

Twice the, delta plain was in undated by the sea. At these times the sandy and muddy substrates were bioturbated and a restricted marine fauna was established. Dolomitization of the cementstone probably occurred due to microbially-mediated early diagenetic reactions in the sediments.

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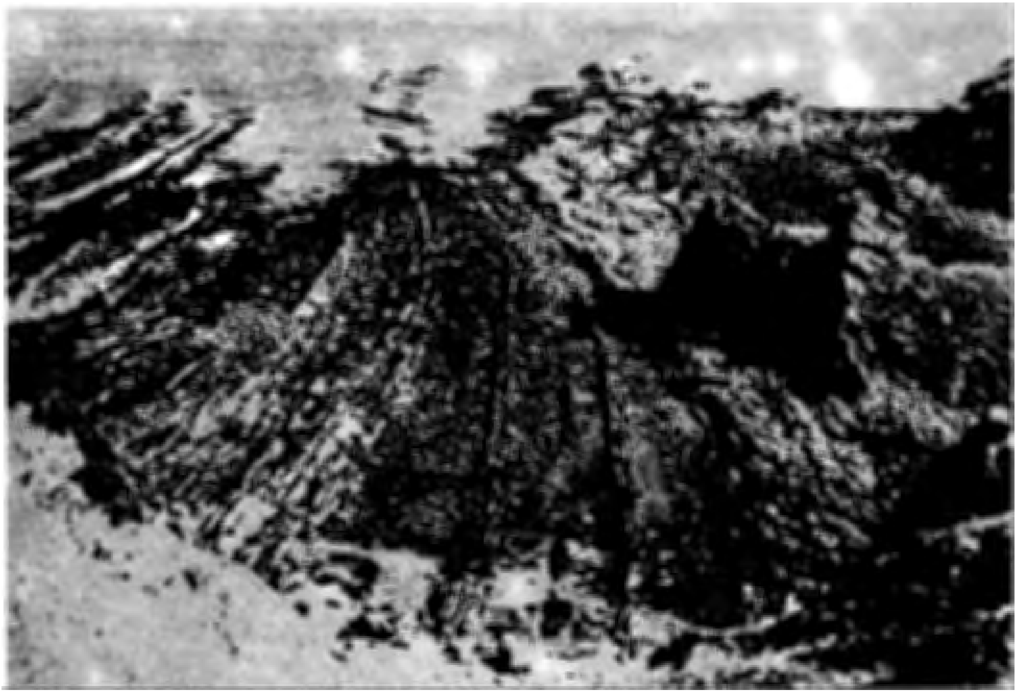

Plate 1a. Mudstone-siltstone-sandstone of sublithofacies Ia and Ib.

Plate 1b. Coal bed (C) and seath earth (S) in sublithofacies Ic and lithofacies III.

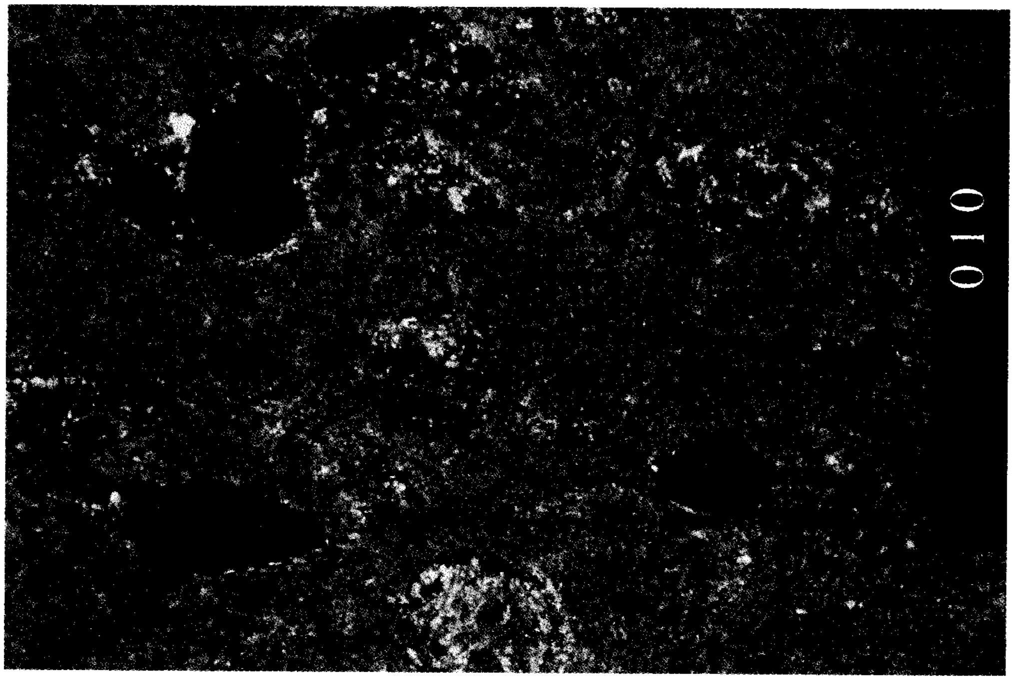

Plate 2. Carapaces and broken ostracod shell in the siltstone of sublithofacies Ia.

Plate 3. Rhombic cleavage of dolomite in sandstone of sublithofacies Ia.

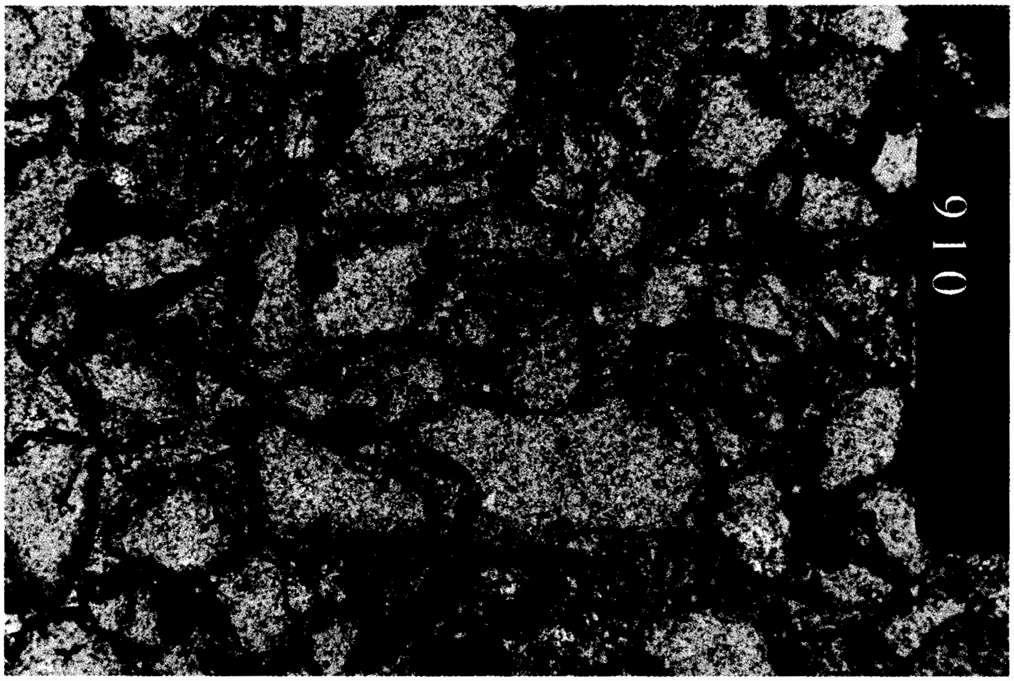

Plate 4. Quartz overgrowth in sandstone of sublithofacies Ib.

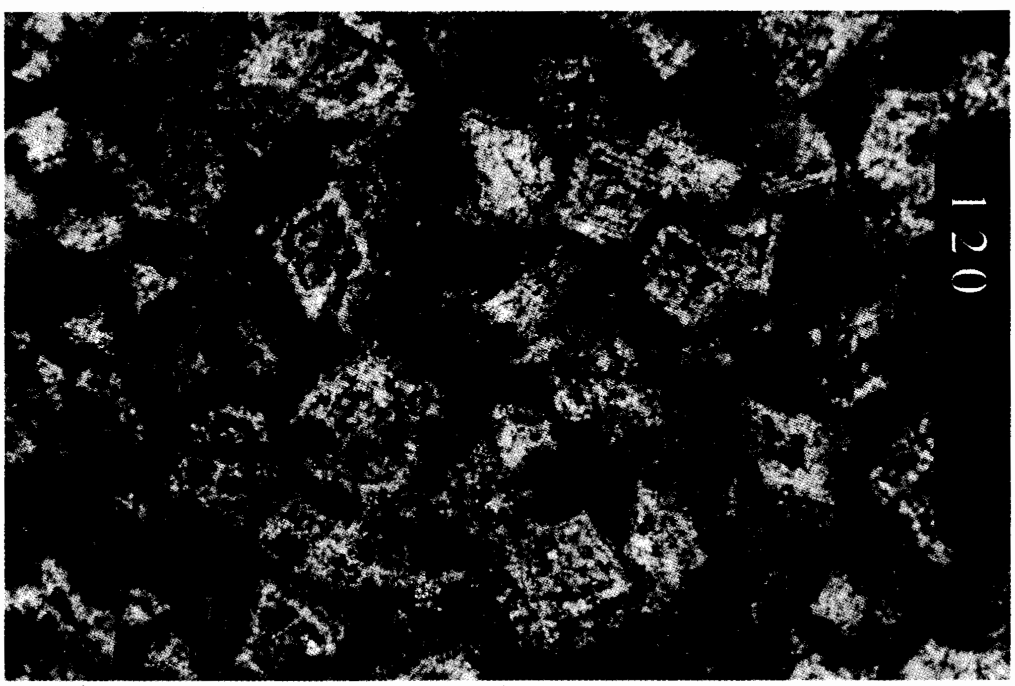

Plate 5. Rhombic shape of siderite in sublithofacies Ic.

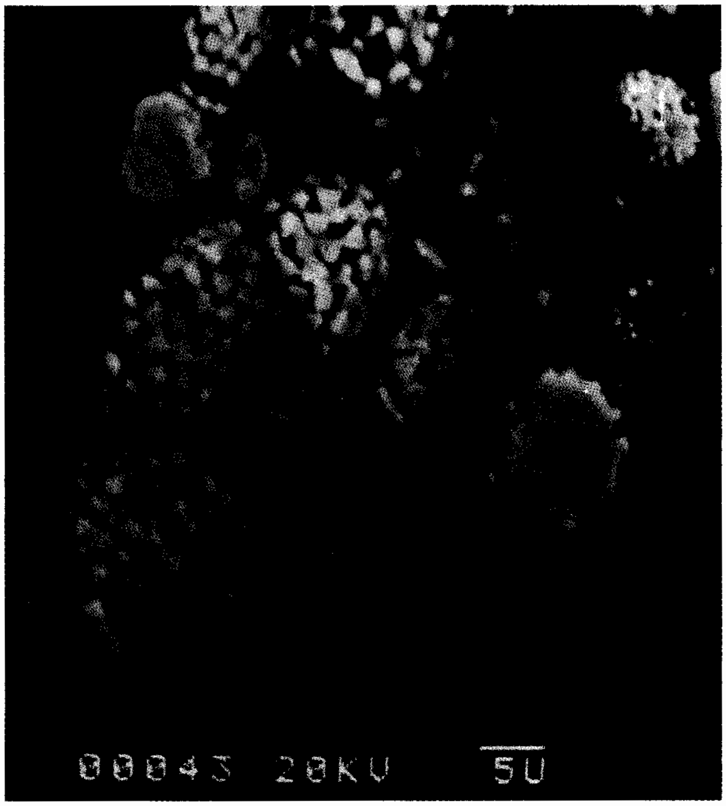

Plate 6. SEM photograph of framboidal pyrite in lithofacies II.

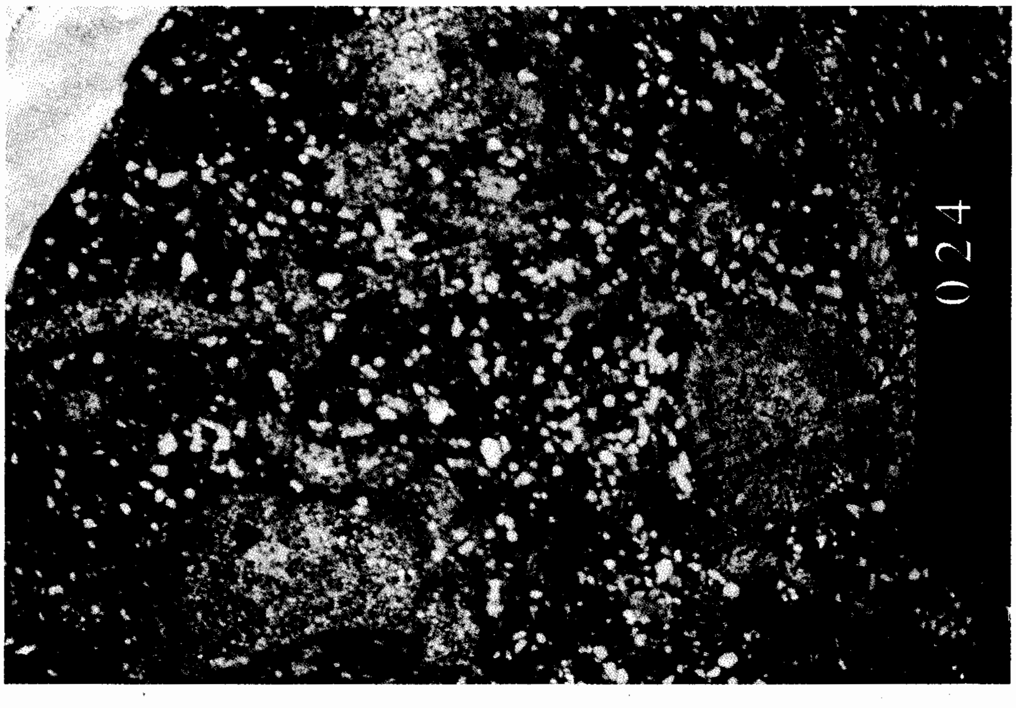

Plate 7. Echinoderms, bivalves and fragments of ostracod in lithofacies II.

Plate 8. SEM photograph of ferron dolomite cement showing rhombic cleavage in lithofacies II.

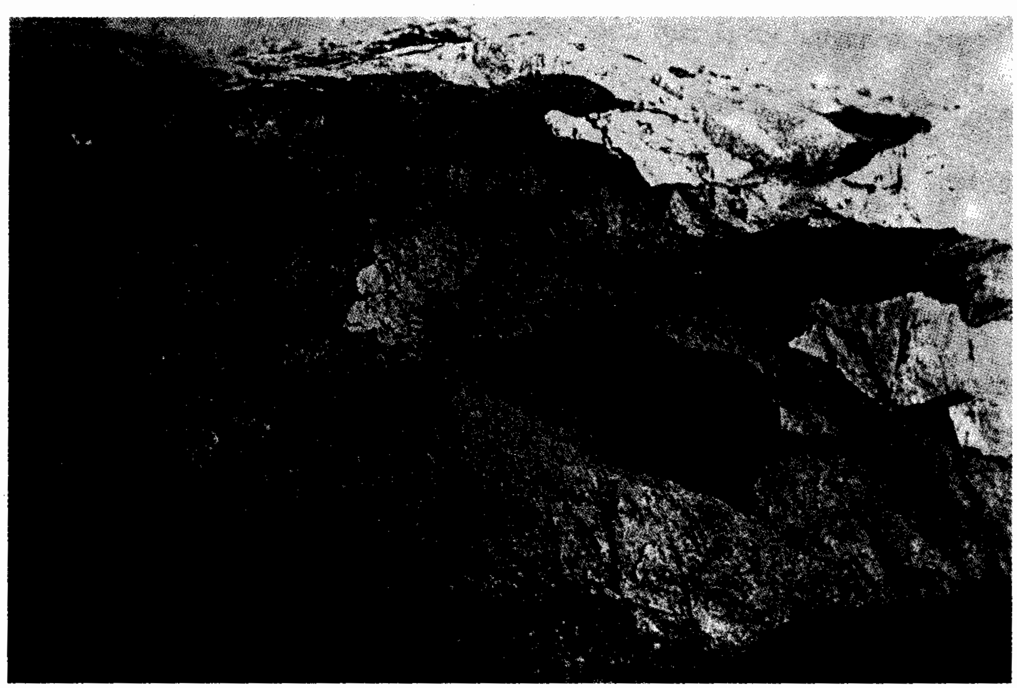

Plate 9. Plant rootlets in seat earth in lithofacies III.

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STRUCTURAL CHARACTERISTICS OF GABBROIC ROCKS FROM SAPLAI TOR GHAR MASSIF, MUSLIM BAGH OPHIOLITE, PAKISTAN

KHALID MAHMOOD AND MEHRAB KHAN BALOCH
Centre of Excellence in Mineralogy, University of Balochistan, Quetta. Pakistan

ABSTRACT

The gabbroic section of the Saplai Tor Ghar massif of Muslim Bagh ophiolite is about 1km thick and consists of layered, foliated and isotropic gabbros. The layered gabbros are less developed, the gradual layering was not observed, except in the south of the sheeted dyke complex. On the contrary, the crustal section is characterized by the bands of gabbro-pyroxenite-wehrlite of the scale varying from 10cm to 10m. The textural facies of gabbros and pyroxenites in Muslim Bagh show intense solid state deformation, developed at high temperature in the stability conditions of clinopyroxene and hornblande. This deformation is penetrative on the scale of crustal section. Most of the gabbros are plastically deformed which exhibits granular, porphyroclastic, mylonitic and mortat textures. The magmatic textures in the gabbros are generally absent, only at some localities can be observed. The synkinematic deformation occurred when the gabbros were still hot, probably in the vicinity of the ridge. The distribution of synkinematic assemblage in the gabbros indicate that this deformation occurred at progressively decreasing temperatures, as may be expected in an oceanic domain, where newly accreted lithosphere spreads away from a ridge axis thermal high.

INTRODUCTION

The Muslim Bagh ophiolite (old name Hindu Bagh Ophiolite) is located to the northeast of Quetta in the Zhob valley region and is one of the well-exposed ophiolites of Pakistan. The ophiolite is a part of the western ophiolite belt (Bela-Muslim Bagh-Waziristan) that separates the Indo-Pakistani plate from the adjacent continental blocks. The Eastern Block (Saplai Tor Ghar massif) of the Muslim Bagh ophiolite (Fig.1) shows a nearly complete ophiolite sequence, as defined by the Penrose Conference on ophiolites (1972). But the uppermost unit consisting of extrusive rocks and related sediments is missing. Only the lower part of the mantle sequence and metamorphic sole rocks occur at the Jang Tor Ghar massif (Western Block).

The transition from the mantle into the crustal sequence is only exposed in the Saplai Tor Ghar massif. The crustal sequence is exposed in the southeast of the massif (Fig. 2a) and consists of layered, foliated and isotropic gabbros, as well as sheeted dike complex. The gabbroic section of the Saplai Tor Ghar massif is different from the other ophiolites of the world as the gabbroic section is less developed here (~1 km thick). It is complex as most of the gabbros are plastically deformed. The gabbroic section rocks of the Muslim Bagh ophiolites are poorly studied so far. In this paper we have attempted to distinguish magmatic deformation from plastic deformation. For this purpose four sections were selected to study the microstructures and textures in the gabbroic rocks.

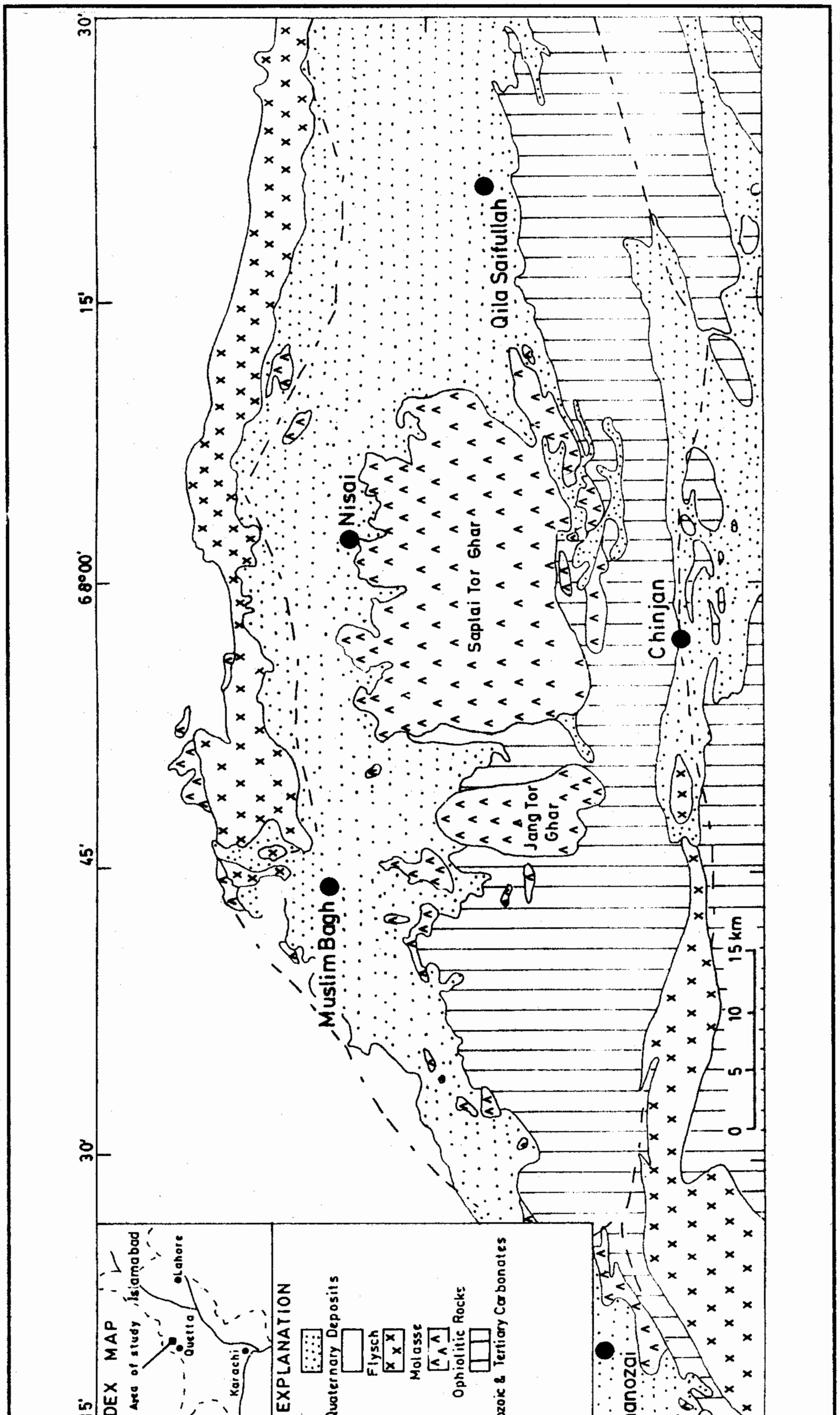

Figure. 1 Geological map of the Muslim Bagh ophiolite (after Hunting Survey Corporation 1960, Farah and Zaigham 1979 and Mahmood et al 1995.

MAGMATIC VS PLASTIC DEFORMATION

Plastic deformation can be recognized by signs of intra-crystalline deformation is expressed by the development of dislocation substructures which have been more or less recovered by kinking and twinning. When it is incomplete, recrystallization gives rise to coexistence of two generations of crystals of the same phase, the neoblasts which are the products of it and the porphyroclasts, which have survived from an earlier stage. When the recrystallization is complete due to intense deformation or physical conditions favoring high mobility of grain boundaries, the identification of plastic deformation becomes difficult.

Crystalline growth in a magma can also produce sub-structures, particularly twins. These magmatic twins are always more widely spaced and regular (Fig. 3a) than twins of tectonic origin which are more closely spaced, curved and tend to be tapered (Fig. 3b).

The macroscopic marks of plastic deformation are sometimes characteristic. For example, augen feldspar in orthogneisses, planar discontinuities due to shearing or boudinage. Another way which can often be decisive in distinguishing a plastic deformation structures from one of magmatic origin is by comparing the shape and lattice preferred orientation of crystals (Nicolas 1987).

GABBROIC ROCKS

Gabbros contain more than 50% plagioclase. This mineral thus may be expected to have controlling influence during plastic deformation. For the microstructural analyses, we chose plagioclase as the key mineral for textural and preferred orientation. Among the mafic minerals, we emphasized olivine because its dislocation substructure can be observed readily using an optical microscope. The crustal section of the Muslim Bagh ophiolite is in the SE of the Saplai Tor Ghar massif (Fig. 2a). The section commences with the gabbros which are either directly in contact with dunite - wehrlite of the mantle section, or are marked by a zone rich in clinopyroxenites of thickness 0 to 500m. The Moho is sub-vertical, with steep dip towards SE. The crustal section forms a synform. The upper most unit consisting of extrusive rocks and related sediments are not present in this structure. The SE contact is a thrust on the melange (volcano-sedimentary melange of Bagh (Siddiqui et al. 1996). The crustal section represents a great diversity of facies and a great complexity in their relationship. Layered gabbros are less developed in the massif of Muslim Bagh, we have not observed the gradual layering except in the south of the sheeted dike complex. On the contrary, the crustal section is characterized by the bands of gabbro-pyroxene-wehrlite of the scale varying from 10cm to 10m. The penetrative structures are well marked in all the facies.

The geological maps of Van Vloten (1967) and Rossman et al., (1971) were used as the base maps for our structural map (Fig. 2a). Here we present the structural relationship between lithological facies of four representative crustal sections (Fig. 2b),

MOHO SECTION NISAI

The layering in this section (Fig. 2b-A) is rarely well expressed in the gabbros and is relatively well preserved in the east of Nisai, on the left bank of Takri Manda. The gabbros show very gentle dip towards East and display the magmatic textures (Fig. 5A). At Moho level the foliation/ layering in the gabbros as well as mineral lineation marked by plagioclase become subvertical abruptly. The gabbros show cycles of concordant pyroxenite/ wehrlite layering with a vertical lineation. It grades into dunite/wehrlite of mantle section with the foliation in the same direction.

At Moho level the gabbros have the plastic granular texture of high temperature (Fig. 5B). The pyroxenites show the granular textures of high temperature (Fig. 5C). With an evolution of texture of dynamic recrystallization (Fig. 5D).

The wehrlites presents a concordant layering to a scale of mm to cm with recrystallization of clinopyroxene and intense deformation of olivine. This textural characteristic indicates that vertical attitude of Moho is related to high temperature plastic deformation (condition of stability of clinopyroxene), occurring immediately after the recrystallization. This section is representative of the general attitude of the Moho. In contrast, the magmatic textures in the gabbros are generally absent, when present are only localized to the NE termination of the section (Fig. 4).

BAGH SECTION

This section (Fig. 2b-B) is representative of the southern part of the crustal section. Layered and foliated gabbros are dominant alternating with concordant ultramafic bands having thickness of few cm to a meter. The SSE termination of the section is rich in doleritic dykes of two generations. The E-W one is older and SE-NW is younger. The rest of the section is locally cut by the swarms of doleritic dykes. The texture is porphyroclastic (Fig. 5E) that indicates strong deformation accompanied by recrystallization of plagioclase and the development of green hornblende.

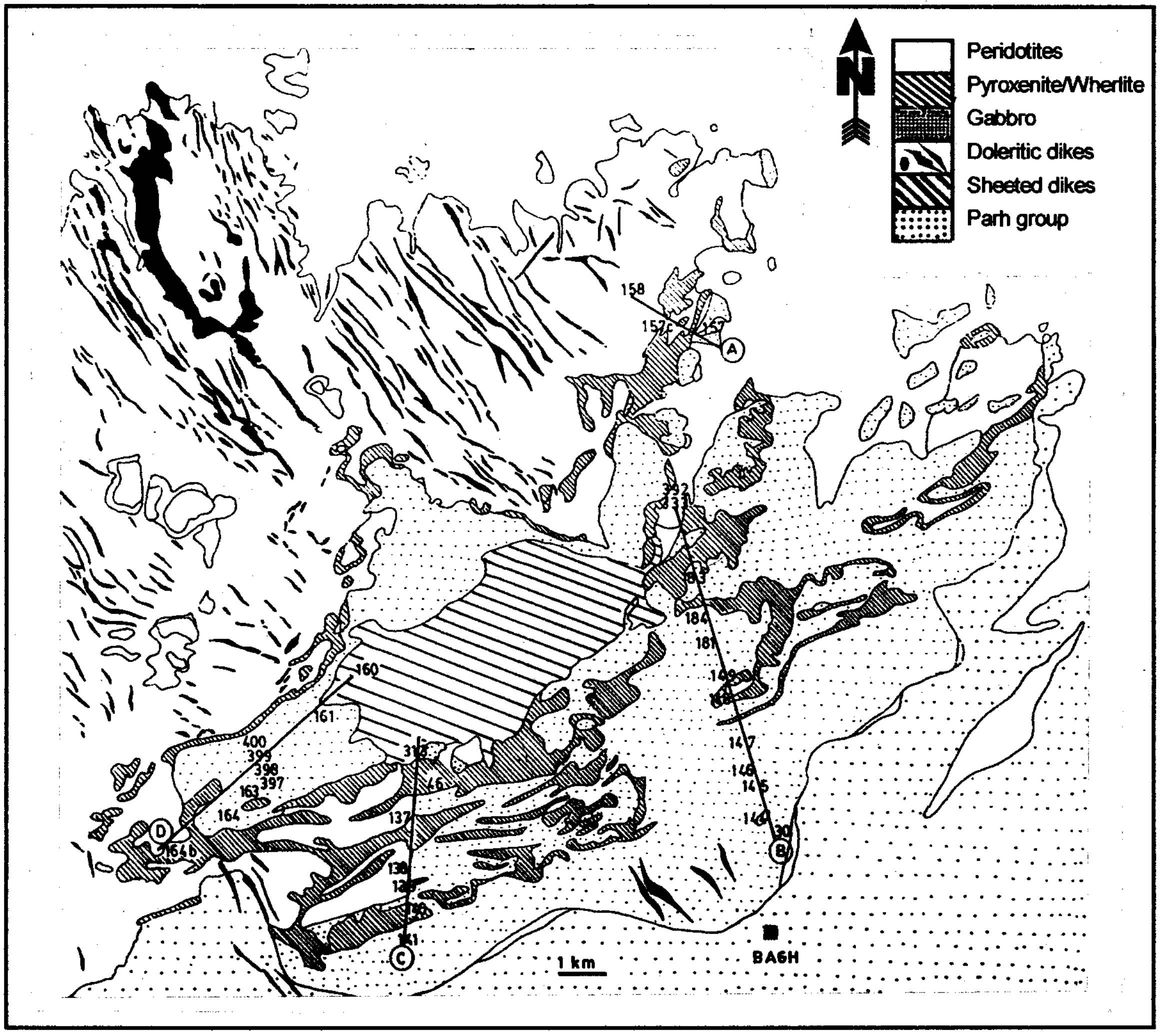

Figure 2a. Geological map of the eastern part of Saplai Tor Ghar massif (after Van Vloten 1967 and Mahmood 1994) with sample location and realized cross sections.

DOLE MANDA SECTION

This section (Fig. 2b-C) traverses across the roots of the sheeted dyke complex and the gabbro of the south zone. The dominant lithology is constituted by the layered and foliated gabbros having sub-vertical structures and porphyroclastic textures developed at intermediate temperature. We often observed the recrystallization of clinopyroxene (Fig.5A). These gabbros include strongly deformed concordant ultramafic bands (Fig.5F). Most oftenly the gabbros are heterogeneous and display an isomodal layering of pyroxenite-anorthosite (Fig. 6A) where the lenses of anorthositic gabbros alternate with the ultramafic bands (Fig.6B). A number of shear zones concordant to vertical thrusts haunch this section; they are preferably in the bands of ultramafics. The contact between gabbros and the root of the sheeted dyke complex is marked by a vertical shear zone. The sheeted dyke complex is composed of doleritic dykes oriented SE-NW showing chilled margins; screens of amphibolitized metadolerites strongly foliated parallel to the dykes. These metadolerites are injected by subconcordant plagiogranites, which also shows strong foliation and mineral lineation steeply plunging southward. The doleritic dykes of the sheeted dyke complex locally cross-cut the gabbros.

BARAK MANDA SECTION

This section (Fig. 2b-D) occurs in the western end of gabbros. It cuts the crustal and mantle section separated by Moho with high dip angle towards east, concordant with layering and foliation in the crustal and mantle section. This section is dominated by heterogeneously foliated gabbros, including remnants of isotropic gabbros, sometimes pegmatitic with amphibole, and the remnants of amphibolitized metadolerites abundant in the NE part of the section. Towards the west, the gabbros are locally cross cut by the wehrlitic bodies and by

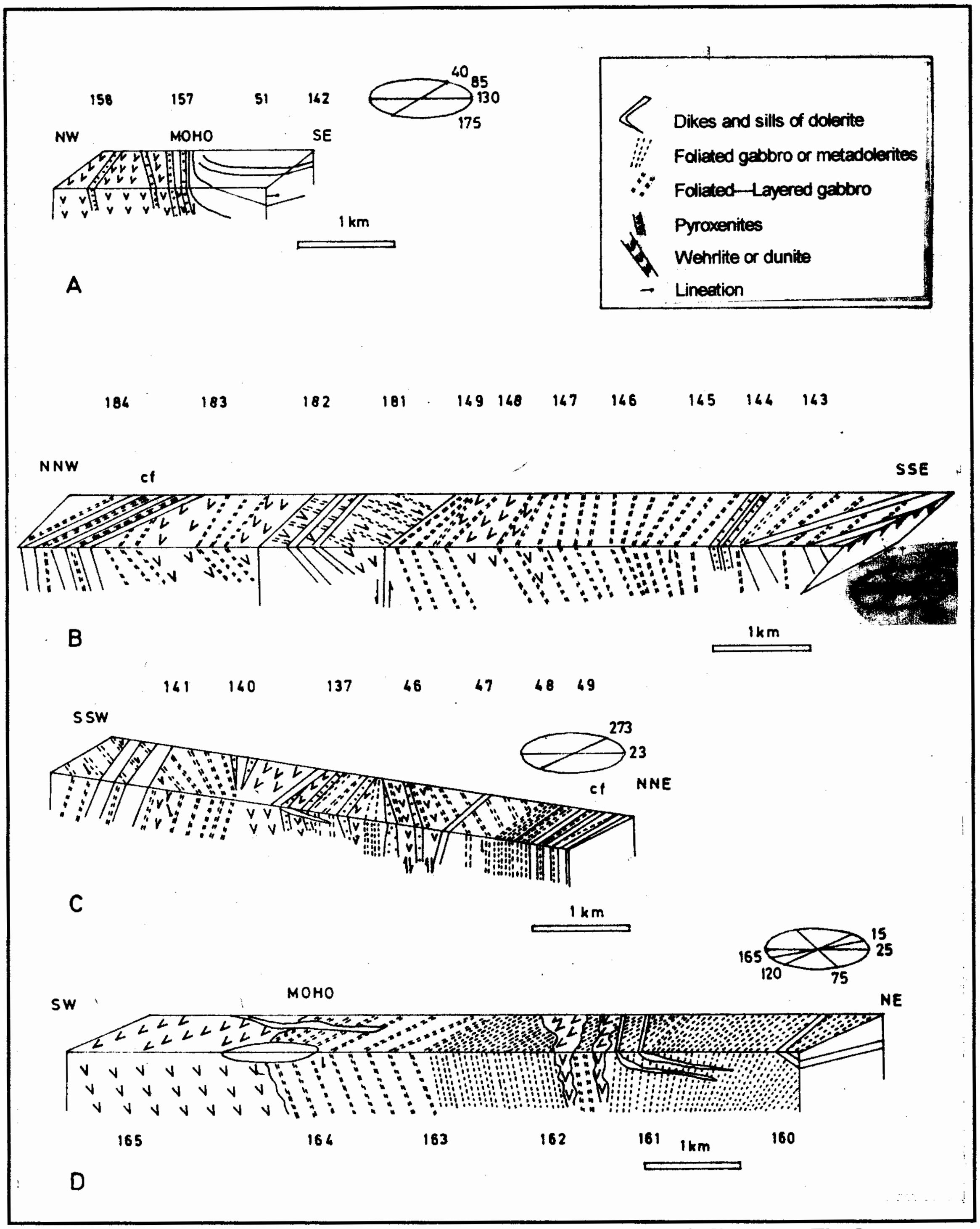

Figure 2b. Realized cross-sections. The locations of the sections are indicated on Fig. 2a.

the numerous doleritic sills. We find porphyroclastic textures of high temperature in the foliated gabbros (Fig. 5A), alternating with the plastic granular texture of high temperature (Fig. 5B), and with the concordant shear zones marked by the development of green hornblende. The penetrative structures of foliation and lineation are sub- vertical to a high dip towards east.

TEXTURAL DIVERSITY IN THE GABBROS

One of the characteristic of the crustal section of the Muslim Bagh ophiolite is the large distribution of porphyroclastic texture. Very few magmatic textures are intact such as described in the Oman ophiolites (Benn et al. 1988, Benn and Allard 1989; Nicolas 1992). The characteristic textures of solid state deformation in the crustal

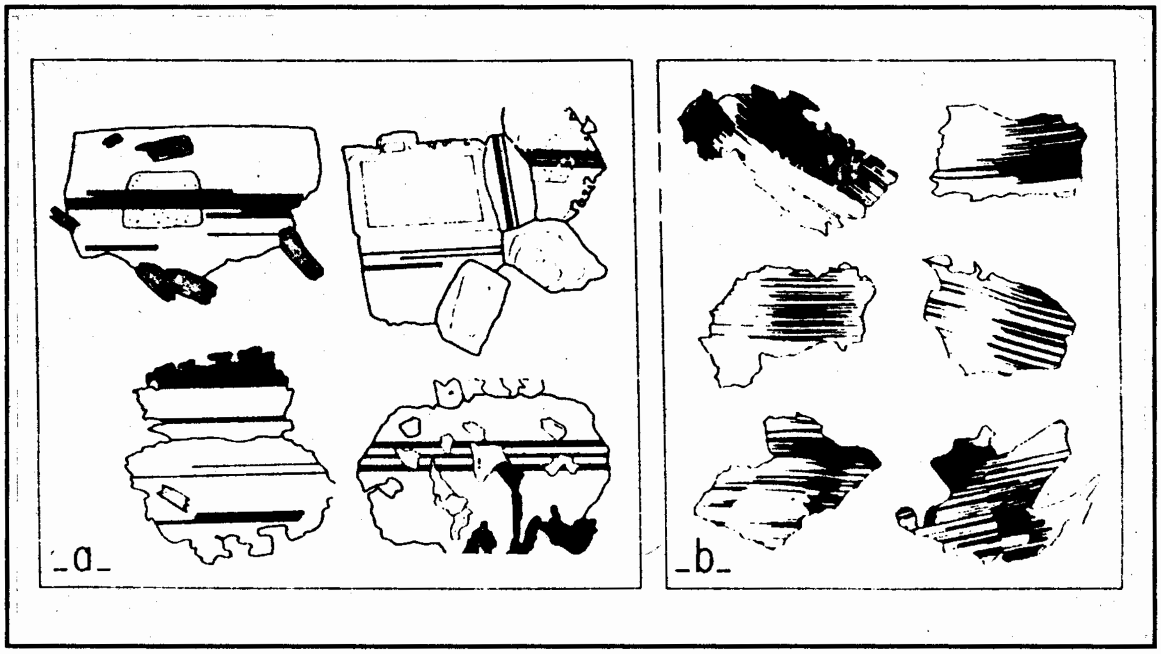

Figure 3. Difference between plagioclase twins of a) magmatic origin and b) tectonic origin. The tectonic twins are narrow, numerous, curved and tend to taper at the edges of the mineral, the magmatic twins are less numerous and rectilinear (Nicolas 1987).

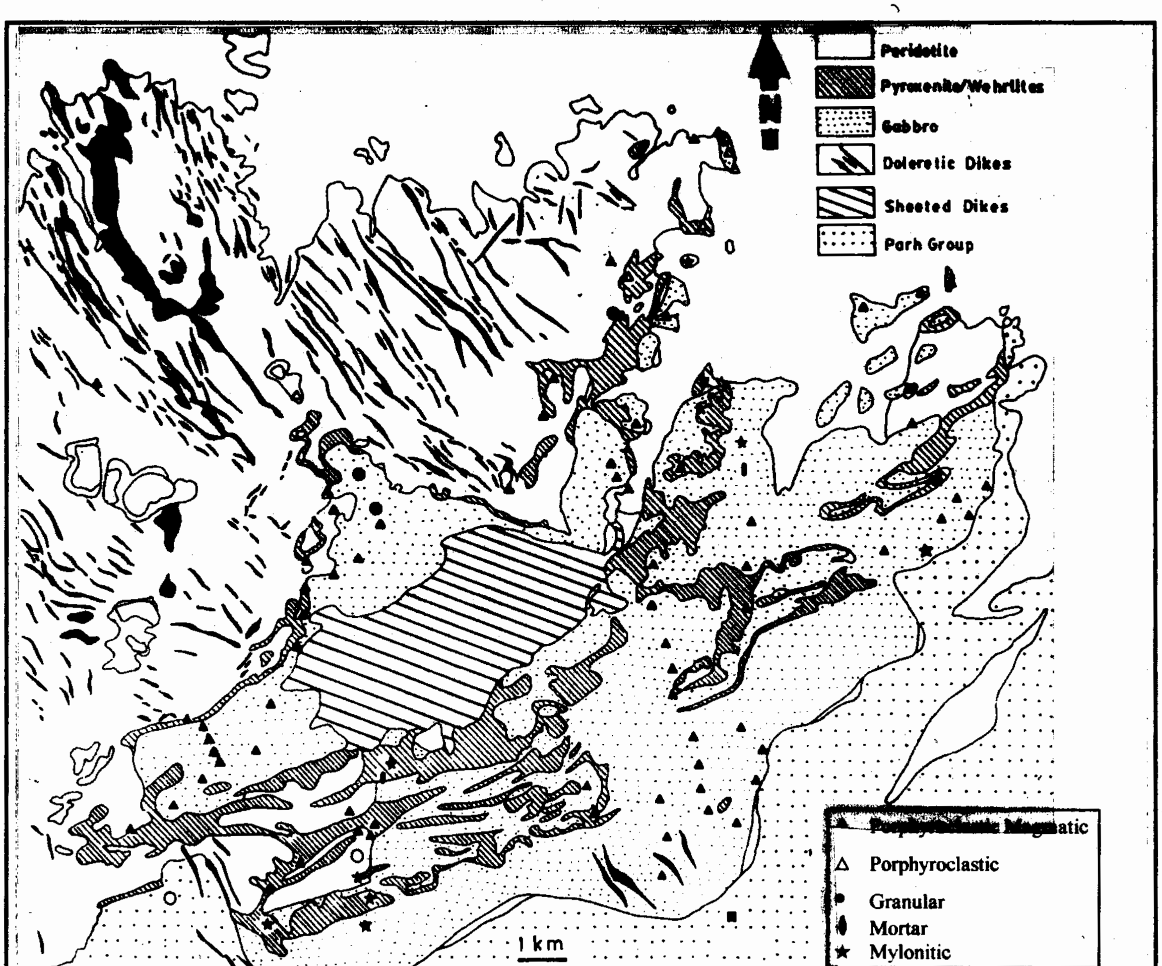

Figure 4. Textural facies in the gabbroic rocks of the Saplai Tor Ghar massif.

section of Muslim Bagh developed from the conditions of stability of clinopyroxene to the amphibolite facies of low temperature. Five facies were selected , serving the reference to the map of textural facies (Fig. 4).

MAGMATIC TEXTURES

These textures are characteristic of olivine gabbro (Fig. 5A) in which layering is very well developed. The feldspars having the orientation of moderate form, the parallel twins of growth, rarely the mechanical twinning (tapering) is found. Average dimension of crystals of plagioclase and clinopyroxene is 2-3mm. We observe locally polygonization of joins of the grains of plagioclase and partial recrystallization of plagioclase and clinopyroxene to polygonal crystals of 0.2mm dimension. The olivine has not been recrystallized, but many grains exhibit dislocations. The porphyroclasts exhibit well-defined sub-grain boundaries. This suggest that dislocation slip occurred along [100], the common slip direction in olivine deformed at high temperature (Nicolas and Poirier 1976).

SOLID STATE DEFORMATION
GRANULAR TEXTURE

This texture (Fig. 5B) is characterized by the recrystallization of clinopyroxene into the mosaic of polygonal crystals of 0.5mm which replace the primary crystals. The plagioclase shows numerous mechanical twinning and recrystallization peripheric to polygonal grains with tipple junctions. This texture is developed at the expense of the earlier. It indicates the solid state deformation at high temperature, accompanying the restoration in the stability conditions of clinopyroxene. In pyroxenites, (Fig. 5C) this texture shows two populations of crystals of clinopyroxene, primary crystals of few millimeters, and polygonal neoblasts of infra milimeter size.

PORPHYROCLASTIC TEXTURE

This texture (Fig. 5E and 6C) is the characteristic of gabbros having brown to green hornblande developed at the expense of clinopyroxene. The average grain size is 0.5mm. The minerals have lobe contours and the plagioclase of irregular form are full of mechanical twinning and of undulatory extinction (Fig. 6C). Certain porphyroclastic textures are marked by a strong reduction of grain from 1 to 0.1mm, including the intensity of deformation.

MYLONITIC AND MORTAR TEXTURE

This is a heterogeneous texture (Fig. 6D and 6E) of porphyroclasts (1mm) set in a matrix of recrystallized grains (<0.1mm). The mortar texture (Fig. 6D), which corresponds to a deformation at high stress oftenly shows /exhibits in equilibration field of clinopyroxene with localisation of the deformation in the intergranular matrix. The mylonitic textures (Fig. 6E) may accompany the amphibolitization of pyroxenes, in such cases these are more homogeneous, marked by the recrystallization of plagioclase into the crystals size <0.1mm, without twinning, and by the development of amphibole in the aligned clinopyroxene porphyroclasts. This type of textures corresponds to the intensification of the stress, and show degree of deformation in the condition of high to moderate temperature characterizing the earlier texture.

DISTRIBUTION OF TEXTURAL FACIES

The textural facies of gabbros and pyroxenites in Muslim Bagh show intense solid state deformation, developed at high temperature in the stability conditions of clinopyroxene and hornblande. This deformation is penetrative on the scale of crustal section. The concentration of more high temperature textural facies are at the Moho level or in the vicinity of Moho (Fig. 4). Few localized porphyroclastic or mylonitic textures of low temperature are associated to paragenesis of greenschist, zoisite, prehnite, and chlorite.

CONCLUSIONS

The gabbroic section of the Saplai Tor Ghar massif is less developed (~ 1km). It is complex, containing some layered gabbros with magmatic texture. Most of the gabbros are deformed plastically indicating high temperature conditions (Stability field for pyroxene up to low-grade amphibolite facies). The upper part of the exposed crustal section (upper level gabbro and base of the sheeted dyke complex) is affected by the local development of amphibolitization of hydrothermal origin associated with tholeiitic magmatism. The Moho has become vertical due to the deformation caused by anhydrous and of high temperature conditions and continue up to very low temperature, marked by a penetrative deformation in the gabbros and by the vertical shear zones due to normal faulting. Tectonism at the ridge site is responsible for the synform structure of the crustal section. The sub-vertical attitude of the Moho is associated with high temperature plastic deformation which continued to the immediate crystallization of the gabbros. This deformation corresponds to a vertical shear with normal component, which means displacing towards the base of the crustal section.

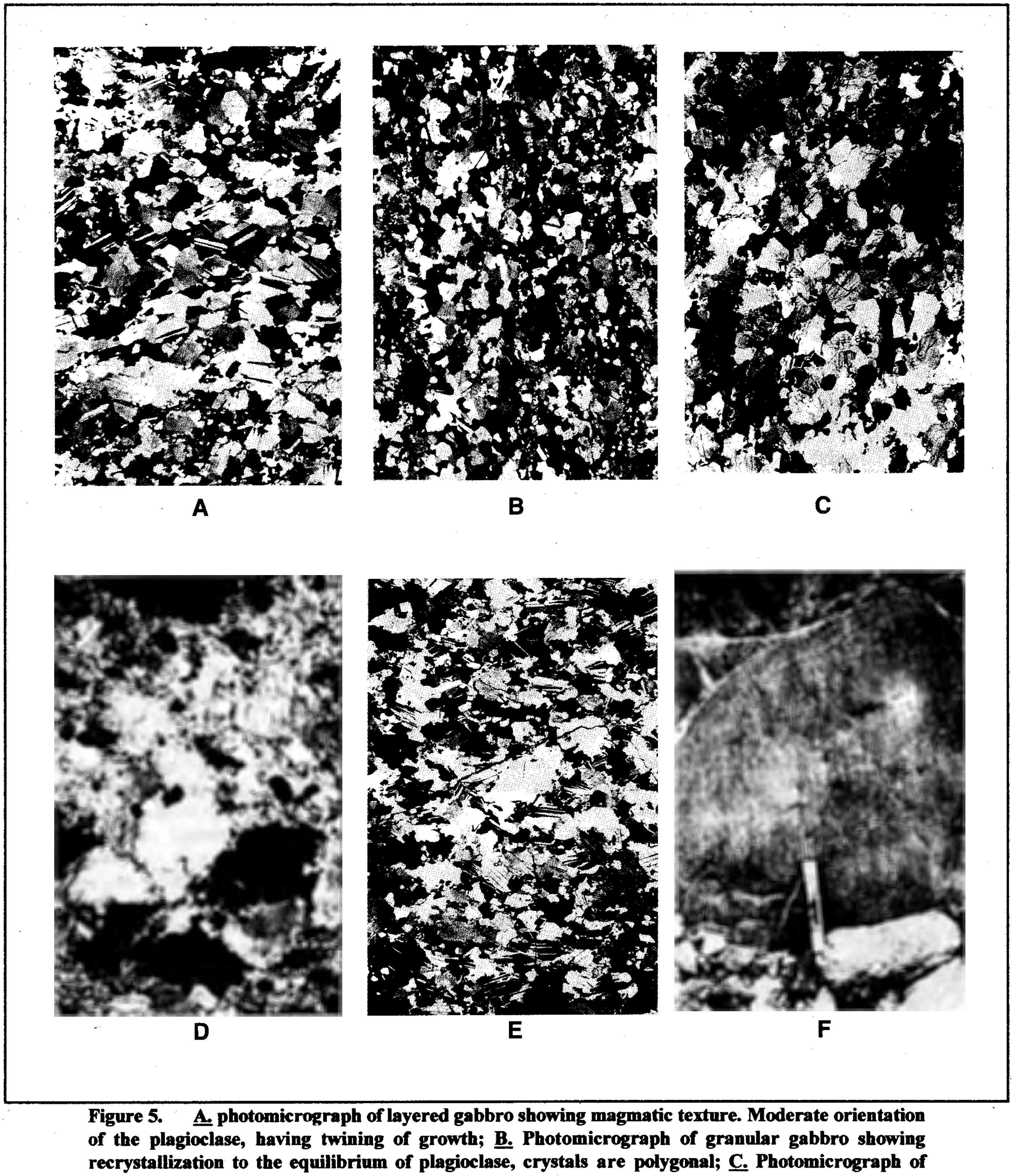

Figure 5. **A.** **photomicrograph of layered gabbro showing magmatic texture. Moderate orientation of the plagioclase, having twining of growth; B. Photomicrograph of granular gabbro showing recrystallization to the equilibrium of plagioclase, crystals are polygonal; C. Photomicrograph of pyroxenite showing high temperature granular texture: Recrystallization of clinopyroxene polygonal at the expense of porphyroclasts; D. Granular texture in pyroxenites with dynamic recrystallization at the borders of the porphyroclasts (some polygonal clinopyroxene); E. Porphyroclastic gabbro. Foliation marked by the orientation of porphyroclasts having undulatory extinction, subgrain boundaries and mechanical twining; F. Distinct layers of dunite and wehrlite.**

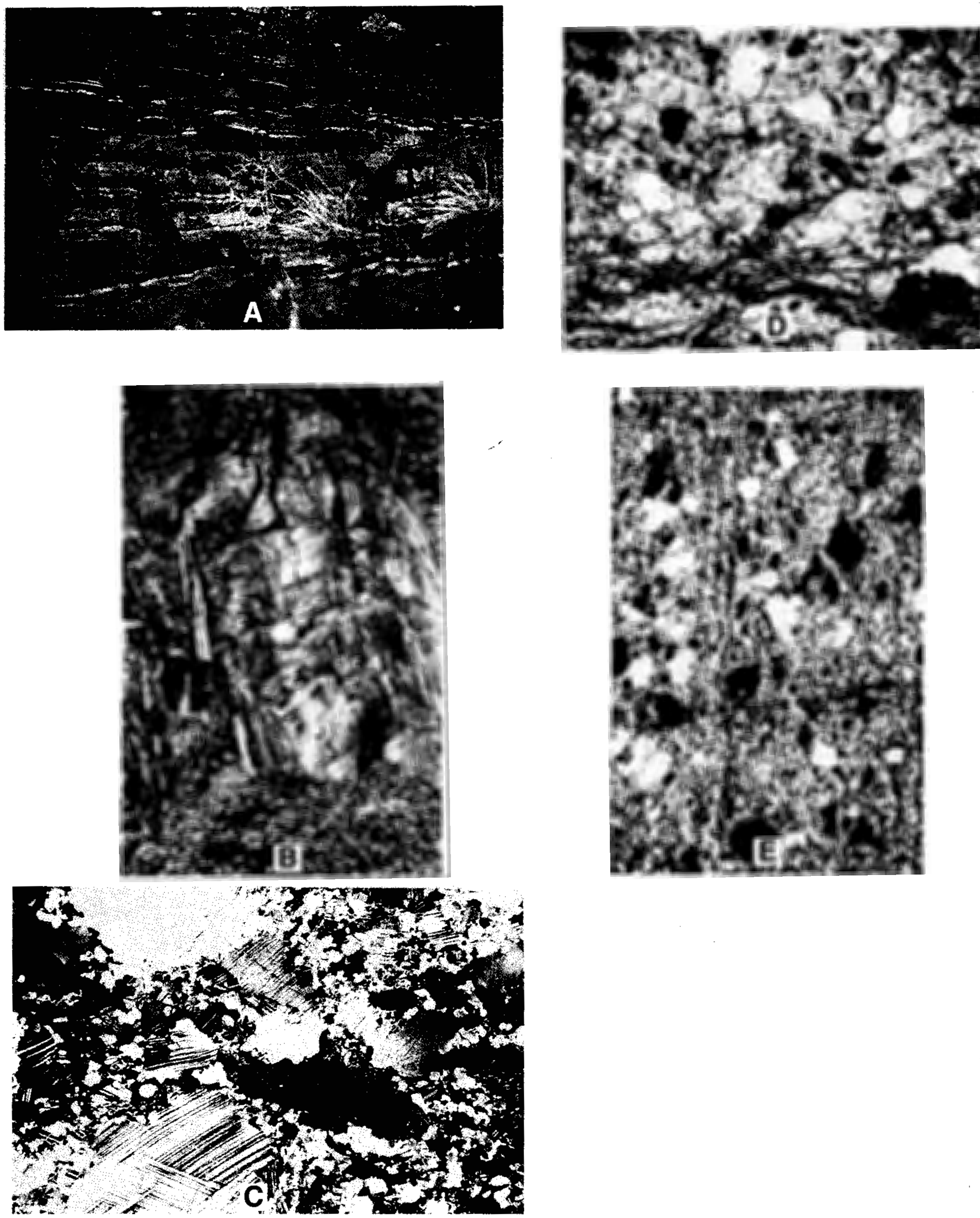

Figure 6. **A.** **Field photograph showing mafic/ultramafic layering in the gabbros;** **B.** **Field photograph showing lenses of anorthosite in layered and foliated gabbro;** **C.** **Porphyroclastic gabbro, Large porphyroclasts of plagioclase with mechanical twining and tapering;** **D.** **Mortar texture, Porphyroclasts of clinopyroxene in recrystallized clinopyroxene matrix;** **E.** **Mylonitic gabbro, Porphyroclasts of clinopyroxene and plagioclase in fine-grained recrystallised matrix.** (Top of 6E is towards left).

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METAMORPHIC ROCKS ASSOCIATED WITH BELA OPHIOLITES, PAKISTAN

MEHRAB KHAN[1], EDWIN GNOS[2], KHALID MAHMOOD[1] and ABDUL SALAM KHAN[1]
[1] Centre of Excellence in Mineralogy University of Balochistan Quetta.
[2] Mineralogisch-Petrographisches institut, Baltzerstrasse 1, 30212 Bern, Switzerland.

ABSTRACT

The intraoceanic subduction of the Bela oceanic lithosphere has been recorded in the metamorphic sole. The metamorphic sequence can be divided into two main facies: an amphibolite facies and a greenschist or lower green schist facies. The metamorphic rocks associated with the Bela ophiolite occur as discontinuous outcrops beneath the ophiolite nappe and overlay tectonically, a nappe, stack of none metamorphic pillow lavas and sediments (accretionary wedge –trench sediments). The metamorphic rocks are directly overlain by serpentinized harzburgite mantle sequence. The lower part of the Bela ophiolite nappe is comprised of peridotite mylonite. It is characterised by the regular bands of dunite and harzburgite. These bands / layerings of peridotite show porphyroclastic, mylonitic to ultramylonitic fabrics. This has been developed due to emplacement of the Bela ophiolite. Kinematics data recorded at the base of the peridotite of the Bela ophiolite are based on six consistent shear sense measurements which indicate NW- SE oriented thrust movement in the present geographical reference system. This thrust movement direction is coherent with the imbrication structures present in the underlying accretionary wedge. $^{39}Ar/Ar^{40}$ dating shows that the intraoceanic subduction initiated between 70 and 65 Ma and final emplacement onto the Indian continental margin occurred in the Early Eocene. (≈ 50 Ma).

INTRODUCTION

The basal contact of many allochthonous ophiolite complexes are characterised by the presence of thin subjacent sheets of relatively high grade of metamorphic rocks. (Williams and Smyth 1973, Coleman 1977, Woodcock and Robertson 1977).

Metamorphic rocks are generated in several tectonic settings.The-forming processes is different in each tectonic setting and gives a metamorphic sequence its characteristic features. The metamorphic sequence associated with ophiolites is characterized by a steep thermal gradient of one or several degrees per meter; comparable to contact metamorphic aureoles.The metamorphic rocks associated with ophiolites show strong planer and linear fabrics instead of static equilibrium textures. It is generally accepted that dynamothermal aureole (Metamorphic sole rocks) have been formed in a subduction (obduction, underplating) regime, and reflect a mega shear zone between the cold downgoing slab and the hot ophiolite hanging wall. The lowest 100- 500m of the peridotite also belongs to that shear zone, and show porphyroclastic to mylonitic fabrics, overprinting the high temperature fabrics of the mantle asthenosphere flow. The zone

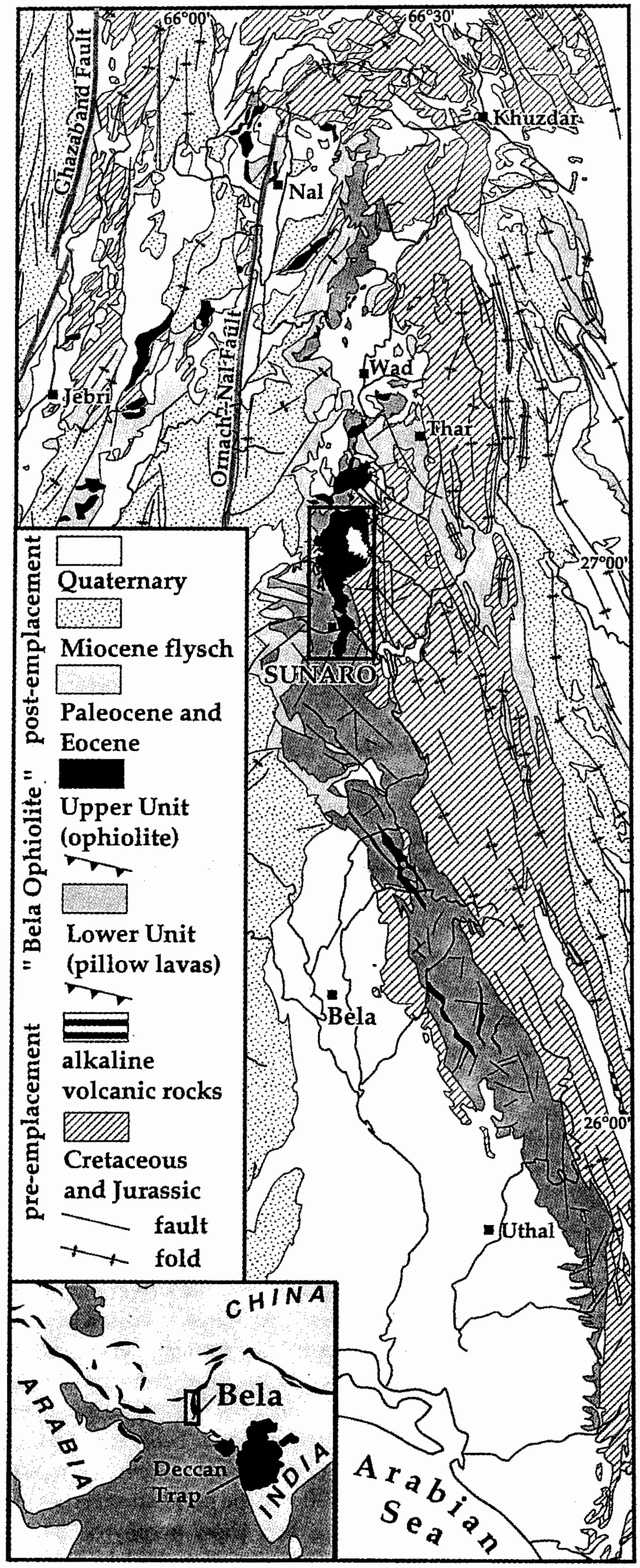

Figure 1. Overview map of the Bela oceanic lithosphere assemblage (Hunting Survey Corporation 1960, Ahsan et al. 1988 and Gnos et al. 1998).

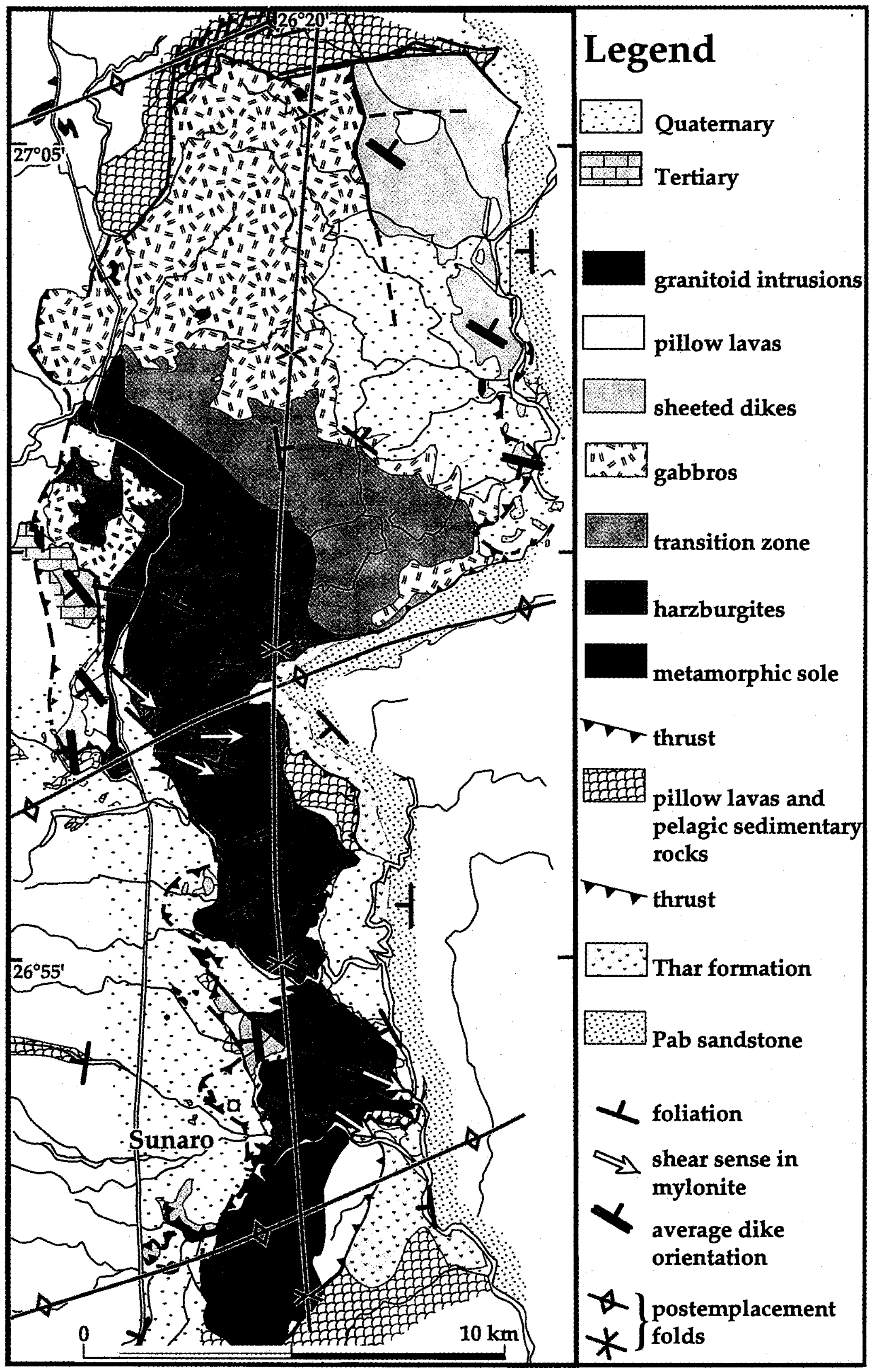

Figure 2. Geological map of the Sunaro ophiolite massif. Synformal structure that has N-plunging fold axis is marked by presence of outward-dipping sheeted dike complex on both limbs.

of sheared peridotites are often called "peridotite mylonites" or "banded units" (Gnos et al. 1998).

Hence the metamorphic sole of the ophiolite contain informations about timing, pressure, and temperature conditions ($PT_{t\text{-}path}$) in the upper part of a subducting zone, direction of plate movement and about the rock type subducted plate. (Boudier et al. 1982).

The metamorphic sole of the Bela ophiolite were not reported before. A poorly preserved metamorphic sole of amphibolite and greenschist to lower green schist facies rocks are exposed near Sunaro village (Fig. 1 and 2). The metamorphic rocks associated with Bela ophiolite occur as discontinuous outcrops beneath the ophiolite nappe and overlay tectonically a nappe, stack of non metamorphic volcanic rocks and sediments (accretionary wedge-trench sediments). The thickness of the metamorphic sole varies at places but kilometer size outcrops of green schist or lower greenschist facies rocks are present in the Sunaro area. The metamorphic sequence can be divided into two main facies : an amphibolite facies and green schist or lower green schist facies rocks.

AMPHIBOLITES

The amphibolites occur as discontinuous bodies having contact with the basal peridotites. The thickness varies from a few meter to deca meter. They consist of brown-green hornblende, sussuritized plagioclase and clinopyroxene. The clinopyroxene is concentrated in some layers. In few samples (95-181) almandine rich garnet is also present. The amphibolites are foliated to gneissic, showing compositional layering within amphibole and plagioclase. Amphibole crystals tend to stubby and lie in the foliation plane marking the lineation. No relict igneous texturé have been observed. The amphibolites are porphyroclastic, medium grained, usually schistose and most of them have under gone varying degrees of cataclasis. Their foliation is defined by aligned horblende with altered (saussuritized) plagioclase.

The majority of the foliation and lineation in the amphibolites are parallel to sub parallel to those found in the basal peridotites. The amphibolites consist of hornblende 50-70%, plagioclase 20-30% clinopyroxene 3-5%, epidote 5-10%, quartz 2-5% clinozoisite 2-3% and apatite ~1%. The precentage of the epidote increases with the alteration of plagioclase and amphibole. The amphibolites show garnoblastic to mylonitic texture, under the microscope.

The rocks at the contact to the peridotite mylonite often show porphyroclastic to cataclastic textures, whereas rock away from the contact is less deformed. Deformations are concentrated in zones.

CHLORITE AND CHLORITE/ ACTINOLITE SCHISTS FACIES

Structurally, beneath the amphibolites the green schists facies are present which are largely exposed (several kilometre thick) near the Sunaro village (Fig. 2) and having direct contact with basal peridotites and at places is intact with thin sheets of amphibolites.

Banded quartzites and marble are common and are often interbanded with green schists facies on a centimetre and metre scale respectively indicating a probably sedimentary origin of many of these rocks. It is also observed that calcite, quartz, white mica and chlorite are strongly deformed.

The assemblage of the green schist facies includes Albite-Actinolite-Epidote/Clinozoisite-Chlorite±Titanium±Ilmenite±Hematite/Magnetite and some times biotite. The schistosity is marked by phyllosilicates. Calcite and epidote are also concentrated in some bands. Some green schist facies are fine grained containing spots of ore minerals (probably hematite).

PENETRATIVE STRUCTURES

More than sixty measurements of the penetrative structures (foliation and lineation) were made in the rocks of the metamorphic sole of the Bela ophiolite. These structures were mapped wherever the metamorphic sole was found. All these measurements are plotted on the lower hemisphere presenting the poles of the foliation planses and the mineral linceation (Fig. 3). In the meatamorphic sole of the study area, the foliation planes shows NE-SW and NW-SE trends with a steep dip toward E and W. The majority of the lineations are oriented SE, with subordinate lineation dipping towards WWN. The foliation plane trending NW-SE with E-ward dipping is considered actual plane of foliation with the lineation oriented towards SE.

BASAL PERIDOTITES

Mylonite harzburgites and dunites at the base of the ophiolites record plastic deformation developed possibly within the granulite facies between 800 and 1000 °C (Boudier and Coleman 1981, Girandeau 1985, Nicolas 1989). The penetrative structures developed in the peridotite section are parallel to that in the highest-grade part of the underlying metamorphic sequence. Olivine from the basal peridotites can be used as a kinematic record of ophiolite obduction due to the homogeneity of deformation (Boudier et al. 1982). In the study area the lower part of the Bela ophiolite nappe consists of the bands of the basal peridotite characterised by the regular bands of dunite and harzburgite. These bands are concordant with the foliation planes of the rocks. The thickness of these bands varies from metre to decametres.

These bands/layerings of peridotite show porphyroclastic, mylonitic to ultramylonitic fabrics, with characteristic bimodal grain size distribution of millimeter sized orthopyroxene porphyroclasts in a finer-grained olivine-dominated matrix. Most of the grains are strongly deformed and elongated, commonly showing a high frequency of subgrains (crystallites) and undulatory extinction. Orthopyroxene porphyroclasts are typically bent or kinked with exsolved clinopyroxene concentrated in the hinges. The porphyroclastic texture is the result of both temperature and pressure and very commonly develops close to the basal thrust plane of the ophiolite. A 900-1000° Celsius temperature

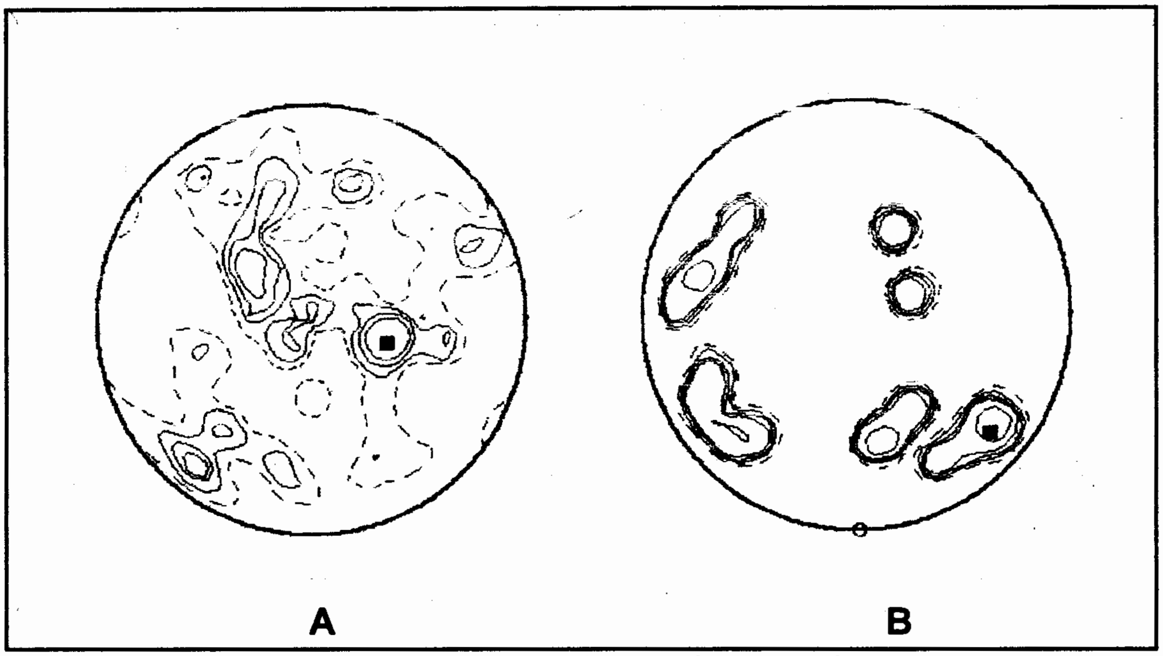

Figure 3. Stereograms of lower hemisphere projections of (A) poles of foliation; 62 measurements and B) lineations 17; measurements in metamorphic rocks.

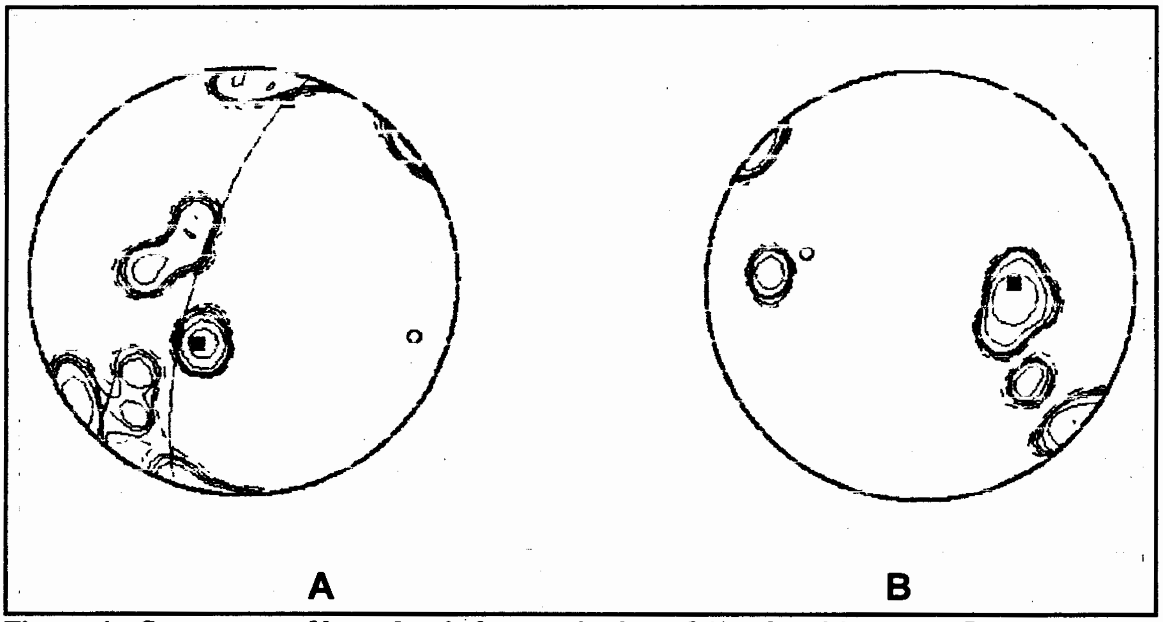

Figure. 4. Stereograms of lower hemisphere projections of A) poles of foliation; 17 measurements, and B) lineations; 9 measurements, in basal peridotites.

range is ascribed to this kind of texture (Mercier and Nicolas 1975). Ultramylonitic, mylonitic to porphyroclastics textures are typically developed at the base of the emplaced ophiolite nappes or along emplacement related shear zone, usually called "low-temperature deformation" (LT). Mylonitic textures with complete recrystallization of olivine (average size < 0.1 mm) are common within a few meters from the contacts with amphibolites.

In basal peridotites, the foliation planes are NE-SE oriented, with an average dip towards East. The majority of the lineations display E to SE orientation (Fig.4). The foliation planes and mineral lineations are close to the planes and direction of the thrust. In the Bela ophiolites a close similarity exists between the penetrative structures of the amphibolites and basal peridotites. The planes of foliation with average dip towards east and the lineation are oriented towards east.

^{40}Ar/^{39}Ar DATING

EXPERIMENTAL TECHNIQUE

The age dating of the selected samples from the study area was carried out in collaboration with Igor M. Villa at the Mineralogisches Institut, Abteilung fur Isotopengeologie, Universitat Bern, Erlachstrasse 9a, 3012 Bern, Switzerland.

The experimental procedure used for ^{40}Ar/^{39}Ar dating by step-heating of mineral population is similar to that reported by McDougall and Harrison (1988). Hornblende and Muscovite were separated from crushed and sieved rock powders using magnetic, heavy liquid, hand-picking and ultrasonic cleaning techniques. Neutron irradiation was performed in the Siloe reactor at the Mineralogisches Institut, Abteilung fur isotopengeologie, Universitat Bern, Erlachstrasse 9a, 3012 Bern, Switzerland, using standard MMHb (Samson and Alexander 1987) and a 344.5 $\pm$ 4 Ma metamorphic hornblende as flux monitors. The samples were shielded by a 0.5 mm thick Cd-foil in order to reduce interferences with slow thermal neutrons. The data were corrected for system blanks, mass discriminations, ^{37}Ar and ^{39}Ar decays and nuclear interferences with Ca. The age error on single step is two sigma and does not include the J-error that has been propagated only into the total fusion and plateau ages.

RESULTS

We conducted dating experiments on three amphiboles from gabbroic and granitoid rocks of the crustal sequence. Two amphiboles were taken from metamorphic sole, and one muscovite was from a late quartz-vein cutting the metamorphic sole. Generally the age spectra obtained are slightly to significantly discordant. By resorting to K-CI-Ca correlation diagrams (Villa et al. 1996). We identified most likely primary ages. In six rocks out of seven they cluster around 65-70 Ma (Table 1). Some minerals were altered (e.g. 95-107 had only 0.1%K), probably during or shortly after obduction, as attested by steep ages of 64-66 Ma. Subsequent minor alteration at ~ 40 Ma can also be identified. Finally, two concentrates from a granodiorite intrusion (95-050) both give internally discordant spectra that concordantly define an ~800 Ma primary age, likely to be an isolated inheritance

Table 1. ^{40}Ar−^{39}Ar results from amphiboles and micas.

Sample/ Mineral	Unit	Latitude	Longitude	^{40}Ar* (nl/g)	K (ppm)	Cl (ppm)	Ca (%)	t_{pl} (Myr)	t_{pri} (Myr)	N	f %	t_{alt} (Myr)
95-007hb	a	27°14' 71"	66°21' 24"	0.28	930	103	3.1	69.5 ± 0.7	69	2	52	40
95-047hb	a	27°33' 36"	66°23' 95"	0.37	1470	170	4.7	68.7 ± 0.7	69	4	56	35
95-050hb	a	27°33' 15"	66°21' 40"	10.50	8900	161	4.2	N.A.	810	1	16	< 700
95-050bt	a	27°33' 15"	66°21' 40"	128	40400	158	0.64	N.A.	812	3	25	< 400
95-077hb	a	26°59' 54"	66°17' 62"	0.09	374	72	4.5	N.A.	66	2	29	< 50
95-107Cms	b	20°56' 00"	66°19' 53"	0.30	1200	231	14.3	N.A.	64	6	64	40
95-185hb	b	26°57' 29"	66°17' 81"	5.7	22500	11	0.30	N.A.	64	7	59	45
95-185Bhb	b	26°57' 29"	66°17' 81"	1.15	4370	15	5.0	N.A.	67	1	11	<50

Note: **Results are from the crustal section (a) and from the metamorphic sole (b) of the Bela ophiolite. (t_{pli}) is the plateau age which is applicable only in two instances. Most spectra are discordant; therefore ages are interpreted as primary (t_{pri}) or alteration (t_{alt}) basing on K-Cl-Ca correlation diagram (Villa et al. 1996). *N* is the number of steps identified with the primary age and *f* is the percent fraction ^{39}Ar therein. Isochrons were all found to have atmosphere intercept and are given no separate entry. N.A.=not applicable.**

from the Indian Proterozoic basement. $^{39}Ar/^{40}Ar$ dating shows that the ophiolite formed around 70 Ma. Emplacement initiated between 70 and 65 Ma and final thrusting onto the continental margin occurred in Early Eocene (Gnos et al. 1998).

DISCUSSION

In the mylonitic harzburgites and dunites of the metamorphic sole of the study area, certain orthopyroxene grains are stretched in plane (100). The obliquity between the trace of the plane (100) and trace of the foliation in the XZ plane gives an indication of the sense of shear (Nicolas et al 1973). In the harzburgites and dunites having mylontic and porphyroclastics texture the sense of shears were obtained from thin sections cut in the XZ plane of the finite strain by determination of the common extinction angle.

Kinematics data recorded at the base of the peridotite of the Bela ophiolites are based on six consistent shear sense mesurements, which indicate a NW-SE, oriented thrust movement in the present geographical reference system. This thrust movement direction is coherent with the imbrication structures present in the underlying accretionary wedge.

We conclude from the kinematic analysis of the peridotite sole in the Bela ophiolite that it record an East to SE thrusting initiated at temperatures about 1000°C and continuing eventually down forming amphibolite conditions. Microstructural studies and fabric measurements in these rocks were carried out particularly to ascertain that the mineral lineation can effectively by equated with the transport direction (Nicolas et al, 1973, Nicolas, 1989). Sense of shear was deduced from detailed fabric data and from thin section examinations. All these indicate that there is a great similarity in style of deformation (directions and sense of shear) in the basal peridotites and those of the underlying amphibolites. Microstructural and fabric data (grain sizes, slip systems) also indicate that the temperature of deformation in the mylonitic peridotites is consistent with the garnet amphibolite facies condition and that recorded stress is on the order of 1 K bar in olivine (Nicolas 1978). $^{39}Ar/^{40}Ar$ dating show that the ophiolite formed around 70 Ma. Emplacement initiated between 70 and 65 Ma and final thrusting onto the continental margin occurred in the Early Eocene (≈50 Ma).

CONCLUSION

A poorly preserved metamorphic sole of amphibolite and greenschist Facies rocks are exposed near Sunaro village. It indicates the intraoceanic subduction of the Bela ophiolites. Intraocanic thrusting initiated between 70 and 65 Ma and final thrusting onto the Indian continental margin occurred in the Early Eocene (≈50 Ma). The metamorphic sole associated with the Bela ophiolite occurs as discontinuous outcrop beneath the ophiolite nappe and overlay tectonically accretionary wedge-trench sediments. In the rocks of metamorphic sole, the foliation planes show NE-SW and NW-NE trends with steep dip toward E and W. The majority of the lineations are oriented SE, with subordinate lineation dipping towards WWN. The foliation plane trending NW-SE with E-ward dipping is considered actual plane of foliation with the lineation oriented towards SE. In basal peridotites, the foliation planes are NE-SE oriented, with an average dip towards East. The majority of the lineations display E to SE orientation. In Bela ophiolites a close similarity exists between the penetrative structures of the amphibolites and basal peridotites..

Kinematics data recorded at the base of the peridotite of the Bela ophiolites are based on six consistent shear sense measurements, which indicate NW-SE, oriented thrust movement in the present geographical reference system. This thrust movement direction is coherent with the imbrication structures present in the underlying accretionary wedge.

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SULFUR ISOTOPIC SIGNATURE OF THE SEDIMENT-HOSTED LEAD-ZINC-BARITE DEPOSITS IN KHUZDAR AND BELA DISTRICTS, PAKISTAN

SHAMIM AHMED SIDDIQUI
Centre of Excellence in Mineralogy, University of Balochistan, Quetta Pakistan.

ABSTRACT

Variations in the sulfur isotopic ratios of the lead-zinc-barite mineral deposits occurring in the Khuzdar-Bela metallogenic province were studied in order to gain some insight into the genesis of these deposits. For this purpose a limited number of representative samples of both sulfide and sulfate minerals, available from Khuzdar and Bela districts were analyzed for their isotopic ratios. Data thus obtained showed low per mil values of $\delta^{34}S$ *in the sulfide minerals, particularly in Khuzdar area; contrary to that, relatively high corresponding values in barites were observed, more so in the deposits at Gunga. It is suggested that the reason for low values of isotopic ratios associated with the sulfide phases is the fractionation brought about by the reduction of sea-water sulfate, most probably by bacteria. High values encountered in the barites are due to mixing of underlying evaporite solution of heavy isotopic sulfur. The anomalously high temperature given by the study of isotopic fractionation factors among coprecipitated mineral pairs revealed mineralization under conditions of isotopic disequilibrium.*

INTRODUCTION

Certain stratigraphic horizons of the Jurassic sequence in the Khuzdar-Bela metallogenic province are host to epigenetic type of Ba-Pb-Zn mineralization. This strata-bound base-metal mineralization crops out at several locations as sporadically distributed siliceous gossans roughly aligned in N-S direction in the districts of Khuzdar and Las Bela. Some of these gossans are associated with barite deposits, particularly those of Gunga and Duddar, while others are devoid of any barite mineralization. In the Khuzdar district, Gunga, Surmai, Malkhor, Ranjlaki, and Sekran are important locations for this type of mineralization, while there is significant amount of barite-associated base-metal mineralization in the Bela district. The gossans are oxidized outcropping cellular masses of reddish brown to dark maroon coloured limonite, goethite, and other oxidized minerals capping the underlying unaltered primary sulfide mineralization. This has been proved in the bore-holes drilled by certain agencies in the past.

The explanation of the causes of the variations in the stable isotopic ratios of sulfur has been, since a very long time, an important basis to interpret the genesis of the most sulfide mineral deposits. However, for meaningful interpretation, investigations must be supplemented with detailed geologic, mineralogic and other geochemical studies. Based on geological field-observations, laboratory studies, microscopic studies of rocks and ore minerals, and some fluid inclusion analysis (only 2 samples), the author has reached the conclusion that these are epigenetic Mississippi Valley type deposits (Siddiqui 1996), which were formed by basinal brines expelled tectonically due to

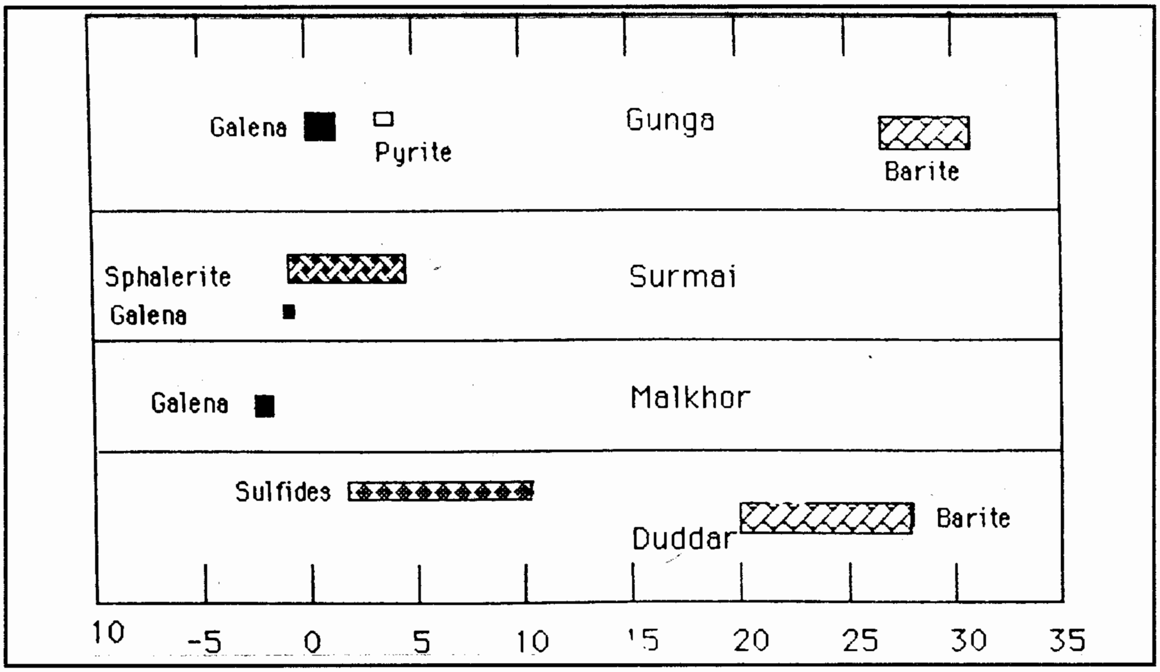

Figure 1. Ranges of S-isotope ratios for various minerals at four locations

compression caused by collision of India with Eurasian plate. The question as to the source of sulfur for the sulfide and sulfate mineralization has been discussed by the author in his previous articles (Siddiqui 1994b,c) in the light of sulfur isotope data obtained from the analysis of a limited number of samples from only Khuzdar district. Now the author has been able to acquire some data on sulfur isotopic ratios of a few galena and barite samples from Duddar deposit, located about 300 km to the south of Khuzdar deposits in the Bela district. In this paper the question of source sulfur for these deposits will be re-examined and looked at in a broader perspective.

GEOLOGIC SETTING

These strata-bound barite and base-metal deposits are hosted by the rocks of Anjira Member and Loralai limestone Member of Jurassic Zidi formation within Kirthar Fold belt. Those belonging to Khuzdar district lie within "Khuzdar knot", which has been so named (Jones 1961) because of the knot-like appearance of the ranges in this area due to the repeated and abrupt changes of their strike through almost 90 degrees. The deposits in the Duddar area of Bela district are also confined within Anjira Member of the same Zidi Formation occurring in the Mor Range. This mineralized zone is a part of about 1250 km long and 180 km wide Sulaiman-Kirthar Fold Belt which is structurally complex and has faulted contacts with thrust belts to the north and west (Kazmi and Jan 1998). The Kirthar Fold Belt is about 380 km long, northerly trending folded zone between Quetta and Karachi. The Sulaiman and Kirthar ranges are the off-shoots of the main Himalayas formed as a result of the closure of the Tethyan sea and collision of Indian subcontinent with the Eurasian plate. The terrane being under intense tectonic stresses has been subjected to much folding, faulting and fracturing. These faults could well be the conduits for the hydrothermal fluids which are supposed to have mineralized the area. The mineralization is located within the Lower to Middle Jurassic sedimentary assemblage deposited on the platform of the passive margin of the Indian subcontinent under shallow water marine environment (Fatmi 1986).

SAMPLE COLLECTION

Since mineralization is indicated on the surface in the form of gossans, only the oxidized and weathered minerals and materials can be collected from the surface which are not of much use for analysis. Only a limited number of samples could be collected from the drill core of the bore-holes, and those too without precisely knowing the depth. Barite samples were easy to collect as huge barite deposits are exposed on the surface. Some galena crystals were found within barite and gossans. Samples were collected from Gunga, Malkhor, and Surmai in the Khuzdar district in such a way as to represent the mineralization in the whole district.

ANALYTICAL METHOD

Samples were crushed in a mortar to a coarse grain sized material and then the desired mineral grains were separated manually from the associated gangue material under the binocular microscope. All the samples were kept submerged under 10 % HCl and rinsed with distilled water to remove any unwanted material sticking to the mineral surfaces.

Sulfur isotopes were determined following the method of Thode et al. (1961). In this method the sulfur in sulfide specimens is burned in a stream of purified oxygen inside a fused quartz tube placed in an electric furnace at a temperature of 1200°C to obtain SO_2. After removal of the impurities from the SO_2 thus produced, it is collected and stored in a sealed pyrex tube for analysis on mass spectrometer. For the sulfate samples, barium sulfate was reduced first to H_2S by boiling them in a mixture of HI, H_3PO_3 and HCl. The H_2S thus obtained was then absorbed in a solution of cadmium acetate, acetic acid, and distilled water to form CdS. This was then converted to Ag_2S by reacting with $AgNO_3$ for easy filtration. Afterwards, the Ag_2S was then burned in a simple combustion tube at high temperature as described above. The final analysis for the isotopic values of the sulfur was carried out with mass spectrometer (VG 903) under standard operating conditions at Krueger Geochron Laboratories, Massachusetts, U.S.A. The analyses are expressed in (per mil) notation computed as follows:

$$\delta^{34}S_{\text{sample}\ ‰} = \left[\frac{S^{34}/S^{32}_{\text{sample}}}{S^{34}/S^{32}_{\text{Standard}}} - 1\right] \times 1000$$

RESULTS AND DISCUSSION

The results of the analyses of the isotopic ratios of sulfide and sulfate mineral samples from both the districts are given in the form of $\delta^{34}S$ values in Table 1 and Table 2. The data reveal that the $\delta^{34}S$ values in the sulfide phases from Khuzdar district (pyrite, sphalerite and galena) range from -1.9 per mil to +4.5 per mil with an average of 0.44 per mil and a total spread of 6.4 per mil. The isotopic composition of galena alone varied between -1.9 and +4.5, sphalerite between -0.9 and +4.5, and the only sample of pyrite had a value of +3.3. The corresponding values in sulfide phases from Duddar, Bela district, range between +3.4 and 10.2 (values of only 2 galenas were available). Barites are strongly enriched in the heavier isotope, ^{34}S, compared to the sulfides. In Khuzdar district the values of sulfur isotopic ratios in barite samples range from 26.8 to 33.0 per mil with an average of 28.60 and a total per mil range of only 6.2., which denotes a rather narrow spread among the values. Eight barite samples from Duddar (Bela) vary in their isotopic values between 20.2 and 27.9 per mil with an average of 21.68 per mil. There is a total spread of 7.2 per mil which is again not very wide.

Table 1. Sulfur isotopic compositions in sulfide minerals from Khudzdar and Bela Districts.

Sample No.	Location	Mineral	$\delta^{34}S$
SS-DD-18	Malkhor	Galena	-1.90
SS-DD-7	Surmai	Sphalerite	-0.90
SS-DD-5	Surmai	Galena	-0.50
SS-DD-11	Surmai	Galena	-0.50
SS-DD-6	Gunga	Galena	0.10
SS-DD-21	Surmai	Sphelarite	0.30
SS-DD-19	Gunga	Galena	1.50
SS-DD-3	Gunga	Pyrite	3.30
SS-DD-13	Surmai	Sphelarite	4.50
SS-DD-1	Duddar	Galena	3.40
SS-DD-3	Duddar	Galena	10.20

Table 2. Sulfur isotopic ratios in barites from Khuzdar and Bela Districts.

Sample No.	Location	Mineral	$\delta^{34}S$
SS-SF-2	Gunga	Barite	22.20
SS-SF-3	Gunga	Barite	26.80
SS-SF-7	Gunga	Barite	27.00
SS-SF-1	Gunga	Barite	27.50
SS-SF-8	Gunga	Barite	30.90
SS-SF-5	Gunga	Barite	33.00
AB-SF-1	Duddar	Barite	20.20
AB-SF-8	Duddar	Barite	20.80
AB-SF-2	Duddar	Barite	21.20
AB-SF-7	Duddar	Barite	21.30
AB-SF-3	Duddar	Barite	22.50
AB-SF-5	Duddar	Barite	22.90
AB-SF-9	Duddar	Barite	26.90
AB-SF-9	Duddar	Barite	27.90

TEMPERATURE OF MINERALIZATION

Under conditions of equilibrium, the isotopic composition of cogenetic mineral pairs may be used to estimate the temperature of deposit formation. The isotopic data of our samples include values for a coexisting sphalerite-galena pair and a barite-galena pair. The equilibrium fractionation factors

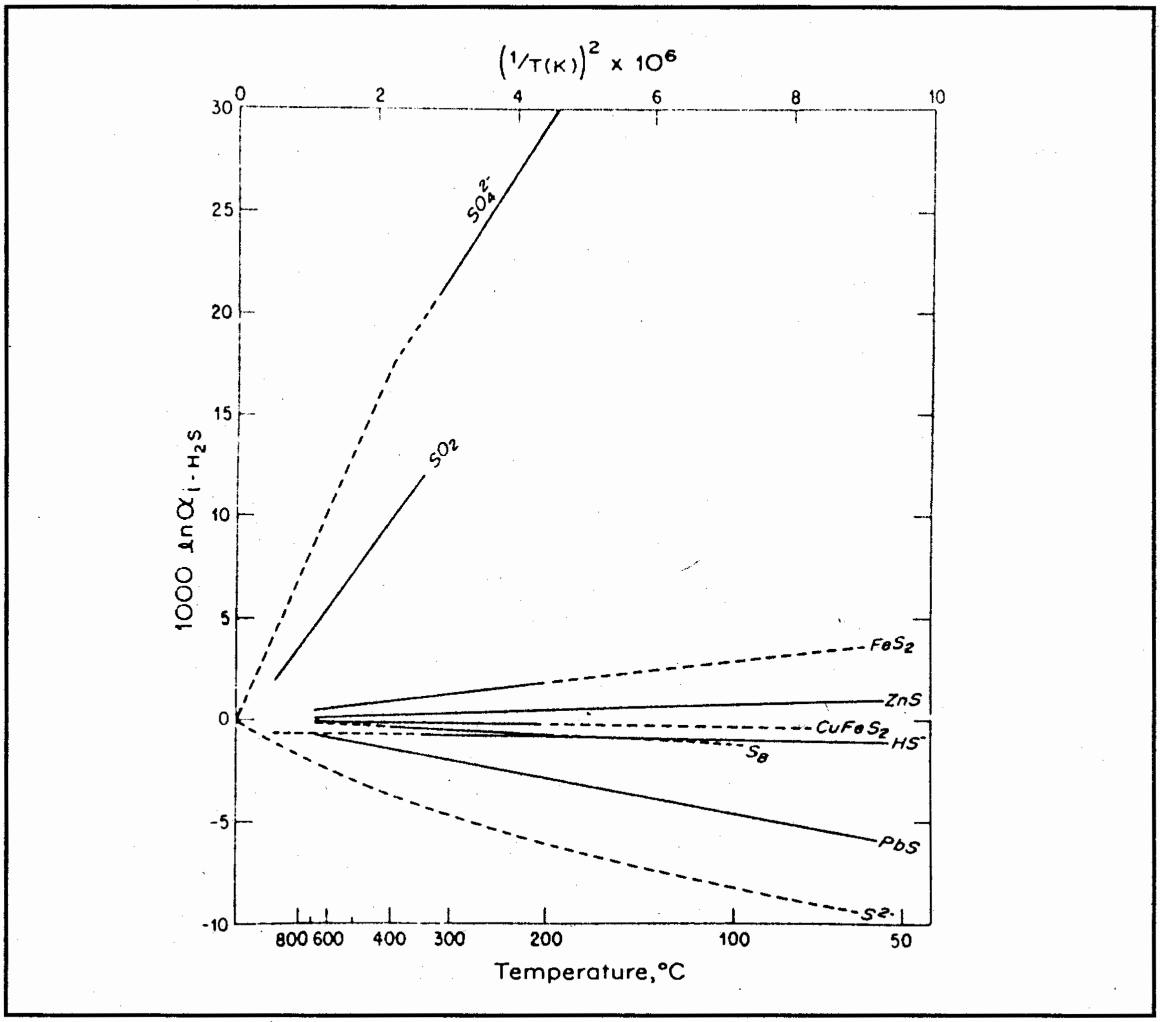

Figure 2. Equilibrium isotopic fractionation factors among sulfur compounds relative to H_2S (after Ohmoto and Rye 1979).

for these pairs (Ohmoto and Rye 1979) can be found as follows:

$\Delta_{ZnS-PbS} = \delta^{34}S_{ZnS} - \delta^{34}S_{SPbS}$

$= -0.9 - (-0.5) = -0.4$ per mil *(for the samples SS-DD-7 and SS-DD-5)*

Using the curves for equilibrium isotopic fractionation factors (Fig. 2) of Ohmoto and Rye (1979) to estimate the temperature of mineralization for ZnS-PbS we see that this temperature comes out to be 575°C. The equilibrium fractionation factor between barite (SS-SF-8) and galena (SS-SD-19) is:

$\Delta_{BaSO_4-PbS} = \delta^{34}S_{BaSO_4} - \delta^{34}S_{PbS}$

$= 30.9 - 1.5 = 29.4$ per mil.

Using the same plot as above for the sulfide and sulfate curves the temperature is read to be 195°C. The temperatures thus obtained using two types of mineral pairs are not consistent with each other. Usually sulfate-sulfide pairs are not considered ideal for estimating the temperature of mineralization in case of low temperature deposits, such as Mississippi Valley type deposits. This is because equilibrium between these phases is not always established at a temperature below 300°C (Ohmoto and Rye 1979). Moreover, due to the fact that these deposits are stratabound and not related to any igneous or volcanic rocks, the prevailing view regarding these deposits is that they are low temperature hydrothermal deposits (the term hydrothermal being used to mean hot-water and not necessarily magmatic fluids). They may be either MVT or SEDEX type, but not magmatic type. Also, there are no signs of metamorphism in the area which could account for a temperature as high as 575°C estimated from the isotope geothermometry. The geothermometric evidence regarding MVT deposits (Jensen 1967) and SEDEX deposits (Large 1981) suggests a low temperature, around 100-150°C or even less. So the temperature 575°C is too high for the geological setting in which these deposits were formed. Furthermore, the study of fluid inclusions in two samples of sphalerite indicates rather low trapping temperatures: 100-

110°C, and 150°C (Siddiqui 1994a). Thus, the high temperature obtained by using the isotopic fractionation factor in the sulfate-sulfide cogenetic pair suggests a state of disequilibrium at the time of formation of these phases.

SOURCE OF SULFUR

The low $\delta^{34}S$ values with a narrow range associated with the sulfide phases would apparently suggest a magmatic sulfur source. But these deposits have no observable link with any igneous activity (Sillitoe 1978); so there seems to be no chance for the sulfur to be magmatic. However, the $\delta^{34}S$ values of sphalerite and pyrite are somewhat on a higher side as compared to galena, but this could be due to the fractionation between sphalerite and galena, and perhaps between pyrite and galena, which is temperature dependent. As far as the sulfates are concerned, their isotopic values are much higher (around 30 per mil) than those of sulfide phases, which is a clear indication that the source was not magmatic.

The possible crustal source for sulfur are sulfide minerals in the country rock, sulfate evaporite lenses, connate formational brine sulfate of sea-water, petroleum organic sulfur, and deep-seated magmatic sulfur (Heyl et al.1974). In order to guess as to what could be the possible origin of the Pb-Zn-barite deposits of our area, a careful examination of the variations in $\delta^{34}S$ values of the samples from this area would be undertaken. Under equilibrium conditions $\delta^{34}S$ of hydrothermal minerals are determined by the physical conditions of the fluids (T, pH, fo2) as well as the isotopic composition of total sulfur ($\delta^{34}S_{\Sigma s}$). Also, the composition of source sulfur and the proportion of oxidized and reduced sulfur species in solution are among the major factors that control the sulfur isotopic composition of minerals (Rye and Ohmoto 1974). However, Sangster (1976) and others have shown that if the base-metal deposits are hosted by sediments and there is no magmatic body in the vicinity, just as in our case, the obvious source for sulfur is sea-water sulfate. Bacteria reduce the sulfate species of sulfur to H_2S which reacts with the metallic cations and precipitation of sulfide minerals is brought about. During the course of reduction carried out by either bacteria or by any other organic or inorganic means, the reduced sulfur becomes enriched in the lighter isotope, S^{32}, leaving the sulfate solution enriched in the heavy sulfur isotope, that is ^{34}S. This fractionation of sulfur isotopes brought about by bacteria is more intense and pronounced if the basin is restricted and there is no supply or only a limited supply of fresh sea-water sulfate. In the absence of any magmatic source of sulfur the relatively low values of isotopic ratios in the sulfide minerals indicate that sulfur was derived from H_2S formed as a result of reduction of sea-water sulfate by bacteria, or organic matter as suggested by Orr (1974), particularly applicable in the deposits formed at a temperature above 80°C. It may be suggested that mineralization occurred in low temperature environment where sea-water sulfate accumulated in the rocks as connate brines where it was reduced by bacteria or by some other agency. It has been estimated that during reduction process bacteria can produce fractionation up to 25 per mil relative to the source composition and the average fractionation is 15 per mil (Sangster 1976).

The $\delta^{34}S$ value of about +20 per mil represents the isotopic composition of sulfur in the modern marine sulfates (Faure 1979). The $\delta^{34}S$ values have varied through periods of geological history and the study of a large number of marine sulfate minerals revealed that they varied from 30 per mil in Cambrian period through about 10 per mil at the end of Permian to 20 per mil at present (Claypool et al. 1980). From Figure 3 it can be seen that the isotopic ratios of sulfur in the coeval sea-water sulfates of Jurassic times, during which the host rock of these deposits was deposited, were about 17 per mil; whereas, the isotopic composition of our barite samples range from +26.8 to +33.0 with an average of 28.60 per mil in Khuzdar, and from 20.2 to 27.9 with an average value of 21.68 per mil in Bela. The $\delta^{34}S$ values of barites are much higher than the corresponding values of the coeval sea-water sulfates, particularly in case of Gunga barite deposits. This shows that the solutions formed from underlying evaporites of probably Cambrian age, which were much heavier than the sulfates of the Jurassic seas, mixed with the mineralizing solutions. Probably more evaporites were mixed in the connate brines in Khuzdar area than in Bela; that is why significantly high isotopic values are observed in Gunga barite deposits. Since there is no concrete evidence of any evaporite bed, except a few pieces of gypsum found near gossan at Gunga, present in or around the area, it is thought that the evaporites involved in the process were those believed to be underlying the Pakistan Fold Belt which perhaps facilitated the tectonic transfer of the Belt southward in a thin-skin fashion (Surwar and DeJong 1979). Groundwater could have also played a role in dissolving the evaporites and bringing them to the site of deposition in a favourable hydrologic regime, but nothing can be said about the mixing of meteoric water with the connate brines in the absence of data on oxygen isotopes. The other possibility of high isotopic values of

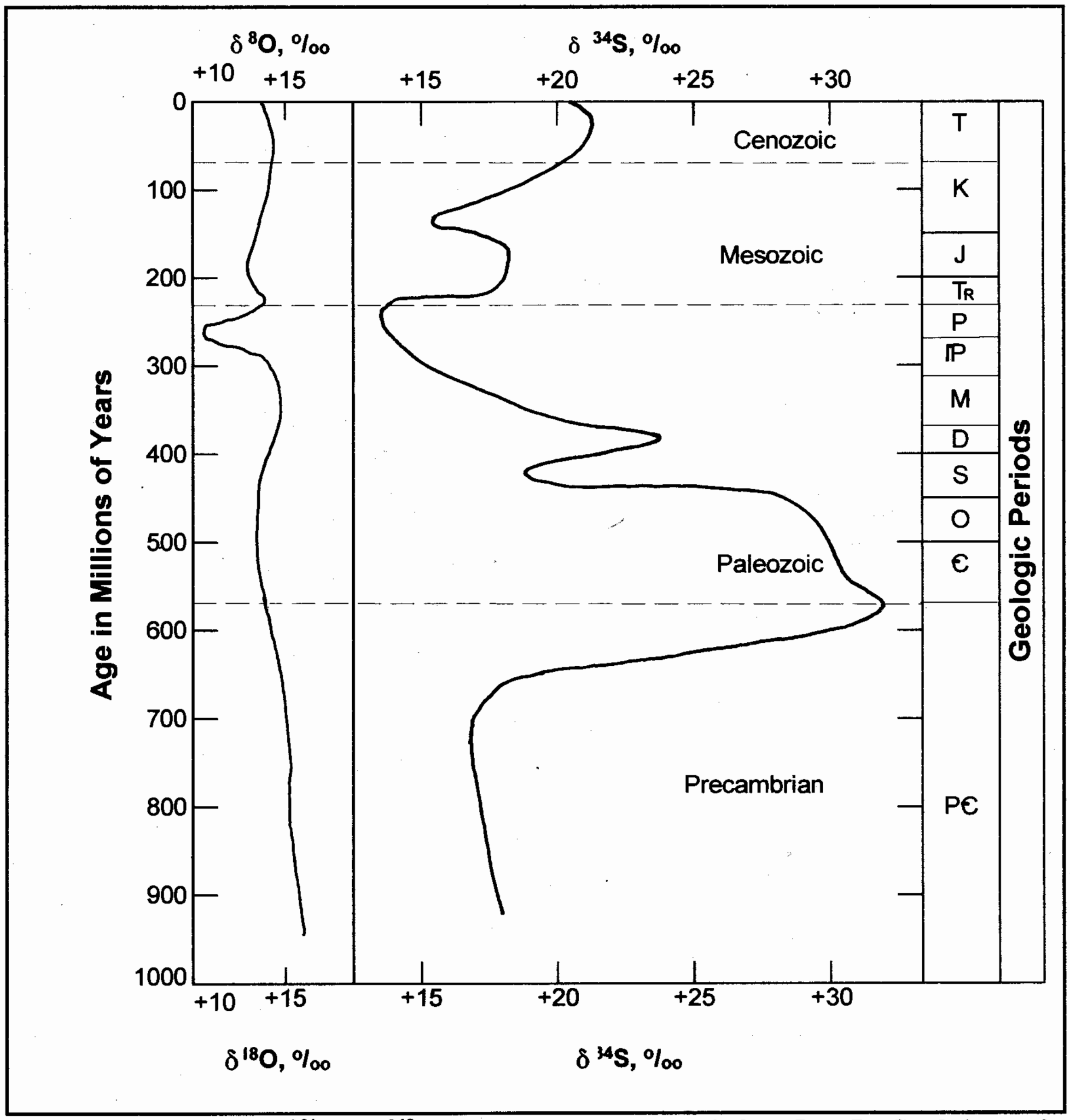

Figure 3. Variation of $\delta^{34}S$ and $\delta^{18}O$ of marine Sulfate minerals from Late PreCambrian to the present (cf. Faure 1986).

barites may be due to reduction of sea-water sulfate brought about by the sulfate reducing bacteria in a restricted or lagoonal Jurassic environment closed to SO_4. As a result of kinetic isotopic effects during reduction evolving H_2S would become depleted in ^{34}S while SO_4 would be enriched in ^{34}S (Jensen 1967) But the process does not seem to be working on such a large scale as our case demands. Yet another cause for observed high isotopic values of barite could be the diagenesis of the host rock, as suggested by the data obtained by Goldhaber and Kaplan (1980) from the sediments of Gulf of California. But in view of other geological factors this explanation also does not seem likely. Instead, sulfur being derived from the connate brines contained in the Cambrian evaporitic rocks seems to offer relatively easy and simple solution for the high isotopic values encountered in the barite of Khuzdar and Bela.

CONCLUSION

1) The fractionation factors among the coprecipitated pair of minerals (ZnS-PbS) in the Khuzdar deposits gave a temperature of more than 500°C; whereas the temperature estimated from fluid inclusion studies ranges between 100°C and 110°C, and 150°C. The anomalously high temperature given by the fractionation factors shows a condition of disequilibrium among the coprecipitated mineral phases.

2) The low $\delta^{34}S$ values among the sulfide mineral deposits in the Khuzdar base-metal deposits are due to the kinetic effects of strong reduction most probably by bacteria or organic matter.
3) The unusually high isotopic ratios observed in the barites of the studied area, particularly in Khuzdar district was due to the mixing of underlying evaporite solutions with the mineralizing fluids.

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STRATIGRAPHY OF BALOCHISTAN-AN OVERVIEW

MOHAMMAD AHMAD FAROOQUI[1] AND MUHAMMAD UMAR[2]
[1] Centre of Excellence in Mineralogy, University of Balochistan Quetta, Pakistan.
[2] Department of Geology, University of Balochistan Quetta, Pakistan.

ABSTRACT

The nomenclature and description of lithostratigraphic units exposed in Balochistan are reviewed. New lithologic units proposed by a large number of workers since the publication of Stratigraphy of Pakistan (Shah 1977) are incorporated and summarized both in the text and in the generalized lithostratigraphic columns. Seven characteristic features of fifty two formations and ten groups, ranging in age from Permian to Recent, are summarized. In some cases, specially the upper Cretaceous rocks, the thickness, distribution and stratigraphic contact relationship are highly variable from place to place. Such variabilities are difficult to be shown on stratigraphic correlation charts. Comprehensive list of obsolete/old stratigraphic names and the currently used names is also presented here. Care must be taken in using the information reported in this article because some of the information specially regarding depositional environment of various lithological units is tentative and speculative. Further detailed and systematic research is needed to interpret the depositional environments, and biostratigraphic and chronostratigraphic boundaries of lithologic units. Stratigraphic Committee of Pakistan needs to be re-activated so that confusion in the nomenclature of stratigraphy be eliminated.

INTRODUCTION

Balochistan represents a mixture of large and small scale geological structures of the convergent and strike slip tectonic regimes that controlled the sedimentation in different basins developed during the course of its geological evolution. The convergent and strike slip tectonic forces caused structural deformations in the form of crustal thickening in most part of Balochistan resulting in the dislocation and relocation of many thrust sheets and folded mountain ranges (Bender and Raza 1995, HSC 1960). On the other hand the volcanic and plutonic activities associated with the convergent tectonic environment and emplacement of ophiolites after Late Mesozoic have further contributed to the complexity of stratigraphic place and position of various lithostratigraphic units.

It has been more than 20 years since the publication of a landmark Memoir by the Geological Survey of Pakistan (Shah 1977) on the nomenclature and description of lithostratigraphic units of Pakistan. During last two decades many new concepts, techniques and models have been evolved, introduced, refined and/or incorporated in stratigraphy and related fields. These changes and developments have compelled geologists to introduce, discard or redefine the stratigraphic nomenclature. Much of the literature containing new stratigraphic information is scattered and is becoming hard to obtain. This is specially true for our university and college students who face tremendous difficulty in obtaining the up-to-date information about the contributions, developments and changes in stratigraphic nomenclature of Pakistan. This paper is presented here with the objective to provide a summarized overview of the stratigraphic nomenclature of Balochistan to the students of geology.

A large number of, both nationally and internationally known geologists, have contributed splendidly to the knowledge and understanding of the stratigraphy of Balochistan. Considering the interpretive nature of geological sciences, it is imperative to expect incorporation of new names in the stratigraphic nomenclature of Balochistan, which has increased the number of names in the list of stratigraphic units exposed in Balochistan. Moreover, different workers assigned different names for same suit of rocks and interpreted them differently. The evaluation and comparison of the interpretative work of all the previous workers, who have contributed to the stratigraphy of Balochistan, is beyond the scope of this paper. In order to keep this paper as concise and simple as possible, specially for the students of geology, we have not cited the names of all the previous workers who have described and proposed different names of the lithologic units. However, HSC (1960), Fatmi (1977), Shah (1977 and 1978), Iqbal and Shah (1980) Arthurton et al. (1982), Otsuki et al. (1989), Kazmi (1995), and Bender and Raza (1995) have been extensively consulted during writing of this overview. For further detailed description of a specific lithologic unit the reader is requested to refer to the original work of these workers and references there in. Generalized lithostratigraphic columns (Fig. 1to 6) are also presented here which appear to be somewhat different than those proposed earlier as the names of the new lithostratigraphic units (Bender and Raza 1995, Arthurton 1982) are incorporated in it. In the following text seven important characteristic features of fifty two formations and seven groups are summarized in alphabetic order. The depositional environment of most of the units are inconclusive as very limited literature is available on this aspect. In depth research is required for better understanding of the depositional environment.

DESCRIPTION OF THE LITHOSTRATIGRAPHIC UNITS

The description of the lithologic units are divided into two parts separating groups from formations. Each formation/group is described in terms of obsolete names, type section, thickness, age, lithology, depositional environment and contact relationship. Where available, the grid reference of the type sections are given in parentheses. The age of individual formations are mostly deduced from Shah (1977) and Kazmi (1995) following the geologic time scale compiled by Palmer (1983). The depositional environments and contact relationships of lithologic units are to a certain extent tentative as sufficient data is not available.

FORMATIONS

Amalaf Formation

Obsolete Names: Cretaceous-Eocene Flysch.
Type Section: Amalaf (Mir Jawa Range) Chaghi.
Thickness: Unknown.
Age: Oligocene.
Lithology: Volcanic ash and agglomerate with subordinate andesitic lava flows that is mottled with feldspar or black pyroxene phenocrysts, occasionally interbedded with shale and sandstone.
Depositional Environment: Marine to continental: Shallowing fore arc basin depsoits.
Contact Relationship: Lower contact is transitional with Saindak Formation whereas the upper contact is unconformable with Dalbandin Red Formation.

Bara Formation

(Ranikot Group)
Obsolete Names: Lower Ranikot Sandstone, Lower Ranikot, Gorge Bed, Ranikot Formation, Lower part of Jekkar, Thar, Rattaro, and Bed Kachu.
Type Section: Bara Nai, Lakhi Range, Sind (26°7'06"N, 67°53'12"E).
Thickness: 450m (Type Section), 600m (Rani Kot).
Age: Middle Paleocene.
Lithology: Fine-to coarse-grained, calcareous, ferruginous, and cross bedded (ripple marked) sandstone interbedded with shale.
Depositional Environment: Marine: Shallow marine to estuarine to fluvial.
Contact Relationship: Lower contact is conformable with Khaddru Formation whereas the upper contact is conformable with Lakhra Formation. In Ranikot area, it is unconformably overlained by Laki Formation

Baska Formation

(Ghazij Group)
Obsolete Names: Ghazij Formation.
Type Section: 2km east of Baska Village (31°29'N; 70°08'E).
Thickness: 160m (northern Sulaiman Range) 820m

(southern Sulaiman Range).
Age: Early Eocene.
Lithology: Shale and claystone intrebedded with alabaster (upto 10m thick) and gypsiferous limestone with minor marl.
Depositional Environment: Marine to fluvial; Deltaic.
Contact Relationship: Lower contact is conformable with Toi Formation whereas the upper contact is conformable with Habib Rahi Formation of Kirther Group.

Bibai Formation

Obsolete Names: Deccan Trap, Bela Volcanic Group, Kahan Conglomerate Member.
Type Section: Bibai, Ziarat District and Bela Town, Lasbela District.
Thickness: 1515-3940m.
Age: Cretaceous.
Lithology: Mainly basalt, coarse agglomerate and bedded tuff interlayerd with sediments (shale, marl, limestone, conglomerate and chert. Ferrugenous, silicified shale is present locally.
Depositional Environment: Shallow Marine (synsedimentary shallow marine volcanic environment).
Contact Relationship: Lower contact is conformable and transitional with Parh Limestone whereas the upper contact is conformable with Upper Cretaceous rocks (Pab Sandstone, Mughal Kot Formation) and Paleocene rocks (Dungan Formation).

Bostan Formation

Obsolete Names: Kamerod Formation and upper part of Pishi Group
Type Section: Pishi Lora Valley, Pishin District.
Thickness: 750m (Pishi Lora), 600m (North Siahan Range).
Age: Pleistocene.
Lithology: Soft, poorly consolidated, gypsifrous, poorly bedded, assemblage of clay and silt, with subordinate thin bedded, salt and pepper textured sandstone and conglomerate that contains subangular to subrounded pebbles and boulders of sandstone and limestone.
Depositional Environment: Continental: Saline lacustrine, Playa lake.
Contact Relationship: Lower contact is transitional with Yak Mach Conglomerate Formation in Dalbandin Area, whereas in other areas unconformable with older rocks of up to Jurassic age. The upper contact with subrecent deposits represents an angular unconformity and in some areas it is transitional.

Dalbandin Red Formation

Obsolete Names: None
Type Section: 40km ENE of Dalbandin.
Thickness: 3000m
Age: Mid-late Miocene.
Lithology: Conglomerate, cross bedded sandstone, and partly dolomitic mudstone. Conglomerate contain coarse, angular clasts (in lower part) to well rounded clasts (in upper part). The Formation is partly gypsiferous.
Depositional Environment: Continental: Lacustrine.
Contact Relationship: Lower contact is unconformable with Amalaf Formation and Khojak Formation. The upper contact is unconformable with Yak Mach Conglomerate Formation.

Dalil Conglomerate Formation

Obsolete Names: Basal conglomerate part of Bostan Formation. Equivalent to Koh-e-Dalil Conglomerate.
Type Section: Immediate north of Koh-e-Dalil Railway Station, 35km west of Alam Reg, Chaghi. Mainly exposed in the western part of the Dalbandin Trough.
Thickness: Not reported.
Age: Pliocene.
Lithology: Sub-angular debris with scattered well rounded pebbles.
Depositional Environment: Continental; fluvial.
Contact Relationship: Lower contact is unconformable (angular) with Dalbandin Red Formation. The Upper contact is unconformable with Haro Conglomerate.

Dhok Pathan Formation
(Siwalik Group)

Obsolete Names: Upper Manchhar, Stages e, d, and c of Siwaliks in Sibi-Pishin area, Sheri Ghasha Formation, Sibi and Urak Group, Shinmatai Formation.
Type Section: Dhok Pathan Village, Attok District (33°07'N, 72°14"E).
Thickness: 1330-2000m (Sibi-Kachhi), 120-300m (Mari-Bugti), 1500m (Gaj River).
Age: Early to Middle Pliocene.
Lithology: Cyclic alternations of thick bedded, calcareous moderately sorted and cross bedded sandstone and soft silty calystone. Minor intercalations (lenses) of siltstone and conglomerate in the upper part.
Depositional Environment: Continental to continental margin: Fluvial, estuarine and lacustrine.

Contact Relationship: Lower contact is transitional with Nagri Formation whereas the upper contact is conformable (gradational) with Soan Formation.

Domanda Formation

(Kirther Group)

Obsolete Names: Sirki member of Kirther Formation.
Type Section: Domanda (31°35'30"N; 70°12'E), Zhob-D.I. Khan Road.
Thickness: 130-330m.
Age: Middle Eocene.
Lithology: Claystone with intercalations of limestone at some places and subordinate, medium-grained, thick bedded to massive calcareous sandstone in the upper part.
Depositional Environment: Shallow marine: Shelf deposits.
Contact Relationship: Lower contact is conformable and transitional with Habib Rahi Formation whereas the upper contact is conformable with Pirkoh Formation of Kirther Group.

Drazinda Formation

(Kirther Group)

Obsolete Names: Drazinda member of Kirther Formation.
Type Section: Northeast of Drazinda (31°46'N; 70°09'E), Zhob-D.I. Khan Road.
Thickness: 15-500m.
Age: Middle Eocene.
Lithology: Claystone and marl that grades into siltstone, with subordinate sandstone (in middle part) and limestone. Contains celestite nodules in northern Sulaiman Range.
Depositional Environment: Shallow marine: Shelf deposits.
Contact Relationship: Lower contact is conformable with Pirkoh Formation whereas the upper contact is unconformable with Hinglaj Formation (Makran Group), Nari Formation (Momani Group) and Khojak Formation.

Drug Formation

(Ghazij Group)

Obsolete Names: Ghazij Formation.
Type Section: Drug Tangi, 3km northeast of Drug Village (30°49'15"N; 70°12'30"E), Musa Khel District.
Thickness: 40m (Drug Tangi), 340m (Zinda Pir area).
Age: Early Eocene.
Lithology: Mainly thin bedded, hard, crystalline, argillaceous, pebbly and nodular limestone with subordinate interbeds of shale. Limestone has commonly marly partings and is bioclastic at places.
Depositional Environment: Marine: Shallow marine to deltaic.
Contact Relationship: Lower contact is conformable with Shaheed Ghat Formation whereas the upper contact is conformable with Toi Formation.

Dungan Formation

Obsolete Names: Alveoline Limestone, Lower Rakhi Gaj Shale, Zindapir Limestone, Dungan Group, Dab Formation, Karhk Group, Brewry Limestone, Siazgai Limestone, Sinjawi Limestone.
Type Section: Mehrab Tangi, 8 km northeast of Harnai (30°08'38"N, 67°59'33"E).
Thickness: 300-365m.
Age: Paleocene to Early Eocene.
Lithology: Thick- to medium-bedded to massive nodular limestone with subordinate shale, marl, conglomerate, and calcareous, fossiliferous sandstone that is interlayerd with shale.
Depositional Environment: Marine: Shallow marine (foreland basin).
Contact Relationship: Lower contact is unconformable with Fort Munro Formation, Pab Sandstone, Parh Limestone. However in Siazgai, Sinjavi (Sulaiman Province) and Karkh (Kirther Province) the contact is transitional with Pab Sandstone and Moro Formation. The upper contact is conformable with Marap Conglomerate of Ghazij Group

Fort Munro Formation

Obsolete Names: Fort Munro Limestone member, Limestone with Hippurites, Hemipneustes Limestone, Upper part of Orbitoides Limestone and Shale.
Type Section: Western flank of Fort Munro anticline (29°57'14"N; 70°10'30"E), Lolarai-D.G. Khan Road.
Thickness: 44-248m, 100m (Type Section), 4m (Quetta).
Age: Late Cretareous.
Lithology: Thin to thick bedded, hard, compact, and reefoid limestone intermixed with calcareous to chalky marl at different level in different regions.
Depositional Environment: Marine: Shallow marine.
Contact Relationship: Lower contact is conformable with Mughal Kot Formation and uncorformable with Parh Limestone whereas the upper contact is conformable and transitional with Pab Sandstone in Sulaiman Province, and conformable and sharp with Moro Formation. In the Fold Belt lower contact is unconformable with

Dungan Formation.

Gaj Formation
(Momani Group)

Obsolete Names: Lower and Upper Gaj, Estuarine Passage Beds, Sibi Group, Lower part of Urak Group.
Type Section: Gaj River, Dadu District (26°51'40"N, 67°17'18"E).
Thickness: 600-750m (Kirther area) 650m (Type Section), 90m (Quetta).
Age: Early to Middle Miocene.
Lithology: Gypsiferous shale with subordinate fossiliferous and argillaceous limestone and calcareous ferrugenous sandstone. Minor pebbly conglomerate.
Depositional Environment: Marine to nearshore: Fluvial to estuarine deposits.
Contact Relationship: Lower contact is conformable and transitional with Nari Formation. At some places in Sulaiman Range it has unconformable lower contact with older rocks. The upper contact is transitional with Siwaliks, however in Manchar area it is unconformable (angular discordance) with Siwaliks.

Goru Formation

Obsolete Names: Upper part of Belemnite Beds, Upper part of Parh Group.
Type Section: Goru Village, Nari River (27°50'N; 66°54'E).
Thickness: 1200-2700m, 536m (Type Section), 70m (Quetta)
Age: Cretaceous.
Lithology: Thin to iregularly bedded, fine grained, calcareous, splintary and fossiliferous limestone that is interbedded with shale and siltstone. Shale is dominant at places.
Depositional Environment: Marine: Shelf to abyssal plane.
Contact Relationship: Lower contact is conformable with Sember Formation whereas the upper contact is conformable and transitional with Parh Limestone.

Gawadar Formation

Obsolete Names: Gawadar Stage, Ormara Formation.
Type Section: Gawadar Peninsula, Makran.
Thickness: 60m-900m, 450m (Type Section).
Age: Late Pliocene to Pliestocene.
Lithology: Soft, poorly consolidated, poorly bedded or massive sandy clay with subordinate interbeds of medium to coarse grained, poorly consolidated, thick (upto 3 m) and fossiliferous sandstone and few thin beds of conglomerate that are composed of well rounded pebbles and cobbles mainly of sandstone in sandy matrix. In Astola Island thinner beds of calcareous sandstone contain rounded and elongated concretions or "doggers" (in lower part) similar to those of underlying Hinglaj Formation.
Depositional Environment: Marine: Shore line deposits.
Contact Relationship: Lower contact is unconformable with Hinglaj Formation whereas the upper contact is unconformable with Jiwani Formation and transitionally conformable at Ormara and Jiwani headlands with Jiwani Formation.

Gawal Formation

Obsolete Names: Allozai group (?)
Type Section: Gawal Village, 60 km northeast of Quetta.
Thickness: More than 350 m thick in the Takai-Gawal section.
Age: Early Triassic
Lithology: Verigated shale and limestone interbeds with marl intercalations and occasional mafic intrusions.
Depositional Environment: Marine; Deep marine (turbidites)
Contact Relationship: Lower contact is not exposed, whereas the upper contact with Wulgai Formation is sharp and conformable.

Habib Rahi Formation
(Kirther Group)

Obsolete Names: Habib Rahi Limestone member of Kirther Formation.
Type Section (proposed): North of Zampost along the Zhob-D. I. Khan Road.
Thickness: 15-150m.
Age: Middle Eocene.
Lithology: Fine grained, platy, thin to thick bedded or massive, hard, argillaceous, fossiliferous limestone with nodules and cherty beds.
Depositional Environment: Shallow marine: Shelf.
Contact Relationship: Lower contact is conformable and transitional with Baska Formation of Ghazij Group whereas the upper contact is conformable with Domanda Formation of Kirther Group.

Haro Conglomerate

Obsolete Names: Kech Conglomerate.
Type Section: Kech Valley. Gishkaur, Kharan.
Thickness: 600-1500m.
Age: Pliestocene.

Lithology: Loosely consolidated conglomerate (pebbles and angular boulders of up to one foot diameter of sandstone and shelly limestone) with minor beds of soft sandstone and silt. Near Bela, boulders and pebbles are limestone and volcanic rocks (derived from Cretaceous and older rocks). Sandstone is pebbly and cross-bedded and appears almost same as that of Hinglaj Formation.
Depositional Environment: Marine: littoral (near shore).
Contact Relationship: Lower contact is unconformable (angular) with Hinglaj Formation but may be conformable at some places whereas the upper contact with subrecent deposits is unconformable.

Hinglaj Formation
(Makran Group)

Obsolete Names: Hinglaj Series, Sandstone Stage, Mudstone Stage, Hinglaj Group, Chatti Mudstone, Shales weathering to Calys, Parkini member, Diz Formation, Talar Sandstone and Greyshak Group.
Type Section: Hinglaj Mounatin area. (Principal sections are located near Talar Gorge, Makran).
Thickness: 3030 to 4545m.
Age: Miocene to Pleistocene.
Lithology: Fine to coarse grained, in places gritty to pebbly, soft and crumbly, hard in upper part, cross stratified, ripple marked, calcareous, and protoquartiztic sandstone: argillaceous, shelly to coquinoid nodular, and mudcracked shale (**Parkini Mudstone Member**), with subordinate siltstone and fine grained sandstone interbeds (**Chatti Mudstone Member**).
Depositional Environment: Marine: Deltaic deposits.
Contact Relationship: Lower contact is transitional with Khojak Formatiom and conformable with Nari Formation in the Bela area. In the southeastern part of the region the Hinglaj Formation overlies unconformably the Nisai Formation, the Parh Limestone, Cretaceous intrusions of Bela area and other older rocks. The Upper contact is unconformable with Gwadar Formation, Dalil Conglomerate Formation and Haro Conglomerate, however conformable with Haro Congomerate at some places.

Humai Formation

Obsolete Names: None
Type Section: Koh-e-Humai Hill, Koh-e-Sultan Chaghi.
Thickness: 91m (Type Section) 306m (Mazanan Rudi).
Age: Cretaceous.
Lithology: Shale, sandstone, siltstone, thin bedded limestone, volcanic conglomerate, and highly fossiliferous massive dense reefoid limestone. In Mazenan Rud limestone laterally grades into thick arenaceous beds. In westerly exposures it consists of conglomerate (boulders of limestone and volcanic rocks) with gritty and tuffaceous beds and thin bedded fossiliferous limestone.
Depositional Environment: Shallow marine associated with submarine volcanism along the continental margin (forearc basin).
Contact Relationship: Lower contact is unconformable with Sinjrani Volcanic Group whereas the upper contact is conformable with Rakhshani Formation.

Ispikan Conglomerate

Obsolete Names: None.
Type Section: Ispikan, 20 km northeast of Mand, Makran.
Thickness: 130-150 meters.
Age: Paleocene?
Lithology: Unbedded, unsorted, angular and short travelled boulders and fragments of limestone (from Jurassic rocks?), igneous (andesitic and granitic) rocks, and quartz pebbles in dark green chlorite matrix.
Depositional Environment: Continental; Intermontane basin (?).
Contact Relationship: Lower contact unconformable with Cretaceous (?) Marl, whereas the upper contact is not exposed.

Jiwani Formation

Obsolete Names: Sub-Recent Shelly Limestone.
Type Section: East of Jiwani, Gang Makran.
Thickness: 30m (Type Section).
Age: Pliestocene to Sub-Recent.
Lithology: Medium to thick bedded, shelly limestone (shell fragments in sandy matrix); with well sorted, medium to coarse grained, pebbly, and cross bedded sandstone (beds up to 3 cm); and conglomerate that contains rounded pebbles and cobbles of sandstone, limestone and red jasper. Formation varies in degree of cementation, proportion of clastics and rock types.
Depositional Environment: Marine: littoral.
Contact Relationship: Lower contact is unconformable (angular) with Gwadar Formation and at places with Hinglaj Formation, whereas upper contact is not known; it is the youngest formation along the coast.

Khadru Formation

(Ranikot Group)

Obsolete Names: Cardita beaumonti Beds, Basal part of Karkh, Gidar Dhor, Jekker Groups, Bed Kachu, and Thar Formation.
Type Section: Khadru Nala, Bara Nai section northern Lakhi Range, Sind (26°07'06"N, 67°53'12"E).
Thickness: 67 m (Type section), 140-180 m (Test holes at Lakhra and Dadu Creek).
Age: Early Paleocene.
Lithology: Mainly fossilifeorous (reptiles and oesters) limestone in the upper part, and medium-grained, fossiliferous, and ferruginous sandstone inetrbedded with gypsiferous shale and limestone in the lower part. Minor basaltic lavaflows are also present.
Depositional Environment: Marine: Shallow marine to estuarine to fluvial.
Contact Relationship: Lower contact unconformable with Pab Sandstone and Moro Formation, whereas upper contact is conformable with Bara Formation.

Kharan Formation

Obsolete Names: Kharan Limestone, Robat Limestone, Lower part of Pishi Group, Washap Formation, and Eriklag Limestone.
Type Section: Near Jalwar, Kharan.
Thickness: 90-600m.
Age: Early to Middle Eocene.
Lithology: Thin to thick bedded, argillaceous, at places reefoid limestone, with minor amounts of calcareous shale and medium grained, calcareous sandstone alternations.
Depositional Environment: Shallow marine.
Contact Relationship: Lower contact is conformable with Mirjawa Flysch Formation (previously part of Rakhshani Formation), whereas upper contact is conformable with Khojak Formation except at Robat where contact is not exposed.

Kharrari Formation

Obsolete Names: Windar Group, Zidi Formation
Type Section: Kharrari Nai, Mor Range (35-K/16)
Thickness: More than 464m (Type Locality), 248m (Ferozababd Section), 824m Lukh Rud Section.
Age:Early Jurassic; may extend into Triassic
Lithology: Limestone, dolomite siltstone and Shale.
Depositional Environment: Shallow Marine.
Contact Relationship: Base is not exposed. The upper contact with Malikhore Fm. is transitional.

Khojak Formation

Obsolete Names: Khojak Shale and Flysch, Nauroze Formation, Turbat Group, Peshi Group, Dalbandin Assemblage, Hoshab Shale, Murgha Faqirzai Shale, Siahan Shale, Panjgur Formation, Shigalu Sandstone, Binga and Multana Formation.
Type Section: Nauroze, 30 km northeast of Kharan.
Thickness: 900m-1500m.
Age: Oligocene [may range from Eocene to Early Miocene].
Lithology: Shale, sandstone, and siltstone with subordinate limestone and conglomerate. In places the Formation is metamorphosed to slate and quartzite. Divided into two members: Shaigalu and Murgha Faqirzai members.
Depositional Environment: Marine to nearshore deposits.
Contact Relationship: Lower contact conformable with Kharan Formation and Nisai Formation, whereas upper contact is unconformable with Bostan, Haro, and Lie Conglomerate in most areas. In parts of Makran, Zhob, and Fold Belt the upper contact is conformable with Parkini Mudstone Member of Hinglaj Formation.

Shigalu Member

Obsolete Names: Upper part of Khojak Formation.
Type Section: Shaigalu, 50km SW of Zhob.
Thickness: 600m.
Age: Oligocene.
Lithology: Crossbedded, coarse-grained, gritty to pebbly, calcareous, micaceous, rarely ferrugenous, ripple marked, in places thick bedded to massive sandstone with subordinate subangular to angular, pebbly (igneous), sandy, matrix-supported conglomerate.
Dep. Environment: Marine to shoreline deposits.
Contact Relationship: Lower contact conformablewith Murgha Faqirzai member whereas upper contact is conformable with Parkini Mudstone Member of Hinglaj Formation.

Murgha Faqirzai Member

Obsolete Names: Lower part of Khojak Formation.
Type Section: Murgha Faqirzai Rud, Qila Saifullah, Principal reference section located at Pishi Rud, south of Dalbandin.
Thickness: 1200m.
Age: Oligocene.
Lithology: Calcareous, in places arenaceous, fine textured, fissile to flaky, in places blocky, locally carbonaceous, and fossiliferous shale with lenses of lignite.
Dep. Environment: Deep marine: Turbidites.
Contact Relationship: Lower contact conformable with Kharan Formation and Nisai Formation

whereas upper contact is conformable with Shagalu Member of Khojak Formation.

Lakhra Formation
(Ranikot Group)

Obsolete Names: Upper Ranikot (Limestone), Upper Rani Kot, Upper Ranikot Formation, Upper part of Bed Kachu, Rattaro, Thar, and Lower part of Jekker Group.
Type Section: Southern part of Lakhra anticline, Sind.
Thickness: 242 m (Type section), 50m (Bara Nai).
Age: Late Paleocene.
Lithology: Thin to thick bedded, nodular, fossiliferous, and sandy limestone that is argillaceous at places with interbeds of sandstone and shale in the upper part.
Depositional Environment: Marine: Eestuarine to fluvial.
Contact Relationship: Lower contact is conformable with Bara Formation, whereas upper contact is unconformable with Laki Formation, in West Pakistan Fold Belt it is transitional and conformable with Nisai Formation.

Lei Conglomerate

Obsolete Names: Boulder Conglomerate, Kalabagh beds, Kalabagh Conglomerate, Kalabagh Hill Conglomerate, Dada Conglomerate.
Type Section: Lei River Section, SE of Rawalpindi. Principal Reference section near Spintangi Railway Station (29°57'N, 68°05'E).
Thickness: 150-900m (Kohat Potwar), 99m (Spintangi Railway Station).
Age: Pliestocene.
Lithology: Poorly sorted, clast-supported conglomerate that contains rounded to subrounded pebbles and boulders.
Depositional Environment: Continental: Fluviatile, lacustrine, and piedmont outwash deposits in structural depressions.
Contact Relationship: Unconformable lower contact with Soan and Dhok Pathan formation, whereas the upper contact is commonly gradational with sub-recent deposits, and is difficult to define. Along the railway cutting near Machh, Bolan it is steeply dipping and shows an angular unconformity with overlying subrecent deposits.

Malikhore Formation

Obsolete Names: Windar Group, Zidi Formation
Type Section: Malikhore Village (35-I/9), 27 km west-northwest of Khuzdar
Thickness: 387m (Type locality), 204m (Kharrari Section), 136 m (Lukh Rud Section).
Age: Early Jurassic
Lithology: Limestone with subordinate calcareous shale/marl.
Depositional Environment: Shallow Marine.
Contact Relationship: Lower contact is transitional with Kharrari Formation and the upper contact is transitional with Anjira Member of the Shirinab Formation.

Marap Conglomerate
(Ghazij Group)

Obsolete Names: Marap Conglomerate member, Ghazij Formation.
Type Section: Marap Valley, Kalat.
Thickness: 910m (Type Section).
Age: Early Eocene.
Lithology: Matrix supported conglomerate that contains well rounded and poorly sorted pebbles and boulders of limestone, shale and sandstone, and interbedded with subordinate shale, sandstone and minor limestone.
Depositional Environment: Marine: Nearshore (?).
Contact Relationship: Lower contact conformable (?) with Dungan Formation and Lakhra Formation, whereas upper contact is conformable with Shaheed Ghat Formation.

Mazar Drik Formation

Obsolete Names: Polyphemus Limestone, Polyphemus Beds.
Type Section: Mazar Drik, Marri Hills.
Thickness: 30m (*Type Section*).
Age: Middle Jurassic.
Lithology: Fossiliferous limestone interbedded with shale.
Depositional Environment: Marine: Shelf.
Contact Relationship: Lower contact conformable and transitional with Takatu Formation where present. The upper Contact with Sember Formation is disconformable.

Mirjawa Flysch Formation

Obsolete Names: Part of Juzzak Formation.
Type Section: Not designated, but probably in the vicinity of Mirjawa.
Thickness: Not reported.
Age: Late Cretaceous to Early Paleocene.
Lithology: Mudstones with an axial-plane cleavage and turbiditic, volcaniclastic sandstone and subordinate lenses of conglomerate including limestone and volcanic debris.
Depositional Environment: Marine: Associated with sub-marine volcanism.

Contact Relationship: Lower contact is not exposed, whereas the upper contact is conformable with Saindak Formation.

Moro Formation

Obsolete Names: Limestone with Hemipnuestes, Part of Dungan and Jamburo groups, Shale and Marl in upper part of Pab Sandstone.
Type Section: Moro River, Johan, Bibi Nani, District Bolan.
Thickness: Unknown.
Age: Cretaceous.
Lithology: Argillaceous limestone with volcanic conglomerate in the lower part, marly and shelly limestone with minor calcareous sandstone in the middle part and argillaceous limestone in the upper part.
Depositional Environment: Shallow marine: shelf.
Contact Relationship: Lower contact conformable and gradational with Pab Sandstone and or Fort Munro Formation and disconformable with Parh Limestone. In the type section the upper contact is disconformable with Khaddru Formation but at some places has a transitional contact with Dungan Formation.

Mughal Kot Formation

Obsolete Names: Mughal Kot minus Fort Munro member, Inoceramus Clays, Bedded Clays, Lower part of Orbitoides Limestone and Shale, Lower part of Pab Sandstone.
Type Section: 5km west of Mughal Kot post (31°26'52"N;70°02'58"E), Zhob-D.I. Khan Road.
Thickness: 1170m (Type Section).
Age: Cretareous.
Lithology: Calcareous shale and mudstone intercalated with quartzose sandstone and argillaceous, fossiliferous limestone. In Dabbo Creek, Karachi area, basalt, and in Kahan Village, Ziarat area, thick sequence of conglomerate with boulders and pebbles of basalt in the lower part is also present.
Depositional Environment: Shallow marine- fluvial.
Contact Relationship: In most areas lower contact is unconformable with Parh Limestone. The upper contact is conformable with Fort Munro Formation in most areas, whereas in Ziarat-Loralai area it has an unconfromable contact with Dungan Formation.

Nagri Formation
(Siwalik Group)

Obsolete Names: Nagri Zone, Nagri Stage, Dandot Sandstone, Parts of Sibi Group and Urak Group, Uzda Pasha Formation.
Type Section: Nagri Village, Attok District (32°45'N;72°14'E).
Thickness: 300-2000m.
Age: Early Pliocene.
Lithology: Medium to coarse grained, cross bedded and massive, moderately cemented calcareous sandstone with subordinate claystone and pebbly conglomerate.
Depositional Environment: Continental: Fluviail.
Contact Relationship: Lower is contact unconformable with Gaj Formation whereas the upper contact with Dhok Pathan Formation is transitional

Nari Formation
(Momani Group)

Obsolete Names: Nari Series, Lower and upper Nari, Nal Formation, Nari limestone, Lower part of Sibi and Urak groups.
Type Section: Gaj River, Dadu District (62°56'12"N;67°10'10"E).
Thickness: 1045 to 1820m (Kirther area)1400m (Type Section), 200m (Quetta), 600m (Nal, Khuzdar).
Age: Oligocene to Early Miocene.
Lithology: Coarse-grained to gritty calcareous sandstone with subordinate shale, limestone and siltstone, and minor conglomerate and ironstone in the upper part. Nodular, shelly, thin bedded to massive limestone with stringes of shale and fine grained, thin bedded sandstone.
Depositional Environment: Marine; Foreland basin deposits.
Contact Relationship: Lower contact unconformable with Drazindah Formation (Kirther Group) and Nisai Formation. The Upper contact is conformable with Gaj and Hinglaj formations.

Nisai Formation

Obsolete Names: Nisai Group, Ghazij Shale, Numulitic Beds, Nimergh Limestone, Wad Limestone, Wakabi Limestone, Wakai Limestone, Khude Limestone and Kasira Group, Upper part of Jakkar and Jumburo Group, Eocene Limestone, Lower Kirther Shale, Ghazaband Limestone, Massive Limestone, Spintangi Limestone, Nari and Khojak Series.
Type Section: 12 Km north of Nisai Railway Station, Qila Saifullah District.
Thickness: 1200m (type locality).
Age: Eocene to Ealry Oligocene.
Lithology: Fossiliferous, brecciated, reefoid, argillaceous and oolitic limestone with suboudinate calcareous, lateritic, carbonaceous and fissile shale,

cross bedded (protoquartzitic and orthoquartzitic) sandstone, and matrix supported conglomerate that contains fragments of volcanic rocks sandstone, limestone and marl.
Depositional Environment: Shallow marine to continental (?).
Contact Relationship: Lower contact unconformable with various Mesozoic and Permian rocks. In the east conformable with Ghazij Group and transitional with Lakhra Formation (Rani Kot Group). The upper contact is conformable with Khojak and Nari formations, except at Gaheto where the upper contact is unconformable with Nari Formation.

Pab Sandstone

Obsolete Names: None.
Type Section: Pab Range, Wirahab Nai, Lasbela (25°31'12"N;67°00'19"E).
Thickness: 490m (Type Section), 1000m (Pab Range), 600m (south of Khuzdar), 450m (Fort Munro), 240m(Mughal Kot).
Age: Late Cretareous.
Lithology: Medium- to coarse-grained, thick bedded to massive and cross-bedded quartzose sandstone with intercalations of subordinate shale and limestone. Calcareous and sandy in Pab and Lakhi ranges respectively.
Depositional Environment: Marine deltaic to fluvial.
Contact Relationship: Lower contact conformable with Fort Munro Formation, and unconformable with Parh Limestone. The upper contact is conformable with Dungan Formation but unconformable with Khaddru Formation.

Parh Limestone

Obsolete Names: Parh Limestone member of Parh Group.
Type Section: Parh Range, Gaj River, (26°54'45"N; 76°05'45"E).
Thickness: 300-600m, 268m (Type Section).
Age: Late Cretaceous.
Lithology: Lithographic to porcellaneous, thin bedded limestone with suboudinate intercalations of calcareous shale and marl.
Depositional Environment: Shallow marine; Shelf.
Contact Relationship: Lower contact conformable and gradational with Goru Formation whereas the upper contact with Pab Sandstone in transitional and conformable but with Dungan Formation it is unconfromable.

Permian of Balochistan

Obsolete Names: Limestone with Crinoidal remains, pre-Triassic Sedimentary Rocks, Basal part of Alozai Group.
Type Section: Not Designated, but it is exposed in Ghazabad area (30°20'N; 66°50'E), Kalat area (29°03'N; 66°36'E), and Wulgai area (30°39'N; 67°29'E).
Thickness: Unknown (base not exposed).
Age: Permian.
Lithology: Fossiliferous, crystalline limestone with minor slate and clay partings.
Depositional Environment: Marine:Shallow to deep.
Contact Relationship: Lower contact not exposed. Upper contact conformable with Wulgai Formation.

Pirkoh Formation
(Kirther Group)

Obsolete Names: Pirkoh Limestone and Marl member of Kirther Formation
Type Section: Pirkoh anticline.
Thickness: 10-175m.
Age: Middle Eocene.
Lithology: Thin bedded limestone with subordinate beds of soft argillaceous limestone and calcareous claystone.
Depositional Environment: Shallow marine: Shelf deposits.
Contact Relationship: Lower contact conformable with Domanda Formation whereas the upper contact is conformable with Drazinda Formation.

Rakhshani Formation

Obsolete Names: Cardita Beaumonti Bed, Volcanic Flysch, Ranikot, Siwalik, Juzzak Formation, Lower half of Giddar Dor Group and Basal Part of Pishi Group, Bunap Formation.
Type Section: Rakhshani, eastern end of Dalbandin, Chaghi.
Thickness: 150m-1600m, more than 2400m (Robat).
Age: Paleocene to Middle Eocene.
Lithology: Medium to coarse grained sandstone with lava flows, and tuffaceous volcanic agglomerate and subordinate, fine grained, argillaceous limestone in the lower part.
Depositional Environment: Marine: Shallow to littoral to sublittoral.
Contact Relationship: Lower contact unconformable with Sinjrani Volcanic Group, whereas the upper contact is transitional with Kharan or Saindak formations.

Ras Koh Flysch Formation

Obsolete Names: Part of Juzzak Formation, Part of Rakhshani Formation and Pishi Group.
Type Section: Not designated, probaly in the vicinity of Ras Koh Range
Thickness: Not reported.

Age: Late Cretaceous to Early Paleocene.
Lithology: Medium to corase-grained sandstone and argillaceous limestone with igneous intrusions (Bunap Intrusions; sheared ultrabasic rocks including pyroxenite and peridotite commonly containig chromite).
Depositional Environment: Marine: Associated with sub-marine volcanism.
Contact Relationship: Lower contact is not exposed, however may be unconformable with Sinjrani Volcanic Group. The upper contact is unconformable with Kharan Formation.

Saindak Formation

Obsolete Names: Kirther Stage in part of Chaghi Eruptive Zone, Washap Formation, Part of Amalaf Formation except its upper volcanic part.
Type Section: Saindak Fort, Chaghi.
Thickness: 60-1500m.
Age: Eocene.
Lithology: Interbeds of calcareous or sandy shale, coarse grained to gritty and calcareous sandstone, fossiliferous and sandy limestone, and fragments of andesitic or basaltic volcanic rocks, agglomerates and lava flows with white and pure gypsum and red shale at places.
Depositional Environment: Marine.
Contact Relationship: Lower contact conformable with Rakshani Formation, whereas the upper contact is conformable with Amalaf Formation.

Sember Formation

Obsolete Names: Lower part of Belemnite Beds, Belemnite Shales, Belemnite Beds, Lower part of Parh Series, Lower part of Parh Group.
Type Section: Sember Pass, Marri Hills (29°55'05"N; 68°34'48"E).
Thickness: 262m (MughalKot), 133m (Type section).
Age: Late Jurassic (?) to Early Cretareous.
Lithology: Fossiliferous, silty and glauconitic shale with interbeds of glauconitic siltstone and nodular, argillaceous limestone. Pyrite, phosphatic nodules and sandy shale in the lower part.
Depositional Environment: Marine: Abyssal plane.
Contact Relationship: Lower contact disconformable with Takatu Limestone, Mazar Drik Formation and Shirinab Formation. The upper contact with Goru Formation is conformable.

Shaheed Ghat Formation
(Ghazij Group)

Obsolete Names: Ghazij Formation.
Type Section: Shaheed Ghat, 5km southwest of Zinda Pir (34°24'N; 70°27E).
Thickness: 680m (Shaheed Ghat), 340m (Moghal Kot).
Age: Early Eocene.
Lithology: Laminated shale with marl.
Depositional Environment: Marine: Deltaic(?).
Contact Relationship: Lower contact conformable with Dungan Formation whereas the upper contact is conformable with Drug and Toi formations.

Shirinab Formation

Obsolete Names: Stratified Limestone, Calcareous Shale, Sulaiman Limestone Group, Anjira Formation, Loralai Limestone, Spingwar Formation, Upper part of Windar, Part of Windar and Alozai Group, Zidi Formation.
Type Section: Shirinab River, Kalat.
Thickness: 1500-3000m.
Age: Early to Middle Jurassic.
Lithology: Interbedded limestone and shale. The Formation is divided into three members namely Anjira Member, Loralai Limestone Member and Spingwar Member.
Depositional Environment: Marine: Shallow to deep marine.
Contact Relationship: Lower contact conformable and transitional with Wulgai Formation, whereas the upper contact is transitional with Takatu Limestone and disconformable with Sember Formation

Anjira Member

Obsolete Names: Shirinab Formation
Type Section: 12 Km east of Anjira, Kalat (28°20'18"N; 66°28'00"E).
Thickness: 100m-400m.
Age: Early to Middle Jurassic.
Lithology: Thin bedded, loacally porcellaneous to sub-lithographic limestone with interbeds of splintary mudstone.
Dep. Environment: Marine: Shelf.
Contact Relationship: Lower contact conformable with Loralai Limestone member of Shirinab Formation whereas the upper contact is conformable with Takatu Limestone and disconformable with Sember Formation.

Loralai Limestone Member

Obsolete Names: Loralai Formation.
Type Section: Zamari Tangi (30°32'10"N; 68°18'40"E), Loralai District.
Thickness: ~800m.
Age: Early Jurassic.
Lithology: Thin to medium bedded hard crystalline limestone.
Dep. Environment: Marine: Shelf.
Contact Relationship: Lower contact conformable

with Spingwar Member of Shirinab Formation whereas upper contact is conformable with Anjira Member.

Spingwar Member

Obsolete Names: Spingwar Formation
Type Section: 35 Km northwest of Loralai (30°32'N; 68°09'E).
Thickness: 600m-1800m.
Age: Early Jurassic.
Lithology: Crystalline, locally oolitic, and shelly limestone interbedded with calcareous sandstone in the lower part.
Dep. Environment: Marine : Shelf to Slope.
Contact Relationship: Lower contact conformable with Wulgai Formation, whereas the upper contact is conformable with Loralai Limestone.

Sinjrani Volcanic Group

Obsolete Names: Flysch, Kuchakki Volcanics
Type Section: Sinjrani, Chaghi.
Thickness: 900-1200m.
Age: Cretaceous (base not known).
Lithology: Agglomerate and volcanic conglomerate, verigated fine ash and tuff interbedded with agglomerate. Lava flows, porphyritic quartz andesite, and some basalt with tuffaceous shale and gritty sandstone. Lenticular layers of argillaceous, crystalline or sublithographic and porcellaneous limestone and calcareous shale in the upper part.
Depositional Environment: Marine: associated with sub-marine volcanism.
Contact Relationship: Lower contact not exposed whereas upper contact is conformable with Saindak or Kharan Formation.

Soan Formation
(Siwalik Group)

Obsolete Names: Upper Siwalik, Pinjor Zone/Stage, Upper Manchhar, Upper division of Siwaliks, Upper dividion of Sibi and Urak Group, Urak Formation.
Type Section: Galijagir Sihal Road, near Mujahid village north of Soan River, Attok District (32°22'N;72°47'E).
Thickness: 120-450 m (Type Section), up to 3000m (near Quetta).
Age: Late Pliocene to Early Pliestocene.
Lithology: Massive and compact conglomerate of variational lithology (i.e. limestone, quartzite, porphyritic rocks, sandstone, gneiss and schist) with subordinate interbeds of siltstone, claystone and coarse-grained sandstone.
Depositional Environment: Continental: Fluvial, lacustrine, and alluvial fan deposits.
Contact Relationship: Lower is contact conformable with Dhok Pathan Formation whereas the upper contact is generally unconformable with Lei Conglomerate.

Chiltan (Takatu) Limestone

Obsolete Names: Chiltan Formation, Massive Limestone, Takatu Limestone, Upper part of Sulaiman Limestone Group.
Type Section: Dra Manda, south of Bostan (30°22'20"N; 67°03'39"E)
Thickness: 750-1800m.
Age: Middle Jurassic.
Lithology: Massive, thick bedded, locally pisolitic, fine grained, sub-lithographic, reefoid/biohermal limestone.
Depositional Environment: Marine: Shelf.
Contact Relationship: Lower contact conformable with Shirinab Formation whereas the upper contact is disconformable with Sember and Mazar Drik formations.

Toi Formation
(Ghazij Group)

Obsolete Names: Ghazij Formation
Type Section: Toi Nala South Waziristan (31°05'N; 70°11'E).
Thickness: 1196m (Moghal Kot area).
Age: Early Eocene.
Lithology: Coarse-grained, cross bedded, pebbly and poorly sorted sandstone that is interbedded with mudstone, siltstone, shale, conglomerate and locally developed coal seams.
Depositional Environment: Deltaic.
Contact Relationship: Lower contact conformable with Drug Formation or Shaheed Gut Formation whereas the upper contact is conformable with Bask or Kirther Formation.

Wulgai Formation

Obsolete Names: Lower part of Alozai Group, Alozai Group (Wulgai near Muslimbagh), Shirinab Formation (Khuzdar), and Windar Group (Lasbela).
Type Section: Wulgai Village, (30°39'35"N; 67°29'25"E), Qila Saifullah District.
Thickness: 1180m (Type Section) (estimated).
Age: Early to Late Triassic.
Lithology: Indurated mudstone and shale with intercalations of thin crystalline limestone, mudstone and sandstone.
Depositional Environment: Marine: Deep marine (turbidite).
Contact Relationship: Lower contact is conformable with Permian rocks in the Shirinab area but is

tectonically disturbed in the Wulgai area. The upper contact is transitional with Shirinab Formation.

Yak Mach Conglomerate Formation

Obsolete Names: Basal conglomerate part of Bostan Formation. Equivalent to Koh-e-Dalil Conglomerate.Mainly exposed in the central and eastern part of the Dalbandin Trough.
Type Section: Not designated. Principal outcrops are located NE of Yak Mach, Chaghi.
Thickness: Not reported.
Age: Pliocene.
Lithology: Sub-angular debris with scattered well rounded pebbles.
Depositional Environment: Continental; fluvial.
Contact Relationship: Lower contact unconformable (angular) with older Cenozoic formations whereas the upper contact is not unconformable with sub-Recent deposits.

GROUPS

Allozai Group

Obsolete Names: None
Type Section: Allozai Village, 30° 38'N 68°38'E (39-B/10).
Thickness: More than 1025 metres in northern Balochistan.
Age: Early to Middle Jurassic
Lithology: Interbedded limestone and shale with subordinate areneceous or ferruginous limestone. Comprised of two formations namely Spingwar Formation and Loralai Limestone.
Depositional Environment: Medium shallow to deep marine (turbidites)
Contact Relationship: Base not exposed. The upper contact is nunconformable with Sember Formation

Ferozabad Group

Equivalent to Shirinab Formation exposed in the Khuzdar District (Fatmi et al. 1986). The main apparent difference between the Ferozababd lithostratigraphic units and Shirinab is the presence of greater amount of clastic sediments in the lower part of Ferozabad Group. The Type Section is located 17 Km WNW of Khuzdar (27°50'N; 66°34'E).The lower age limit of the Ferozabad Group is doubtfully Triassic to Early Jurassic.
Upper Unit: (~300m), thick bedded limestone with marl and shale.
Middle Unit: (387m), thick to massive, oolitic, coquinoid or micritic limestone with abundant biturbated beds and marly limestone intercalations.
Lower Unit: (248m), micritic limestone, sandy limestone and sandstone interbedded with shale. A paraconformity is present between the Ferozabad Group and overlying Sember Formation, whereas the lower contact is not exposed.

Khanozai Group

Obsolete Names: Allozai group, Wulgai Formation
Type Section: Khanozai town 75 km northeast of Quetta., 30°N 67°20'E (34-J/6).
Thickness: More than 530 metres in the Takai Gawal section
Age: Triassic
Lithology: Interbedded shale and limestone
Depositional Environment: Deep marine, Clastic and crbonate turbidites
Contact Relationship: Base not exposed. The upper contact is not well known and is probably transitional with Allozai group as reported from Tazi Kach-Kozh Kach sections.

Ghazij Group

Obsolete Names: Ghazij Formation, Ghazij Group, Shale with Alabaster, Rubbly Limestone, Green and Nodular Shale Group, Rakhi Gaj Shale and Zinda Pir Limestone, Chat Beds, Ghazij Shale, Tiyon Formation and Upper part of Giddar Dhor Group.
Type Section: Spintangi, Harnai (29°57'N, 68°05'E).
Thickness: 590m (Type Section), 3300m (Mughal Kot), 160m (Bara Nai, Kirther Range).
Age: Early Eocene.
Lithology: Calcareous, flacky, shale with interbeds and lenses of claystone, mudstone, sandstone, arenaceous limestone conglomerate and alabaster. It contains numerous coal seams of variable thickness.
Depositional Environment: Partly marine and partly fluvial deltaic.
Contact Relationship: Lower contact conformable with Dungan Formation whereas the upper contact is conformable with Kirther group in Suklaiman and Kirther Ranges, but is unconformable with Kirther group in other parts of the West Pakistan Foldbelt. .

Kirther Group

Obsolete Names: Spintangi Limestone, Brahvi Limestone.
Type Section: Gaj River, Dadu District (26°56'10"N; 76°09'06"E).
Thickness: 1270m (*Type Section*), 300m (Spintangi, Quetta).
Age: Middle Eocene to Early Oligocene.
Lithology: Thick bedded to massive, nodular, fossiliferous limestone that is interbedded with calcareous shale. Divided into four formations namely Drazinda, Pirkoh, Domanda, and Habib

Rahi.
Depositional Environment: Shallow marine.
Contact Relationship: Lower contact conformable with Ghazij Group whereas the upper contact is unconformable with Nari Formation.

Makran Group

Obsolete Names: Mekran Series, Mekran System, Hinglaj Series, Gwadar and Talar Stages, Flysch and Khojak Shales.
Type Section: Not designated; (relates to Makran Coast).
Thickness: 3800m (Jangal) 7100m (Jiwani), 5700m (Diz).
Age: Oligocene.
Lithology: Thick shale sequence in the upper part and sandstone sequence in the lower part. The group is divided into Khojak and Hinglaj formations described above.
Depositional Environment: Deltaic to marine; Estuarine.
Contact Relationship: Lower contact transitional and conformable with Khojak Formation whereas the upper contact is unconformable with Gwadar Formation.

Momani Group

Obsolete Names: Lower part of Sibi and Urak Group.
Type Section: Momani River, Dadu, Sind.
Thickness: 660m (Type Section), 1700m (Gaj River), 300-600m (West Pakistan Fold Belt)
Age: Late Oligocene to Middle Miocene.
Lithology: Limestone, sandstone, shale. Comprised of two formations namely Gaj and Nari formations.
Depositional Environment: Marine to fluvial.
Contact Relationship: Upper contact unconformable with Siwalik Group whereas the lower contact unconformable with Kirther group.

Mona Jhal Group

Obsolete Names: None
Type Section: Mona Jhal anticline, 13 kilometers north of Khuzdar (35-I/9).
Thickness: The thickness of the group variies from place to place. The thicknesses of individual formations within the group are given earlier in the description of formations.
Age: Late Jurassic to late Cretaceous.
Lithology: Verigated siliceous shale, dense siliceous limestone, and calcareous siltstone. Minor snadstone with barite nodules and silty shale. The group is comprised of four formations namely Sember Formations, Goru Formation, Parh Limestone and Mughal Kot Formation.
Depositional Environment: Deep to shallow marine.
Contact Relationship: The lower contact is unconformable with Anjira Formation (southern Balochiostan) with Chiltan Limestone (Cerntral Balochoistan) and Loralai Limestone (northen Balochistan). The upper contact with Late Cretaceous rocks (Pab Sandstone and Fort Munro Formation) is variable but is commonly conformable.

Ranikot Group

Obsolete Names: Strata lying between Volcanic and Kirther or lower Nummulitic Group, Cardita beaumonti Beds, Trap Group, Lower Ranikot Sandstone, and Upper Ranikot Limestone.
Age: Paleocene
Lithology: Upper part limestone, with some sandstone and shale. Lower part dominantly sandstone and shale which is interbedded with limestone. Group is divided into three formations namely Lakhra Formation, Bara Formation and Khaddro Formation.
Depositional Environment: Marine: Esturine to fluvial.
Contact Relationship: Lower Contact unconformable with Pab Sandstone, and Moro Formation, whereas the upper contact is conformable with Laki or Nisai Formation

Siwalik Group

Obsolete Names: Upper Part of Sub-Himalayan System, Siwalik Series, Siwalik System, Manchhar Formation, Sibi and Urak groups.
Type Section: Not Designated.
Thickness: Variable. Several thousand meters.
Age: Early Pliocene to Pliestocene.
Lithology: Alternations of sandstone and argillaceous material of clastic origin. Comprised of four formations, however, only three i.e. Soan, Dhok Pathan and Nagri formations are exposed in Balochistan. The fourth- Chinji Formatio, is exposed in the Kohat-Pothwar Province.
Depositional Environment: Marine to estuarine and fluvial.
Contact Relationship: Upper contact unconformable with Lie Conglomerate and lower contact unconformable with Momani and Kirther groups.

Table 1. List of stratigraphic names proposed by previous workers and those currently used in the modern literature. Obsolete/old names are arranged alphabetically. References are omitted for clarity and may be found in Shah (1977), Iqbal et al. (1980), and Bender and Raza (1995).

Obsolete/Old Names	Names currently in use
Allozai Group	Allozai Group
Allozai Grou	Khanozai Group
Allozai Group	Gawal Formation
Alozai Group	Wulgai Formation
Alveoline Limestone	Dungan Formation
Anjira Formation	Shirinab Formation
Basal conglomerate part of Bostan Formation	Dalil Conglomerate Formation
Basal conglomerate part of Bostan Formation	Yak Mach Conglomerate Formation
Basal part of Allozai Group	Permian of Balochistan
Basal part of Karkh	Khadru Formation
Basal Part of Pishi Group Bunap Formation	Rakhshani Formation
Bed Kachu	Khadru Formation
Bedded Clays	Mughal Kot Formation
Bela Volcanic Group	Bibai Formation
Belemnite Beds	Sember Formation
Belemnite Shales	Sember Formation
Binga Formation	Khojak Formation
Boulder Conglomerate	Lei Conglomerate
Brahvi Limestone	Kirther Group
Brewry Limestone	Dungan Formation
Calcareous Shale	Shirinab Formation
Cardita beaumonti Bed	Rakhshani Formation
Cardita beaumonti Beds	Khadru Formation
Cardita beaumonti Beds	Ranikot Group
Chat Beds	Ghazij Group
Chatti Mudstone	Hinglaj Formation
Chiltan Formation	Takatu Limestone
Chiltan Limestone	Takatu Limestone
Cretaceous-Eocene Flysch	Amalaf Formation
Dab Formation	Dungan Formation
Dada Conglomerate	Lei Conglomerate
Dalbandin Assemblage	Khojak Formation
Dandot Sandstone	Nagri Formation
Deccan Trap	Bibai Formation
Diz Formation	Hinglaj Formation
Drazinda member of Kirther Formation	Drazinda Formation
Dungan Group	Dungan Formation
Eocene Limestone	Nisai Formation
Eriklag Limestone	Kharan Formation
Estuarine Passage Beds	Gaj Formation
Flysch and Khojak Shales	Makran Group
Flysch Kuchakki Volcanics	Sinjrani Volcanic Group
Fort Munro Limestone member	Fort Munro Formation
Gawadar Stage	Gwadar Formation
Ghazaband Limestone	Nisai Formation
Ghazij Formation	Toi Formation
Ghazij Formation	Ghazij Group
Ghazij Formation	Drug Formation
Ghazij Formation	Baska Formation
Ghazij Formation	Shaheed Ghat Formation
Ghazij Formation	Marap Conglomerate

Obsolete/Old Names	Names currently in use
Ghazij Group	Ghazij Group
Ghazij Shale	Ghazij Group
Ghazij Shale	Nisai Formation
Gidar Dhor Group	Khadru Formation
Gorge Bed	Bara Formation
Green and Nodular Shale Group	Ghazij Group
Greyshak Group	Hinglaj Formation
Gwadar and Talar Stages	Makran Group
Habib Rahi Limestone member of Kirther Formation	Habib Rahi Formation
Hemipneustes Limestone	Fort Munro Formation
Hinglaj Group	Hinglaj Formation
Hinglaj Series	Makran Group
Hinglaj Series	Hinglaj Formation
Hoshab Shale	Khojak Formation
Inoceramus Clays	Mughal Kot Formation
Jekker Groups	Khadru Formation
Juzzak Formation	Rakhshani Formation
Kahan Conglomerate Member	Bibai Formation
Kalabagh beds	Lei Conglomerate
Kalabagh Conglomerate	Lei Conglomerate
Kalabagh Hill Conglomerate	Lei Conglomerate
Kamerod Formation	Bostan Formation
Karhk Group	Dungan Formation
Kasira Group	Nisai Formation
Kech Conglomerate	Haro Conglomerate
Kharan Limestone	Kharan Formation
Khojak Shale and Flysch	Khojak Formation
Khude Limestone	Nisai Formation
Kirther Stage in part of Chaghi Eruptive Zone	Saindak Formation
Limestone with Crinoidal remains	Permian of Balochistan
Limestone with Hemipnuestes	Moro Formation
Limestone with Hippurites	Fort Munro Formation
Loralai Formation	Loralai Limestone Mem.
Loralai Limestone	Shirinab Formation
Lower and Upper Gaj	Gaj Formation
Lower and upper Nari	Nari Formation
Lower half of Giddar Dor Group	Rakhshani Formation
Lower Kirther Shale	Nisai Formation
Lower Nummulitic Group	Ranikot Group
Lower part of Alozai Group	Wulgai Formation
Lower part of Belemnite Beds	Sember Formation
Lower part of Jekkar, Thar, Rattaro, and Bed Kachu	Bara Formation
Lower part of Jekker Group	Lakhra Formation
Lower part of Khojak Formation	Murgha Faqirzai Member
Lower part of Orbitoides Limestone and Shale	Mughal Kot Formation
Lower part of Pab Sandstone	Mughal Kot Formation
Lower part of Parh Group	Sember Formation
Lower part of Parh Series	Sember Formation
Lower part of Pishi Group	Kharan Formation
Lower part of Sibi and Urak Groups	Momani Group
Lower part of Sibi and Urak Groups	Nari Formation
Lower part of Urak Group	Gaj Formation
Lower Rakhi Gaj Shale	Dungan Formation
Lower Ranikot	Bara Formation
Lower Ranikot Sandstone	Ranikot Group
Lower Ranikot Sandstone	Bara Formation

Obsolete/Old Names	Names currently in use
Manchhar Formation	Siwalik Group
Marap Conglomerate member	Marap Conglomerate
Marl member of Kirther Formation	Pirkoh Formation
Massive Limestone	Nisai Formation
Massive Limestone	Takatu Limestone
Mekran Series	Makran Group
Mekran System	Makran Group
Mudstone Stage	Hinglaj Formation
Mughal Kot minus Fort Munro member	Mughal Kot Formation
Multana Formation	Khojak Formation
Murgha Faqirzai Shale	Khojak Formation
Nagri Stage	Nagri Formation
Nagri Zone	Nagri Formation
Nal Formation	Nari Formation
Nari and Khojak Series	Nisai Formation
Nari limestone	Nari Formation
Nari Series	Nari Formation
Nauroze Formation	Khojak Formation
Nimergh Limestone	Nisai Formation
Nisai Group	Nisai Formation
Numulitic Beds	Nisai Formation
Ormara Formation	Gwadar Formation
Panjgur Formation	Khojak Formation
Parh Limestone member of Parh Group	Parh Limestone
Parkini member	Hinglaj Formation
Part of Amalaf Formation minus upper volcanic part	Saindak Formation
Part of Dungan and Jamburo groups	Moro Formation
Part of Juzzak Formation	Ras Koh Flysch Formation
Part of Juzzak Formation	Mirjawa Flysch Formation
Part of Rakhshani Formation and Pishi Group	Ras Koh Flysch Formation
Part of Windar and Allozai Group	Shirinab Formation
Parts of Sibi Group and Urak Group	Nagri Formation
Peshi Group	Khojak Formation
Pinjor Zone/Stage	Soan Formation
Pirkoh Limestone	Pirkoh Formation
Polyphemus Beds	Mazar Drik Formation
Polyphemus Limestone	Mazar Drik Formation
pre-Triassic Sedimentary Rocks	Permian of Balochistan
Rakhi Gaj Shale	Ghazij Group
Ranikot Formation	Rakhshani Formation
Ranikot Formation	Bara Formation
Robat Limestone	Kharan Formation
Rubbly Limestone	Ghazij Group
Sandstone Stage	Hinglaj Formation
Shale and Marl in upper part of Pab Sandstone	Moro Formation
Shale with Alabaster	Ghazij Group
Shales weathering to Calys	Hinglaj Formation
Sheri Ghasha Formation	Dhok Pathan Formation
Shigalu Sandstone	Khojak Formation
Shinmatai Formation	Dhok Pathan Formation
Shirinab Formation	Anjira Member
Shirinab Formation	Wulgai Formation
Siahan Shale	Khojak Formation
Siazgai Limestone	Dungan Formation
Sibi and Urak Group	Dhok Pathan Formation
Sibi and Urak groups	Siwalik Group

Obsolete/Old Names	**Names currently in use**
Sibi Group	Gaj Formation
Sinjawi Limestone	Dungan Formation
Sirki member of Kirther Formation	Domanda Formation
Siwalik Formation	Rakhshani Formation
Siwalik Series	Siwalik Group
Siwalik System	Siwalik Group
Spingwar Formation	Spingwar Member (Shirinab Formation)
Spintangi Limestone	Nisai Formation
Spintangi Limestone	Kirther Group
Stratified Limestone	Shirinab Formation
Sub-Recent Shelly Limestone	Jiwani Formation
Sulaiman Limestone Group	Shirinab Formation
Takatu Limestone	Chiltan Limestone
Talar Sandstone	Hinglaj Formation
Thar Formation	Khadru Formation
Tiyon Formation	Ghazij Group
Trap Group	Ranikot Group
Turbat Group	Khojak Formation
Upper dividion of Sibi and Urak Group	Soan Formation
Upper division of Siwaliks	Soan Formation
Upper Manchhar	Soan Formation
Upper Manchhar Stages e, d, and c, of Siwaliks in Sibi-Pishin area	Dhok Pathan Formation
Upper part of Bed Kachu, Rattaro, and Thar Formation	Lakhra Formation
Upper part of Belemnite Beds	Goru Formation
Upper part of Giddar Dhor Group	Ghazij Group
Upper part of Jakkar and Jumburo Group	Nisai Formation
Upper part of Khojak Formation	Shigalu Member
Upper part of Orbitoides Limestone and Shale	Fort Munro Formation
Upper part of Parh Group	Goru Formation
Upper part of Pishi Group	Bostan Formation
Upper Part of Sub-Himalayan System	Siwalik Group
Upper part of Sulaiman Limestone Group	Takatu Limestone
Upper part of Windar	Shirinab Formation
Upper Rani Kot	Lakhra Formation
Upper Ranikot (Limestone)	Lakhra Formation
Upper Ranikot Formation	Lakhra Formation
Upper Ranikot Limestone	Ranikot Group
Upper Siwalik	Soan Formation
Urak Formation	Soan Formation
Uzda Pasha Formation	Nagri Formation
Volcanic Flysch	Rakhshani Formation
Wad Limestone	Nisai Formation
Wakabi Limestone	Nisai Formation
Wakai Limestone	Nisai Formation
Washap Formation	Kharan Formation
Washap Formation	Saindak Formation
Windar Group	Malikhore Formation
Windar Group	Kharrari Formation
Windar Group	Wulgai Formation
Wulgai Formation	Khanozai Group
Zidi Formation	Kharrari Formation
Zidi Formation	Malikhore Formation
Zidi Formation	Shirinab Formation
Zinda Pir Limestone	Ghazij Group
Zinda Pir Limestone	Dungan Formation

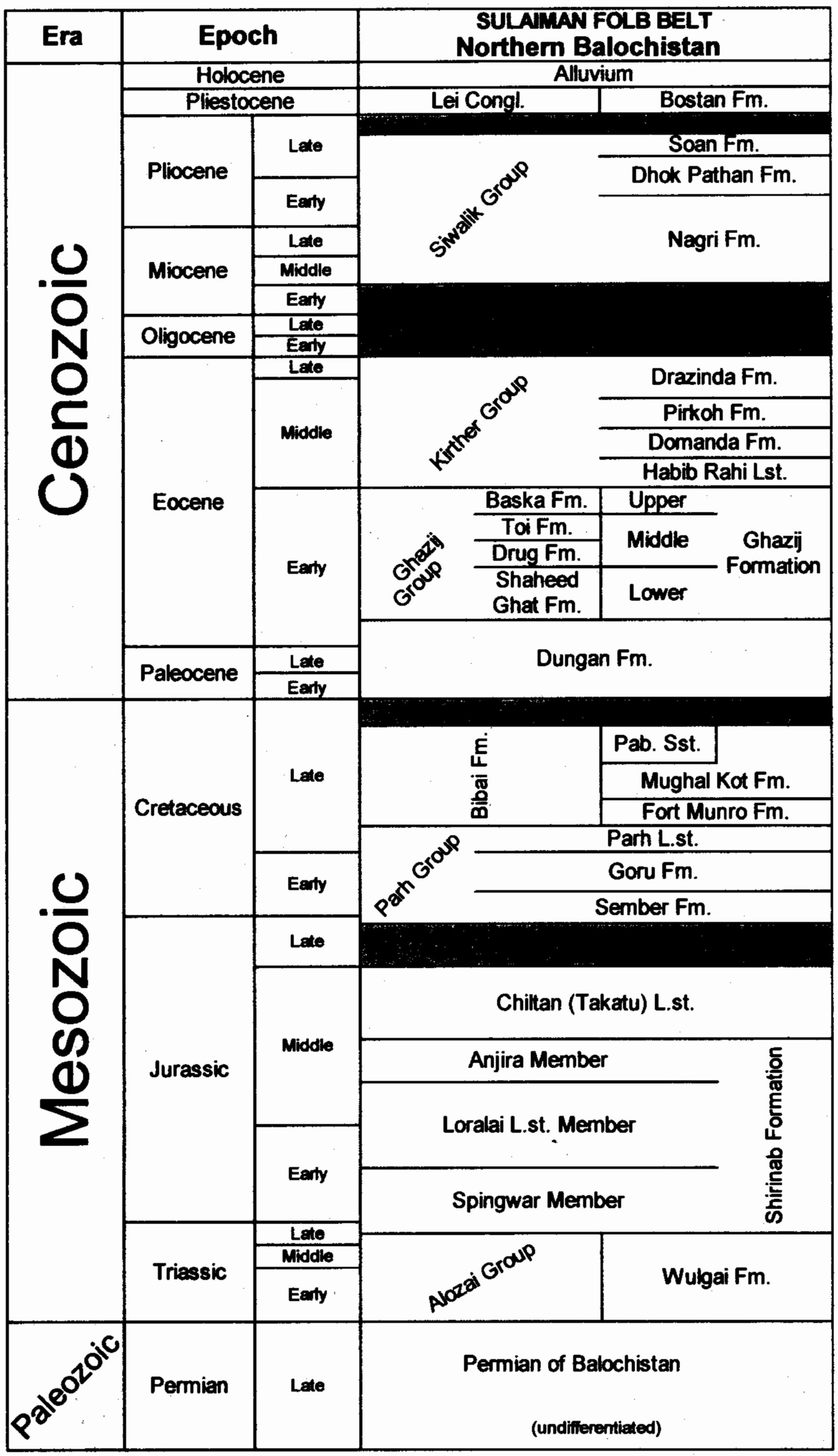

Figure 1. Generalized lithostratigraphic column of exposed, mostly Phanerozoic, rocks in Sulaiman Fold Belt (Northern Balochistan). To the west of the Sulaiman Fold Belt, thick sequence of Paleogene Flysch deposits (Khojak Formation) are contained in the "Khojak Basin" (Jadoon and others 1990) and Makran Basin which are not shown in this column because depositionally these deposits are not associated with any deposits in the Axial Fold Belt. They are, however, shown in the generalized lithostratigraphic column of Makran Basin (Fig. 4 and 5)

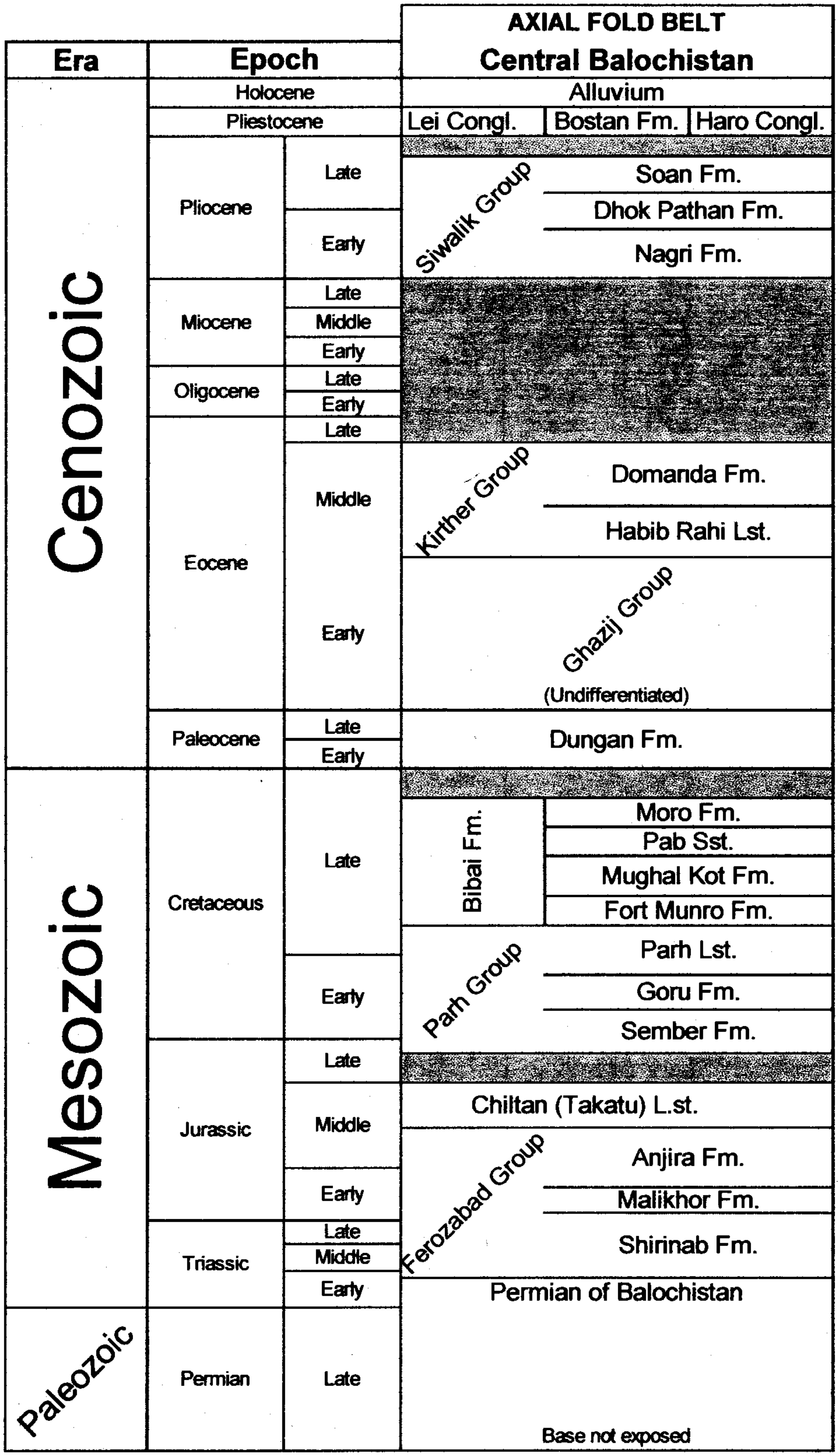

Figure 2. Generalized lithostratrigraphic column of the rocks exposed in the central part of Axial Fold Belt, Balochistan (Quetta Syntaxis).

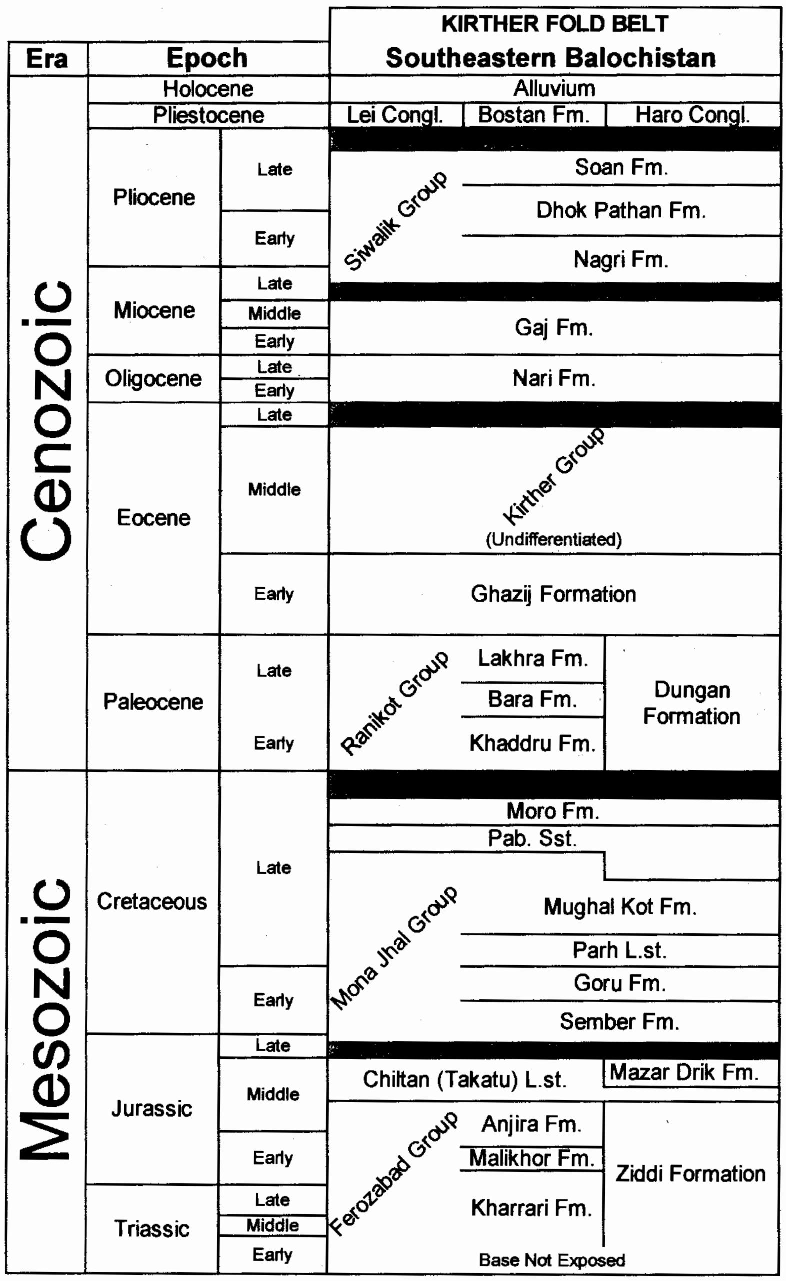

Figure 3. Generalized lithostratrigraphic column of the rocks exposed in the Kirther Fold Belt, (Southeastern Balochistan).

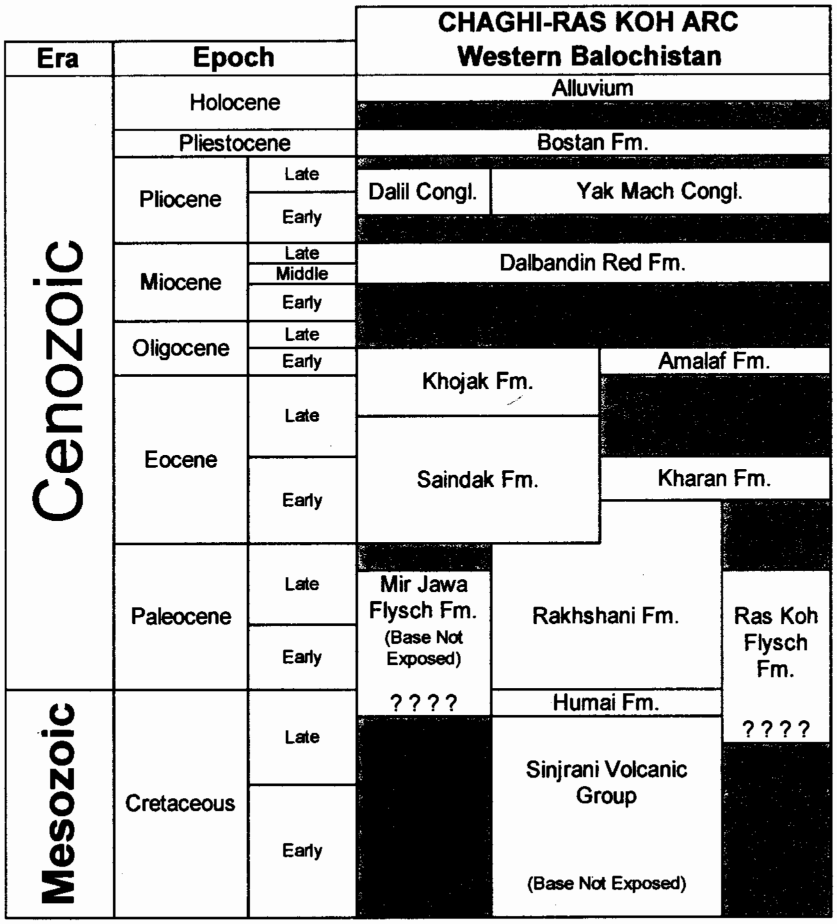

Figure 4. Generalized lithostratrigraphic column of the rocks exposed in the Chaghi-Ras Koh Arc (Northwestern Balochistan).

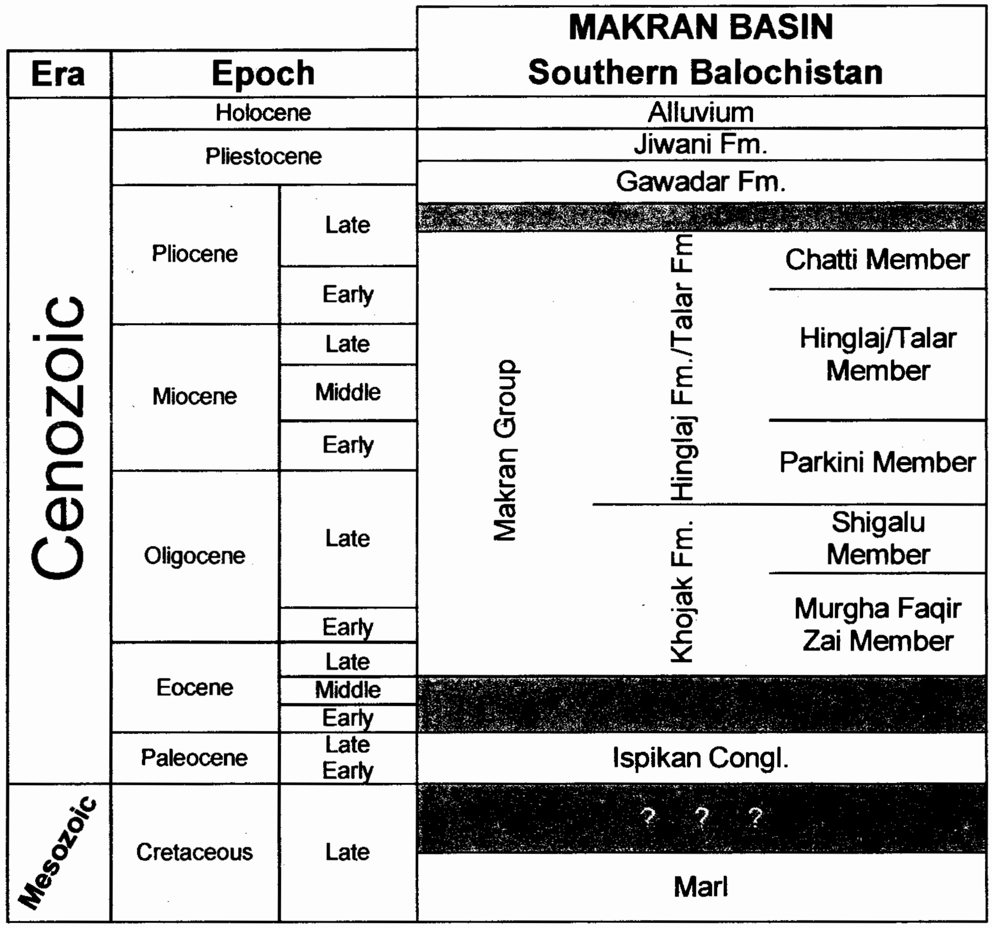

Figure 5. Generalized lithostratrigraphic column of the rocks exposed in the Makran Basin (southern Balochistan).

Era	Epoch		Khanozai-Loralai Area	
Mesozoic	Cretaceous	Late	Parh Group	
		Early		
	Jurassic	Late		
		Middle	Alozai Group	Loralai Fm.
		Early		Spingwar Fm.
	Triassic	Late	Khanozai Group	Wulgai Fm.
		Middle		
		Early		Gawal Fm.

Figure 6. Generalized lithostratrigraphic column of the Mesozoic rocks exposed in the Khanozai-Loralai area of the Axial Fold Belt.

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ECONOMIC VIABILITY OF GROUNDWATER BASED TOWNSHIP WATER SUPPLY SCHEMES OF BALOCHISTAN, PAKISTAN

SYED MOBASHER AFTAB
Public Health Engineering Department, Government of Balochistan Quetta, Pakistan.

ABSTRACT

In Balochistan groundwater is the source of about 98% of all water supply schemes. These are expensive to install, difficult to maintain and low revenue collection makes them unsustainable. In this paper the under construction groundwater based Kharan, Kuchlak, Mastung and Ziarat township schemes were selected for economic analysis. The capital cost of the schemes varies from Rupees (Rs.) 25.4-53.7 million (1 US$=Rs. 50). The expenditure of tubewell installation upto a depth of 150 meter along-with pumping machinery and energization ranges from Rs. 1.25-1.55 million. The cost of one cubic meter of water produced vary from Rs. 4-18 based on capital cost. Average income per house hold deviates from Rs. 5567-10024 per month. Domestic number of connections for the year 1997 and projected for 2010 are 99-1827 and 471-5517 respectively. New connection costs Rs. 500-800, the cost per connection per month differs from Rs. 89-264 and Rs. 93-109 for the same periods. Allocated and projected operation and maintenance (O&M) costs varies from Rs. 0.19-3.33 and 0.61-6.16 million. Break even tariff per month in the year 2010 with collection efficiencies 10%, 70% and 100% are 715-1066, 79-118 and 71-107 respectively. The break even tariff is sensitive to the number of connections and collection efficiency. The number of connections is most sensitive to total revenues required for recovering O&M costs. The break even projections indicate that water tariff for O&M of schemes increases from existing Rs. 30 per month during 1997 to Rs. 54-111 per month in 2010 while deficit is negligible. This indicates that the schemes are sustainable and economically viable, as the 70-97% consumers are willing to pay Rs. 35-151 per month in terms of 1997 prices which is sufficient for the recovery of O&M costs of the schemes. The increased tariff is under 2% of the average income per house hold and affordable as water charges.

INTRODUCTION

A Strategic Investment Plan was undertaken during 1988-89 to increase water supply coverage in Balochistan (wardrope-Acres 1989). An investment plan of Rs. 1,247 million was proposed over the period of 1990-2000, to increase the coverage from 22% in 1988 to 70% by 2000. As an outcome the Balochistan Rural Water Supply and Sanitation Project (BRWSSP) was initiated based on the feasibility report prepared by National Engineering Services of Pakistan (NESPAK). The project was financed by the International Development Agency/World Bank and the Government of Balochistan through Public Health Engineering Department (PHED). The BRWSSP includes a number of components, the significant are the construction of six new township water supply schemes (WSS). Economic analyses of these water

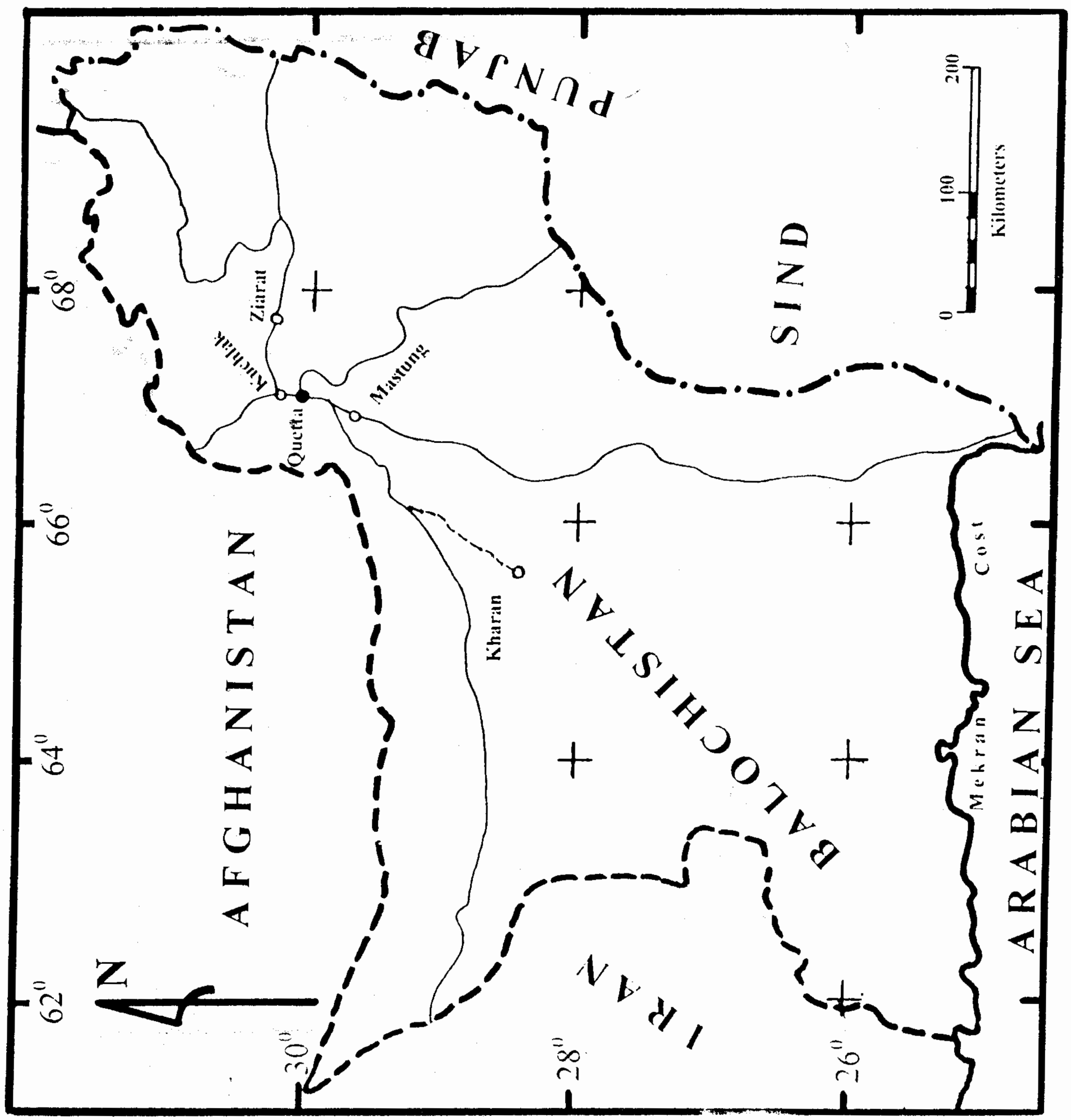

Figure 1. Map of Balochistan showing geographical location of Kharan, Kuchlak, Mastung and Ziarat townships where the economic viability of the water supply schemes is evaluated.

supply schemes in for districts of Balochistan (Fig. 1) is carried out to examine their viability in terms of cost. The communities of proposed townships are facing acute shortage of water supply. Presently in twenty four hours about half an hour water is supplied to all the inhabitants of the four townships. The shortage of water is most common and about every household has to pay extra amount to meet additional water demands. The intermittent water supply leads to many problems. The pressure distributions are also not even owing to large elevation differences in topography. The existing water supply system is without properly designed distribution network, it is generally of small size and has not been laid on defined routes. To enhance the existing facilities new water supply systems for the same townships were designed for a design horizon of 23 years i.e. from 1993-2015 in two phases: phase I upto the year 2000 and phase II for 2015. The economic viability analyses for the first phase are presented in this paper. The proposed schemes consists of installation of new tubewells, replacement of existing pumping equipment, booster stations, construction of new water storage tanks, laying of new transmission mains and construction of water distribution networks. House connections, stand posts, fire hydrants, animal drinking and tanker filling units are also part of the new system. The number of domestic connections have been increased substantially and ultimately the inhabitants are expected to enjoy better and enhanced service levels and larger water supply hours.

HOUSEHOLD SURVEY AND ECONOMIC ANALYSIS

The population projections of the four townships are made on the basis of 1981 Census and sample demographic surveys (NESPAK 1996a,d). However distinctive considerations were given to specific birth rates, mortality rates, resource endowment, industrial development, rate of immigration and emigration etc. The projected population in year 2000 and 2010 are varies from 5,125-44,405 and 7,996-65,350 respectively. The assessment of economic aspects of beneficiary communities of Kharan, Kuchlak, Mastung and Ziarat townships were made with a house hold survey (Sidat 1997d). The survey focused on the average house hold size, average number of earners per house hold, income levels and source of income, education level of the community, house size and living style, expenditure patterns etc. The number of households in all the four townships are varies from 420-5035 and the number of persons per household from 11.5-21.8. The number of earners per household vary from 1.5-3.3 and the dependency ratio from 1:4.4-1:7.7. The average income per household per month ranges from 5,567-10,024, which is lowest in Kharan and highest in Kuchlak town.

The economic survey is also supported by the consumer satisfaction, perception of new scheme, affordability and willingness to pay for four hours and twenty four hours of water supply per day etc. The results of the survey are given in Table 1.

Table 1. Economic profile and consumers willingness to pay for new water supply schemes.

DESCRIPTION	KHARAN	KUCHLAK	MASTUNG	ZIARAT
Total population projections				
Year 2000	24583	32187	44405	5125
Year 2010	35407	43256	65350	7996
No. of households	2744	3763	5035	420
No. of persons per households	12.8	21.2	11.5	12.0
No. of earners per households	1.7	3.3	1.5	2.7
Dependency ratio	1:7.5	1:6.4	1:7.7	1:4.4
Average incom per household per month (Rs.)	5567	10024	7576	8280
Incom Pattern (%)				
Rs. < 4,000	22	19	37	26
Rs. 4,000 - 8,000	68	45	36	41
Rs. > 8,000	10	36	27	33
Willingness to pay for 4 hours water supply (%)				
Rs. 0 - 50	70	74	91	97
Rs. 60 - 100	29	16	6	-
Rs. > 100	1	10	3	3

About 70-97% house holds are willing to pay upto Rs. 50 per month as water charges irrespective of their economic conditions. This indicate their positive behavior towards new water supply schemes. The existing level of water supply is not enough to encourage the consumers to pay for the services. If the water supply is increased from the existing half an hour to about four hour per day than they are willing to pay even a higher tariff up to Rs.50 or more per month. The average income of per household is Rs. 4000 and more. If the water tariff is increased to Rs. 50 this would be under 2% of the average income per household, which is considered as affordable for water charges. More than 50% house holds are willing to pay Rs. 50 per month. The highest response received from Mastung 80%, and lowest from Kharan 45%.

WATER SOURCE, SUPPLY AND DEMAND ANALYSES

The tubewells are the main source of existing and new water supply schemes, although open surface wells and springs are also part of the system to a lesser extent. In Mastung Township, the discharge of two existing tubewells are decreased to a considerable extent due to the declination of water table and shallow depths of tubewells. It has been proposed to replace them by new tubewells of 241-245 meter depth. Installation of two new tubewells for Kuchlak and one for Ziarat towns are proposed to meet the acquired supply of water. The depth of tubewell are ranges from 102-245 meters, depth of water table from 28-114 meter, discharge from 12-100 cubic meter per hour (m^3/h), and draw down from 2-47 meter (PHED 1972-1999). All the tubewells are installed in the valley fill materials where boulder, gravel and sandy admixture formed productive aquifers. Existing supply of water to four townships varies from 675-2250 cubic meter per day (m^3/d), and estimated total supply for proposed system from all sources fluctuates from 1328-3810 m^3/d. The tubewell information recorded at the time of installation are given in Table 2. In new WSS, the domestic and stand post demands are fixed at a ratio of 60 and 20 liter per capita per day (lpcd). Industrial and commercial demands at 3 lpcd, while public use and live stock 6 and 3 lpcd respectively. Unaccounted for water are fixed as 18 lpcd (NESPAK 1996a,d). On the basis of the said fixed ratio the total daily demand of all the four townships are computed. The total daily demand deviates from 368-2,931 m^3/d. For the coming years it has also been planned to increase the said quantities at a considerable ratio. Water source, supply and demand comparison of the existing and proposed systems are given in Table 2.

Table 2. Water source, supply and demand comparision of existing and new water supply schemes.

Components	KHARAN		KUCHLAK		MASTUNG		ZIARAT	
	Existing	Proposed	Existing	Proposed	Existing	Proposed	Existing	Proposed
Water Sources (Nos.)								
Tubewells	3	-	3	2	6	2	-	1
Open surface wells	2	-	-	-	-	-	3	-
Springs	1	-	-	-	-	-	1	-
Tubewells installed on	1972-88	-	1988-90	1998-99	1981-90	1998-99	-	1988
Depth of tubewells (m)	122-137	-	136-166	213-223	102-150	241-245	-	198
Depth of water table at	29-37	-	28-67	104-114	41-56	43-49	-	60
Discharge (m^3/h)	22-45	-	22-27	12-14	27-54	19-20	-	100
Drawdown (m)	6-15	-	3-6	2-3	6-47	43-46	-	18
Per capita per day (lt)	42	60	42	60	50	60	-	60
Total supply (m^3/day)	810	1623	1178	2762	2250	3810	675	1328
Total water demand (m^3/d)	-	1622	-	2124	-	2931	-	368

Table 3. Capital and water produced cost comparison of new water supply schemes (Rs. Million).

COMPNENTS	KHARAN	KUCHLAK	MASTUNG	ZIARAT
Civil Wroks	3.16	1.93	-	3.14
Pipe lines	26.34	23.68	36.13	15.23
General Items	3.55	3.18	4.23	2.00
Electrical & mechanical equipment	6.00	3.97	6.16	1.64
Sub Total	39.05	32.76	46.52	22.00
Contingencies (10%)	3.90	3.28	4.65	2.20
Consultancy and supervision(5%)	2.15	1.81	2.56	1.21
Grand Total	45.10	37.85	53.73	25.41
Costs of new connection (Rs.)	800.00	709.00	500.00	500.00
Cost of 1m^3 water produced (Rs.)				
Based on capital cost	5.80	4.00	3.80	17.80
Based on O&M cost	2.20	2.20	2.70	6.90

COST ANALYSIS OF NEW SUPPLY SYSTEMS

The costs of the major components of the proposed townships WSS are the civil works which includes the construction of the overhead, surface and ground tanks. Lying of pipe lines for transmission system and distribution network. Installation of electrical and mechanical equipments for pumping and boosting the groundwater etc. The estimated capital costs of the Kharan, Kuchlak, Mastung and Zariat WSS are ranges from Rs. 25.414 to Rs. 53.726 millions (NESPAK 1996a,d). The costs includes 10% contingencies and 5% consultancy and supervision charges. The break-up of the capital cost analysis and cost of water produced are given in Table 3.

Drilling, development and installation of tubewell upto a depth of 150 meter costs about Rs. 500,00, rate fixed by the Government of Balochistan for all parts of the province (P&D 1996). Eneragization cost ranges from Rs. 300,000-400,000. Installation of pumping machinery of about 40 horse power costs Rs. 350,000-500,000. The construction of pump house and other relevant structures costs Rs. 100,000-150,000 approximately (PHED 1996-99). The total cost of tubewell installation and completion in all respects ranges from Rs. 1.25-1.55 million. The costs are increased with the increase of tubewell depths as in the case of Kuchlak township where new tubewells upto a depth of 245 meter were installed. For new water supply schemes, the average cost of new domestic connections ranges from Rs. 500-800 on the basis of the capital costs. The average cost of one cubic meter of water produced ranges from Rs. 3.8-17.8 on the basis of the capital cost of the schemes. While on the basis of the operation and maintenance of the scheme, the cost of one cubic meter of water ranges from Rs. 2.2-6.9. The cost analysis exhibit that the maximum cost per new connection is for Kharan while the maximum cost of produced water is for Ziarat township.

FINANCIAL ANALYSIS OF EXISTING SCHEMES

Presently, the Government is responsible for the O&M of all township water supply schemes. The O&M budget of PHED was Rs. 155.6 million for 1996-97(Sidat 1997d). The flat tariff rates are Rs. 30 per month for domestic and Rs. 250 for commercial and government connections prevailed for all water supply schemes of the province. For the fiscal year 1996-97 the share of PHED for running the 701 water supply schemes was Rs. 337.472 million. Out of which Rs. 181.872 million (53.9%) for staff salaries and allowances. The major portion of the non development budget earmarked for O&M of water supply schemes whereas no direct revenue from these schemes is budgeted. The O&M costs of 1996-97 are summarized in Table 4, the costs are prior to the implementation of new schemes. No of connections are the aggregate of domestic plus government plus commercial registered connections. The scheme-wise O&M cost comparison shaos that salaries range from 29-60%, POL form 1-12%, whereas repairs and spares from 1025% of the total O&M costs. Kharan, Kuchlak and Mastung WSS are considered as complex schemes. The more a scheme is complex the higher is electricity cost. In Ziarat, electricity constitutes 3% of the total O&M cost since it is a simple scheme, based on gravity as well as pumping. The total cost per connection of existing water supply system ranges from Rs. 1070-3173. Average cost per connection per month varies from Rs. 89-264. To enhance the cost recovery mechanism and for institutional strengthening of PHED different studies were carried out and a number of propsals were recommended. (e.g. NESPAK 1989, Wardrop-Acres 1994), but no positive results were achieved due to one or the other reason. The tariff analysis of existing system shows that the recovery percentage ranges from 11-34%. In order to develop a financially sustainable operation, it is necessary that the water tariff be increased to a level which is sufficient to recover operating costs. The water tariff collection efficiency is also very poor which increases the shortfall. Cost recovery may also be increased by savings in electricity cost by improving tubewel efficiency, reduction in establishment costs, increasing in revenue by the registration of unregistered connections and by improving water tariff collection efficiency. The water tariff for each scheme would be different depending on the cost of the scheme, population, number of households, O&M costs, capacity and willingness to pay etc.

FINANCIAL ANALYSIS OF NEW SCHEMES

The financial model of the new schemes feasibility were developed by confiscating the financial figures of the existing schemes and by adding the incremental costs (Sidat 1997d). In new schemes almost all the physical structures of the existing schemes will be replaced. Financially the depreciation of the new schemes will be considered from the year of replacement i.e. 2000-01 while that of the old equipment will be ignored in the projections of the new schemes. Domestic connections have been assumed to increase annually by 4.7% which is the same as the population growth rate. For revenue calculations it has been assumed that the facilities and level of service will be improved in accordance with the increase in population. This increase is 30% for the year 1999 and 2000 to allow for the surge in connections upon commissioning of the new schemes. Registration of the un-registered connections are assumed to be made at a pace of 10 % per annum. The water tariff per month was Rs. 30 per month from the year 1992-93 to 1996-97. In the year 1997-98 an increase to Rs. 50/month for domestic connections and Rs. 250/month for government and commercial connections has been levied. Thereafter, large increases have been assumed in the tariff over the next couple of years when the level of service is likely to be enhanced. The level of increase has been kept so as to give a break even result on a cash flow basis by the year 2010 which is the time at which the improvement in collection efficiency will have been achieved. Water tariff collection efficiency for domestic connections has been assumed to increase from 35% in the year 1996-97 to a maximum of 70% in the year 2000-2001 and onwards. Financial projections of O&M costs has developed for scheme wise recovery of water tariff. The O&M costs comprise the salaries and wages of staff, electricity, depreciation, repairs, maintenance and POL charges. The projections have been made upto the year 2010 and based on 1996-97 prices, without taking into account the effect of inflation. For the analysis of O&M costs, salaries have been assumed to increase by 5% annually due to annual increments in the pay. Depreciation of the new schemes includes the charges of the civil works, pipelines, electrical and mechanical works on the basis of their estimated useful life. Petrol, oil and lubricants have been assumed to be constant. Repair of the civil works and equipments have been assumed to be 0.2% and 2.0% of capital cost respectively. Electricity has been assumed to

Table 4. Operation and maintenance (O&M) cost analysis of existing water supply schemes

	KHARAN	KUCHLAK	MASTUNG	ZIARAT
No. of conncections	1362	1853	1168	267
No. of employees	19	16	41	9
Salary cost (Rs. In '000s)	833	541	1446	343
Electricity cost (Rs. In '000s)	1454	1406	1480	18
Repairs & spares (Rs. In '000s)	600	28	341	129
Depreciation (Rs. In '000s)	531	294	648	130
POL (Rs. In '000s)	30	8	439	31
Total cost, exclusive of depreciation	**2917**	**1983**	**3706**	**520**
Connections / employee	72	116	28	30
Electricity cost per connection (Rs.)	1068	759	1267	67
Total cost per connection (Rs.)	**2141**	**1070**	**3173**	**1948**
Cost per connection per month (Rs.)	**179**	**89**	**264**	**162**
Percentage of cost recovery	16.8	33.8	11.4	18.5

increase by 5% per annum in real terms and increase in the number of tubewell due to projected increase in the number of connections. Tariff analysis for only domestic connections on cash flow basis are given in Table 5. The analyses reflect a difference between cost per connection per month (2010) and breakeven at 100% collection efficiency. It is because of cennection fee of new domestic households. Breakeven tariff is a combination of domestic tariff and connection fee. The collection efficiency at 10%, 70%, and 100% indicate the trends of tariff and their comparison with cost per connection. The analyses show that collection efficiency is a major variable in determining the breakeven tariff. The analyses represent that different types of schemes have different costs per connection and every scheme requires a different cost recovery mechanisms.

The water tariff projections were prepared to arrive at the break even tariffs for recovery of O&M costs (Sidat 1997a, 1998), and to assess whether cost recovery can be made at the break even tariff given the affordability and willingness to pay. The projections of water tariff are given in Table 6. The projections indicate that domestic water tariff has been increased rapidly in the year in which the new schemes have to be implemented with the objective of achieving break even by the year 2009-10 insofar as recovery of O&M costs are concerned. The break even is due to the increase of water tariff which

Table 5. Tariff analysis for domestic connections on cashflow basis.

Scheme	Number of connections		Allocated O&M cost (Rs. in '000)		Cost per connection per month (Rs.)		Breakeven tariff per month in year 2000 (collection efficiency)		
	1997	2010	1997	2010	1997	2010	10%	70%	100%
Kharan	1344	3749	2878	4914	179	109	1066	118	107
Kuchlak	1827	4170	1955	3678	89	74	715	79	71
Mastung	1049	5517	3328	6156	264	93	879	100	90
Ziarat	99	471	193	607	162	107	1042	116	104

Table 6. Water tariff projections for operation and maintenance of new water supply schemes. Numbers in parenthesis, e.g (2), are the surplus amounts.

Year	KHARAN Tariff per month (Rs.)	KHARAN Deficit (Rs.in 000) cash flow	KHARAN Deficit as % of revenue	KUCHLAK Tariff per month (Rs.)	KUCHLAK Deficit (Rs.in 000) cash flow	KUCHLAK Deficit as % of revenue	MASTUNG Tariff per month (Rs.)	MASTUNG Deficit (Rs.in 000) cash flow	MASTUNG Deficit as % of revenue	ZIARAT Tariff per month (Rs.)	ZIARAT Deficit (Rs.in 000) cash flow	ZIARAT Deficit as % of revenue
1997	30	2604	833	30	853	73	30	3288	786.6	30	366	431.2
1998	50	2429	403	50	1284	161	50	2974	338.6	50	239	105.9
1999	75	1939	102	60	1257	57	50	2317	112.1	53	122	34.3
2000	84	906	29	63	266	8	51	1457	47.2	57	84	20.3
2001	95	1292	45	66	1227	48	51	2218	88.9	61	298	45.9
2002	107	914	27	69	1157	41	51	2083	74.2	65	281	39.8
2003	107	860	24	72	1088	35	52	1938	61.7	69	390	60.8
2004	107	790	20	75	998	30	52	1772	50.6	74	363	50.7
2005	107	712	17	79	896	24	52	1586	40.7	79	328	41.1
2006	107	619	14	82	769	19	53	1362	31.4	85	286	32
2007	107	505	11	86	623	14	53	1105	22.9	91	233	23.3
2008	107	368	7	90	446	9	53	795	14.8	97	169	15.2
2009	107	202	4	94	241	5	54	433	7.2	104	92	7.3
2010	107	1	0	98	(5)	0	54	(2)	0	111	(1)	0

seems to be sustainable after expected improvements in service levels of new schemes. The maximum tariff level which is sustainable in real terms over the next ten years varies from scheme to scheme and is around Rs. 54-111 per month in terms of 1995-97 prices. The monthly tariff rates from 1997 to 2010 for Kharan township range from Rs. 30 to 107, for Kuchlak Rs 30 to 98, for Mastung Rs. 30 to 54, and for Ziarat Rs. 30 to 111. The calculated tariff rates are within the affordability limits and 70-97% households are willing to pay the increased amount.

CONCLUSION AND RECOMMENDATIONS

The results of the revenue, O&M costs and break even tariff projections indicate that the new township WSS of Kharan, Kuchlak, Mastung and Ziarat are economically viable.

For sustainability of the new schemes, the following credible measures are recommended:

1. Proper legislation is indispensable for PHED to enforce and collect water tariff, disconnection, imposition of fines etc.

2. Institutional arrangements should be made for billing and tariff collection system and enforced contemporaneously either through private contractors or trained PHED staff.

3. Revenue generated from one scheme should be disbursed unconditionally on the same scheme for the improvement of supply system.

4. O&M system of new schemes should ameliorate, otherwise the water tariff collection efficiency may drop if the improved level of service is not maintained consistently.

5. Registration of unregistered connections and new connection policy should be effortless and tolerable for the consumers.

6. Social mobilization should be consolidated with the technical intricacy in the implementation and management of new schemes.

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PETROCHEMICAL ACCOUNT OF VARIOUS TYPES OF ROCKS OF TIMARGARA AND SAMERBAGH AREAS OF SOUTHERN DIR, KOHISTAN ARC TERRANE, NORTHERN PAKISTAN

MOHAMMAD TAHIR SHAH[1], ALI SERWAR[2], MOHAMMAD UMAR KHAN KHATTAK[1] AND SHAMIM AHMAD SIDDIQUI[3]

[1] National Centre of Excellence in Geology, University of Peshawar, Peshawar.
[2] Sarhad Development Authority, Peshawar.
[3] National Centre of Excellence in Mineralogy, University of Balochistan, Quetta.

ABSTRACT

The study area (Timargara and Samerbagh) is a part of the Kohistan arc terrane and is located in the southern Dir district. It is mainly composed of amphibolites, metadiorites, metaquartz-diorites, and metagabbro-norites, with lesser amount of metagranodiorite, metagranites, tonalites, ultramafites, hornbledites and metavolcanics. The field, petrographic and geochemical studies of metadiorites, metaquartz-diorite, metagranodiorites, metagabbro-norites, and metagra-nites of the area suggest that these rocks are comagmatic. The fractionation of 1) clinopyroxene +plagio-clase+orthopyroxene ñ olivine and 2) plagioclase+k-feldspar+quartz has played a major role in the formation of basic rocks and intermediate to acidic rocks respectively. These rocks have close affinity to the calc-alkaline rocks and are considered to be generated by the fractional crystalliza-tion of basaltic magma in subduction related environment at the base of the Kohistan island arc.

INTRODUCTION

The Timergara-Samerbagh area of Dir district, northern Pakistan (Fig. 1) is a part of the Kohistan island arc and covers about 900 km^2. Preliminary geological work has been carried out in Tora Tiga, Dir, Barwa, Kambat and Usheri areas (Ahmad 1962; Banaras and Ghani 1982; Butt et al.; 1980; Chaudhry et al. 1974; Hamidullah et al. 1990, Hyden 1915; Jan et al. 1983; Shah 1991, Shah et al. 1994; Sullivan et al. 1992; Tahirkheli 1979). Kakar et. al. (1971) presented a geological map of Jandul valley and classified the rocks, from young to old, into hornblendites, pyroxenites, peridotites, diorites and amphibolites. Chaudhry et al. (1974) and Butt et al. (1980) prepared a geological map of Timargara and surrounding areas. In the present paper we propose slightly different nomenclature for the igneous rock-types based on their petrographic, geochemical and field features.

GEOLOGY OF THE AREA

The area comprises metasedimentary, plutonic and volcanic rocks which probably represent part of the north-western extension of the southern Kamila amphibolite belt of Jan et al. (1979) and Jan (1988). We have classified the dominant rock units into amphibolites, metadiorites, metaquartz-diorites, and metagabbro-norites and the subordinate rock types

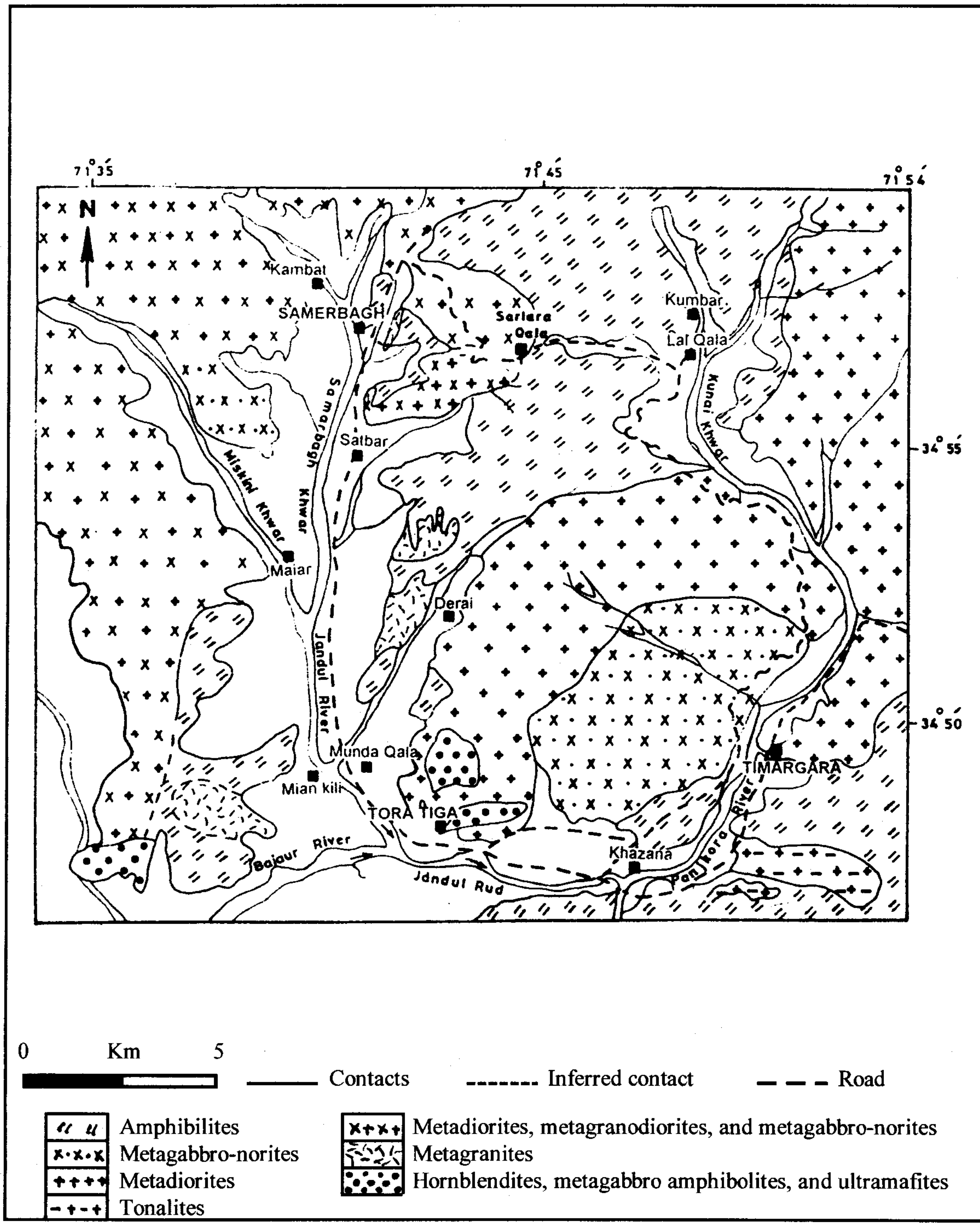

Figure 1. Geological map of the Timergara and Samarbagh areas, Distric Dir, N.W.F.P., Pakistan (Modified after Kakar et al. 1971; Chaudhry et al. 1974 and Butt et al. 1981).

into metagranodiorites, metagranites, tonali-tes, ultramafites, hornblendites and metavolcanics.

AMPHIBOLITES

On the basis of field observations amphibolites of the area are distinguished as banded amphibolites (para-amphibolites), mainly exposed in the southern and northern part with minor sheets in central part of the studied area (Fig. 1). These amphibolites are banded, strongly deformed and foliated, and generally strike from E-W in the south to NE in the north. Chaudhry et al. (1974) named similar amphibolites in other parts of Dir district as southern Dir amphibolites. The alternate dark and light bands are mainly due to different proportion of plagioclase and quartz, with minor pink garnet concentrated in the light color bands. At places the bands of cherty material up to 2 inches thick are present. The amphibolites are intruded by dioritic, aplitic and mafic dikes, some in the form of small plugs that contain xenoliths of banded amphibolite. Bedded quartzites up to 2m thick and more than 20 meter long are locally exposed within this unit at various places.

The banded amphibolites are strongly sheared and folded and faulted. Locally, microfolds of recumbent and chevron type found within the amphibolites indicate thrust sense of movement (such as near Sarlara Qala, probably indicating the existence of thrust fault in the vicinity). Isolated outcrops of banded amphibolites occur in the north-east of Samerbagh (Fig. 1). These outcrops are in contact with porphyritic augen gneiss. The contact relations of the augen gneiss with the amphibolite are not known. The amphibolites are cut by hornblende pegmatite veins, which are probably the latest phase of intrusion in the rocks.

METADIORITE, METAQUARTZ-DIORITE AND METAGRANO-DIORITE

These rocks cover most of the study area (Fig.1). Those exposed near Samerbagh in Jandul valley have a complex nature due to the associated metagabbro-norites, hence are shown as single unit in figure 1. Two varieties of meta-diorites, leuco and mela, can be recognized in the field (containing various contents of pyroxenes). Both the varieties are medium- to course-grained, highly deformed and sheared having well developed foliation, and are cut by quartz veins.

A fine-to medium-grained variety, having unique banded appearance of alternate mafic- and felsic-rich phases is exposed in the south-east of Samerbagh and north-east of Satbar (Fig.1). These rocks are deformed and display microfolding. The banding may either be primary igneous layering or may have formed due to metamorphic segregation. These rocks are intruded by ~cm long hornblende-bearing pegmatitic veins, both concordant and disconcordant to the layering/banding. Iron-bearing phase (probably pyrite) is disseminated through out the rock which imparts reddish brown weathered surface due to oxidation. These rocks are extensively weatherd and granulated along faults.

METAGABBRO-NORITES

These were previously named as norites by Kakar et al. (1971), Chaudhry et al. (1974) and Butt et al. (1980). The metagabbro-norites are medium- to course-grained, contain well-developed fabrics, and are foliated, trending NE-SW, parallel to the regional trend of the southern (Kamila) amphibolite belt of Tahirkheli (1979). Locally the development of metamorphic hornblende is extensive. These rocks are intruded by hornblendite, aplite and micro-dioritic dikes and quartz veins. Apparently, maximum weathering and alteration has taken place in the vicinity of intrusions. Shearing is common along local faults. The shear zones generally show a network of microveins of epidote, probably forming mainly at the expense of feldspars. These shear zones are cut by quartz veins. Occasionally, dark patches (about less than 30cm thick) containing >90% amphibole occur within the metagabbro-norites.

METAGRANITES

These are light colored, coarse-grained granites with well-developed fabrics, locally intensively faulted and folded, and are cut by quartz and pegmatitic veins.

METAVOLCANICS

Patches of meta-volcanic rocks (now greenschists) and meta-volcanic porphyry dikes are common in the banded amphibolites. These meta-volcanics display foliation and are intruded by dioritic dikes. The dioritic dikes have chilling and alteration effects along their margins within the meta-volcanics and contain xenoliths of meta-volcanics in them. The meta-volcanics mainly contain epidote and chlorite. Occasionally, epidotization is so intense that the parent rock attains a patchy appearance. Micro veins containing limonite, chalcopyrite and pyrite also intrude the meta-volcanics.

HORNBLENDITE, METAGABBRO, AMPHIBOLITE AND ULTRAMAFITE OF THE TORA TIGA COMPLEX

The Tora Tiga complex is exposed in the south-central part of the study area (Fig. 1; Banaras and Ghani 1982; Jan and Tahirkheli 1990). This complex is mainly composed of amphibolites, metagabbros, ultramafics, hornblendites and minor dikes and veins. The amphibolites are banded, fine- to medium-grained in texture and similar in appearance to the banded amphibolites of the so-called southern amphibolites of Jan et al. (1979). Some of the amphibolite contains garnet porphyroblasts, is massive and texturally appears metagabbroic. The metagabbros, that occur in the southern part of the complex, are medium- to course-grained, homogeneous (massive) and gneissose. The metagabbros are cut by dikelets and veins (as well as patches) of hornblendite. The metagabbros grade into banded amphibolites in the central part of the complex. The contact of the metagabbros with the lower lying ultramafics is sharp and locally sheared. The banded amphibolites form linear belts between the metagabbros and the garnet-amphibolites.

Two main hornblendite exposures occur at Tora Tiga and Hashim village while several other bodies of variable size are present in other parts of the complex. The hornblendites have sharp contacts with metagabbro and amhibolites and a gradational contact with the ultramafic rocks. The hornblendites are characterized by a heterogeneous textures. The ultramafics consist of olivine ultramafites and pyroxene ultramafites. The olivine-ultramafites include peridotite, dunite and serpentinite. These rocks occur as elongated to subcircular bodies or small irregular patches. The pyroxene-ultramafites are the second most abundant ultramafites and occur as east-west trending bodies. These are hard and massive rocks, generally medium-grained, though coarse- and fine-grained varieties are also found locally. Felsic and pegmatitic veins and dikes are common throughout the Tora Tiga Complex.

PETROGRAPHY

Metadiorite, meta-quartz-diorite and metagranodiorite: These rocks are generally massive and medium- to coarse-grained but locally are banded and mylonitized. These are dark gray to greenish gray on fresh surface and dirty dark brown on weathered surface. Petrographically, these contain plagioclase (30-60%), alkali-feldspar (1-20%), hornblende (5-30%), pyroxene (up to 5%) and biotite (up to 3%) with varying amounts of quartz (up to 25%). The accessory minerals include sphene, apatite, rutile, prehnite and ore. Kaolinite, serecite, epidote, chlorite muscovite and tremolite/actinolite occur as alteration products. These rocks generally have hypidiomorphic texture, however, poikilitic and gneisose textures with well-developed fabrics are common. The metadiorites are distinguished into leuco- and mela-varieties based on the relative proportion of hornblende and felsic minerals. Along shear zones the mela-diorites are sheared so that they appear texturally and mineralogically like amphibolites.

Plagioclase (An_{35-45}) generally occurs as anhedral to subhedral bent grains with pressure shadows. It is often partially or completely altered to serecite, epidote, carbonates and kaolinite. In case of extensive alteration both pseudomorphs and relics of plagioclase are well-preserved. The alkali-feldspar (mainly orthoclase) is the main constituent of metagranodiorite and usually shows partial alteration to kaolinite and serecite. Hornblende generally occurs as prismatic light-green to dark -green homogeneously pleochroic phase. It sometimes poikilitically encloses quartz and ore which exhibits pepper-mesh/sieve-type texture. This could be related to the release of silica during transformation of pyroxenes to hornblende. No relic primary pyroxenes, however, have been found. Chorite, locally, occurs as core material to hornblende. This could be attributed to the progressive metamorphism from greenschist to amphibolite facies along shear zones. During this transformation the mafic phase (probably pyroxene) may have been altered to chlorite which in turn has been replaced by hornblende. Clinopyroxene (augite to diopsidic-augite) is, however, a common mineral phase in some of the metadiorites exposed near Semerbagh (Fig. 1). It is occasionally replaced by hornblende along the margins and fractures.

Quartz in metadiorite occurs as rounded to subrounded inclusions within hornblende while in meta-quartz-diorite and metagranodiorite it displays anhedral medium-grained grains, having undulose extinction. Biotite generally occurs as flakes of light-to dark-brown colour with greenish tint of chloritization. Epidote usually occurs as small granular aggregates, however, few prismatic grains of epidote (zoisite and clinozoisite) also occur at places. Tremolite/actinolite in the form of bundles occur in association with hornblende. Garnet, as colourless small granules, adjacent to opaque phases are common within metagranodiorites.

Metagabbro-norites: These are medium- to course-grained and massive, and display dark-grey on fresh and light to yellowish-brown on weathered surface. Petrographically they contain plagioclase (40-60%), hornblende (2-40%), clinopyroxene (10-20%), and orthopyroxene (5-15%), with minor amounts of quartz (tr-2%) and biotite. Sphene, apatite and ore occur as accessories. Kaolinite, sericite, epidote, carbonates, chlorite and serpentine occur as alteration products. These rocks generally have hypidiomorphic texture, however, poikilitic and gneissose textures are also common.

Plagioclase (An_{45-60}) occurs as anhedral to subhedral grains having elongation in the fabric direction. Near Timergara the plagioclase is commonly altered to epidote, carbonates and a kind of dirty mass, but near Samerbagh, plagioclase is fresh. Hornblende is the major constituent after plagioclase in metagabbro-norites near Timergara. Locally, hornblende content exceeds that of plagioclase. Hornblende is light-green to green and generally occurs as prismatic grains, however, hornblende surrounding pyroxene is not uncommon. Occasionally, hornblende is sieved with rounded to subrounded inclusions of quartz. This quartz probably formed due to release of excess silica during the transformation of pyroxene to hornblende, suggesting metamorphic nature of the hornblende.

Clinopyroxene is medium- to coarse-grained, rounded to subhedral, generally colourless and augite or diopsidic-augite in composition. Occasionally, clinopyroxene is corroded along margins; exhibits parallel parting and exsolution lamellae. It also has exsolution of hematite and is replaced along margins and fractures by hornblende. Orthopyroxene (hypersthene) occurs as anhedral to subhedral medium- to coarse-grained. Generally the orthopyroxene is partially or completely replaced by chlorite and serpentine along margins and fractures. The chlorite and serpentine may in turn be replaced by hornblende, such as near Timergara, forming a corona structure. In a well-preserved corona, relic pyroxene at the core is rimmed by chlorite and serpentine, which is then encircled by biotite. This reaction occurs in close association with opaque phases. Excess silica released during this process of corona formation occurs as tiny grains of quartz within the chlorite+serpentine mass.

Triple point grain boundaries and polygonal grain growths are common, especially in the case of smaller pyroxene grains. The minerals are strained, having non-uniform extinction, micro-fractures and, in some cases, the grains are bent and show pressure shadows. The textural behaviour of pyroxenes-chlorite+serpentine-hornblende coronas suggests that the primary orthopyroxenes and to some extent clinopyroxenes have been replaced by hornblende with an intermediate phase of chlorite and serpentine during progressive metamorphism. Locally, tremolite/actinolite also occurs as alteration product of orthopyroxene in metagabbro-norites. Biotite has light- to dark-brown flakes with occasional chloritic tint. Apparently, metamorphism is more pronounced in metagabbro-norites near Timergara (Fig. 1) relative to those near Samerbagh. The metagabbro-norite near Timergara have greater abundance of hornblende and are more altered.

METAGRANITES

The metagranite is generally coarse-grained and foliated, trending parallel to the regional foliation. Petrographically, alkali feldspar is 30-40%, plagioclase is 20-30%, quartz is 25-35% and hornblende varies from traces to 5%. Garnet, sphene, biotite, muscovite apatite, and leucoxene occur as accessories. Kaolinite, sericite, carbonates and epidote occur as alteration products. Alkali feldspar is mainly orthoclase and microcline while plagioclase is of albite-oligoclase composition. Both the phases usually exhibit partial alteration to kaolinite, sericite, carbonates and epidote. Unaltered grains of feldspar show pressure shadows at places. Quartz is generally anhedral with typical undulose extinction. Quartz also occurs as rounded to subrounded inclusions within hornblende and feldspar. Hornblende is prismatic light-green to bluish-green. Garnet, biotite and muscovite are rare, but if present, are found in association with hornblende and opaque phases. Garnet occurs as colourless, rounded to subrouded, fractured grains. Biotite and muscovite occur as small flakes. Epidote occurs as granular aggregates, probably representing alteration product of feldspar.

WHOLE ROCK GEOCHEMISTRY

Twenty metagabbros and metagabbro-norites, fifteen metadiorite/quartz diorite, three metagranodiorite and five metagranites have been analyzed for major and a few trace elements. SiO_2, Al_2O_3, TiO_2 and P_2O_5 were determined by coloremitric method while rest of the major oxides and trace elements were determined by using flame atomic absorption spectrophotometer. Gold, after extraction with MIBK, was determined by flameless atomic absorption equipped with graphite furnace. Loss on ignition (LOI) was performed in duplicate by heating about 2g sample at 950°C for more than four hours. All these analyses were performed in the geochemistry laboratory of the National Centre of Excellence in Geology, University of Peshawar. Major and trace element chemistry and CIPW norms are presented in Table 1.

The rocks of the studied area when plotted in the classification scheme (Fig. 2) of Cox et al., (1979) most of the gabbros, gabbro-norites and diorite/quartz diorite plot in the overlapping fields of gabbro and diorite. Granodiorites take the position in the field of quartz diorite / granodiorite. On the other hand the granitic rocks, are plotted out side but very close to the granite field in this diagram (Fig. 2).

MAJOR ELEMENTS

Gabbros and gabbro-norites have SiO_2: 51.42-52.67 wt%, Al_2O_3: 16.23-17.98 wt% TiO_2 0.45-1.28 wt%, Fe_2O_3: 7.18-9.08 wt%, MgO: 5-7 wt%, CaO: 9.31-10.45 wt%, Na_2O: 2.50-2.98 wt%, and K_2O: 0.18-0.66 wt% (Table 1).These rocks are quartz normative with variable amount of normative quartz (0.16 to 5.40%). These rocks have normative An:31.12-37.96%, Ab:21.68-25.56%, Or:1.09-4.02%, Di:9.32-14.27%, Hy:17.58-21.96%, Mt:1.30-1.62%, Il:0.91-2.50% and Ap: 0.18-1.20%.

Diorites, quartz diorites and granodiorites are having SiO_2 from 54.12 to 56.45%, TiO_2 from 0.78 to 1.70%, Al_2O_3 from 15.98 to 17.34%, Fe_2O_3 from 7.12 to 8.43%, MgO from 3.05 to 5.97%, CaO from 6.56 to 8.95%, Na_2O from 3.02 to 3.50%, K_2O from 0.67 to 1.12% and P_2O_5 from 0.13 to 0.41%. These

Table 1. Major and trace elements along with C.I.P.W norms of various rocks of Timargara and Samerbagh areas,southern Dir. TMG = samples from Timurgara area.SMR = samples from Samerbagh area.

	Metadiorite and metaquartz-diorite								Metagabbro-norites								Metagranodiorotes			Metagranites				
S.No.	TMG-1	TMG-3	TMG-4	TMG-5	TMG-6	TMG-114	TMG-115	TMG-117	TMG-28	TMG-29	TMG-30	TMG-31	TMG-33	TMG-35	SMR-37	SMR-38	SMR-24	SMR-25	SMR-26	SM R-99	SMR-103	SMR-104	SMR-108	SMR-109
Major elements in percent																								
SiO_2	54.12	53.58	54.76	54.50	56.45	55.23	55.34	54.34	52.67	52.32	51.23	51.42	52.30	52.12	52.67	52.54	65.45	65.87	64.87	72.89	73.56	73.76	74.32	74.23
TiO_2	0.81	0.87	0.82	0.80	0.82	1.11	0.78	1.25	0.86	0.46	0.54	0.80	0.83	0.67	1.28	1.02	0.73	0.79	0.69	0.88	0.61	0.39	0.26	0.75
Al_2O_3	16.54	16.34	16.67	16.12	16.23	16.25	17.34	16.12	16.23	17.42	16.98	17.34	17.98	17.87	17.12	16.78	15.78	15.34	16.56	13.12	13.67	13.23	13.78	13.03
Fe_2O_3	7.97	7.86	7.73	8.43	7.63	8.04	7.38	7.23	7.39	7.18	7.98	7.18	7.16	7.59	7.75	9.08	4.98	4.63	5.34	3.18	2.57	2.08	2.85	2.75
MnO	0.13	0.14	0.15	0.19	0.12	0.16	0.17	0.20	0.14	0.14	0.16	0.15	0.14	0.13	0.15	0.15	0.07	0.04	0.02	0.10	0.02	0.03	0.02	0.05
MgO	5.56	5.97	5.67	4.75	3.05	4.08	4.46	5.55	5.93	6.01	6.43	6.13	5.85	5.45	5.66	5.89	2.45	2.32	2.87	0.95	0.68	0.66	0.46	0.48
CaO	8.12	8.43	8.43	6.56	7.15	8.95	8.59	8.45	9.56	9.67	10.12	10.13	9.56	9.31	9.65	9.87	5.51	5.34	5.63	2.56	2.22	2.12	2.15	2.11
Na_2O	3.32	3.02	3.42	3.12	3.50	3.25	3.28	3.02	2.79	2.86	2.78	2.58	2.84	2.89	2.75	2.98	3.81	3.92	3.98	3.34	3.45	3.56	3.73	3.74
K_2O	0.83	0.72	0.83	0.95	1.12	0.88	0.83	0.75	0.56	0.65	0.38	0.41	0.58	0.59	0.66	0.59	0.90	0.98	0.95	2.65	2.78	2.80	2.89	2.88
P_2O_5	0.29	0.36	0.13	0.27	0.07	0.40	0.33	0.29	0.28	0.33	0.53	0.25	0.16	0.12	0.24	0.47	0.20	0.19	0.02	0.17	0.16	0.17	0.00	0.19
LOI	2.05	1.24	1.46	3.49	1.89	0.40	1.08	2.46	2.37	2.45	3.37	2.19	1.86	2.49	1.67	0.34	1.21	0.44	0.42	0.32	0.30	0.21	0.12	0.13
Total	99.74	98.53	100.07	99.18	98.03	98.75	99.58	99.66	98.78	99.49	100.50	98.58	99.26	99.23	99.60	99.71	101.09	99.86	101.35	100.1	100.02	99.01	100.58	100.34
Trace elements in ppm (Au in ppb)																								
Zn	68.00	78.00	63.00	67.00	51.00	60.00	61.00	95.00	67.00	69.00	62.00	71.00	78.00	68.00	75.00	65.00	43.00	30.00	15.00	29.00	22.00	26.00	15.00	16.00
Pb	47.00	44.00	46.00	35.00	32.00	32.00	30.00	39.00	31.00	32.00	41.00	52.00	53.00	43.00	40.00	36.00	41.00	40.00	35.00	22.00	31.00	42.00	33.00	29.00
Cu	44.00	44.00	104.00	59.00	86.00	70.00	48.00	56.00	46.00	73.00	54.00	64.00	42.00	45.00	77.00	75.00	52.00	56.00	44.00	38.00	39.00	43.00	50.00	41.00
Ni	68.00	54.00	52.00	32.00	30.00	24.00	38.00	35.00	52.00	49.00	77.00	51.00	41.00	59.00	92.00	86.00	16.00	15.00	12.00	12.00	17.00	15.00	14.00	13.00
Cr	56.00	55.00	61.00	45.00	32.00	34.00	43.00	52.00	69.00	79.00	114.00	84.00	62.00	56.00	105.00	102.00	24.00	13.00	8.00	14.00	12.00	12.00	13.00	15.00
Co	63.00	63.00	59.00	65.00	63.00	63.00	58.00	61.00	58.00	62.00	61.00	65.00	64.00	47.00	68.00	67.00	71.00	93.00	56.00	57.00	73.00	62.00	62.00	66.00
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Au	4.00	7.00	7.00	9.00	3.00	5.00	8.00	6.00	0.00	0.00	0.00	4.00	6.00	3.00	6.00	7.00	3.00	4.00	0.00	2.00	4.00	5.00	2.00	0.00
C.I.P.W. norms																								
Q	4.89	5.57	4.32	8.93	10.66	8.04	7.35	7.56	5.40	3.27	2.38	4.05	3.65	3.73	5.00	2.83	23.20	23.84	19.73	36.03	36.97	37.72	34.56	35.68
Or	5.07	4.42	5.02	5.93	6.95	5.34	5.02	4.60	3.46	3.99	2.33	2.54	3.55	3.64	4.02	3.55	5.36	5.86	5.60	15.68	16.45	16.57	17.09	17.05
Ab	28.97	26.46	29.55	27.81	31.02	28.17	28.37	26.47	24.66	25.11	24.41	22.80	24.83	25.45	23.93	25.60	32.41	33.49	33.51	28.23	29.16	30.09	31.52	31.62
An	28.64	29.92	28.26	28.62	26.45	27.81	30.80	29.22	31.44	34.00	33.96	36.05	35.75	35.43	33.34	31.12	23.41	21.56	24.38	11.60	9.98	9.42	10.67	9.24
Di	9.00	8.97	11.13	3.18	8.55	12.42	8.72	10.00	13.22	11.08	11.91	12.02	9.96	9.72	11.69	12.72	2.31	3.27	2.73	0.49	1.32	0.88	0.59	0.36
Hy	19.74	20.69	18.45	21.73	13.17	13.70	16.15	17.72	18.11	19.59	21.28	19.06	18.97	19.04	17.58	19.55	10.59	9.22	11.76	5.29	4.11	3.80	4.51	3.67
Mt	1.45	1.43	1.39	1.57	1.41	1.45	1.33	1.32	1.36	1.31	1.46	1.32	1.30	1.39	1.41	1.62	0.88	0.82	0.94	0.62	0.50	0.41	0.56	0.54
Il	1.59	1.71	1.59	1.60	1.63	2.16	1.52	2.46	1.71	0.91	1.07	1.59	1.63	1.33	2.50	1.97	1.40	1.52	1.31	1.67	1.16	0.74	0.49	1.43
Ap	0.65	0.81	0.29	0.62	0.16	0.90	0.74	0.66	0.64	0.75	1.20	0.57	0.36	0.27	0.54	1.04	0.44	0.42	0.04	0.37	0.35	0.37	0.00	0.41
Na_2O/CaO																				1.30	1.55	1.68	1.73	1.77
Na_2O/K_2O																				1.26	1.24	1.27	1.29	1.30
$MgO/FeO_{(t)}$																				0.30	0.26	0.32	0.16	0.17
MgO/MnO																				9.50	34.00	22.00	23.00	9.60
$Al_2O_3/(CaO+Na_2O+K_2O)$ mole																				1.01	1.07	1.04	1.04	0.99
$Al_2O_3/(Na_2O+K_2O)$ mole																				1.57	1.57	1.49	1.49	1.40

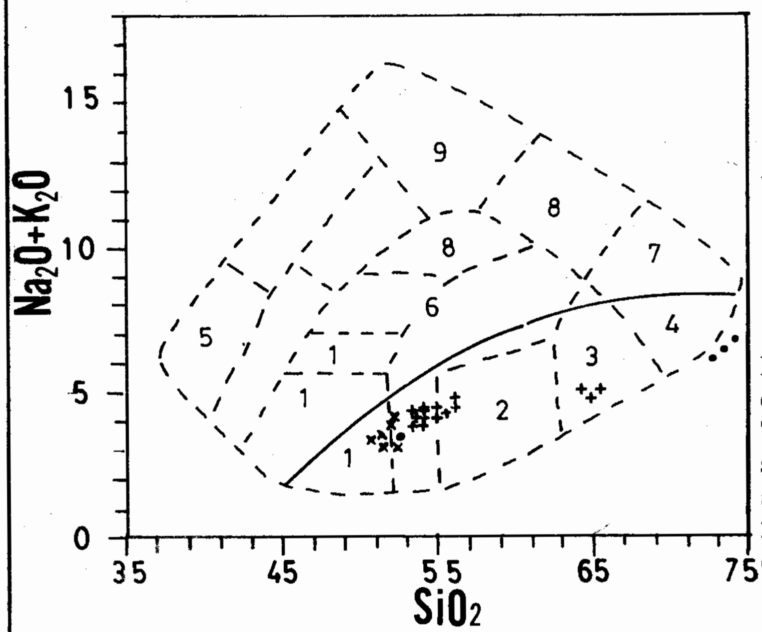

Figure 2. Total alkalis Vs silica diagram for the rocks of Timargara and Semerbagh areas, southern Dir. Various fields are after Cox et al. (1979). 1=gabbro, 2=diorite 3=quartz diorite/granodiorite, 4=granite, 5=ijolite, 6= synodiorite, 7=Alkali granite, 8=syenite 9= nepheline syenite.

rocks are generally contain normative quartz (4.32-10.66%), diopside (2.18-12.60) and hypersthene (13.7-21.73%).

In granodiorite, there is very less variation in SiO_2 (64.87-65.87), TiO_2 (0.69-0.79), Al_2O_3 (15.34-16.56), Fe_2O_3 (4.63-5.34), MgO (2.32-2.87), CaO (5.34-5.63), Na_2O (3.81-3.98) and K_2O (0.90-0.98). CIPW norms show that these rocks are having normative quartz in the range of 19.73 to 23.84, Or from 5.36 to 5.86, Ab from 32.41 to 33.51 and An from 21.56 to 24.38. These rocks are Diopside (2.31-2.73) and Hypersthen (9.22-11.76) normative.

Granites of the studied area have SiO_2 in the range of 72.89- 74.34%, TiO_2 is 0.26-0.88%, Al_2O_3 is 13.02-13.78%, Fe_2O_3 is 2.08-3.18%, MgO is 0.46-0.95%, CaO is 2.11-2.56%, Na_2O is 3.34-3.74%, K_2O is 2.65-2.89% and P_2O_5 is 0.00-0.19%. CIPW norms show that these granites have normative Q in the range of 34.56-37.72%, Or from 15.68 to 17.09%, Ab from 28.23 to 31.62, An from 9.24 to 11.60%, C from 0.36 to 1.32%, Hy from 3.67 to 5.29, Mt from 0.41 to 0.62%, Il from 0.49 to 1.67% and Ap up to 0.41% (Table 1). The ratios of Na_2O/CaO, Na_2O/K_2O, $MgO/FeO_{(t)}$ and MgO/MnO varies from 1.30 to 1.77, 1.24 to 1.30, 0.16 to 0.32 and 9 to 34 respectively (Table 1).

Major element oxides of the studied rocks are plotted against the differentiation index (D.I.= normative quartz+albite+orthoclase) of Thornton and Tuttle (1960). In order to establish the correlation between the studied rocks and those of Tora Tiga Complex (Jan et al. 1983; Jan and Tahirkheli 1990), few analyses of the ultramafics and mafic rocks of the later are also plotted.

There is an increase in SiO_2, K2O and Na_2O balanced by a decrease in MgO, CaO, and Fe_2O_3. These trends are smooth and near linear throughout most of the ranges (Fig. 3). A distinct compositional gap in the region 48-58 and 64-80 D.I., probably represent either the sampling gap or real absence of rocks in this composition range. TiO_2 shows a trend which differ markedly from other oxides in that it initially increase with increasing D.I. (Fig. 3) to maximum in the gabbros and gabbro-norites and then become gradually depleted in diorite, granodiorite and granites. This type of pattern is common in rock suites produced by anhydrous fractional crystallization of basic magma controlled by clinopyroxene + plagioclase and olivine removal (Key 1987). If these rocks are considered to be derived from the same magma then the TiO_2 pattern is well explained. There may be early fractionation of TiO_2-poor phases such as two pryoxene which caused enrichment of TiO_2 in the magma. With further fractionation the TiO_2-bearing phases such as titanomagnetite started fractionating with other phases like plagioclase and K-feldspar, thus causes its decline during further fractionation. The decrease in TiO_2 and Fe_2O_3 and increase in SiO_2 with differentiation are considered to be typical of calc-alkaline rocks (Miyashiro 1975).

On the AFM diagram (Fig. 4) the gabbros, gabbro-norites and diorites/quartz diorites plot as

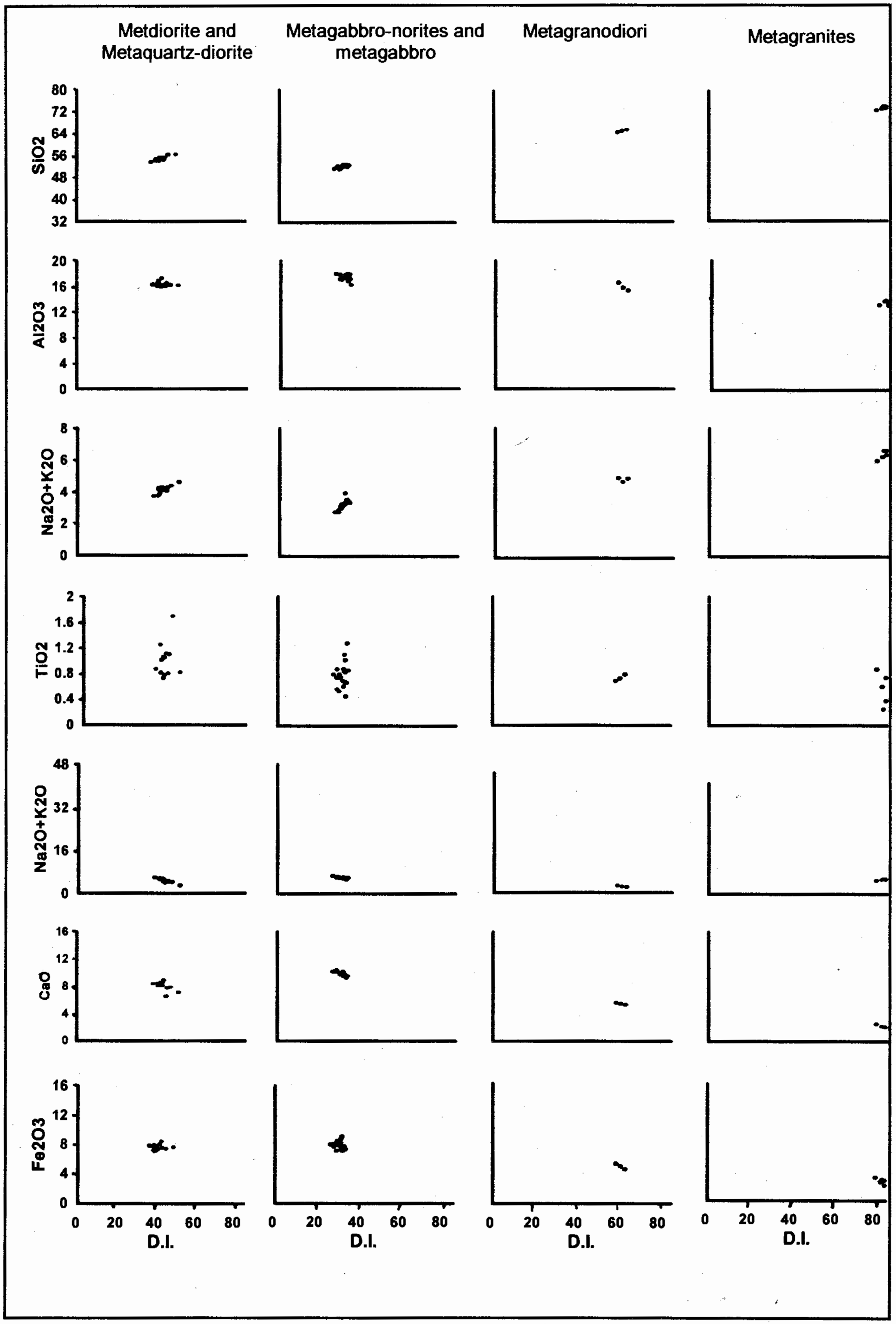

Figure 3. **Oxide VS Differential Index plot for the rocks of Timargara, Semerbagh and Tora Tiga area, southern Dir.**

two separate but continuous groups, although the compositional gap between these units and granodiorites and granites is still evident. The gabbro to granite sequence is typical calc-alkaline. Note that some of the gabbro and gabbro-norite compositions overlap the diorite/quartz diorite in the AFM diagram (Fig. 4) and could be interpreted to follow the early part of calc-alkaline trend. The calc-alkaline nature as depicted by AFM diagram is further confirmed by plotting the studied rock samples in the K-Na-Ca triangle (Fig. 5) leading to a distinction between the calc-alkaline differentiation series and trondhjemitic series (Baker and Arth 1976). The studied rocks follow a calc-alkaline trend and show no affinity with the trondhjemitic trend.

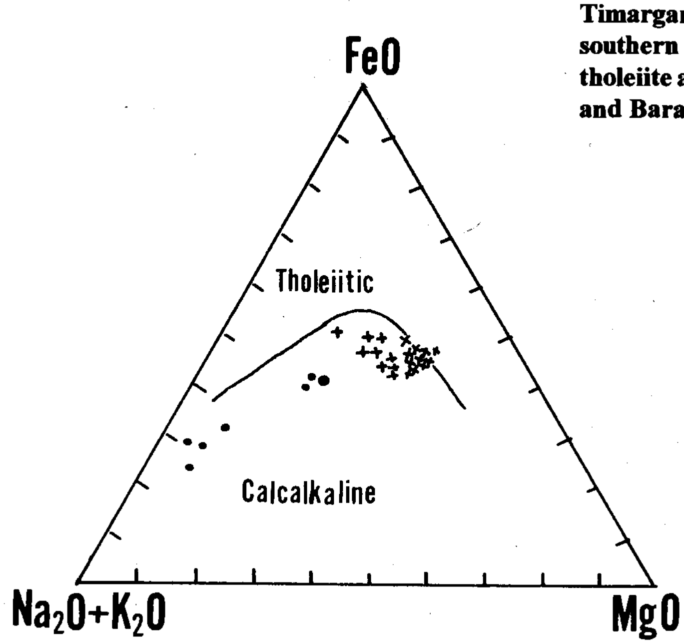

Figure 4. AFM plot for the rocks of Timargara and Sarmerbagh areas, southern Dir. The boundry between tholeiite and calc-alkaline is from irvine and Baragar (1971).

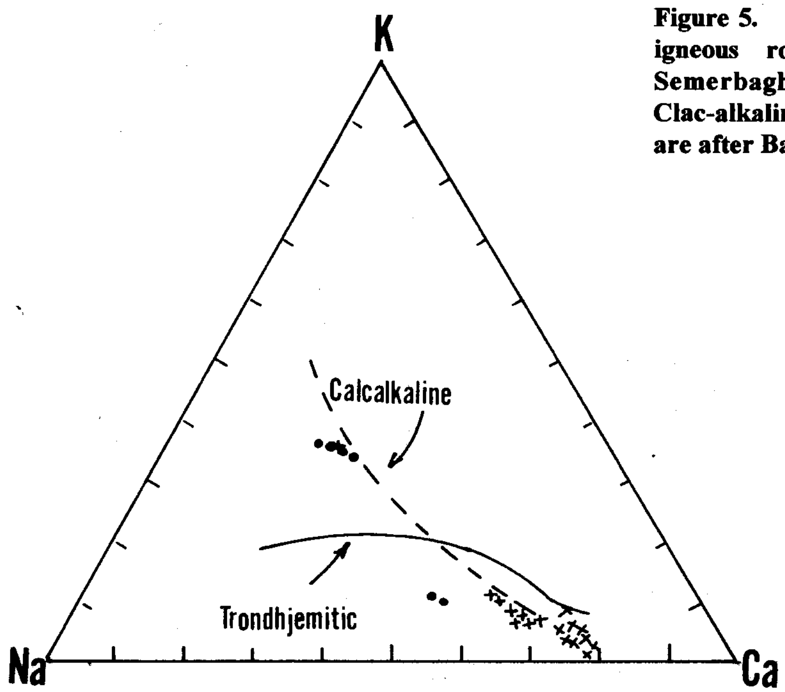

Figure 5. K-Na-Ca diagram for the igneous rocks of Timargara and Semerbagh area, southern Dir. Clac-alkaline and trondhjemitic trends are after Barker and Arth (1976).

TRACE ELEMENTS

Gabbros and gabbro-norites on average have Zn: 69 ppm, Pb: 43 ppm, cu; 57 ppm, Ni: 64 ppm, Cr: 95 ppm, Co: 62 ppm Ag: 0.5 ppm and Au: 5 ppb. In diorites, Zn on average is 71 ppm , Pb is 39 ppm, Cu is 64 ppm, Ni is 44 ppm, Cr is 46 ppm, Ag is 0.5 ppm and Au is 5 ppb. Granodiorites have an average concentration of Zn, Pb, Cu, Ni Cr, Co, Ag and Au as 29 ppm, 35 ppm, 44 ppm, 12 ppm, 8 ppm, 56 ppm, <0.5 ppm and 2 ppb respectively. Granites have average trace element content as Zn: 22 ppm, Pb: 31 ppm, Cu: 42 ppm, Ni: 14 ppm Cr: 13 ppm, Co: 64 ppm, Ag 0.5 ppm and Au: 3 ppb.

The transitional elements Cr, Ni, Zn and Cu behave in similar way in showing a progressive decrease with increasing D.I. (Fig. 6) Although there is greater spread of the data points in the most basic compositions. The Co and Pb show a more or less constant behavior with the increase of D.I. The relative rates of decrease in these metals, especially Ni, Cr, and Zn, is roughly consistent with variation produced by fractional crystallization. Cr and Ni are withdrawn from the magma, especially during the formation of gabbros and gabbro-norites. Cr being preferentially accommodated in cliropyroxene, and Ni in both ortho and cliropyroxene during fractionation. The strong depletion of Cr and Ni in the studied gabbros and gabbro-norites suggest the role of ortho and clrioproxene and ± spinel at low pressure (8 Kbar) (Sivell and Rankin 1993).

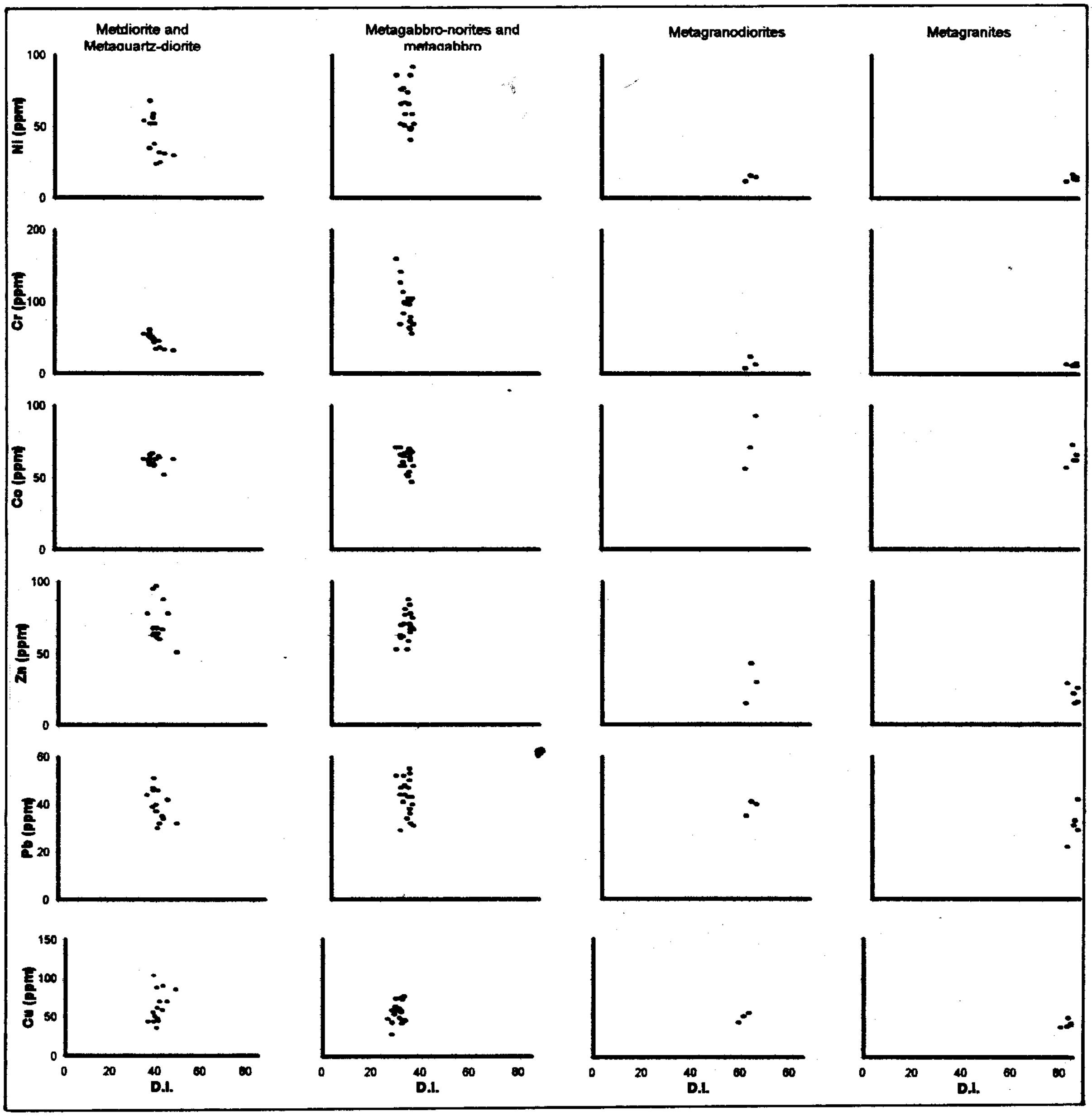

Figure 6. Trace elements Vs Differentiation Index plot for the rocks of Timargara, Semerbagh and Tora Tiga area, southern Dir.

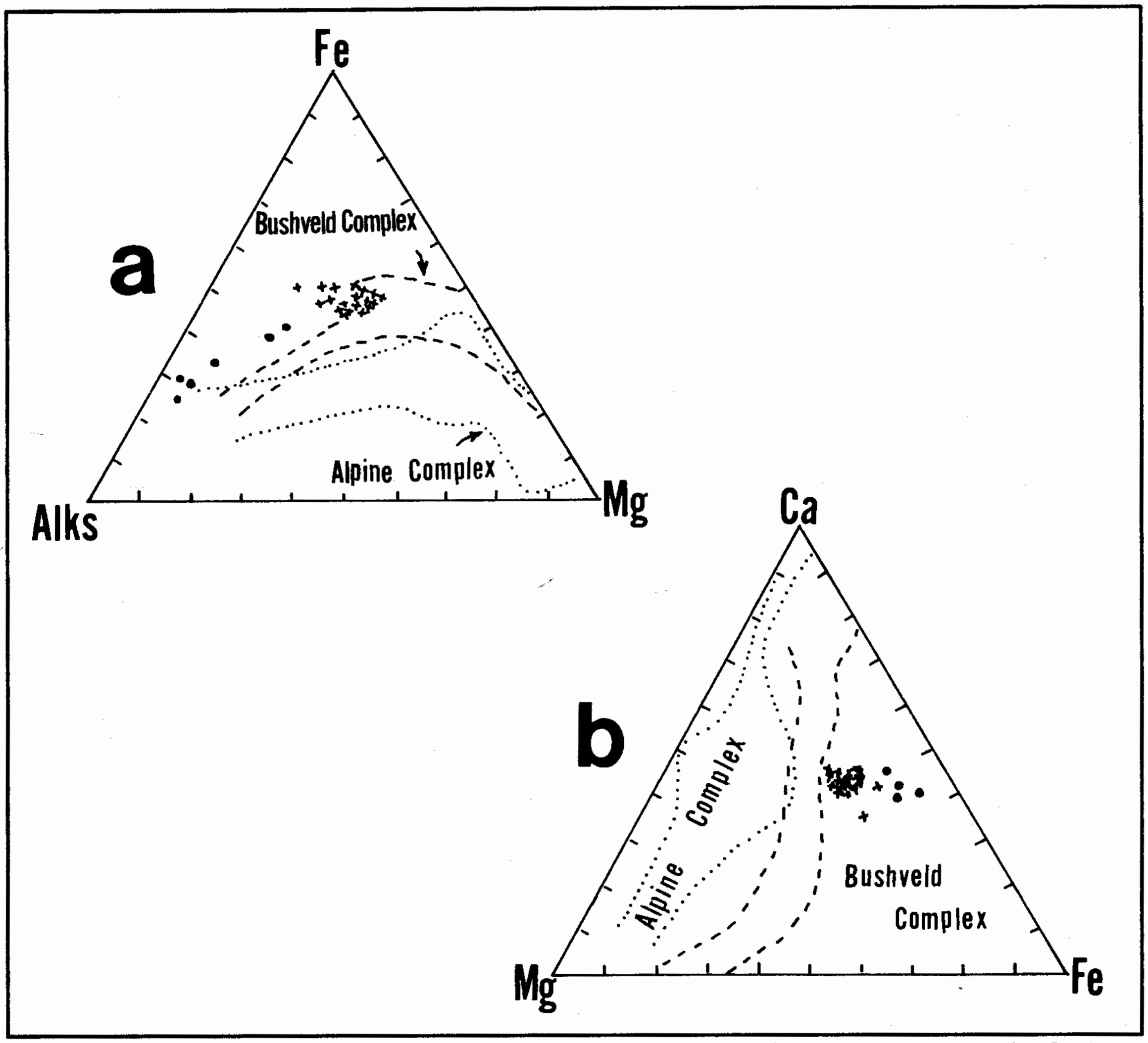

Figure 7. a) Alk-Fe-Mg and b) Fe-Ca-Mg plots for the rocks of Timargara and Semerbagh areas, southern Dir. The fields of alpine type rocks and Bushveld complex are after Weedon (1970).

TECTONIC AFFINITY OF THE ROCKS

In order to identify the tectonic affinity of the studied rocks, various discrimination diagrams are used. As this study is mainly based on the major and minor element chemistry, therefore, only those discrimination diagrams are used here which use the major and minor elements chemistry. It is further to mention that most of these tectonic-discrimination diagrams are meant for basic volcanic rocks which could be questionable in the case of rocks under discussion. However, in the absence of other means, they are relied upon here. Therefore, gabbro, gabbro-norite and diorite/quartz diorite are plotted in these diagrams.

Weedon, (1970) has differentiated the "alpine" type mafic and ultramafic rocks from that of Bushveld complex on the basis of Alks-Fe-Mg plot (Fig. 7a) and Mg-Ca-Fe plot (Fig. 7b). The studied gabbros, gabbro-norite and diorite/quartz diorite when plotted in these diagrams exhibit close affinity to the Bushveld field. In the Alks-Fe-Mg diagram (Fig. 7a) most of data points fall within the Bushveld field, however, in Mg-Ca-Fe diagram (Fig. 7b) the data points fall out side the fields defined for alpine type and Bushveld type but closer to the field of Bushveld. This suggest that these rocks are non-ophiolitic and might be either cumulate or non-cumulate rocks from island arc.

The rocks of the study area, when plotted in the diagram (Fig. 8a) of Mullen (1983), generally show scattering of data within the fields of calc-alkaline basalt and island arc tholeiites. The studied data is mainly restricted to the field of orogenic basalt of Pearce et al. (1977) in the figure 8b and to calc-alkaline field in the figure 8c of Yoder (1969). The calc-alkaline behavior of the studied rocks is also evident from the diagram (Fig. 8d) of SiO_2 vs $FeO_{(t)}/MgO$ of Miyashiro (1974). The studied rocks are poor in TiO_2 and are, therefore, located in the

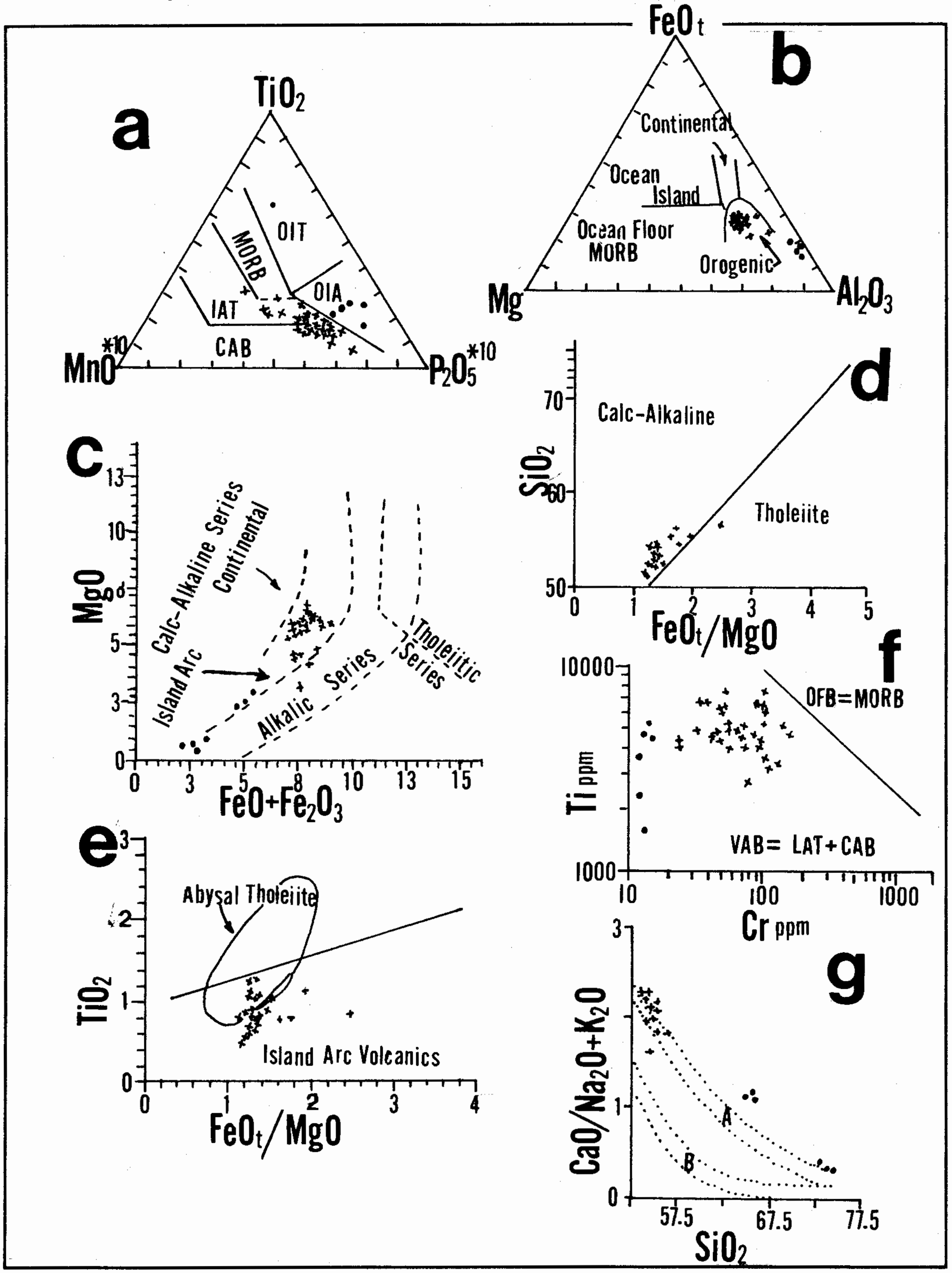

Figure 8. Plots of a) TiO_2 - MnO - P_2O_5 (after Mullen 1984); b) MgO - FeO(t) - Al_2O_3 (after Pearce et al. 1977); c) MgO vs FeO + Fe_2O_3 (after Yoder 1969); d) SiO_2 vs FeO(t) / MgO (after Miyashiro 1974); e) TiO_2 vs $FeO_{(t)}$ / MgO (after Miyashiro 1977); f) Ti vs Cr (after Pearce 1975); and g) CaO / Na2O + K2O vs SiO2 (after Petro et al. 1980) for the rocks of Timargara and Semerbagh area, southern Dir. OIT= Oceanic island tholeiites, OIA= Oceanic island alkali basalt, CAB= calc-alkaline basalts, IAT= Island arc tholeiites, MORB= mid-ocean ridge basalts, VAB= volcanic arc basalt, indcluding island arc toleiites (IAT) and calc-alkaline basalts (CAB), OFB= field of ocean floor or mid ocean ridge basalts (MORB).

field of island arc volcanics in TiO_2 vs FeO(t) /MgO diagram (Fig. 8e) of Miyashiro (1977).

Pearce (1975) has constructed a Ti vs Cr diagram (Fig. 8f) for the rocks of basaltic composition. This diagram separate the field of volcanic arc basalt (VAB), including island arc tholeiites and calc-alkaline basalt from the field of Ocean floor (OFB) or mid-Ocean ridge basalts (MORB). The rocks under discussion when plotted in this diagram, all of the analyses fall within the field of volcanic arc basalts and are clearly distinguished from ocean floor basalts.

Petro et al. (1979) has presented a plot of $CaO/Na_2O + K_2O$ vs SiO_2, with general fields for plutonic rocks from type extensional (British Isles, Iceland, E. Green land) and compressional (Sierra Nevada Batholith) environment (Fig. 8g). The rocks under discussion either fall close or within the field defined for the compressional environments and suggestive of formation of these rocks in orogenic environment.

In order to identify the tectonic character of the studied granodiorites and granites, these are plotted in the diagrams of Maniar and Piccoli (1989) in figure 9. On the plots of Al_2O_3 versus SiO_2 (Fig. 9a), $FeO_{(t)}$ / $FeO_{(t)}$ + MgO versus SiO_2 (Fig. 9b), and on ACF (Fig. 9c) and AFM (Fig. 9d) ternaries, these rocks classify as orogenic granitoids; could be Island arc granitodis (IAG)/ continental arc granitoids (CAG)/continental collision granitoids (CCG) and or post-orogenic granitoids (POG) of group 1 of Maniar and Piccoli (1989). This clearly indicates that the studied granitoids at least display orogenic characteristics and are related to the other basic to intermediate igneous rocks of the study area.

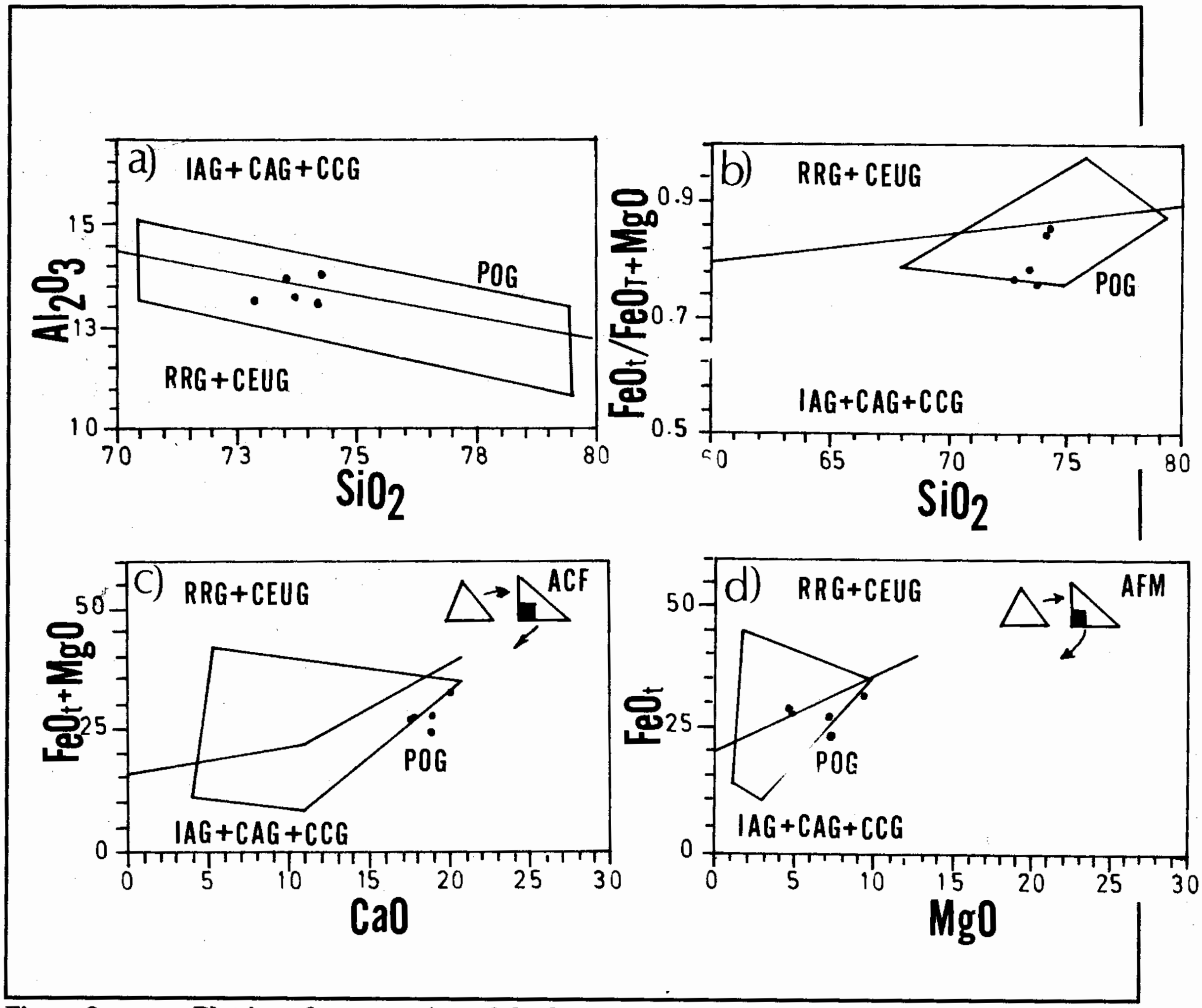

Figure 9. **Plotting of metagranites of the Samerbagh area, southern Dir in the diserimination diagram of Maniar and Piccoli (1989). Symbols as for Fig. 3.** ***Orogenic granitoid rocks:*** **1AG=Island arc granitoids, CAG=Continental granitoids, CCG=Continental collision granitoids, POG= Post-orogenic granitoids,** ***Anorogenic granitoid rocks:*** **RRG= Rift related granitoids, CEUG= continental epirogenic granitoids, OP= Oceanic plagiogranite.**

DISCUSSION

Petrochemical studies of the rocks under discussion suggest the principal role of fractional crystallization controlled by clinopyroxene + plagioclase + orthopyroxene ± olivine removal in the basic units (e.i. gabbros, gabbro-norites and diorites) and plagioclase + K-feldspar +quartz in the intermediate to acidic units (e.i., quartz diorite, granodiorites and granites). These observations are consistent with the hypothesis that all these rocks are comagmatic.

If the mafic and ultramafic rocks of Tora Tiga Complex (Jan and Tahirkheli 1990), having spatial association with the studied rocks in the field, are considered to be magmatically related with the studied rocks of Timergara and Samerbagh then the fractionation of various phases during differentiation process might be very well explained. It would appear that the olivine and chromite fractionation started at the early stages in the magmatic chamber and is joined and latter followed by the ortho and clinopyroxene and ± hornblende resulted in the formation of dunite, peridotite, clinopyroxenite and hornblendite of the Tora Tiga complex (see Jan and Tahirkheli 1990). The continuos fractionation is followed by the dominant plagioclase fractionation along with ortho and clinopyroxenes ± hornblende resulted in the formation of gabbros and gabbro-norites and diorites. This is then joined by the fractionation of K-feldspar and resulted in the formation of quartz diorite and granodiorite in the area. The granites of the area might be the product of residual liquid.

According to the classification of Chappell and white (1974), the studied granites are I-type granites [Molecular $Al_2O_3/(K_2O + Na_2O + CaO) < 1.11$)] with very low amount of normative corundum. It is observed that all the granites including the other igneous rocks of the area (i.e. gabbros, gabbro-norites, diorites/quartz diorites and granodiorite) plot in the region for igneous rocks in the diagram (Fig. 10) of Garrels and Mackenzie (1971). This indicate the igneous character of the granites of the area. It is also concluded that this diagram is equally valid for the rocks of basic to intermediate composition. This suggest that the fractional crystallization process has played a major role in the development of the studied granites rather than the partial melting processes of suitable sedimentary material.

The depth of magma generation for granitic rocks can be obtained by comparison to water saturated minimum in the granite system of Tuttle and Bowen (1958). This can give an estimate of the depth of the melting if the magma has experienced minimal changes in composition since melt generation (Anderson and Bender 1989). The studied granites are plotted in the normative Q-Ab-Or diagram (Fig. 11a) of Tuttle and Bowen (1958) where the water-saturated minimum composition at various PH_2O are given. The data fall in the region of less than 500 bars, showing that the PH2O of the magma probably does not exceeds 500 bars. The temperature of crystallization could be ~ 800 C0 as suggested by the isotherms in Q-Ab-Or ternary (Fig. 11b) of Tuttle and Bown (1958).

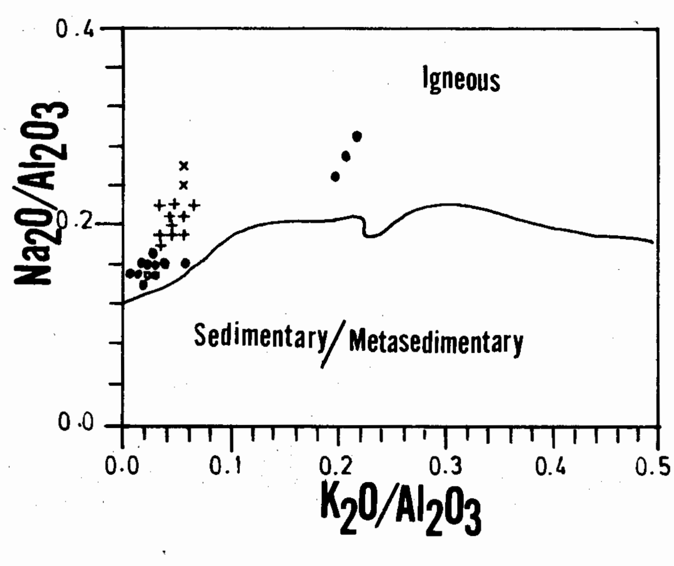

Figure 10. Na_2O/Al_2O_3 vs K_2O/Al_2O_3 plot for the igneous rocks of Timargara and Semerbagh areas, souther Dir. Fields are after Garrels and Mackenzie (1971).

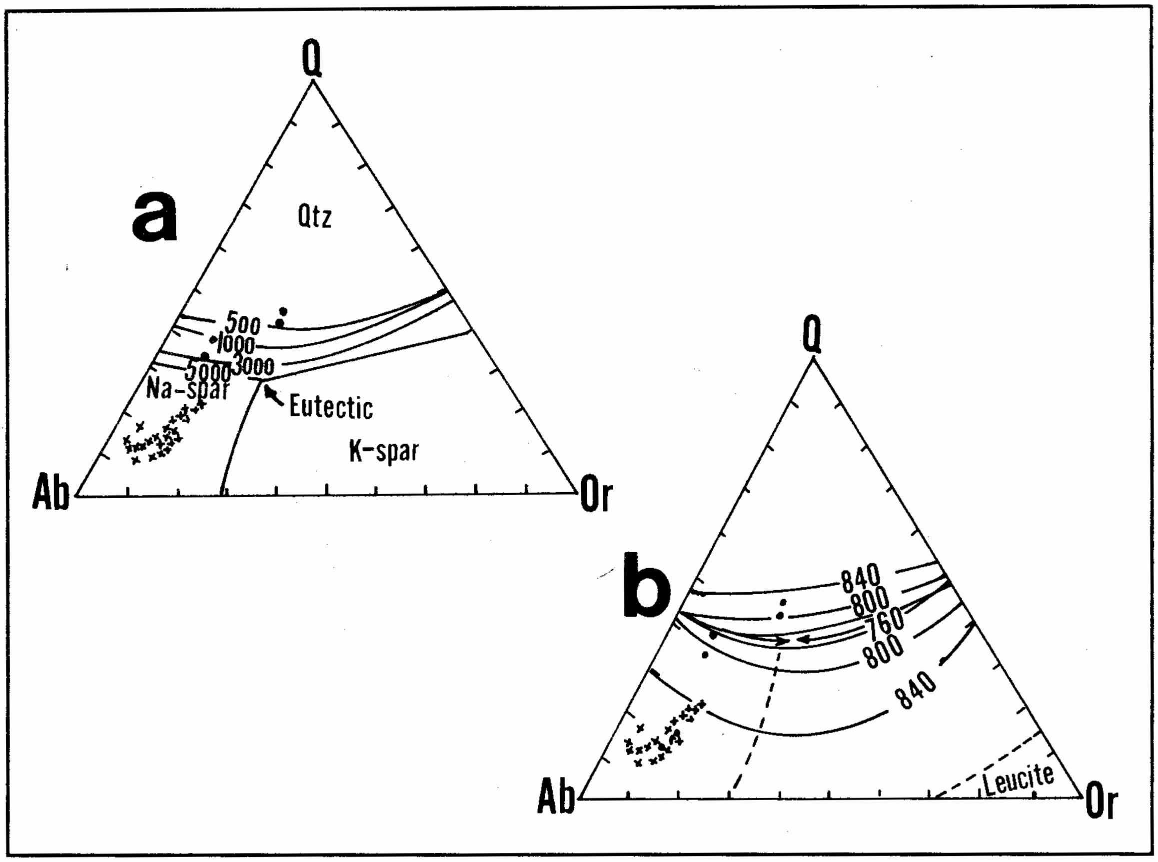

Figure 11. Plot of normative Q-Ab-Or for the granites of Semerbagh area, southern Dir. a) shows various PH_2O minimum, b) shows various temperature conditions (Tuttle and Bowen 1958).

The plotting of the rocks of the studied area in the tectonic discrimination diagram suggest that these rocks have close affinity to the calc-alkaline rocks which are produced in the subduction-related compressional environments. Such rocks occur both in island arc and continental margins and the distinction between the two is not always easy. However, the MgO vs (FeO and Fe_2O_3) plot of Yoder (1969) has provided a clear distinction of these rocks to have been formed in the island arc type of setup instead of continental margin.

The composition and origin of the primary island arc magmas are the main concern of the present day scientists. As more and more petrological, geochemical and geophysical information about the world's active volcanic arcs is coming in, new ideas have developed on many fundamental aspects of island arc petrogenesis. On one hand the great volume of high alumina basaltic (HAB) lavas are considered to be the primary mantle arc magmas generated by the partial melting of subducted oceanic crust or quartz eclogite (Kuno 1960; Marsh 1979; Marsh and Carmichael 1974; Brophy and Marsh 1986; Johston 1986; Borphy 1986; Myers et al. 1986). On the other hand, other petrologists and geochemists believe that sporadic occurrence of basalts with more primitive (MgO rich) characteristics provide evidence for the existence of mantle derived olivine tholeiite parental basalt (MgO>65) from a source similar to that of ocean ridge tholeiites. In this context they consider the high alumina basalt to be generated by partial melting of peridotite in the mantle wedg above the descending slab of subducted oceanic crust (see Ewart et al; 1977; Key 1977; Perfit et al; 1980; Gill 1981; 1984; Cornad and Kay 1984; Kay and Kayy 1985; Nye and Reid 1986; Crawford et al; 1987; Gust and Perfit 1987).

Considering the over all aspects, as mentioned above, for the generation of island arc magmatism, it is believed that the rocks of the Timergara and Samerbagh including those of Tora Tiga have been derived by fractionation of basaltic magma formed either by partial melting of subducting oceanic crust or by partial melting of the peridotite in the mantle wedge above the descending slab of subducted oceanic crust at the base of Kohistan Island arc. These speculations are made by considering the major oxide chemistry of the rocks under discussion. Detail trace element and rare earth element (REE) geochemical studies are required to confirm these observations.

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PETROGRAPHY, GEOCHEMISTRY AND PROVENANCE OF THE VOLCANIC CONGLOMERATE AND SANDSTONE OF THE UPPER CRETACEOUS BIBAI FORMATION, KACH-ZIARAT VALLEY, BALOCHISTAN

ABDUL TAWAB KHAN[1], ABDUL SALAM KHAN[2] AND AKHTAR MOHAMMAD KASSI[1]

[1]Department of Geology, University of Balochistan, Quetta, Pakistan.
[2]Centre of Excellence in Mineralogy, University of Balochistan, Quetta, Pakistan.

ABSTRACT

Detailed petrographic and geochemical analyses of clasts of the volcanic conglomerate and sandstone were carried out to determine the origin and provenance of volcaniclastic sediments of the Bibai Formation. The sedimentary succession of the Upper Cretaceous Bibai Formation is composed of volcanic conglomerate, sandstone and mudstone deposited by various processes of sediment gravity flows on the western margin of the Indian Plate. Volcanic conglomerate contains clasts of alkali basalt, picrite, trachy basalt, tepherite/phonolite, trachy andesite, dolerite, diorite and granodiorite/granite. All these rocks are varieties of the alkaline magma suite. Sandstones of the Bibai formation are also dominantly composed of the basaltic rock fragments and pyroxene crystals. Geochemical data of both major and trace elements were plotted in various discrimination diagrams to identify the origin of the volcanic and associated intrusive rocks from which these fragments were derived. Most of the samples fall in the field if within-plate alkali basalt or close to it that suggest that the volcaniclastic sediments of the Bibai Formation were derived from a volcanic terrain composed of alkali basalts originated by hotspot volcanism. Trace elements presented in various spider diagrams suggest that the parent magma was enriched in mantle source and confirm that the fragments of the volcanic conglomerate of the Bibai Formation were derived from a hotspot related (within-plate setting) volcanic terrane. The paleocurrent data confirms that these sediments were derived from the Bibai Volcanics to the north-northeast of the study area.

INTRODUCTION

The Upper Cretaceous Bibai Formation is exposed within the western part of the Suleman Thrust Fold-belt, east of the Quetta Syntaxis (Fig. 1). The formation is generally composed of basic volcanic rocks and volcaniclastic sediments including volcanic conglomerate, volcanic breccia, volcanogenic sandstone and mudstone. It is dominantly composed of volcaniclastic sediments with rare *in situ* volcanic rocks in the Ziarat Vellay whereas in the Spera Ragha Vellay it is dominantly composed of *in situ* basic volcanic rocks. The volcaniclastic succession conformably and transitionally overlies the Cretaceous Parh Limestone and also conformably and transitionally underlies the Maestrichtian Pab Sandstone and near Kach it conformably underlies the Paleocene Dungan Formation.

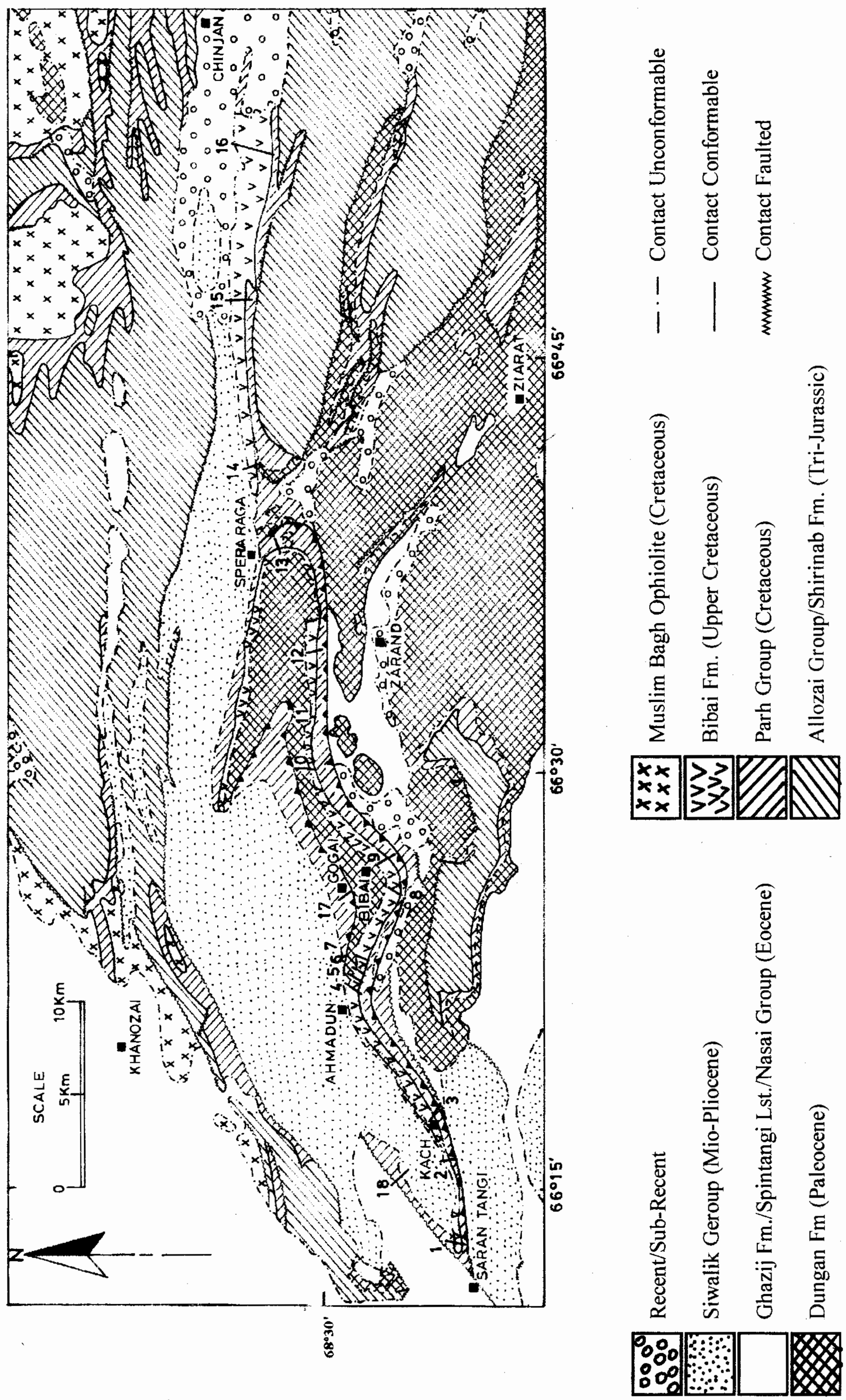

Figure 1. Geological Map of the study area (modified after HSC 1960) showing outcrop of the Bibai Formation.

Kazmi (1955, 1979) was the first who described the lithology and proposed the name Bibai Formation for the volcanic and volcaniclastic succession that were considered part of the Moghal Kot Formation (Kahan Conglomerate Member) by Williams (1959). The Hunting Survey Corporation (1960) referred to it as "Parh related volcanics" and included it as part of the Parh Group. DeJong and Subhani (1979) and Otsuki et al. (1989) studied the volcanic rocks around Muslimbagh area and interpreted them as Andean-Type volcanics formed at the northwestern margin of the Indian Plate. Based on petrography and geochemistry, the *in situ* volcanics of the Spera Ragh- Chinjan Vellay have been interpreted as hotspot related volcanics (Baloch and McCormick, 1995, Khan, 1986, McCormick, 1985, 1989, 1991, Sawada et al. 1992, Siddiqui et al, 1994, 1996). Kassi et al. (1993) carried out preliminary sedimentological study of the volcaniclastic succcession of the Bibai Formation and interpreted them as turbidites. Based on the K-Ar dating, Sawada et al. (1995) proposed $74.4 \underline{+} 3$ My for the Bibai volcanics. This paper presents petrography and geochemistry of the volcanic conglomerate and sandstone, based on what the provenance of the Bibai Formation is discussed.

PETROGRAPHY

VOLCANIC CONGLOMERATE

Volcanic conglomerate of the Bibai Formation consists dominantly of rock fragments mostly volcanic and rarely plutonic. One hundred and fifty thin sections of the rock fragments have been studied to describe their texture and composition. The following rock types were recognized. Alkali basalt, Picrite (olivine rich basalt), Trachy basalt (plagioclase rich basalt), Tephrite/phonolite (nepheline basalt), Hornblende basalt, Trachy andesite, Dolerite, Diorite and Alkali Granite/ granodiorite

Alkali Basalt

Fragments of the alkali basalt are very common in volcanic conglomerate. They are generally black, amygdaloidal and mesocrystalline. Up to 2cm phenocrysts of greenish black pyroxene embedded in black aphanitic ground mass are common. Vesicles are filled with zeolites and calcite. Phenocrysts of clinopyroxene (Ti-augite), plagioclase, magnetite and olivine occur as clusters in a glomeroporphyritic texture. (Fig.2) Some samples show sub-ophitic texture and laths of plagioclase are partly enclosed by large phenocrysts of clinopyroxene. The ground mass is microcrystalline to cryptocrystalline. An intersertal and subpilotaxitic texture in the ground mass can also be observed in some cases. Some of these rocks are fine grained, aphanitic and non-porphyritic in hand specimen.

Alkali basalts are dominantly composed of clinopyroxene, plagioclase and magnetite with minor olivine. Apatite and zircon occur as accessory minerals. Chlorite, uralite, epidote, iddingsite and antigorite are the altered minerals. Ti-augite is more common than any other mineral. It is mostly pale brown, pleochroic, euhedral to subhedral and occurs both as phenocrysts (ranging in size from less than 1 mm to 6mm) and in ground mass. Some of the large tabular phenocrysts show well developed twinning and those of the polygonal phenocrysts exhibit oscillatory zoning . Most phenocrysts show a dark brown rim along the boundary. Inclusions of magnetite are very common in the phenocrysts and are confined to the centre. The Ti-augite in the ground mass mostly occurs as small tabular and polygonal crystals.

Plagioclase is the second most abundant and occurs both in the ground mass and as phenocrysts. It ranges in composition from andesine to labradorite (An_{45-56}), mostly lath shaped with some bladed and equant grains showing vague concentric compositional zoning. In some rocks the lath shaped phenocrysts and microlites within the ground mass are randomly oriented, whereas, in others they show sub-parallel orientation. Phenocrysts of olivine are present in some alkali basalt. It is generally euhedral and in some cases corroded showing irregular fractures filled with secondary magnetite, antigorite and iddingsite. Inclusions of magnetite occur along the boundary of some olivine phenocrysts making a rim around them. Some of the olivine crystals show twinning and vague compositional zoning. Magnetite is third most abundant mineral in most of these rocks. It occurs both as phenocrysts and in ground mass. It also occurs as inclusions in the phenocrysts of clinopyroxene and olivine.

The alkali basalts are slightly to moderately altered. Altered minerals are uralite, iddingsite, antigorite, chlorite, epidote, calcite, zeolite, magnetite and hematite. Uralite is the altered product of Ti-augite. It is green and pleochroic from pale green to bright green. Alteration has occurred along the margins and in fractures. Chlorite is yellowish green, slightly pleochroic and is the altered product of the augite. Iddingsite is the altered product of the augite and olivine . It is dark brown and usually occurs in fractures and along the margins. In some cases it occurs as pseudomorphs of augite and olivine. Antigorite is the altered

Figure 2. Photomicrograph of porphyritic alkali basalt showing glomeroporphyritic texture. Clinopyroxene (ti-augite) and olivine phenocrysts occur in cluster (X40 XPL).

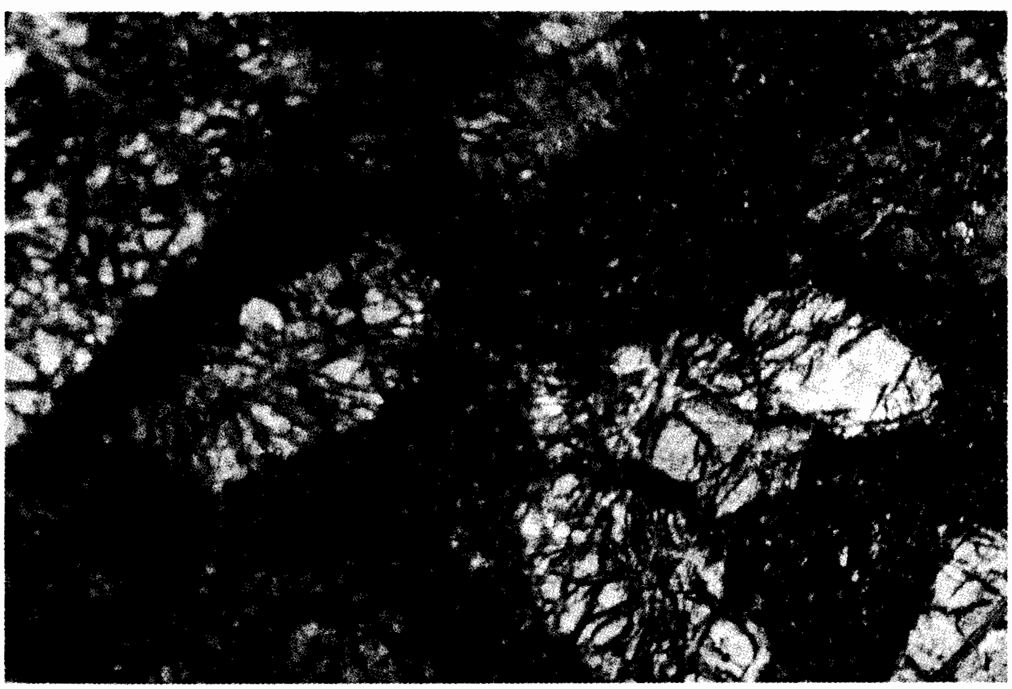

Figure 3. Photomicrograph of the picrite showing phenocrysts of olivine set in microcrystalline groundmass of dominantly olivine with some pyroxene. Some of the phenocrysts show resorbed margins (X40 XPL).

product of olivine. It is pale green and usually occurs in fractures and along the grain margins. Epidote is the altered product of plagioclase. It is bright green to yellowish green and replaces plagioclase in centre and some plagioclase grains are completely altered into plagioclase. Secondary magnetite occurs in fractures of olivine and augite. Hematite is the altered product of magnetite. Zeolite and calcite fill vesicles as secondary minerals.

Picrite (Olivine Rich Basalt)

Fragments of the olivine rich basalt are not very common within the volcanic conglomerate of the Bibai Formation. These fragments are black, mesocrystalline, in some cases holocrystalline, porphyritic and amygdaloidal; vesicles are filled with white and light grey zeolite and calcite. Phenocrysts of olivine are set in a microcrystalline and cryptocrystalline ground mass consisting mainly of olivine with subordinate pyroxene, opaque iron oxide (Fig.3) and minor amounts of plagioclase.

Fragments of the olivine rich basalt are dominantly composed of olivine with subordinate clinopyroxene, opaque iron oxide and plagioclase. Olivine occurs as phenocrysts and in ground mass. Phenocrysts are polygonal and mostly corroded along the margins, however, in some cases they are euhedral to subhedral. Olivine crystals are colourless or faint green and are highly fractured. They contain inclusions of tiny crystals of pyroxene, plagioclase and magnetite. Clinopyroxene is diopside that occurs mostly in ground mass and less frequently as phenocrysts. Plagioclase is labradorite (An_{66}) showing compositional zoning with a more calcic core. They are lath shaped and contain inclusions of diopside and olivine. Magnetite occurs in the interstices of diopside, olivine and plagioclase and in the ground mass as tiny rounded grains.

These rocks are slightly to moderately altered. Altered minerals are serpentine, chlorophaeite, magnetite and saussurite. Serpentine has developed at the expense of olivine. Antigorite and iddingsite occur in cracks and in some cases they have replaced a major part of the olivine phenocrysts with some olivine left in the centre. Chlorophaeite is also a common alteration product of olivine and is dark to bright green and occurs in the cracks. Secondary magnetite also occurs in fractures. Plagioclase is slightly altered to saussurite. Fibrous zeolite (natrolite) is filled in the vesicles exhibiting and amygdaloidal structure to the rock.

Trachy Basalt (Plagioclase Rich Basalt)

Fragments of trachy basalt are also common in the volcanic conglomerate and are difficult to be distinguished from the alkali basalts. In hand specimens, these are dark grey, mesocrystalline and porphyritic. Phenocrysts are dark brownish grey and embedded in fine grained, aphanitic, dark grey to light grey ground mass. Most of these rocks show amygdaloidal structure. Vesicles are filled with white to light grey zeolite and calcite. The size of the amygdules ranges from less than 1mm to 2 cm and shape ranges from circular to elliptical. Under microscope, these rocks are commonly glomeroporphyritic and porphyritic. Phenocrysts of clinopyroxene, plagioclase, olivine and magnetite occur as clusters and isolated. These rocks also show pilotaxitic and hyalophitic texture in which laths of plagioclase are oriented in parallel to sub-parallel manner and embedded in dark brown glassy material.

These rocks are dominantly composed of plagioclase, clinopyroxene, K-feldspar with some olivine, magnetite and nepheline. Plagioclase is usually higher in amount than clinopyroxene and K-feldspar. Plagioclase ranges in composition from andesine to labradorite (An_{32-52}). They contain more andesine compared to the alkali basalt. Phenocrysts of plagioclase are platy, lath-shaped and polygonal showing oscillatory zoning. They are altered to saussurite in the centre whereas, margins are altered to sericite indicating calcic cores and sodic margins. Phenocrysts of plagioclase contain inclusions of magnetite. Pyroxene is next in abundance after plagioclase. It is mostly Ti-augite and aegerine augite. Ti-augite is more common as phenocrysts which are euhedral to subhedral, polygonal and platy showing well developed concentric compositional zoning (hourglass) (Fig. 4). The Ti-augite is pale brown and slightly pleochroic whereas the aegirine-augite is green and moderately pleochroic from pale green to dark green. In some samples aegirine-augite is more abundant than plagioclase within the ground mass. In most cases, phenocrysts contain inclusions of magnetite and apatite. K-feldspar is sanidine which is present commonly in ground mass and rarely as small phenocrysts. Olivine occurs as phenocrysts which are mostly altered to serpentine with some relics of olivine in the centre. It is characterised by irregular and curved fractures which produce a mesh structure. It has corroded and resorbed margins indicating an early crystallization. Nepheline is present in minor amounts. It commonly occurs in the ground mass as anhedral crystals in the interstices of plagioclase Magnetite is present in the ground mass, in some rocks as phenocrysts. In the ground mass it is uniformly distributed throughout the rock, anhedral to subhedral in form and look like beads. In some cases grains of magnetite occur as aggregates.

These rocks are slightly to highly altered.

Figure 4. Photomicrograph of the trachy basalt showing well developed concentric zoning (hourglass structure) in the euhedral phenocryst of clinopyroxene (ti-augite).

Figure 5. Photomicrograph of tephrite/phonolite showing euhedral phenocrysts of nepheline and clinopyroxen (ti-augite) set in microcrystalline groundmass, dominantly composed of nepheline with some aegirine (X40 XPL).

Alteration products are saussurite, sericite, chlorite, serpentine, magnetite, zeolitic and calcite. Saussurite and sericite are the altered products of plagioclase. Saussuritization has taken place in the centre, whereas, sericitization has taken place along margins indicating its calcic and sodic composition respectively. In some cases calcite has formed at the expense of plagioclase. Chlorite has developed after augite. It is light yellow in colour and pleochroic from light yellow to bright yellow. In some case vesicles are filled with chlorite. Two types of serpentine have developed as altered products. The reddish brown is iddingsite which has developed after augite, whereas, the yellowish one is antigorite, which has developed after olivine. Magnetite has developed at the expense of augite. In some cases complete grains of augite have been replaced by a black opaque mineral, most likely magnetite. Zeolite and calcite are present as vesicle fillings producing an amygdaloidal structure.

Tephrite/Phonolite (Nepheline Basalt)

Fragments of tephrite/phonolite are less common in the volcanic conglomerate. These are dark grey, greenish grey, weather to brownish grey, mesocrystalline, porphyritic and aphanitic. Phenocrysts are only seen in a polished surface and are dark brown and light grey, embedded in aphanitic or very fine grained dark grey ground mass. Texturally, these rocks are porphyritic and glomeroporphyritic. Euhedral phenocrysts of nepheline and clinopyroxene (Fig.5) occur as clusters and/or isolated grains that are set in a microcrystalline and cryptocrystalline ground mass consisting mostly of nepheline, clinopyroxene with subordinate plagioclase, magnetite and hornblende. Prismatic phenocrysts of hornblende are also present.

These rocks are dominantly composed of nepheline and clinopyroxene with subordinate plagioclase, magnetite and hornblende. Nepheline is most abundant and occurs as phenocrysts, miro-phenocrysts and in ground mass. Phenocrysts of nepheline are euhedral to subhedral, and rectangular, equant and platy whereas, in ground mass they are anhedral occurring in the interstices. Some of the microphenocrysts show well developed cleavages in one and/or two directions. It contains inclusions of opaque iron oxide and tiny crystals of pyroxene.

Clinopyroxene is mostly aegirine, aegirine-augite and Ti-augite. Aegirine is green and pleochroic from pale green to dark green and mostly present in the ground mass, whereas, Ti-augite is purplish brown, slightly pleochroic and occurs commonly as phenocrysts. Some of the Ti-augite phenocrysts have rims of aegirine or green hornblende. They contain inclusions of apatite and magnetite. Hornblende is less common and occurs as phenocrysts. It is subhedral and pleochroic from light brown to dark reddish brown.

These rocks are slightly to moderately altered. Altered minerals are green hornblende, magnetite, hematite and calcite. Green hornblende and magnetite are altered products of Ti-augite and occur in fractures and along grain margins. Hematite is reddish brown and has been developed at the expense of magnetite. Calcite has developed at the expense of nepheline.

Hornblende Basalt

Fragments of the hornblende basalt are also less common. These are grey to dark grey, porphyritic having up to 5 mm long phenocrysts of black hornblende (visible with naked eyes) embedded in an aphanitic and grey ground mass. Microscopically these are glomeroporphyritic. Phenocrysts of clinopyroxene (Fig.6), hornblende and micro-phenocrysts of plagioclase and magnetite occur in clusters and as isolated crystals set in a microcrystalline ground mass, composed of plagioclase, hornblende, pyroxene and magnetite. These rocks also show sub-pilotaxitic texture. Microlites of plagioclase and tiny platy crystals of pyroxene have parallel to subparallel orientation around phenocrysts.

These rocks are dominantly composed of hornblende, plagioclase, clinopyroxene and magnetite. Hornblende occurs as phenocrysts and in ground mass. Phenocrysts are euhedral to subhedral, polygonal and platy. They are brown and pleochroic from pale green to dark brown. Polygonal and equant grains show cleavage traces in two directions intersecting at acute and obtuse angles and has dark brown to black rims around the margins (Fig. 6). It contains inclusions of magnetite and apatite. Plagioclase comes next in abundance and occurs dominantly in the ground mass, however, euhedral and equant micro-phenocrysts are also common. Phenocrysts are mostly altered to pale green material, probably saussurite, but are difficult to identify with certainty. Within the ground mass it is less altered and occurs as microlites. It seems to be more sodic (andesine) in ground mass and more calcic (labradorite) in phenocrysts. Pyroxene is also common and is mostly Ti-augite and augite, present as phenocrysts which are euhedral to subhedral, polygonal, bladed and platy. The polygonal and equant phenocrysts show well developed concentric compositional zoning and contain inclusions of

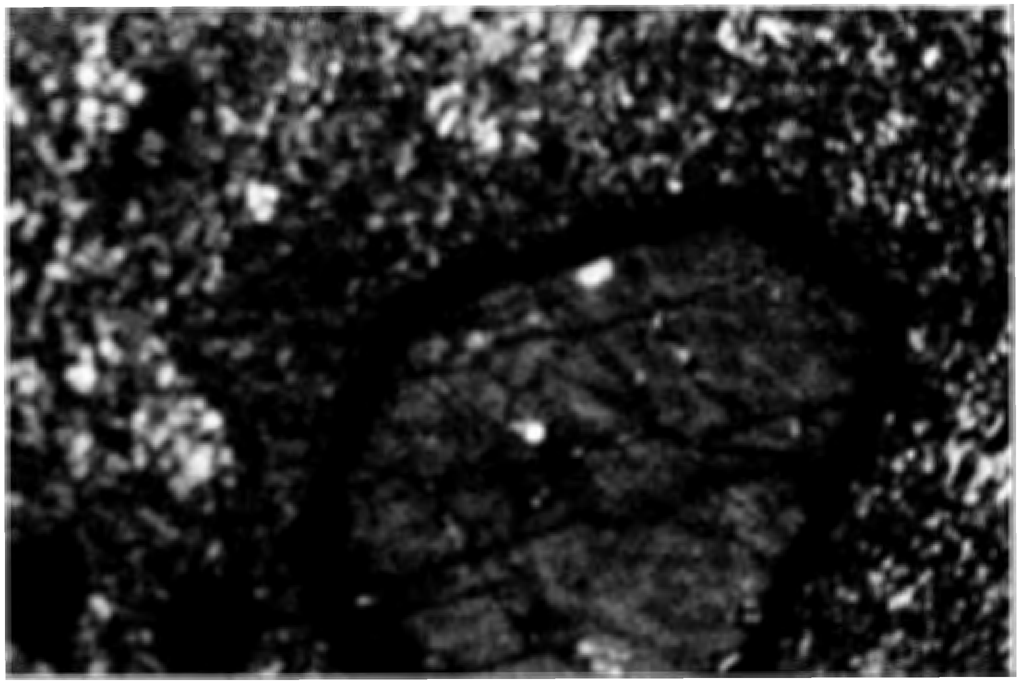

Figure 6. Photomicrograph of hornblende basalt showing euhedral and polygonal phenocryst of hornblende. Note a rim of opaque mineral (magnetite) along the margin of hornblende (X40 XPL).

Figure 7. Photomicrograph of trachy andesite showing phenocrysts of sanidine displaying carlsbad twining.

apatite and magnetite. Magnetite occurs as micro-phenocrysts and in ground mass. It is black and subhedral to anhedral.

These rocks are slightly altered. The altered products are saussurite, magnetite and sericite. Saussurite has developed at the expense of calcic plagioclase, whereas, sericite is the result of sodic plagioclase and alkali feldspar. Green hornblende is the altered product of clinopyroxene which usually occurs along the margins as rims and fillings in the fractures. Magnetite is present in fractures of clinopyroxene. In some rocks hematite is the common alteration product of magnetite.

Trachy Andesite

Fragments of trachy andesite are less common. These are light grey to greenish grey, mesocrystalline and porphyritic. Phenocrysts of both dark and light coloured minerals are embedded in light grey aphanitic ground mass. These rocks fragments show porphyritic and glomeroporphyritic texture. Euhedral to subhedral phenocrysts of plagioclase, pyroxene, K-feldspar, nepheline and magnetite occur in clusters and as isolated grains. Some samples show trachytic texture. Microlites of plagioclase and K-feldspar show flow structure. Some samples show sub-pilotaxitic and intersertal texture. Plagioclase laths and platy grains of pyroxene exhibit sub-parallel orientation and the interstices are filled with glassy material.

These rocks are composed of plagioclase, K-feldspar, clinopyroxene (mostly aegirine with some Ti-augite), and nepheline. Magnetite, ilmenite and apatite are the accessory minerals. Plagioclase is mostly andesine (An_{30-40}), present both as phenocrysts and in ground mass. Phenocrysts are euhedral to subhedral, lath shaped and platy, some are rhomb shaped. Equant grains show oscillatory zoning and contain inclusions of magnetite and ilmenite. K-feldspar is sanidine which is easily distinguishable from andesine by its simple carlsbad twining and clear appearance (Fig.7). It occurs as phenocrysts and in the ground mass. Phenocrysts are subhedral and anhedral with corroded margins. It is prismatic and microlitic in the ground mass. Clinopyroxene is less common compared to plagioclase and K-feldspar. It is mostly aegirine which is green in colour and pleochroic from pale and yellowish green to bright green. It occurs as phenocrysts and in the ground mass. Phenocrysts are euhedral to subhedral and contain inclusions of apatite, magnetite and ilmenite. It is micro- to cryptocrystalline, anhedral and uniformly distributed in the ground mass. Nepheline is less common in these rocks. It also occurs as phenocrysts and in the ground mass. Phenocrysts are euhedral to subhedral, rectangular and equant. Some phenocrysts show zoning along the margins and contain inclusions of apatite crystals. In the ground mass it is interstitial and is recognized by its low relief, low birefringence (grey) and uniform extinction. Magnetite and ilmenite are also common and occur as microphenocrysts and also in ground mass. They are black to dark brown, skeletal and rounded. A few crystals of nosean are also present which are pyramidal. They are recognized by their high relief and dark brown rims along margins.

These rocks are slightly to moderately altered. The altered products are calcite, sericite, saussurite, magnetite and hematite. Calcite is most common, developed at the expense of plagioclase and also occurs in veins and amygdales. Some plagioclase phenocrysts have been replaced completely by calcite. Sericitization is also common in these rocks which is developed after sodic plagioclase. Saussuritization is less common, confined to the core of some of the plagioclase phenocrysts. Secondary magnetite is present in fractures of the Ti-augite. Reddish brown hematite has developed at the expense of magnetite.

Dolerite

Fragments of doleritic rock are light grey on fresh surfaces with a mottled appearance due to intermixing of light (plagioclase) and dark (mostly pyroxene) minerals. They are holocrystalline, pheneritic and rarely porphyritic. Under microscope, these rocks show hypidiomorphic and porphyritic texture (Fig. 8). Phenocrysts of olivine, pyroxene and plagioclase are set in a granular ground mass of plagioclase, pyroxene, olivine, magnetite and ilmenite. Intergranular texture is common in the ground mass. Pyroxene and in some cases olivine grains occupy spaces between the randomly oriented laths of plagioclase. They also show subophitic texture, small laths of plagioclase are partially enclosed by the pyroxene phenocrysts.

These rocks are composed of plagioclase, pyroxene and olivine whereas magnetite, ilmenite and apatite are accessory minerals. The ratio between plagioclase and clinopyroxene is highly variable. Plagioclase varies in composition from andesine to labradorite (An_{44-58}). Laths of plagioclase are euhedral to subhedral and randomly oriented. The majority of plagioclase grains show compositional zoning and albite twining and contain inclusions of tiny prismatic crystals of apatite. Augite occurs as phenocrysts and in the ground mass. It is colourless or pale green and non-pleochroic, usually subhedral with resorbed

Figure 8. Photomicrograph of dolerite showing intergranular texture and phenocrysts of clinopyroxen and olivine. Augite occupies the interspace of plagioclase laths (X40 XPL).

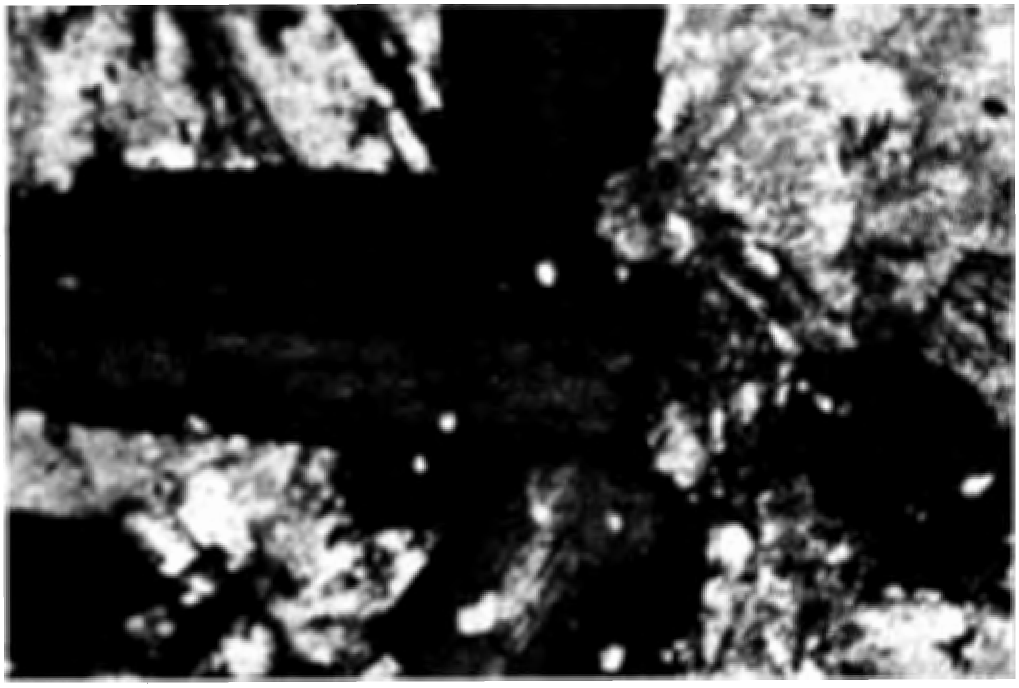

Figure 9. Photomicrograph of diorite showing perthitic texture that is characterized by the intergrowth of plagioclase with potash feldspar. Hornblende grains are euhedral while potash feldspar anhedral present in the interspaces (X40 PPL).

margins. It shows traces of cleavage in one direction and irregular fractures. Olivine is third most abundant mineral. It commonly occurs as euhedral and polygonal phenocrysts with corroded margins in some cases. They show irregular fractures filled with secondary magnetite. Magnetite and ilmenite are also common in these rocks and occur as microphenocrysts and in the ground mass. These are usually subhedral to anhedral and skeletal.

These rocks are slightly to moderately altered. Altered products are serpentine, saussurite, calcite, uralite, chlorite and magnetite. Yellowish green serpentine is the most common altered mineral which has developed at the expense of olivine. In most cases it occurs as pseudomorph of olivine. Saussurite is the alteration product of plagioclase. It is pale yellow and pleochroic. Calcite has developed at the expense of plagioclase, whereas uralite and chlorite are the altered products of augite.

Diorite

Fragments of dioritic rock are less common. These rocks are pinkish grey to light grey on fresh surfaces, holocrystalline, pheneritic and coarse grained with mottled appearance. The large (up to 2cm) and prismatic crystals of hornblende, K-feldspar and plagioclase are intermixed with one another. The texture of these rocks is allotriomorphic to hypidiomorphic granular. Hornblende and pyroxene grains are euhedral to subhedral whereas, K-feldspar and plagioclase grains are mostly anhedral to subhedral and occupy the interstices, showing perthitic texture (Fig. 9) that is characterised by the intergrowths of sodic plagioclase with K-feldspar. The clear and white blebs are of sodic plagioclase, whereas K-feldspar appears as by earthy brown material. In some cases K-feldspar form large poikilitic grains that contains euhedral to subhedral grains of hornblende, biotite and apatite.

These rocks contain K-feldspar, sodic plagioclase, hornblende with some pyroxene and minor proportions of olivine and biotite. Magnetite, ilmenite and apatite are present as accessory minerals. The K-feldspar is anhedral orthoclase and occupies the spaces between plagioclase and hornblende. It contains euhedral inclusions of plagioclase, hornblende, biotite, magnetite and apatite. Plagioclase is andesine to albite, euhedral to subhedral and partially altered to sericite. It is characterised by well developed albite-type twining giving extinction angles that range from 6° to 22°. Oscillatory zoning is common in plagioclase grains. Hornblende is euhedral to subhedral with prismatic, bladder and polygonal shapes. It is brown and green exhibiting strong pleochroism from pale brown to dark reddish brown. Tabular grains show traces of cleavage in one direction, whereas, polygonal grains show cleavage traces in two directions intersecting each other at 60° and 120°. Up to 10% clinopyroxene (augite), mostly pale green, non-pleochroic and usually subhedral with platy shape is present that are filled with secondary magnetite. Olivine is less common, constituting up to 5% of the total mineral assemblage. It is subhedral due to its resorbed margins. It is highly fractured that are filled with secondary magnetite. Quartz makes less than 5% of the total mineral assemblage and occurs in those rock which contain no olivine. It is anhedral and occurs in the interstices between plagioclase and K-feldspar. Biotite constitutes about 6% of the total minerals. It is brown in colour and strongly pleochroic from pale brown to dark brown. It is euhedral to subhedral and platy. It can be easily distinguished from the brown hornblende due to its halos in cross nicols. It is usually enclosed by the large grains of K-feldspar. Magnetite is common among the accessary minerals. It is black and anhedral to skeletal. It usually occurs as dense mass associated with hornblende.

These rocks are moderately altered. Altered products are light to dark brown clay mineral, sericite, saussurite, chlorite and magnetite. Clay mineral is the most common altered product which has developed at the expense of K-feldspar. Sericite has developed after plagioclase, specially along boundaries indicating more sodic composition, whereas, minor saussurite has developed in centres of plagioclase grains indicating its more calcic nature. Chlorite has developed after augite which is green and pleochroic from pale green to bright green. Secondary magnetite has developed in fractures of olivine. Hornblende has partly been replaced by magnetite.

Alkali granite/ Granodiorite

Fragments of alkali granite and granodiorite are common in upper most conglomeratic beds of the volcaniclastic succession of the Bibai Formation. These fragments are pink, buff red and blood red on fresh surfaces, whereas weathered surfaces are dark brown. They are holocrystalline, equigranular, pheneritic and coarse grained. Granitic fragments have been derived from the granitic dikes present in the Bibai Volcanics. It is evidenced from the textural change from fine grtained at the margin to coarse grained towards centre indicating chilled margins. Some granitic fragments show volcanic rock fragments as xenoliths which also indicate its origin as dike. These rocks are allotriomorphic to hypidiomorphic. K-feldspar and plagioclase grains are mostly subhedral, whereas, quartz grains are anhedral that occur in interstices of K-feldspar and plagioclase grains. Perthitic texture is common and represented by intergrowths of K-feldspar and sodic plagioclase. Micro-pegmatitic texture is also present in these rocks which is represented by the intergrowths of quartz and K-feldspar along their boundaries.

These rocks are mainly composed of quartz (20-32%), K-feldspar (55-66%) and plagioclase (5-15%). The rest include opaque iron oxide and in some cases hornblende and biotite. Quartz is anhedral in form and shows undulatory extinction. It occurs in the interstices of K-feldspar and contains inclusions of magnetite. K-feldspar is mostly orthoclase with some microcline. It is anhedral to subhedral, highly altered to dark brown opaque clay and contains perthitic inclusions of plagioclase. The less altered grains, which are not common, show carlsbad twining. Microcline grains are less common which are recognized by their cross-hatch twining.

Plagioclase is less common in these rocks. It is albite in composition and is easily recognisable by polysynthetic albite-type twining and extinction angle that ranges from 10°-18°. It is highly altered to sericite. Hornblende is less common which is euhedral to subhedral and platy. It is green and pleochroic from pale green to bright green. Opaque iron oxides are magnetite and ilmenite which are anhedral and skeletal. They occur along the boundaries of quartz and K-feldspar, as inclusions in K-feldspar and associated with hornblende and biotite.

These rocks are highly altered. The altered products are clay minerals and chlorite. Clay minerals have developed very extensively after K-feldspar. They are dark brown to red brown and, in some cases, shows weak pleochroism from brown to red. Chlorite has developed at the expense of hornblende. It is yellowish green and pleochroic from yellowish green to pale green.

Sandstone

Ten samples of sandstone of the Bibai Formation, obtained from different localities, were studied in detail to determine its composition and texture for the purpose of provenance. They are very fine to very coarse grained and moderately to very poorly sorted (Fig. 10). The shapes of the grains vary depending on the composition. Volcanic rock

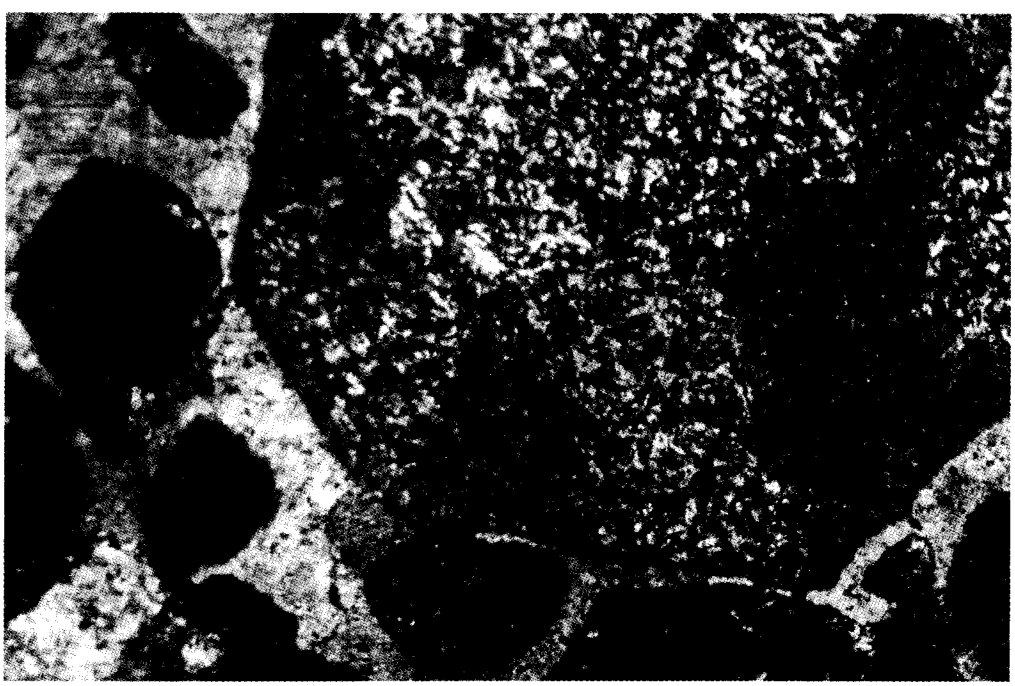

Figure 10. Photomicrograph of volcanogenic lithic graywacke. Volcanic fragments are rounded to subrounded with sparite as cementing materail (X40 PPL).

fragments are generally rounded to sub-rounded, the grains of magnetite, and ilmenite are mostly angular, whereas isolated grains of pyroxene, olivine, plagioclase and quartz (few samples) are also angular.

Sandstones of the Bibai Formation are dominantly composed of volcanic lithic fragments with subordinate opaque iron oxide, pyroxene and olivine crystals. Quartz fragments are present in some of these rocks but are not more than 2%. Quartz grains are generally monocrystalline showing undulose extinction and angular in shape probably derived from erosion of alkali granite and granodioritic dykes associated with the basaltic rocks of the Bibai Formation. Plagioclase is also less common. It is not more than 3% of the total detrital fragments of the sandstone. Olivine grains are also present in these sandstones which are angular to subangular and have been derived from the porphyritic alkali basalt and picrite of the Bibai Volcanics. Pyroxene grains, mostly Ti-augite and augite are common in the sandstones which are angular to sub-angular and have been derived from porphyritic alkali basalts. Magnetite and ilmenite grains are also common in fine grained sandstone. They are angular and have been derived from the Bibai Volcanics and associated intrusive rocks.

All the textural and compositional varieties of the volcanic fragments recognised within volcanic conglomerates of the Bibai Formation are present in these sandstones. The cementing material is mostly sparite, however, in some sandstones zeolite is the common cementing material. Based on mineralogical and textural characteristics these sandstones are classified as volcanogenic lithic arenite.

GEOCHEMISTRY

After careful petrography, 17 representative samples of the volcanic and intrusive rock fragments from the volcanic conglomerate of the Bibai Formation were selected and analysed for whole-rock geochemistry. The analyses were carried out on the energy dispersive X-ray fluorescence (XRF) system at the Geoscience Laboratory of the G.S.P., Islamabad.

For major elements, glass beads made from powdered sample (<200 mesh) were thoroughly mixed with Lithium tetra-borate (flux) in a 1:5 ratio. For trace elements, discs were made from the powdered sample by putting 5-7 grams sample powder in an aluminium cup and pressing between two Tungston Carbide plates. Analytical results of the major and trace elements are given in Table 1. To characterise the petrogenic and paleotectonic setting of the rock fragments, both major and trace elements are plotted in various diagrams.

MAJOR ELEMENTS

Major elements are plotted in various classification diagrams. Plots of the SiO_2 versus Na_2O +K_2O (alkali) diagram (after Le Maitre et al. 1989, Fig. 11) indicate that the volcanic rocks fall within the field of picro-basalt, basalt, trachy basalt, tephrite/basanite, phono-tephrite, tepheri-phonolite and trachy andesite, whereas, the intrusive rocks fall within the field of trachy-dacite and dacite which are volcanic equivalents of syno-granodiorite and granodiorite/quartz diorite. All these rocks come under the category of alkali basalt and alkali intrusive rocks. In terms of the alkaline and subalkaline classification (after Irvine & Baragar 1971), the volcanic rocks fall in the field of alkaline or close to it (Fig.12), however, the intrusive rocks which are intermediate to acidic in composition fall within the field of subalkaline. This may be due to contamination at the lower part of the crust before intrusion.

TRACE ELEMENTS

Trace elements data of the volcanic fragments are presented in spider diagrams (Fig.13, 14 and 15). Data has been normalized to the primordial mantle (after Wood et al. 1979 and chondrite (after Sun 1980). Trace elements show a pattern sloping towards right, suggesting enrichment in the large-ion lithophile elements (LILE). There is marked positive anomalies at Ba and Nb and negative anomalies at Rb and K which suggest that parent magma was enriched in mantle source confirming that fragments were derived from a volcanic terranes that originated at a within-plate tectonic setting (Clague and Frey, 1982). In the case of MORB normalization (Fig.15) after Pearce (1983), trace elements show a pattern in which both the mobile elements (elements on the left side) and immobile elements (elements on the right side) increase towards the centre producing a humped structure. This also indicates that the parent magma was enrichment in mantle source and confirms its origin at a within-plate setting (Clague and Frey, 1982).

TECTONOMAGMATIC DISCRIMINATION DIAGRAMS

Geochemical data from the volcanic fragments is plotted in various tectonomagmatic discrimination diagrams to identify the paleotectonic setting of the volcanic and associated intrusive rocks from which these fragments were derived. A triangular plot (Fig. 16) involving Nb, Zr and Y trace elements

Table 1. Chemical composition of clasts of the volcanic conglomerate of the Bibai Formation.

Sample No.	TK-B1	TK-22	TK-23	TK-28	TK-29	TK-59	TK-64	TK-65	TK-80	TK-96	ST-111	TK-112	TK-A1	TK-25	TK-47	TK-70	TK-79
Major Elements, Wt%																	
SiO_2	59.35	52.92	47.79	55.16	55.26	48.05	46.26	49.36	65.39	56	43	45	49	47	69	41	43
TiO_2	1.234	0.685	2.004	0.289	2.104	2.131	2.52	2.188	0.415	2	0.8	2.6	2.1	3.8	1.2	4	2.6
Al_2O_3	17.42	21.32	17.94	20.52	13.43	16.55	16.86	15.49	17.24	15	7	12	17	13	15	13	15
Fe_2O_3	5.11	5.12	8.82	3.89	9.1	9.43	10.69	10.07	4.66	7.5	11	12	11	14	6.6	19	16
MnO	0.062	0.181	0.184	0.107	0.23	0.12	0.247	0.104	0.037	0.1	0.1	0.2	0.2	0.4	0.1	0.2	0.2
MgO	2.09	2.19	3.61	2.54	5.72	5.69	5	6.63	0.43	2.5	27	8.3	3.4	3.9	6.2	3.6	2.8
CaO	3.52	3.44	6.33	1.76	9.98	10.16	10.15	9.43	1.42	4.3	5.9	14	5.5	11	1.9	12	9.3
Na_2O	7.26	5.68	6.69	5.63	1.58	3.07	2.67	2.8	8.36	6.3	0.6	1.8	1.1	1.7	3.2	1.8	1.8
K_2O	0.92	4.66	1.53	5.3	1.02	0.68	2.43	0.38	0.93	1.1	0.3	1.2	4.2	2	1.8	2.2	3.6
P_2O_5	0.348	0.15	0.801	0.039	0.361	0.325	0.731	0.35	0.041	0.5	0.1	0.3	0.8	0.6	0.2	0.8	1.6
LOI	2.69	3.66	4.31	4.77	1.22	3.79	2.45	3.21	1.09	4.1	3.4	2.1	4.9	1.5	1.7	3.6	5.3
Trace Elements (ppm)																	
Nb	90	183	146	178	38	32	106	33	96	67	45	10	294	84	168	112	182
Zr	446	336	319	406	161	180	292	196	482	298	188	53	747	384	939	473	495
Y	27	29	23	33	19	20	28	21	24	27	19	12	N.A.	N.A.	N.A.	N.A.	N.A.
Sr	716	1745	1003	1423	666	666	1442	492	419	470	670	166	2877	1191	507	1732	2011
Rb	30	98	18	142	22	17	60	10	30	32	24	10	82	73	0	36	145
Zn	59	111	114	123	84	71	94	117	39	56	82	77	N.A.	N.A.	N.A.	N.A.	N.A.
Ni	27	30	58	8	154	116	22	113	11	25	196	1240	0	0	39	0	0
Cr	75	45	133	15	270	188	65	225	54	33	409	1751	N.A.	N.A.	N.A.	N.A.	N.A.
V	105	23	188	BDL	318	251	257	312	126	157	350	142	0	0	0	0	151
Ba	2819	1865	1015	1107	365	181	1166	780	2685	1091	608	93	N.A.	N.A.	N.A.	N.A.	N.A.
Cu	42	7	45	6	107	29	21	362	108	60	213	60	0	0	0	142	0
Co	12	10	36	BDL	54	43	30	39	BDL	21	54	108	N.A.	N.A.	N.A.	N.A.	N.A.
Ce	130	130	148	110	43	68	133	88	93	109	62	BDL	N.A.	N.A.	N.A.	N.A.	N.A.
Th	11	18	12	23	BDL	BDL	BDL	BDL	11	BDL	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Nd	59	55	46	44	28	21	45	27	24	30	33	8	N.A.	N.A.	N.A.	N.A.	N.A.
Ga	24	18	15	20	17	19	17	19	29	22	16	5	N.A.	N.A.	N.A.	N.A.	N.A.
U	BDL	5	BDL	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	N.A.	N.A.	N.A.	N.A.	N.A.

BDL; Below Detection Limit, **N.N.**; Not Analysed For, **0**; Calculated Zero

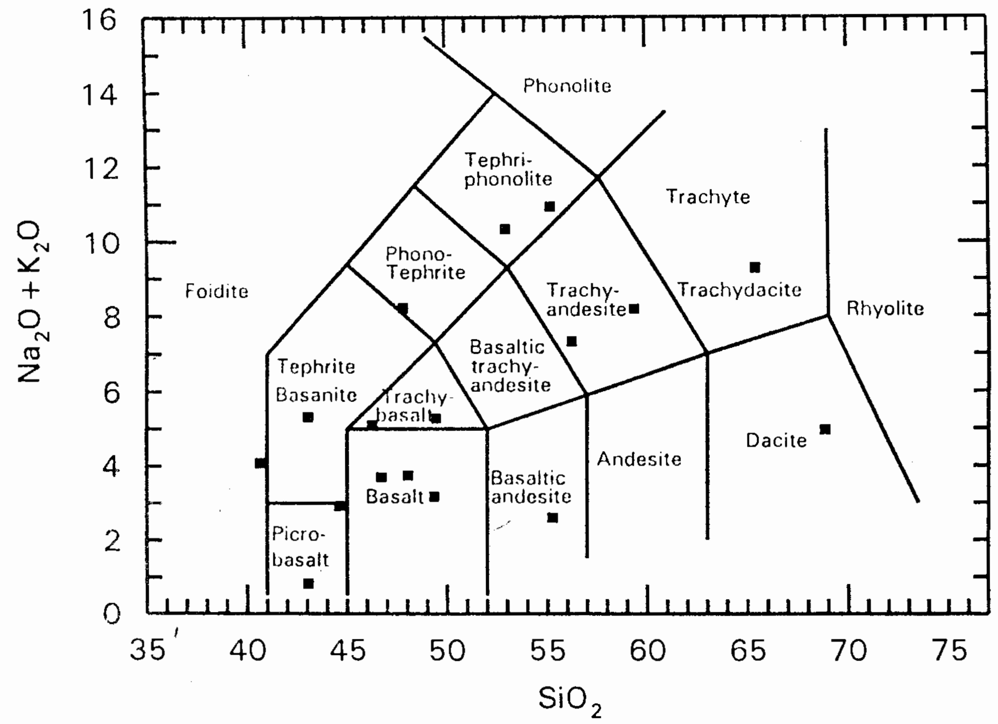

Figure 11. SiO_2 **versus** Na_2O+K_2O **plot for the volcanogenic conglomerate clasts of the Bibai Formation (after Le Maitre et al., 1989).**

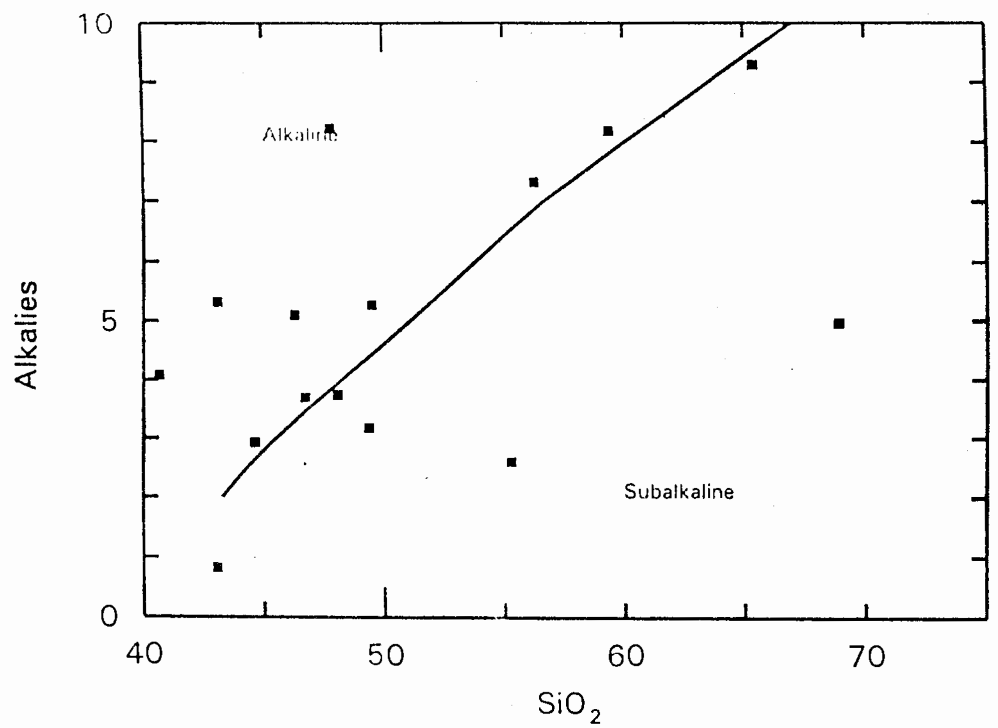

Figure 12. SiO_2 **versus** Na_2O+K_2O **plot for the volcanogenic conglomerate clasts of the Bibai Formation (after Irvine and Baragar 1971).**

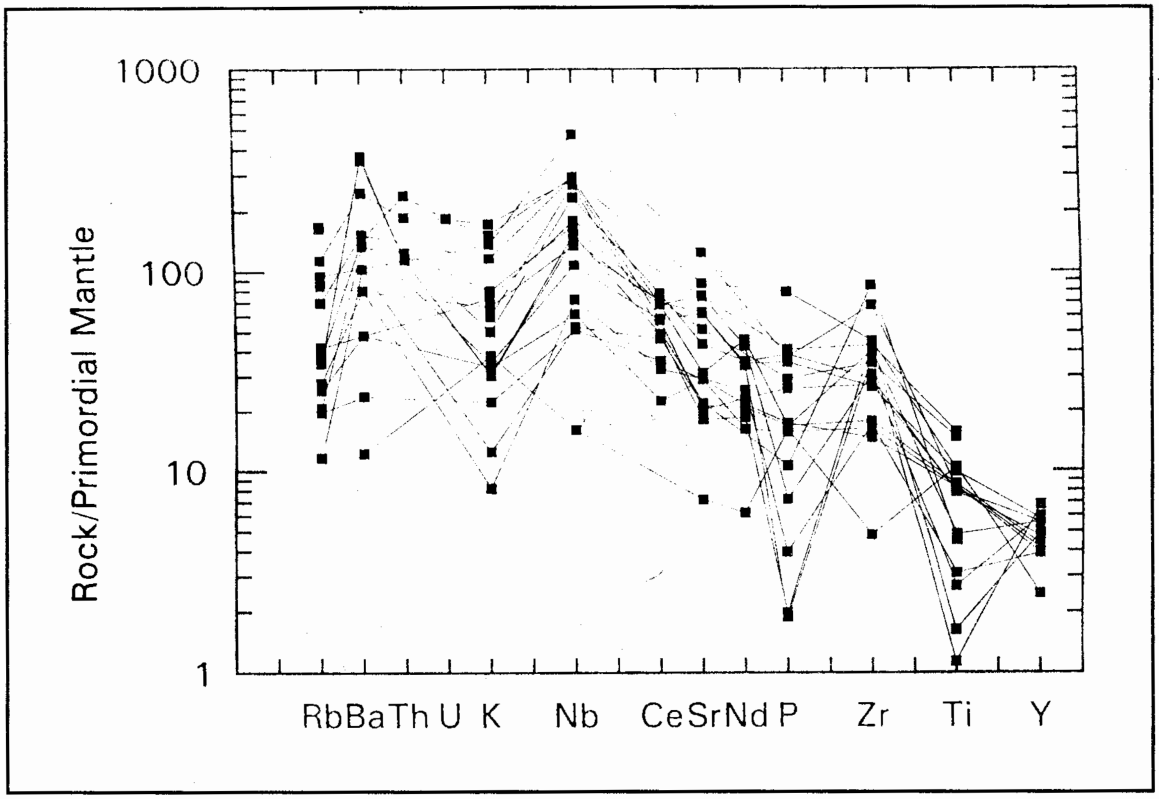

Figure 13. Primordial mantle normalized spider diagram for volcanogenic conglomerate clasts of the Bibai Formation (after Wood et al., 1979).

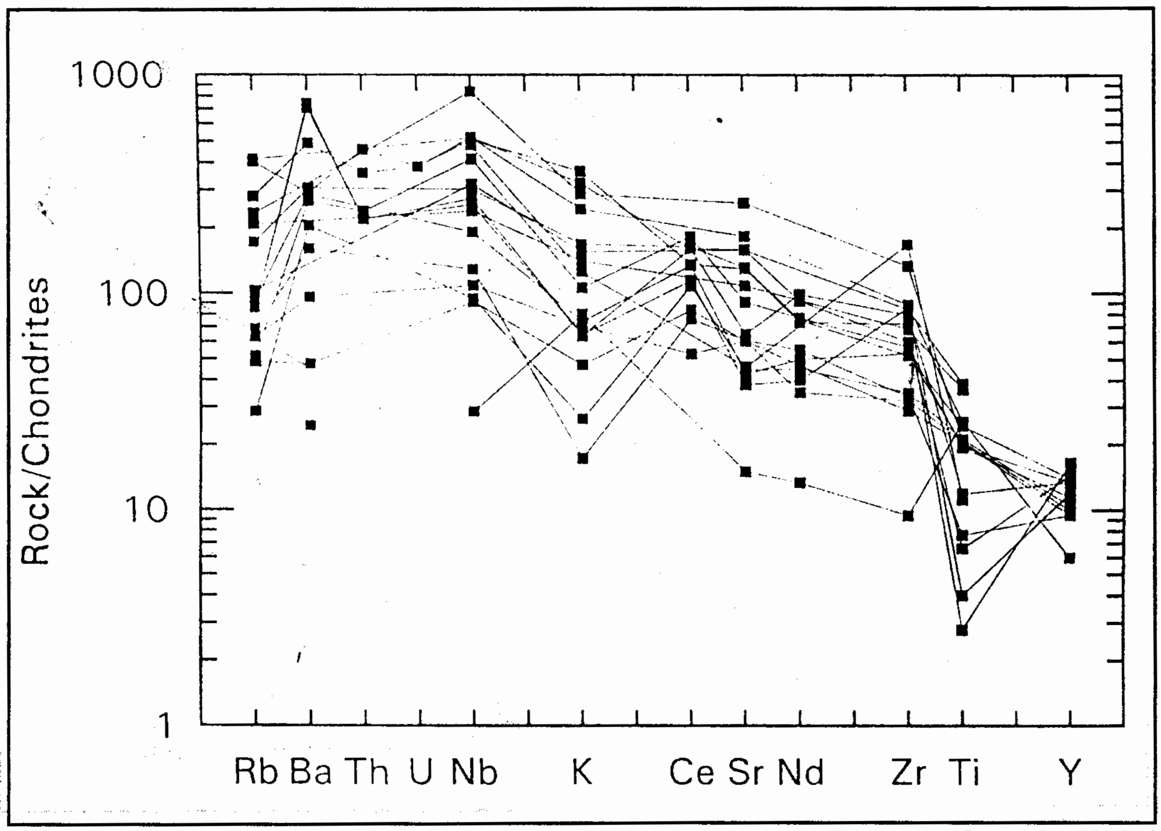

Figure 14. Chondrite normalized spider diagram for volcanogenic conglomerate clasts of the Bibai Formation (after Sun, 1980).

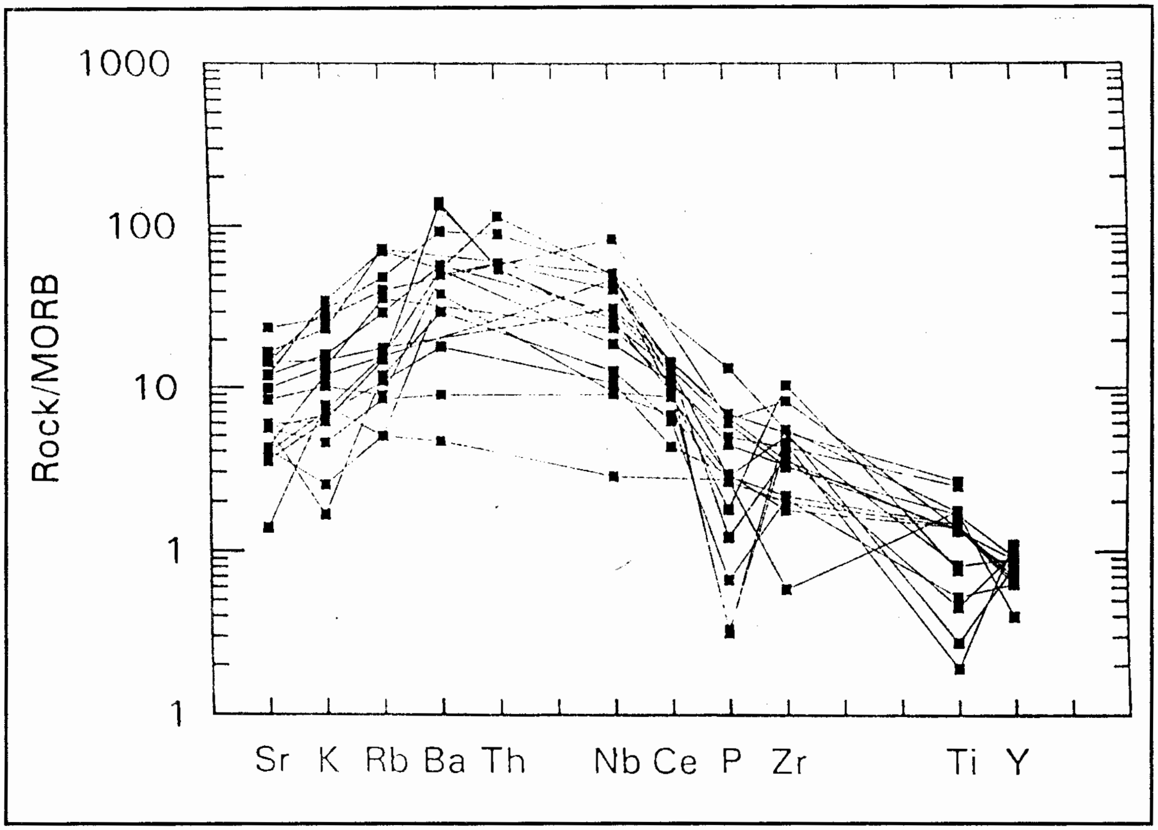

Figure 15. **MORB normalized spider diagram for volcanogenic conglomerate clasts of the Bibai Formation (after Pearce, 1983).**

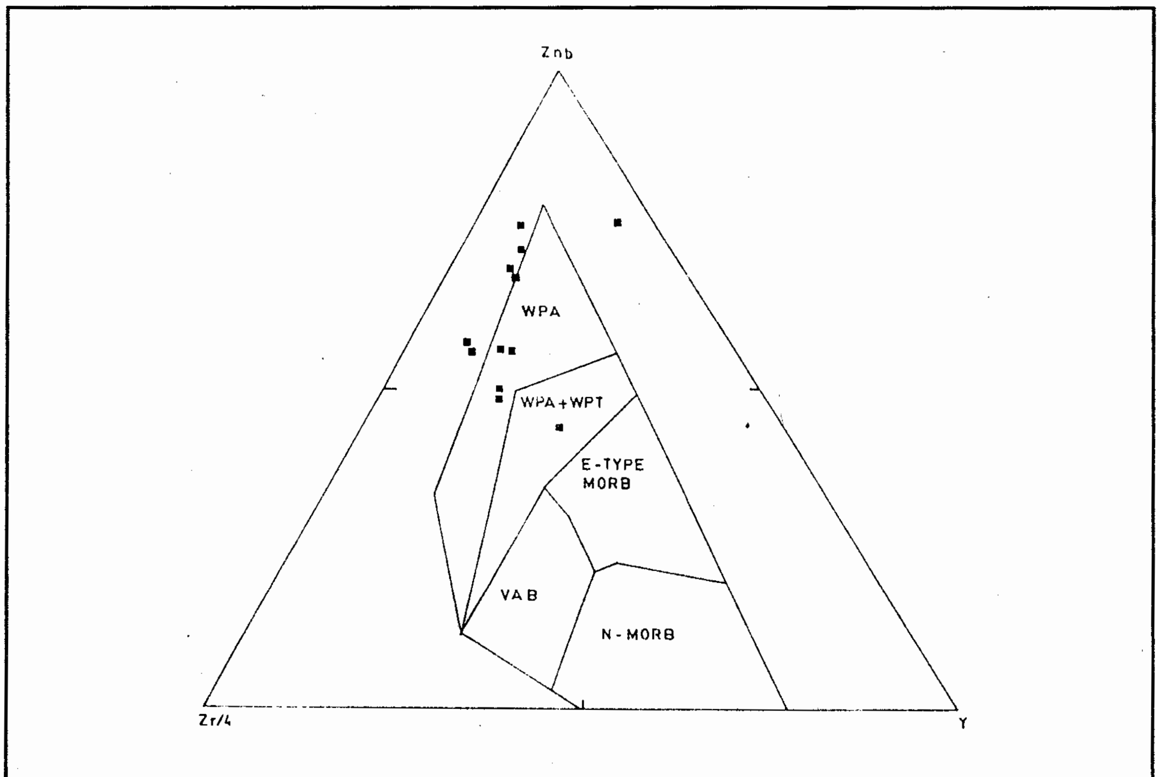

Figure 16. **2Nb-Zr/4-Y tectonomagmatic discrimination diagram for volcanogenic conglomerate clasts of the Bibai Formation (after Meschede,1986).**

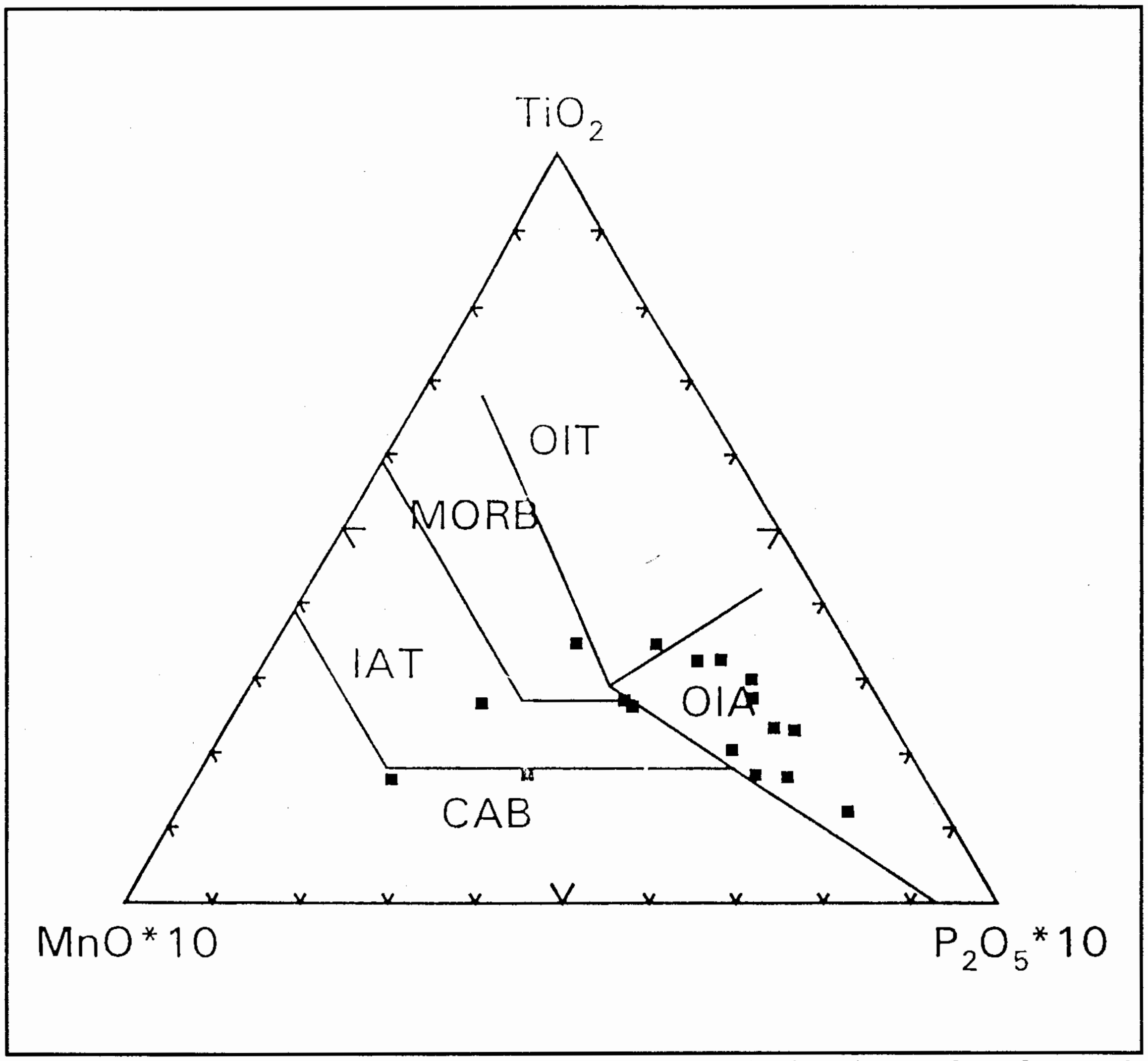

Figure 17. TiO_2 - MnO*10-P_2O_5*10 tectonomagmatic discrimination diagram for volcanogenic conglomerate clasts of the Bibai Formation (after Mullen, 1983)

(after Meschede 1986) shows that almost all samples fall within the field of within-plate alkali (WPA) basalt or close to this field, except one sample which falls in the combined field representing Within-Plate Alkali Basalt and Within-Plate Tholeiite (WPA+WPT). None of them fall in the field of Mid-Oceanic Ridge Basalt (MORB) and Volcanic Arc Basalt(VAB). Similarly, when the data is plotted in a triangular diagram (after Mullen 1983) with TiO_2, MnO and P_2O_5(Fig. 17), 12 out of 17 samples plot in the field of Ocean Island Alkali Basalt (OIA) and the rest in other fields which may be due to some contamination with crustal/country rocks.

All the plots of major elements and trace elements indicate that the volcanic and associated intrusive rock fragments of conglomerate of the Bibai Formation are alkalic in composition and have been derived from a hotspot related volcanic terranes.

DISCUSSION

PROVENANCE

The petrography and whole rock geochemistry of the volcanic conglomerate and associated sandstone indicate that sediments of the Bibai formation have been derived from a volcanic source area. Volcanims in general, occurs in diverse tectonic settings. The major ones are: (i) mid-ocean ridge volcanism, (ii) intra-plate ocean and continental volcanism and (iii) subduction related volcanism. Each one is characterised by a particular mineral assemblage and geochemical signature. Detailed petrography and geochemistry are important tools for the recognition of tectonic affinities of ancient volcaniclastic successions (Can and Wright 1987, Wilson 1989). However, petrographic and geochemical characteristics of

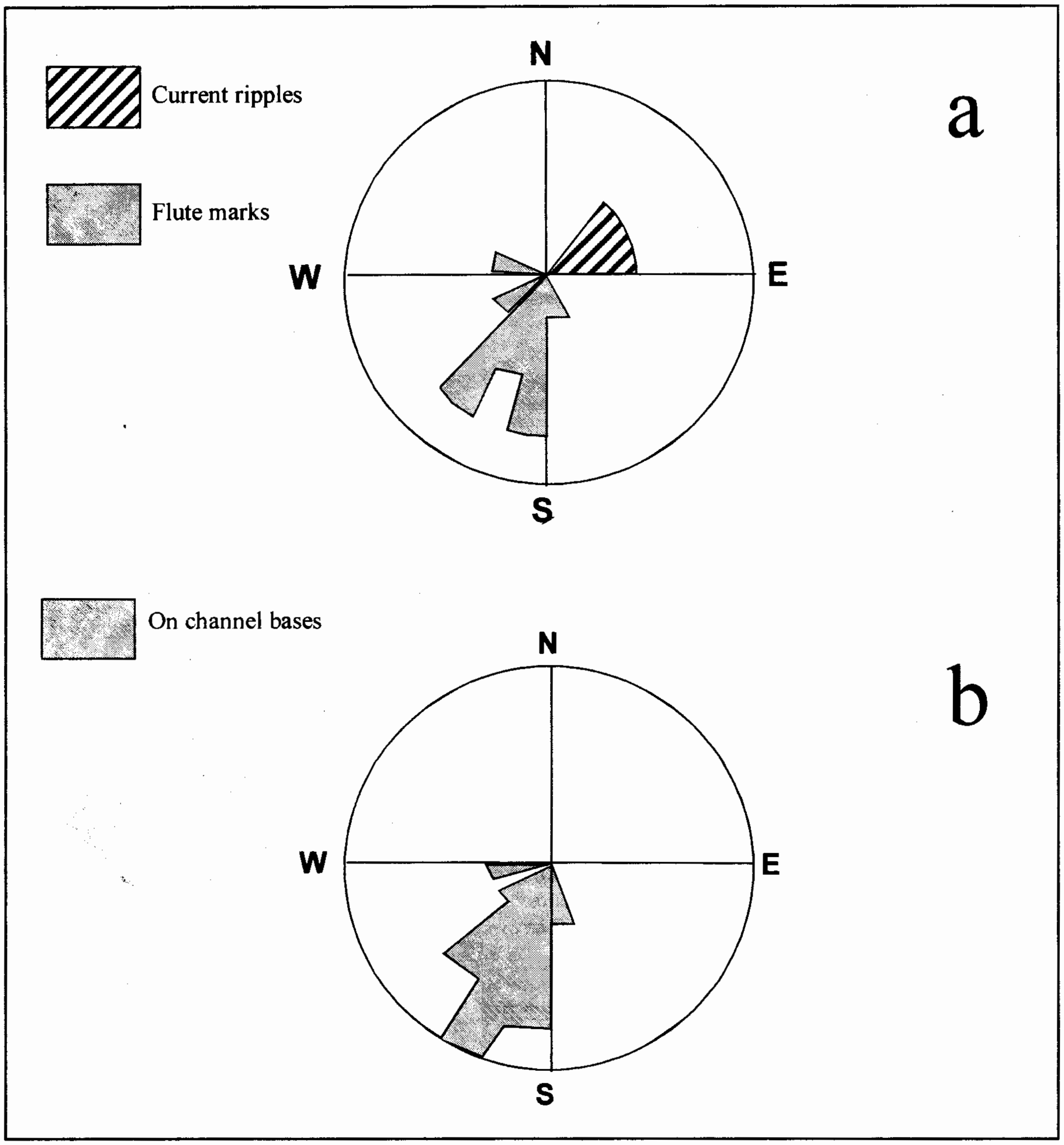

Figure 18. Comprehensive rose diagram of paleocurrent pattern; a) based on flute marks and current ripples within the SSMS facies; Scale: 2 cm = 1 reading; n = 12; b) based on longitudinal ridges and flute marks; Scale: 1cm = 4 readings; n = 83.

volcanic facies may be significantly influenced by post depositional processes which may hinder recognition of original composition and texture of the rock. Volcaniclastic sediments of the Bibai Formation are relatively fresh and less deformed and provide a reliable petrographic and geochemical data, in addition to paleocurrent data, to identify its provenance.

Geochemical data involving both major and trace elements have been used to identify source area and origin of the volcanic terrain. Data plotted in various classification diagram of Irvine and Baragar (1971) show that most of the clasts of the volcanic conglomerate were derived from an alkali volcanic source (Fig. 12). Trace elements data plotted in various spider diagrams (Fig. 13, 14 & 15) show that clasts are enriched in mantle source and tectono-magmatic discrimination diagrams (Figs. 16, 17) confirm that they originated in an intra-plate ocean tectonic setting.

Considering the paleocurrent directions (Fig.18), clasts of the volcanic conglomerate and sandstone were derived from north-northeast. Two different types of volcanic terrains are exposed northeast of the study area. One mostly tholeiitic (Siddiqui et al. 1996) and associated with

Muslimbagh Ophiolites. Emplacement of the Muslimbagh Ophiolites took place between 67 and 65 My (Sawada et al. 1995) which is later than the eruption of the Bibai Volcanics i.e. 71.4± 3.4 My (Sawada et al. 1995) and also not a single fragment of the ophiolites is present within the conglomerate of the Bibai Formation, therefore, the Muslim Bagh Ophiolites as a source area for the volcaniclastic sediments is unlikely. The other volcanic terrain "the Bibai Volcanics" have been interpreted by others as alkalic and of hotspot origin (McCormick 1985; Khan 1994; Siddiqui et al. 1996b). Hence it is proposed that the volcaniclastic sediments of the Bibai Formation were erived from the Bibai Volcanics to the north of the study area.

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ANNUAL REPORT
(1999)

NATIONAL CENTRE OF EXCELLENCE IN MINERALOGY, QUETTA

ACADEMIC STAFF

Director

Dr. Akhtar Mohammad Kassi, Professor of Geology, University of Balochistan has been given additional charge of the Director, C.E.M. The appointment of a permanent Director is still awaited. Dr. Kassi is Ph.D. from U.K. and has been teaching geology at the Department of Geology for the last 23 years.

		Date of Joining C.E.M.
Associate Professors		
Shamim Ahmad Siddiqui	*Ph.D. (U.S.A.)*	01-Jan-1998
Abdul Salam Khan	*Ph.D. (U.K.)*	01-Jan-1998
Javed Ahmad	*M.Phil. (University of Balochistan)*	01-Apr-1980
Khalid Mahmood	*Ph.D. (France)*	05-Nov-1989
Mohammad Ahmad Farooqui	*Ph.D. (U.S.A.)*	05-Nov-1989
Assisstant Professors		
Mehrab Khan	*Ph.D. (University of Balochistan)*	05-Nov-1989
Visiting Professors		
Syed Mobasher Aftab	*Ph.D. (Turkey)*	
Din Mohammad Kakar	*M.Phil. (University of Balochistan)*	

ADMIN./TECHNICAL STAFF

S. Shahabuddin	Administrative Officer	28-May-1977
Mirza Manzoor Ahmad	Accounts Officer	07-May-1980
Khushnood Ahmad	Senior Technician	13-Jul-1976
Abdul Ghafoor	Assistant Librarian	02-May-1985
Lal Mohammad	Superintendent	12-May-1973
Hussainuddin	Photographer	16-Jun-1981
Ghalib Shaheen	Stenotypist	17-Jul-1985
S.R. Mahjoor	Stenographer	06-Jun-1990
Ahmad Khan Mangi	Draughtsman	01-Jul-1981
Musa Khan	Laboratory Supervisor	20-Aug-1977
Sher Hassan	Store Keeper	22-Aug-1977
Mohammad Anwar	Assistant	18-Sep-1973
Juma Khan	Assistant	12-Jun-1985
Abdul Malik	Senior Clerk	28-Apr-1987
Manzoor Ahmad	Junior Clerk	26-May-1995
Ali Mohammad	Driver	17-Jul-1984
Saleh Mohammad	Driver	18-Aug-1990
Ghulam Rasool	Junior. Mechanic	20-Aug-1977
Mohammad Rafiq	Peon *(Naib Qasid)*	12-Oct-1978
Sikandar Khan	Peon *(Naib Qasid)*	30-Apr-1976
Atta Mohammad	Peon *(Naib Qasid)*	25-Mar-1986
Abdul Wadood	Chowkidar	26-Jan-1992
Nazir Masih	Janitor	01-Apr-1977

ACADEMIC ACTIVITIES

Mehrab Khan successfully completed his Ph.D. work on the *Petrological and Structural (Kinematic) Studies of the Igneous Rocks of Barabn Lak Area, District Bela and Khuzdar, Balochistan*, under the supervision of Abdul Salam Khan and Khalid Mahmood. His dissertation has been approved by the Committee for Advanced Studies & Research and the Syndicate of the University of Balochistan.

Abdul Tawab Khan also completed his research work for Ph.D. on *Sedimentology and Petrology of the Volcaniclastic Succession of the Bibai Formation (Cretaceous) District Ziarat, Balochistan,* under the supervision of Akhtar Mohammad Kassi and Abdul Salam Khan. His dissertation has also been approved by the Committee for Advanced Studies & Research and the Syndicate of the University of Balochistan.

By the end of December 1999, the C.E.M had two Ph.D. and fourteen M.Phil. students working on the following aspects of the geology of Balochistan:

Student	Supervisor	Co-Supervisor	Project Title
		Ph.D. PROJECTS	
Din Muhammad Kakar	Akhtar M. Kassi	Mohammad Ahmad Farooqui	Geology of the Tertiary Khojak Formation of Pishin, Muslimbagh and Chaghi Districts, Balochistan
Ghulam Nabi	Abdul Salam	Javed Ahmad	Petrography and depositional environment of Ghazij Formation (Eocene). Balochistan
		M. PHIL. PROJECTS	
Atif Saleem	Khalid Mahmood	Mehrab Khan Baloch	Nature of mafic intrusions in the mantle section of Saplai Tor Ghar Ophiolites related to mantle rocks, Muslim Bagh, Balochistan.
Ahmad Jan	Abdul Salam Khan	Jawed Ahmad	Sedimentological and structural studies of the coal bearing Ghazij Formation near Khost/Shahrig, Balochistan.
Khalil-Ur-Rehman	Mohammad Ahmad Farooqui	Akhtar Mohammad Kassi	Petrology and provenance of Paleocene (?) Ispikan Conglomerate, SW Makran and its implications on the tectonic evolution of Makran Region.
Mohammad Zahir Kakar	Mohammad Ahmad Farooqui	Din Mohammad Kakar	Depositional environment and Diagenesis of Lower Cretaceous Sembar Formation, Balochistan.
Syed Ashrafuddin	Mohammad Ahmad Farooqui	Mehrab Khan Baloch	Study of K-T Boundary in the western Sulaiman Foldbelt, Pakistan.
Mohammad Rahim Jan	Mohammad Ahmad Farooqui	--	Geology and mineral resources of part of Makran Coast, Balochistan.
Azhar Hussain	Mohammad Ahmad Farooqui	Khalid Mehmood	Petrology, stratigraphy and lithofacies analysis of Dungan Formation (Paleocene), Sulaiman Foldbelt, Balochistan.
Abdul Rahim Kassi	Abdul Salam	Mohammad Ahmad Farooqui	Facies distribution and environmental analysis of the Parh Group, Balochistan.
Shah Zaman Kakar	Javed Ahmad	Abdul Salam Khan	Facies analysis and reservoir properties of Chiltan Formation (Jurassic) northern Balochistan.
Khawar Sohail	Abdul Salam	Javed Ahmad	Petrology, sedimentology and diagenesis of (Mio-Pliesto) Hinglaj Formation, District Khuzdar and Bela Balochistan.
Hussain Buksh	Mobasher Aftab	Javed Ahmad	Hydrogeological investigations of Kalat Sub-Basin, Balochistan.

Student	Supervisor	Co-Supervisor	Project Title
Abdul Hadi	Mobasher Aftab	Mehrab Khan Baloch	Hydrogeological investigation of Pishin Sub-Basin Balochistan.
Arif Ali	Mobasher Aftab	Javed Ahmad	Assessment of groundwater budget of Mangocher Valley, Balochistan.
Mohammad Sarwar	Akhtar M. Kassi	Abdul Salam	Geology of the area west of Spera Ragha, District Ziarat, Balochistan.

Faculty members continued supervision of their research students. A number of students completed their field studies/work. Following field studies were carried out during 1999:

Research Supervisor	Student	Program of Study	Areas visited
Akhtar M. Kassi and Mohammad A. Farooqui	Din Mohammad	Ph.D.	Turbat, Gawadar, and Pasni areas of Makran (13).
Mohammd Ahmad Farooqui	Rahim Jan	M.Phil.	Makran coast between Gawadar and Ormara (35 days).
Mohammad Ahmad Farooqui	Azhar Hussain, Ashrafuddin and Mohammad Zahir	M.Phil.	Kach, Ahmadoon,Chappar Rift, Ziarat, Spera Ragha, Zhob, Mughal Kot, Murgha Kibzai, Mekhtar, Loralai and Harnai areas of Sulaimna Fold belt (15 days).
Abdul Salam and Jawed Ahmad	Ahmad Jan	M.Phil.	Shahrag and Harnai areas where coal bearing Eocene Ghazij Formation is extensively exposed (15 days).
Akhtar Mohammad Kassi and Abdul Salam	Mohammad Sarwar	M.Phil.	Area west of Spera Ragha, District Ziarat (30 days).

Khalid Mahmood continued working on the UGC-sponsored research projecton structural and textural characteristics of Muslim Bagh ophiolites for which he and Mehrab Khan (co-investigator) made 13 days visits to the Muslim Bagh area.

Akkhtar M. Kassi, Abdul Salam and M.A.Farooqui carried out 13 days fieldwork in the Mekran in connection with a project sponsored by University Grants Commission in February, 1999. The researchers are studying the Sedimentological and Structural Aspects of Selected Sites in the Makran Accretionary Belt.

Khalid Mehmood and Mehrab Khan participated in the Training Course on Instrumental Chemical Analysis of Rocks And Minerals (ICARM V) held at the Geoscience Laboratory, Geological Survey of Pakistan Islamabad.

Abdul Salam started to study the Foreland Basin sediments of the Kirther Foldbelt near Khuzdar and spent 10 days in the field collecting samples and measuring sections. This project is sponsored by Pakistan Science Foundation.

Shamim A. Siddiqi, Jawed Ahmed and A.M.Kassi attended series of lectures on Sedimentology delivered by Dr. H.G. Reading of University of Oxford. The lectures were organized by the Department of Geology, University of Sind, Jamshoro.

A.M. Kassi, M.A.Farooqui, and Abdul Salam participated in the Sequence Startigraphy and Clastic Systems Workshop organized by the National Centre of Excellence in Geology, University of Peshawar. A.M. Kassi and M.A.Farooqui also presented papers (case studies) during the workshop on Allozai Turbidite (Triassic), Bibai Turbidites (Cretaceous) and Upper Creataceous-lower Paleocene stratigraphy between Quetta and Spera Ragha areas.

M.A.Farooqui and Shamim Ahmed Siddiqi have initiated a joint research Project with Pakistan Council for Scientific and Industrial Research (Quetta) Laboratories, to investigate and explore the industrail utilization of Nickel deposits associated with Muslim Bagh and Zhob Ophiolites.

Abdul Salam has been awarded the postdoctoral fellowship by the Commonwealth Organization for the year 1999-2000. He plans to study the sedimentology of Upper Cretaceous Pab Sandstone, Kirther

Foldbelt Pakistan during this fellowship.

The University of Balochistan has approved the admission of six more students in the M.Phil. programme of the Centre of Excellence in Mineralogy for the session 1999-2001. Some of the new students have already completed the process of registration whereas others are planning to do so after winter vacation in March-April 2000.

Student	Supervisor	Co-Supervisor	Project Title
Muhammad Umar	Abdul Salam	Akhtar M. Kassi	Sedimentological studies of Upper Cretaceous Pab Sandstone, Kirther Fold Belt Balochistan.
Abdul Razzique	Shamim Ahmed Siddiqi	--	Copper mineralization in Chaghi metallogenic province, Balochistan.
Muhammad Ishaq	Mehrab Khan Baloch	Khalid Mehmood	Metamorphic rocks associated with Muslim Bagh Ophiolites, Balochistan.
Mushtaq Ahmad Pathan	Khalid Mehmood	Mehrab Khan Baloch	Origin and mode of occurrence of chromites in the mantle section of Muslim Bagh Ophiolites..
Hafeez-ur-Rehman	Shamim Ahmed Siddiqi	--	Copper mineralization around Koh-e-Dalil in Chaghi metallogenic province, Balochistan.
Razzak Abdul Manan	Shamim Ahmed Siddiqi	--	Iron ore deposits of Dilband area, Kalat.

Correction

Figure 1 of Khan et al., (1998) could not be printed correctly as some of the computer generated graphic symbols in the geological map were not recognizable after printing. Therefore, the same figure is reproduced here in correct form. Readers are requested to please use this figure instead of the one which was published on page 28 of Acta Mineralogica Pakistanica. Vol. 9, 1998.

Reference

Khan, M, Gnos, E., Khan A. S. and Mahmood, K. (1998) Genetically two different types of basaltic rocks from Bela Ophiolite Balochistan, Pakistan; Acta Mineralogica Pakistanica, vol. 9, p. 27-36.

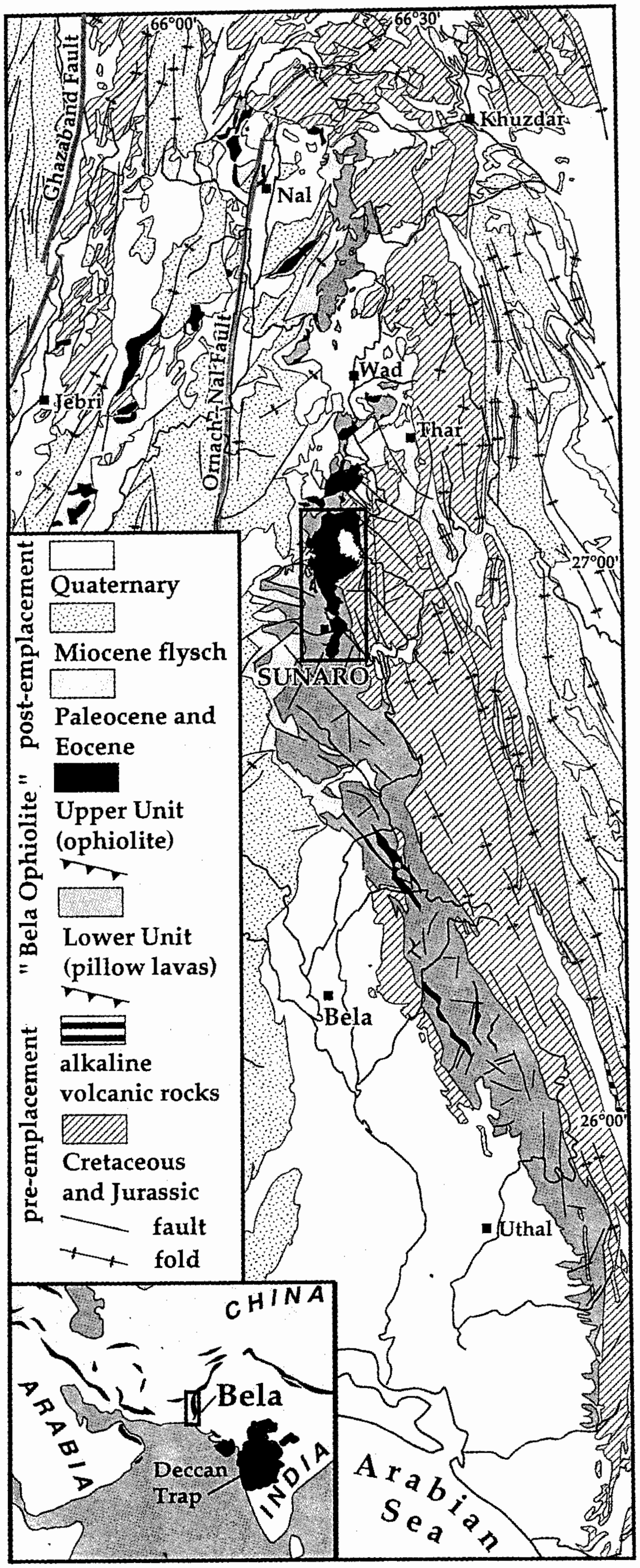

Figure 1. Overview map of the Bela oceanic lithosphere asemblage based on Hunting Survey Corporation (1960), Ahsan et al. (1988) and Gnos et al. (1998).

INSTRUCTIONS FOR AUTHORS

Send three unbound copies, not stapled, of the complete manuscript to Editor *Acta Mineralogica Pakistanica*, Centre of Excellence in Mineralogy, University of Balochistan, Quetta Pakistan, along with a computer disk. Create and format your document in WordPerfect 5 or higher (for windows), or MS Word, however, manuscripts saved in any major wordprocessor will also be accepted. Mark the computer disk with the name of the principal author, abbreviated title of the paper, name of the file and the software in which the document was created. We will not retype manuscripts! Except for minor editing, content will be printed as it is received on computer disk or returned to be redone if required. **Please note that manuscripts received without a computer disk shall not be considered for publication.**

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