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CONTENTS

PETROLOGY OF LOWER SIWALIK SANDSTONES OF THATI AREA, KHUSHAB DISTRICT, PUNJAB, PAKISTAN

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Abstract : *Nearly 1300 metres thick sequence of Lower Siwalik rocks of Miocene-Pliocene age is exposed in the Thati area, Khushab district. This sequence has been differentiated into Kamlial and Chinji Formations for the purpose of petrological studies. The sandstones of these formations have be n studied lithologically, petrographically and chemically. The evidences suggest that the sediments of Lower-Siwalik formations were derived from igneous, metamorphic and sedimentary rocks of Northern Pakistan and were deposited in a shallow fast sinking basin, under condition of rapid erosion, short transportation and rapid deposition. It is also suggested that at about 11 m. y. B. P., blue green hornblendes appeared in the Siwalik channel sands. Percentage of blue green hornblende increases upwards.*

INTRODUCTION

This paper is based on the data collected by the author from Thati area during 1984-85 field season, in collaboration with P & S branch of the Geological Survey of Pakistan, Quetta and USA. study groups.

The investigated area is bounded by latitudes 32° 40′ and 32° 45′ N ; longitudes 72° 15′ and 72° 30′ E, covered by Survey of Pakistan topographic sheet No. 43 D/6 and is a part of Attock and Khushab districts of the Punjab Province.

The various aspects of the Siwalik formations of the Thati area has been studied by a number of workers (Gee, 1980 ; Fatmi, 1973 ; Barndt, Johnsons, Tahirkheli and others, 1978 ; Stir, 1982 ; Abid and others, 1983 ; Brannon, 1983 ; Gronseth, 1983 ; Raza, 1983, unpub ; Sheikh and Shah, 1984 ; and Johnson, Tahirkheli and others, 1985), but no detailed petrological account is available in literature. In order to fill this gap, detailed petrological studies of the sandstone specimens were carried out.

The paper in hand contains petrological studies of the Lower Siwalik sandstones. However, the work on the Middle and Upper Siwalik formations will be published separately.

GEOLOGICAL SETTING

A sequence about 1300 metres thick of the Lower Siwalik formations is exposed in the southern part of the investigated area, whereas central and northern part is covered by the Middle Siwaliks, nearly 2000 meters thick. On the basis of lithology the Lower Siwalik rocks are divided into Kamlial and Chinji formations and Middle Siwalik rocks into Nagri and Dhok Pathan formations. Nagri Formation is mainly covered by a thick mantle of alluvium. Chorgali Formation is exposed in the south-eastern part of the area.

The Siwalik formations of the study area comprise sandstones, clay/claystones and conglomerates. The sandstones are grey and greenish-grey, medium grained, moderately sorted, medium to thick bedded, medium hard to soft and calcareous. Interbedded clays are reddish, reddish brown and orange brown. Generally the sandstones are tough to moderately compacted rocks, forming strike ridges, whereas the clays are relatively loose and soft, resulting in strike valleys.

Structurally the area is very simple. The Siwalik sequence of the investigated area is the southern limb of a broad syncline. No major fault is present. The beds have low dips, ranging from 10—15° north.

The sandstone beds are 2 to 25 meters thick, and contain concretions and coarse pebbles at some places. Cross bedding is also seen. On the mineralogical basis, the sandstones of the Thati area are classified as subgreywackes.

TABLE 1

Stratigraphic sequence of Thati area

	Alluvium	Recent
	—Unconformity—	
	Loessic clays & sand	Sub Recent
	—Unconformity—	
Upper Siwalik	Soan Formation	Early Pleistocene
Middle Siwalik	Dhok Pathan Formation	Middle Pliocene
	Nagri Formation	Early Pliocene
Lower Siwalik	Chinji Formation	Late Miocene
	Kamlial Formation	Middle to Late Miocene
Chharat Group	Murree Formation ?	Early to Middle Miocene
	Chorgali Formation	Early Eocene

PETROGRAPHY

Texture

The sandstones of the Lower Siwalik formations in the Thati area are grey to greenish grey, medium to fine grained, hard, compact, well-indurated and subangular to sub rounded. The grains are mostly quartz, rock fragments, chert, quartzite, felspars, micas, hornblende, epidote and tourmaline. Cement is composed of calcite/dolomite, sericite, clay and very small grains of the above minerals.

Mineral Composition

Quartz occurs as medium to fine grained, subangular to sub-rounded Some small quartz grains also occur in the cement. In the chert fragments quartz is fine grained, but in the quartzite fragments it is medium grained. Some grains have inclusions of muscovite and opaque minerals. Some quartz grains are milky but most of them are transparent. Some grains also exhibit good crystal faces. 22%—43%; X=34%.

Rock fragments are medium to coarse grained, subangular to subrounded but some are also angular. The fragments are igneous, metamorphic and sodimentary. Igneous rock fragments include andesitic, basaltic, and acidic fragments. Whereas, metamorphic are low grade regional metamorphics, like phyllites, schists and quartzites. The sedimentary rock-fragments are mostly of chert, quartzite, shale, limestones & dolomite. Quartzite / chert fragments =08% – 11% ; X=8.5%. Other fragments = 02% – 09% ; X = 05%.

K-feldspar occure both as microcline and orthoclase. They are medium-grained, sub-angular to subrounded, moderately altered to sericite and clay. Small K-feldspar grains also occur in some volcanic fragments.

Plagioclase occurs as individual grains as well as in volcanic rock-fragments. Some grains show alteration to clay and sericite. Some plagioclase grains have inclusions of orthoclase/microcline. Feldspars are 1.5 – 3.5%; X=2.5.

Calcite/dolomite are very important constituents of matrix/cement. They occur mainly as precipitated matter, but clastic carbonate grains are also present. 25% – 50% ; X=35%.

Muscovite/biotite/sericite occur as fine to very fine anhedral grains in the cement. Muscovite and biotite occur as small flakes and long laths and also as coarse flakes. Biotite flakes show moderate pleochroism from brown to yellow brown. Sericite is closely associated with clay and as an alteration product of feldspar. Clay occurs predominently in the matrix, which is extremely fine grained. Muscovite and sericite are 01% – 8.5% ; X=03% and biotite is 01% – 3.5% ; X=02%.

Chlorite occurs as small individual flakes and as small aggregates. It is green, poorly pleochroic and shows anomalous inter-ference colours.

TABLE 2

Petrographic Composition of Lower Siwalik Sandstones

Locality :- Lat. 32° 40′ N ; Long. 72° 22′ 30″ E Chinji — Thati Area,
& Lat. 32° 43′ N ; Long. 72° 28′ 30″ E Khushab District

Sample Nos.		Kamlial Formation				Chinji Formation			
		K1	K2	K3	K4	C1	C2	C3	C4
Quartz	...	22%	34%	36%	43%	42%	40%	32%	23%
Feldspar	...	02.0	02.5	03.5	02.0	01.5	03.0	02.8	02.5
Calcite/Dolomite		50.0	32.0	33.0	26.0	25.0	26.0	40.0	48.0
Rock Fragments		04.0	09.0	07.5	05.0	04.0	02.5	03.0	06.0
Quartzite / Chert-Fragments	...	08.5	11.0	09.5	11.0	09.0	08.0	08.3	09.3
Hornblende	...	00.5	01.0	00.5	00.2	00.3	00.8	01.0	01.5
Tourmaline		00.3	00.5	00.1	00.2	00.3	00.2	00.5	00.3
Garnet		00.2	00.5	00.2	00.5	00.2	00.5	00.3	00.5
Epidote	...	00.3	01.0	00.3	01.0	02.0	01.0	01.0	01.5
Rutile	...	00.2	00.2	00.3	00.1	Tr.	00.1	Tr.	00.2
Muscovite/Sericite		05.0	01.8	01.0	03.0	08.5	01.0	02.2	01.5
Biotite	...	03.0	01.2	01.5	01.0	03.5	01.8	02.3	01.0
Chlori e	...	00.3	00.4	01.0	00.5	00.6	00.9	05.0	02.4
Iron Ore	...	02.4	04.5	04.4	06.0	04.0	06.7	05.0	04.2

Analysis at G.S.P. Labs by M.S. Bajwa.

Blue-green hornblends occurs as fine to medium grained, angular to subangular individual grains and show moderate pleochroism.

Epidote occurs as anhedral to subhedral grains, light green, showing anomalous colours. Some small epidote grains are also present in volcanic rock fragments.

Tourmaline occurs as green and black, medium to fine grained, subangular randomly distributed grains, which show moderate pleochroism from brownish green to dark greenish-brown.

Garnet is colourless to light pink, fine to medium grained, subangular to subrounded grains. It is also present in the cement.

Rutile is red, fine grained, angular to subangular. It is found only as trace in the cement.

Hematite / limonite are very intimately associated. They are brown to yellowish-brown in the reflected light and occur as stains, thin streaks and veins in the zone of weathering, as well as in the cement.

Magnetite/ilmenite occur as small individual grains and aggregates. The grains are black and opaque and show metallic silvery lustre in the reflected light.

It is evident from the mineral analysis (Table 2) that percentage of quartz (including quartzite and chert) is 31% at the base of Kamlial Formation (sample No. 197), increased systematically and reached 54% at the top of Kamlial Formation (sample No. 203). At the base of Chinji-Formation it is 49% (sample No. 205), then it starts decreasing and reaches 32% at the top of Chinji Formation (sample No. 211). Calcite/dolomite is 50% at the base of Chinji Formation (sample No. 197), it decreases towards the top of Kamlial and base of Chinji Formations (26%-25% in the sample Nos. 203 & 205), then it again increases towards the top of Chinji Formation (48% in sample No. 211). Rock fragments (excluding quartzite and chert) range from 4% – 9% in Kamlial Formation and 2.5 – 6% in Chinji Formation. Feldspars range from 2% – 3.5 in Kamlial Formation and 1.5 – 3% in Chinji Formation. Heavy minerals (excluding iron ranges from 1.4 – 2% in Kamlial Formation and 2.8 – 4% in Chinji Formation. Blue-green hornblende, among heavy minerals ranges from 0.2 to 1.0% in Kamlial Formation and 0.3 – 1.5% in Chinji Formation. It shows an increase towards the younger side. Iron ores ranges from 2.4 – 06% in Kamlial Formation and 0.4 – 6.7% in Chinji Formation.

CHEMISTRY

Eight samples of Lower Siwalik sandstones (four samples of Kamlial Fm. and four of Chinji Fm.) of Thati area were chemically analysed. The percentages of major minerals of different sandstone samples were calculated from the results of chemical analyses (Table 3).

Sample No. 197, basal part of Kamlial Formation contains 31% quartz ; 46% calcite ; 2.5% dolomite and 2% iron ore. Sample No. 199 : 44% quartz ; 24% calcite ; 5.5% dolomite and 4% iron ore. Sample No. 201 ; 45% quartz ; 23% calcite ; 6.7% dolomite and 4.4% iron ore. Sample No. 203, upper part of Kamlial Formation 55% quartz ; 6% calcite ; 3% dolomite and 6% iron ore. Sample No. 205, basal part of Chinji Formation : 50% quartz ; 20% calcite ; 5.5% dolomite and 4.2% iron ore. Sample No. 206 : 47% quartz ; 13% calcite ; 9.7% dolomite and 7% iron ore. Sample No. 209 : 40% quartz ; 30% calcite ; 8% dolomite and 5% iron ore. Sample No. 211, upper part of Chinji Formation : 3:% quartz ; 45% calcite ; 4.2% dolomite and 4% iron ore.

It is apparent that percentage of quartz increases gradually towards the middle part of the Lower Siwaliks (50-55%), then it starts-decreasing towards the upper part and reaches 33% in sample 211. The percentage of calcite/dolomite is 48% at the basal part of Lower Siwaliks, decreases gradually towards the middle part (9%) and then increases gradually towards the upper part and reaches 40% in the sample No. 211.

TABLE 3

Chemical Composition of Lower Siwalik Sandstones

Locality :- Lat. 32° 40′ N ; Long. 72° 22′ 30″ E & Lat. 32° 43′ N ; Long. 72° 28′ 30″ E — Chinji — Thati Area, Khushab District.

		Kamlial	Formation			Chinji	Formation		
Sample Nos.		K1	K2	K3	K4	C1	C2	C3	C4
SiO_2	...	32.14%	45.22%	46.36%	55.74%	50.84%	48.00%	41.12%	33.96%
Fe_2O_3	...	02.39	03.59	04.38	06.05	04.19	06.69	04.83	04.25
Al_2O_3	...	11.61	15.01	16.42	16.25	13.01	13.61	11.27	08.75
CaO	...	25.79	13.45	12.89	03.36	11.21	07.29	16.82	25.23
MgO	...	01.20	02.62	03.22	01.41	02.62	04.63	03.83	02.01
L/I	...	24.28	15.80	16.18	06.95	13.08	12.16	19.04	24.30

(Samples analysed by Mr. Azhar Khan, at the G. S. P. Labs.)

PROVENANCE AND ENVIRONMENTS OF DEPOSITION

Siwalik sedimentation in the Thati area started at 18.3 m. y. B. P. and continued until 7.9 m. y. B. P., extending for about 10.4 m. y. Deposition of Kamlial Formation occurred from 18.3 to 14.3 m. y. B P. and Chinji Formation from 14 3 to 10.8 m. y. B. P. (Johnson, Tahirkheli and others, 1985).

Siwalik deposition in the Thati area was associated with a river system which flowed essentially from west to east (Johnson, Tahirkheli and others, 1985).

Presence of igneous, metamorphic and sedimentary rock fragments ; chert and calcareous cementing material indicate igneous, metamorphic, and sedimentary provinances.

Low textural and mineralogical index of maturity of sediments favour high relief and humid climate of the provinance (Farshori, 1966).

Presence of calcite/dolomite as detrital grains is an indication of rapid erosion, short transportation and rapid deposition, due to high relief of the source rocks. Subangular to subrounded mineral grains also indicate short transportation.

High percentage of the heavy minerals attribute to basaltic and metamorphic parent rocks. The unaltered grains of most of the heavy minerals is an indication of break down of parent rocks by mechanical disintegration of the rocks in the deeply incised canyon (Farshori, 1966).

The sandstones are classified as subgreywackes. These are immature product of denudation. Sedimentation of this type may be termed as paralic, which took place when the last phase of Himalayan movement had begun (Farshori, 1966).

The rates of Siwalik sedimentation increased systematically over time from 0.12 to 0.30 mm/yr. in the Thati area. A prominent increase in sedimentation rate occurred at about 11 m. y. B. P. Simultaneously blue green hornblendes also appeared in the Siwalik channel sands. These events are connected with the initial uplift of the Nanga Parbat region and the associated erosion of the ultramafic rocks in northern Pakistan (Johnson, Tahirkheli and others, 1985). It is observed that the percentage of blue-green hornblende increased towards the younger strata.

The author supports the view that the Siwalik sedimentation in the Thati area started at about 18 m. y. B. P. and continued until about 8 m. y. B. P., extending for about 10 m. y. B. P. The rates of sedimentation increased systematically over time from 0.12 to 0.30 mm/yr. Prominent increase in sedimentation rate occurred at about 11 m. y. B. P. and at this time blue green hornblendes appeared in the Siwalk channel sands and its ratio increases towards the younger strata.

The sandstones are of subgreywacke type and have igneous metamorphic and sedimentary provinances. The constituents of these sandstones were derived from igneous, metamorphic and sedimentary rocks of Northern Pakistan and were deposited in a shallow fast sinking basin, after their short and rapid transportation from the high reliefed source rocks.

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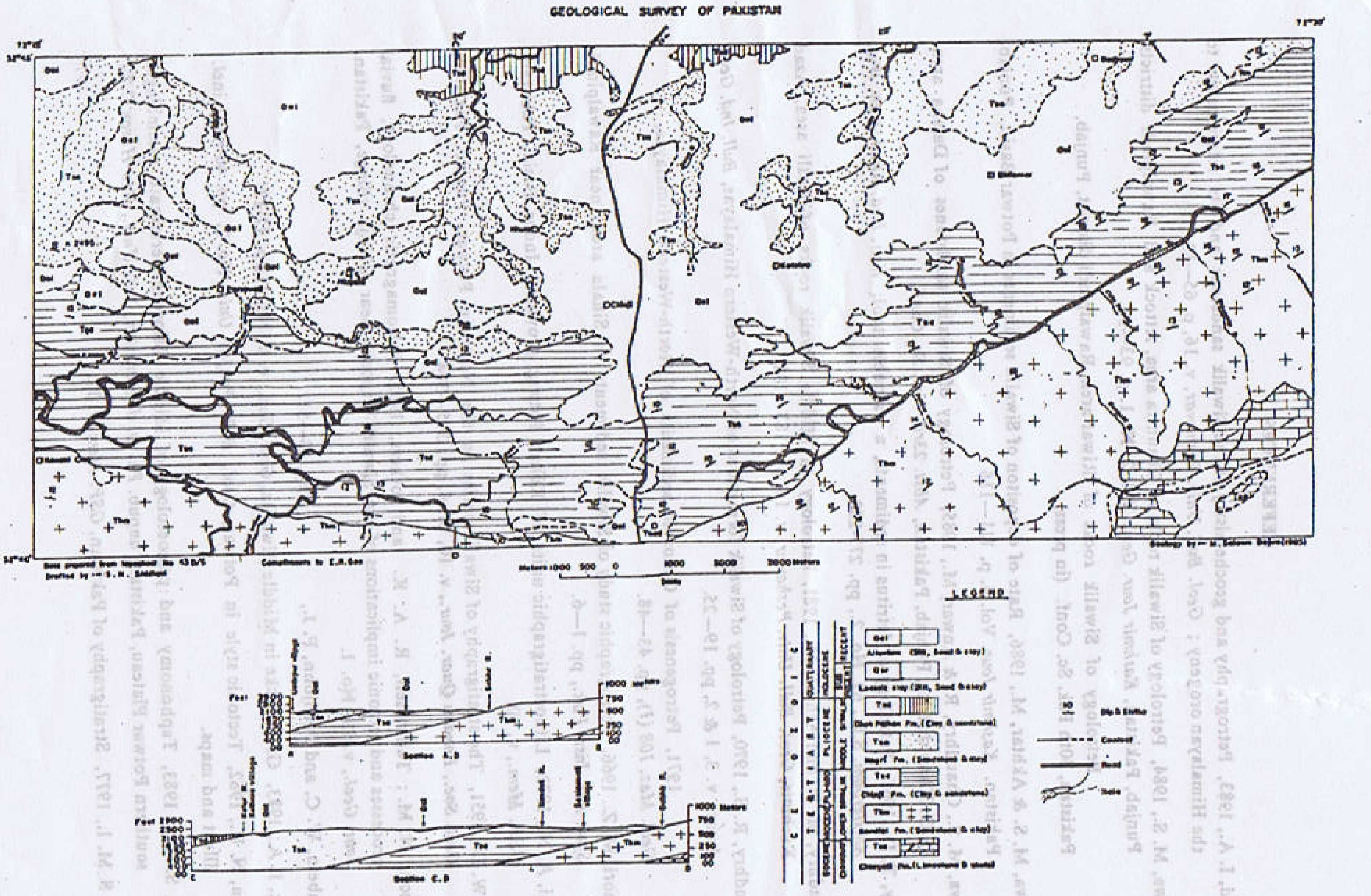

GEOLOGICAL MAP OF CHINJI AREA, ATTOCK AND KHUSHAB DISTRICTS PUNJAB, PAKISTAN.

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REPORTING MCT IN NORTHWEST HIMALAYA, PAKISTAN

BY

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Abstract : *Work in Neelum Valley, Azad Kashmir and Kaghan Valley has now made it possible to locate the Main Central Trust, MCT, in Northwest Himalaya. Geological mapping and investigations in the two valleys indicate that the MCT extends in a NE-SW direction between Luat in Neelum Valley and Batal (South of Naran) in Kaghan Valley crossing the Kaghan watershed near Thod Bhaik. There is a marked difference in the tectonic style, stratigraphy and metamorphism north and south of this line. This difference compares well with that reported from India. This discovery of M.C.T. in Pakistan now, for the first time, enables us to compare and tentatively extend the tectonic zones of Central Himalaya in India into Northwest Himalaya in Pakistan.*

INTRODUCTION

The Kumaun Himalaya and the part of Northwest Himalaya around the vale of Kashmir compared to extreme western Himalaya have received the attention of a much larger number of geological workers in the past few decades. As a result there has now emerged a much better clarity regarding the stratigraphy, structure and tectonics of those parts of Himalayas. On the other hand the part of Northwest Himalaya falling in Pakistan or Azad Kashmir received the attention of geological workers only more recently especially since the upsurge of interest in tectonics in seventies consequent upon the advent of the concept of plate tectonics. Because of this paucity of field and ground information researchers with regional geological interests have found it difficult to extend the geologic and tectonic trends coming from Eastern Kashmir into western Kashmir and Pakistan. The Westward continuation and extension of Indus Suture posed one such problem. This was resolved in the seventies by the demarcation of at least two major suture zones MMT and MKT in the western part of Northwest Himalaya, Karakoram and Hindu Kush (Shams 1972, Tahirkheli et al. 1979, Bard et al 1980, Chaudhry et al. 1984, etc.). Since then a westward bifurcation of the Indus Suture in Pakistan has come to be accepted.

As regards the westward continuation of MBT both Murree Fault and Panjal Fault have been traced right around the Hazara Kashmir syntaxis in Kaghan valley. Although the relative displacement along these faults is a disputed matter their presence around the syntaxis is not.

The westward extension into Azad Kashmir and Pakistan of the Main Central Thrust, MCT, running along the southern margin of the Central Crystalline Axis, CCA, however has continued to pose a challenge uptil today. Various workers have tried to connect the M.C.T. trend from India and Eastern Kashmir with Panjal Fault, Murree Thrust (MBT), and even with the Main Mantle Thurst, MMT Others, more appropriately, have left the matter as unsettled.

Work by the present writers in Neelum Valley (Ghazanfar, Baig and Chaudhry 1983) and later in Kaghan Valley (Ghazanfar and Chaudhry 1985, Chaudhry and Ghazanfar 1986) has now made it possible to demarcate the Main Central Thrust, MCT, in Pakistan. In 1983 and in 1985 (op cit) we marked two segments of this MCT, as separate faults, Luat Fault in Neelum Valley and Batal Fault in Kaghan Valley. This work has revealed that there is an analogous relationship between the tectono-stratigraphic blocks north and south of these faults in Neelum and Kaghan Valleys. The tectonostratigraphy and NW-SE trend of both Batal and Luat faults confirm a continuation of this tectonic scar right across the great Kaghan watershed separating the two parallel Neelum and Kaghan Valleys. Further east the MCT, then enters Eastern Kashmir, an area under Indian control.

Tectonostratigraphy in Kaghan Valley

Two radically different geological terrains occur on two sides, north and south, of Batal Fault in Kaghan Valley. The Batal fault is a northeast dipping high angle fault with a NW-SE extension. It traverses the Kaghan Valley main road close to the mouth of Batal Katha. Towards northwest, it passes close to Barthi and Sangal and crosses the Nili Nadi south of Chhalayyan. Southeastward it moves along Batal Katha and then apparently passes close to Manur peak and Mahlika Parbat peak—until it crosses the Kaghan watershed near Thod Bhaik.

Ghazanfar and Chaudhry, 1985, grouped the rock units occurring north and south of the Batal fault into two separate groups, the Sharda Group and Kaghan Formation. We now consider it more appropriate to call the latter as Kaghan Group. The different mapped units within the Kaghan and Sharda Groups are given below in a tabular form :

TABLE 1

Table of Stratigraphic Units Across Batal Fault in Kaghan

Kaghan Group (Cambrian to Precambrian)	Mahandri Formation.	Biari quartzites, metaconglomerates, quartz mica-schist, calc-shist and pegmatites.
		Doga-schists, marbles, quartzites and meta-conglomerates.
		Phagal quartz mica-schists and quartzites.
		Lohar Banda Marble.
		Kamalban quartz mica-schists, quartzites, calc-schists and marbles.
	Kaghan Formation.	Kaghan pelites.
	Rajwal Formation.	Rajwal quartzites, quartz mica schist, pegmatites, aplites and granite.
		Paludaran graphitic schist.
		Batal quartzites and quartz mica schist.
—MCT (Batal Fault in Kaghan)—		
Sharda Group (Precambrian)		Naran and Burawai garnetiferous calc-pelitic gneisses graphitic gneisses and pelitic gneisses, marbles, with sheet granites, migmatites and amphibolite.

Tectonostratigraphy in Neelum Valley

A number of granites and exposures of metamorphics alternate with each other in the Neelum Valley. In the past the entire sequence had been considered as Salkhalas intruded by younger granites. It is now possible to subdivide these into at least 3 major units. However, no geological differences are as well marked anywhere in Neelum Valley as those in the area north and south of Luat Fault which marks the contact between a quartzite band and the Doarian garnetiferous schists/gneisses and passes north of Tarli Luat.

TABLE 2

Table of Stratigraphic Units Across Luat Fault in Neelum Valley

Authmuqam Slate Formation.	Phyllites, quartzites and slates including phyllites and subphyllites, feldspathic micaceous quartzites, graphitic schists, micrometaconglomerates.
Kundalshahi Formation.	Tithwal garnetiferous chlorite schist including chlorite schist, quartz mica schist and garnet mica schist.
	Kundalshahi-Nagdar garnet mica schists including garnetiferous quartzites and garnetiferous quartzitic schists and garnet mica schists.
——MCT (Luat Fault in Neelum)——	
Sharda Group (Precambrian)	Including garnet mica schist, kyanite gniesses, calcareous quartz mica gneisses, marbles, pelitic gneisses graphitic gneisses, amphibolites and sheet granites.

Ambiguities Regarding Salkhala Formation

In the past all the sequence north of Nauseri in Neelum Valley and north of Jared in the Kaghan Valley upto MMT had been considered the Salkhala Formation (Wadia 1928, 1931, Calkins et al. 1975, Bossart et al. 1984). Marble, graphitic schist, quartz schist, quartzites and quartzofeldspathic gneiss had been reported as major constituents of this formation from different areas including Kaghan Valley, Neelum Valley, Gilgit—Hispur Valley (Stauffer, 1968) and Hazara. Work in Neelum Valley and Kaghan Valley has, however revealed that a number of ambiguities exist regarding the stratigraphy and distribution of Precambrian basement rocks which have been rather generally referred to as Salkhala wherever exposed in Northwest Pakistan. As can be seen in the tables 1 and 2 above it is now possible to subdivide the so-called monotonous Salkhalas of Neelem and Kaghan Valleys into distinct stratigraphic units each of which is characterized by a unique and specific set of tectonostratigraphic characteristics.

In the Neelum Valley the main units are the Tithwal — Kundalshahi — Nagdar quartz schists and quartzites, Authmuqam slates, phyllites, and quartzites and beyond Luat the Sharda Group of calc-gneisses and granites. In the Kaghan Valley the main units are the

Jared quartz schists and quartzites, the Kaghan Group of quartz schists, calc-schists and quartzites and the Sharda Group of calc-gneisses and granites occurring north of Batal near Naran.

We have tentatively tried to correlate Jared and Tithwal Kundalshahi-Nagdar units to Tanawal Formation of Kashmir, the Kaghan Group or part to Hazara Slates and the Authmuqam unit was correlated by Wadia to Dogra Slates. All these correlations remain open to question.

The Special Nature of Sharda Group

A matter which comes out more clearly, however, is that both the stratigraphy and tectonics of the rock units north of Luat fault in Neelum Valley and Batal Fault in Kaghan Valley are similar to each other and distinctly different from that of units to the South (which comprise Jared, Kaghan, Tithwal-Kundalshahi-Nagdar and Authmuqam units). We have called the rocks north of Luat and Batal as the Sharda Group and consider that the term Salkhala Formation should be replaced with the term Sharda Group for these rocks. (Ghazanfar, Baig and Chaudhry, 1983, Ghazanfar and Chaudhry 1985).

The pelites, calc-pelites, marbles and sheet granites of Sharda Group occurring in Northern Neelum and Kaghan Valleys represent an unparalleled uniformity and a marked singularity of origin (deep water calc-pelitic sequence). It is characterized by the near absence of quartzites and other coarse grained rocks such as conglomerates and even flvschoid graded sediments like greywackes. The few quartzites present are pure and fine grained. Graphitic schists are present but more so on the Neelum Valley side and in very small proportion on the Kaghan Valley side.

The Sharda group is also characterized by a distinctive tectonic style. The numerous thrust faults of the sequence occurring to the south are absent here. The folding is in the form of open elongated structural basins and domes in which sheet granites are fully involved.

The presence of high grade gneieses and para-autochthonous sheet granites and the ubiquitous occurrence of amphibolite bodies (mainly sills), too, characterize the Sharda Group. The metamorphism in these rocks is dealt with more fully below.

Metamorphism Across Batal and Luat Faults

The MCT, in Kaghan (Batal fault) marks a significant break in P-T continuum. Chaudhry, Ghazanfar and Qayyum (1986) have discussed the metamorphism in Kaghan Valley at length. The unit exposed south of Batal fault e.g. Batal quartzities and quartz-mica schist falls in the epidote amphibolite facies. The pelites of this unit contain ubiquitous garnet. However they lack staurolite, kyanite and sillimanite. The amphibolites of this unit contain only oligoclase or lower andesine.

The rock units lying to the north of this fault belong to the Sharda group. The Sharda groupbeyond the Batal fault represents a sudden jump in metamorphic grade. Kyanite and sillimanite appear in metapelites. In fact a part of the kyanite grade appears to have been faulted out and sillimanite soon makes its first appearance some distance north of the Batal fault.

The amphibolites of the Sharda Group are invariably garnetiferous. Plagioclase is very often a labradorite. This unit contains a number of migmatite horizons. Migmatisation is widespread in suitable lithologies of this unit. Extensive migmatisation is evident near Dhrir, in valleys of Dadar Nar, Khote Nar and Jora Nala etc. Presence of kyanite and sillimanite, high grade garnet-labradorite amphibolites and partial anatexis of suitable lithologies show that these rocks belong to the uppre amphibolite facies.

The MCT, in Neelum valley (the Luat fault) similarly marks a significant P-T break. The rocks lying immediately south of the Luat fault contain tiny almandine garnet crystals. However, in these rocks chlorite is a stable associate of muscovite. These rocks, therefore, fall in the greenschist facies. North of this fault the Sharda group is strongly gneissic. Chlorite does not occur in stable association with muscovite and well developed garnet is ubiquitous. Recent geological work shows that kyanite is present quite close to the north of Luat fault in some metapelites. Further north the suitable horizons of Sharda group have undergone partial anatexis. Here Sharda group belongs to the almandine-amphibolite facies. Therefore a part of the greenschist and epidote amphibolite facies may be assumed to have been faulted out.

Nature and Location of MCT

Valdiya (1984) describes the MCT, in the Indian Himalaya as follows.

"The Main Central Thrust (MCT), inclined 30—45° northwards, constitutes the southern (Lower) boundary of the Great Himalaya—a plane of abrupt change in the grade of metamorphism from the higher amphibolite facies of the Great Himalaya to the greenschist facies of the lesser Himalayan assemblage, and of change in the style and orientation of folds. It represents a zone of strong mylonitization and related cataclastic changes and development of schuppen structure. Hot springs occur in close proximity as in Kameng, Bhutan, Central Nepal and Kumaun" (Valdiya, 1980).

"According to Valdiya (1979, 1981) the Great Himalayan rocks represent the basement that has been thrust up very high over and above the Lesser Himalayan rocks along the intracrustal Mian Central Thrust, the net vertical displacement being of the order of 20 km".

Regarding the region to the north of MCT, Valdiya (1984) continue, "In the north, the Great Himalayan metamorphics normally grade imperceptibly into the sediments of the Tethys zone as discernible in Zanskar, Spiti and West Nepal. However, in Kumaun, eastern Nepal and Sikkim a thrust or fault separates the two domains".

If the Batal-Luat faults are the MCT, then the zone lying south of it between Laut and Nauseri in the Neelum Valley and between Batal and Paras in the Kaghan Valley could be compared to the Himalayan schuppen zone of Powell and Conaghan(1973) and the basement crystalline of Sharda group north of Batal—Luat faults represent the Great Himalaya in Neelum and Kaghan Valleys. These basement crystallines are in the form of a wedge-shaped tectonic slab. This slab narrows to the west where the MCT, comes close to MMT near Chhlayyan in Nili Nadi in Kaghan. From here onwards MCT and MMT, may run close to each other diverging or closing at places. So there is a possibility of getting older basement slices between MCT and MMT, further west.

In India the crystallines of Great Himalaya are followed by sediments of the Tethys zone to the north until we reach the Indus Tsangpo Suture Zone, ITSZ. However, the northern edge of the former Indian continent is not preserved in Kaghan Valley and the Tethys sediments have been sliced off. Here the basement crystallines directly abut against the Kohistan Ladakh Island Arc system across the Main Mantle Thrust, MMT, the so-called southern branch of the ITSZ.

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THE APPLICATION OF ELECTRON BEAM ANALYTICAL DEVICES IN THE MINERALS INDUSTRY

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Abstract : *Analytical electron microscopy and electron microprobe analysis have many uses in the minerals industry. They can give information to solve problems in the location, assessment, processing and manufacture of products made from minerals. The principles, mode of operation, flexibility and present limitations of these methods will be outlined. Such methods have been used by the authors to characterise raw materials, assess chemical changes taking place during manufacture, determine the nature of deleterious materials, and diagnose the nature of mineral particles causing health problems. Such analytical methods are also of the utmost value in primary research into the origin of natural mineral deposits. Examples of some of the above will be presented from our own experience. Finally, the problems in setting up a laboratory to use these techniques will be discussed.*

INTRODUCTION

Electron microprobes and analytical electron microscopes are used for a number of purposes in mineralogy. Scanning electron microscopes (SEM) can be used to examine rough surfaces giving excellent images, with a resolution of around 60A°, and an excellent depth of field. Some discrimination between different phase (i e. those with different atomic numbers) can be made with modern backscattered electron detectors. Many SEM's are now fitted with Energy Dispersive X-ray Spectrometers (EDS). Such a system can be used either qualitatively to find out what elements are present, or the system might be used to make fully quantitative analyses, provided that certain conditions are met. The sample must have a highly polished, flat surface and must have a conductive coating of carbon on it. The relative geometry of the electron beam, the sample surface and the X-ray detector must be known, so that various corrections can be made to the raw X-ray count rates, and perhaps most important of all there must be standard material of the highest quality available, to compare with the unknown materials.

Wavelength Dispersive Spectrometers (WDS) may alse be fitted to scanning electron microscope. These can give the same analytical information, with the added advantage of having better detection limits. However, such spectrometers set up for fully quantitative analysis are more expensive than EDS systems, aad each spectrometer can only accumulate information about one element at a time before being reset. Much of the expense comes in the very high quality moving mechanical parts needed, and in the sophisticated computing required to operate the system. Without the automated operation WDS analysis is very slow.

The scanning facility of SEM's can be linked to an X-ray output to give visual maps of the relative abundance of an element over the scanned area. By using a number of such scans a very detailed picture of the qualitative chemistry of an area can be built up.

Transmission Electron Microscopes (TEM) give images with the highest resolution, and can also be fitted with EDS analytical systems. Such a system allows tolerable quantitative analyses of very small volumes of material. The main problem with transmission electron microscopy is the need for ultra-thin samples - just a few tens of Angstroms thick. This can be achieved using ion-beam thinners, but it is time consuming and expensive. The TEM would not be used for routine mineral analysis.

Electron microprobes differ from SEM and TEM in the size of the electron beam-normally 0.5 to 1 micron in the microprobe. The object of this is to ensure that enough eletron energy is put into the sample to generate statistically viable number of X-ray counts in a reasonable time. The main purpose of Electron Microprobe Analysis (EMPA) is to make fully quantitative analyses of volumes of material whose diameter on the polished sample is around 3 microns. Modern microprobe often have several crystal spectrometers (WDS) and/or an EDS system. Only one of the latter is required because the system collects, stores and evaluates the X-rays generated from all the elements present in the analysed spot, using the difference in the energies of X-rays from different elements, rather than the differences in the wavelengths used by a crystal spectrometer. The crystal spectrometer has to be mechanically set to solve Bragg's Law for one element at a time, whereas the energy dispersive detector is a semiconductor device, using electronic principles rather than diffraction to discriminate between elements. An excellent account of the principles and practice of electron beam analysis has been given by Long (1977) and Dunham and Wilkinson (1978) have examined the accuracy, precision and detection limits of EDS methods.

The purpose of the present paper is to review the use of such data to the mineral and metal industries, using examples obtained by the authors and others, using a Cambridge Instrument Company's Geoscan electron microprobe, fitted with a Link Systems Model 290 fully quantitative EDS. We also use a Cambridge Instrument Company's S600 SEM fitted with another Link Systems EDS for qualitative work. Finally we have an AEI EM6G transmission eletron microscope, but with no analytical facilities. The examples to be described in the following pages will illustrate applications of these methods to the study of copper deposits, potential manganese and chromite, olivine, plagioclase, sulphide deposits, clays, bricksand fine ceramics, limestones, steels and fused basalts.

EXAMPLES

(a) *Copper deposits* have been known in various parts of the *Cheshire Basin*, England, for several hundred years. The copper mineralization, which is a mixture of primary sulphide and perhaps secondary oxides, carbonates and silicates, is found filling fractures and pore spaces in Triassic sandstones. Barytes and wad (manganese oxide) are also found.

EMPA of the ores at Bickerton shows the presence of at least two types of mineral assemblage : a covellite-bornite-barytes assemblage, and a pyrite-bravoite-chalcopyrite assemblage. Also found within the zoned pyrite-bravoite grains are layers of As-Sb sulphosalts. The covellite is found by EMPA to be a mixture of covellite and blaubleibender covellite, often mixed with anilite. Within the covellite are many tiny blebs (up to 5 microns across) of copper-bearing dzulukulite. This mineral assemblage suggests very strongly that the mineralization formed at low temperatures, from the slightly warm ground waters flowing through the still-porous sandstones. The electron microprobe analyses have helped to elucidate the origin of these deposits, and also provide a part of the basic mineralogical data needed to design a suitable mineral separation system, should any of those deposits become economically viable again.

(b) *Chromite, olivine, plagioclase and sulphides on Rhum, West Scotland.* The layered intrusion of the Island of Rhum has large accumulations of olivine (possible refractory material), plagioclase (possible ceramic raw material), chromite, and sulphide materials. The olivine-rich rocks (peridotites) form nearly horizontal layers beneath bands of allivalite (in some cases an almost pure plagioclase rock). Each pair of layers may reach up to 100 m in thickness, in the eastern part of the Island. Beneath some of the peridotite layers occur thin chromitite layers, which in some cases are associated with very thin layers of immiscible sulphide droplets. The chromitite layers are never thicker than 5 mm, so are not of economic interest : the sulphide layer however, is the type of environment where noble metal enrichments occur (e.g. the Merensky Reef in the Bushveldt Intrusion in South Africa).

Electron microprobe analyses of the olivines have shown that the olivines may vary in composition from Fo_{88-78}, depending on the height of the sample within the olivine layer. Cryptic layering is present (Dunham and Wadsworth, 1978). Typical analyses of the olivine, pyroxene, plagioclase and minor chromite from one rock are presented in Table 1. The chromites within the thin chromitite layers vary strongly in composition, being highly aluminous at the base of the layer, but reverting to normal chromite at the top of the layer, only 4 or 5 mm away (Table 1, analyses 5 and 6).

TABLE 1

Analyses of minerals from the layered ultrabasic rocks of Rhum, Western Scotland.

	Olivine	Pyroxene	Plagioclase	Chromite 1	Chromite 2	Chromite 3
SiO_2	40.44	50.52	45.08	—	—	—
TiO_2	—	1.40	—	1.08	0.93	1.00
Al_2O_3	—	3.09	34.29	31.79	37.65	31.55
FeO	12.57	4.97	0.57	16.71	14.97	16.92
MnO	—	0.27	—	—	—	—
MgO	46.45	15.36	—	14.02	15.82	13.49
CaO	0.15	23.32	18.17	—	—	—
Na_2O	—	0.65	1.19	—	—	—
K_2O	—	—	—	—	—	—
NiO	0.42	—	—	—	—	—
Cr_2O_3	—	0.68	—	26.06	22.87	25.85
Fe_2O_3*				11.21	7.92	10.44
Total	100.03	100.26	99.30	100.87	100.16	99.24

* Fe_2O_3 calculated in the chromites assuming the presence of 24 cations and 32 oxygens.

Chromite 1 is from the same olivine-rich peridotite as the olivine, pyroxene and plagioclase, from the base of Unit 12, Eastern Layered Series, Rhum.

Chromites 2 and 3 are from the base and top respectively of the chromite band between Units 11 and 12.

Analysts : F. C. F. Wilkinson and A. C. Dunham.

—Means element not detected.

The sulphide minerals are contained within ovoid to irregluar patches, between the olivine grains at the base of the olivine layer. Such a horizon is well developed at the junction between Units 11 and 12. In Table 2, a typical suite of analyses is shown from one droplet—a complex group of minerals. Note the presence of electrum.

TABLE 2

Analyses of sulphide minerals from immiscible droplets just above the Units 11/12 chromitite, Rhum.

	Pentlandite	Chalcopyrite	Bornite	Pyrrhotite	Electrum
S	33.24	34.77	26.31	36.58	—
Mn	—	—	—	—	—
Fe	35.23	31.72	11.42	62.84	2.46
Ni	30.39	0.40	—	—	0.89
Cu	0.92	33.20	62.23	—	1.02
Au	—	—	—	—	46.03
Ag	—	—	—	—	49.48
Total	99.78	100.09	99.96	99.42	99.88

— Analysts : F. C. F. Wilkinson and A. C. Dunham.

Each of these rock types, the olivine-rich peridotite, the feldspar-rich allivalite, the chromitites and the sulphide-bearing rocks might be worked. As with the Cheshire sulphides, the electron microprobe has provided primary mineralogical data forming part of the quantitative assessment of each rock type. However, the Island of Rhum is a National Nature Reserve so these particular rocks will never be worked as ore deposits, but are there for use in testing ideas of the genesis of such rocks, of use in working actual deposits elsewhere.

(c) *Manganese minerals at Tudun Kudu, Zaria Province, Nigeria.* Monome, Scott and Dunham (1983) have examined the Mn-prospect at Tudun Kudu, using EMPA, SEM, reflected light microscopy, X-ray diffraction and X-ray fluorescence analysis. The deposit consists of the weathering product of a spessartite-bearing quartzite. The Mn-garnet has been shown to alter to iron-rich lithium-free lithiophorite, iron-free lithiophorite and lead-rich lithiophorite. Cryptomelane replaces the lithiophorite. Typical analyses of each phase are shown in Table 3. Note that Li could not be determined with our EDS spectrometer : Na is the lowest

TABLE 3
Analyses of Mn-minerals from Tudum Kudu, Zaria, Nigeria

	Lithiophorite	Fe-Lithiophorite	Pb-Lithiophorite+	Cryphomelane	Garnet
SiO_2	0.30	1.50	1.95	0.30	36.19
TiO_2	—	0.32	—	—	—
Al_2O_3	20.83	13.68	10.77	0.77	20.37
Fe_2O_3					
FeO_2	0.90	24.12	15.75	1.31	
FeO					14.90
MnO_2	62.26	37.07	38.02	91.53	
MnO					25.44
MgO	—	—	0.31	—	0.68
CaO	—	—	0.60	0.36	2.43
K_2O	0.31	—	0.31	3.94	—
P_2O_5	—	1.46	0.36		—
Total ...	84.60	78.15	74.27	98.21	100.01

+ Analysis also contain 0.75% SO_3 and 5.45% PbO
* Fe_2O_3 or FeO or MnO are used as appropriate to the mineral

Analysts : A. C. Dunham, P. W. Scott and F. C. F. Wilkinson. Data from Monome, Scott and Dunham, 1983.

atomic number element that we can detect. However, windowless detectors are now available which extend the elemental range. Li was looked for by X-ray fluorescence methods, but none was detected. It is important to note that no one machine can provide all the answers : each has its part to play. This investigation showed that this Mn-prospect was probably not suitable for further work, because of the presence of so much Al in the Mn-phases. The entirely unsuspected presence of Pb does not help either.

(d) *Clays.* The chemical investigation of individual grains of clay is now possible, using electron beam devices fitted with X-ray spectrometers. Colleagues in the Department of Geology, University of Hull, have used EMPA to investigate the clay minerals occurring in sandstone oil reservoir rocks : a topic of great importance in predicting the engineering properties of the reservoir, and in predicting extensions of reservoirs. Some typical analyses of clay minerals are presented in Table 4.

TABLE 4

Analyses of clay minerals in oil reservoir sandstones

	Kaolinite	Illite	Mixed Layer Clay	Chlorite	Goethite*
SiO_2	44.65	44.71	43.92	25.40	1.81
TiO_2	—	0.50	0.49	—	0.36
Al_2O_3	36.84	35.15	21.02	18.57	3.34
FeO	0.30	0.63	14.35	30.34	76.12
MnO	—	—	—	0.95	1.43
MgO	—	0 32	1.86	10.59	—
CaO	—	—	0.76	—	—
Na_2O	—	0.46	—	—	—
K_2O	0.13	6.95	5.50	—	—
Total	81.92	88.72	87.90	85.85	84.88

* The analysis of Geothite is from Tudum Kudu. Iron is shown as Fe_2O_3, and the total includes 1.82% P_2O_5

Analysts : Clays by S. Burley, Goethite by Dunham, Scott and Wilkinson. Data from Dunham, Scott and Wilkinson, 1983.

(e) *Clay Products.* We have investigated a number of different types of heavy clay product bricks, roofing tiles and sewer pipes. Not only can the EMPA be used to characterise the starting materials (clays, feldspars, iron and titanium oxides) but has also proved invaluable in the investigations of the nature of the final products. The firing of the raw materials causes the breakdown of the clay minerals and others to form new phases (e.g. mullite, critoballite and glass). Unfortunately, the grain size of the new phases is generally very small (very much less than 1 micron) making the conventional analysis of any single phase impossible. However, we have used graphical and numerical methods to treat analyses of several phases, to derive the compositions of the glasses in particular. Such data has led to a better understanding of the phase compositions of such materials, and will, we believe, lead to a more energy-effective means of production, by finding the optimum heating path to produce a material of particular properties. Possible glass compositions from three commercial bricks are shown in Table 5.

TABLE 5

Possible composition of glass in bricks from Broomfleet, Humberside

	Red Brick	Mottled Red Brick	Buff Brick
SiO_2	49.6	49.8	43.2
TiO_2	0.5	0.5	0.5
Al_2O_3	31.9	27.8	22.7
FeO	5.5	10.6	7.1
MgO	3.3	2.9	2.9
CaO	2.5	1.3	3.0
Na_2O	1.2	1.2	0.6
K_2O	5.5	5.9	20.0

Data from Dunham and Mwakarukwa, 1984

We have also examined fine ceramics using the same sorts of methods. The analysis of glaze *in situ* is now possible, even though the glaze may be only a few tens of microns thick. The analysis of fired glaze is difficult by any other means, because of the difficulty of obtaining an uncontaminated sample, and because many glazes are not etirely glassy. We have been able to analyse both glass and crystals in 14th Century pottery and on modern products. Two such glaze analyses are presented in Table 6. The main body of these ceramics can also be examined in the same way as the heavy clay products.

TABLE 6

Analyses of ceramic glazes

	Modern Whiteware	Ancient Sherd
SiO_2	55.72	23.07
TiO_2	—	0.58
Al_2O_3	13.83	5.75
FeO	0.56	2.75
MgO	0.59	0.88
CaO	5.18	0.45
Na_2O	2.90	—
K_2O	3.18	—
PbO	11.76	66.59
BaO	1.02	—
Total	94.74*	100.07

* The total is low because of the probable presence of Boron.

Analysts : A.C. Dunham and F.C.F. Wilkinson. Data from Dunham, Scott and Wilkinson, 1983.

(f) *Impurities in calcite in limestone.* Limestone has many uses ranging from building stone or aggregate to the more sophisticated uses as a raw material for cement, or as a cheap white filler. It is becoming increasingly important to know not just the bulk composition of the limestone rock, but also the distribution of elements within different phases, and indeed within the same phase: many minerals are zoned and calcite is no exception. Table 7 shows the bulk composition of Carrara Marble, Italy, and chalk, North Humberside, England, and the range of minor elements present within 5 micron areas within these same two rocks. The detection limits for each element for our EDS are also shown. The electron microprobe analyses indicate the presence of inhomogeneities within individual phases, which may become more important as the processing and the specifications for raw materials becomes more stringent.

TABLE 7

Bulk analyses of limestones and the range shown by electron microprobe analyses of 5μm diameter spots

	Chalk		Carrara Marble		
	Bulk	EMPA	Bulk	EMPA	DL*
SiO_2	1.82	0—2.95	0.11	0—0.18	0.17
Al_2O_3	0.17	0—0.80	0.05	n.d.	0.15
Fe_2O_3	0.10	0—0.48	0.02	n.d.	0.22
MgO	0.22	0—0.66	1.12	0—0.79	0.16
K_2O	—	—	0.02	—	
Na_2O	—	0—0.39	—	—	
S	0.04	0—0.48	—	—	

* Detection limits for our EDS system.

Data from Scott and Dunham (1984) and Scott, Thanoon and Arodiogbu (1983).

(g) *Iron and Steel raw materials and products.* Work on materials connected with the iron and steel industry in our laboratory has included a wide variety of types of investigation. For example, sintered iron ore contains a variety of phases: two generations of hematite, megnetite and ferrite, as well as glass. All of these phases can be well characterised using EMPA, though the oxidation state of the iron cannot be determined. In some cases the ratio of FeO/Fe_2O_3 may be calculated with reasonable certainty, but this is not always possible. This work was reported by D.S. Scott (1980) and by Dunham, P. W. Scott and Wilkinson (1983).

We have a project currently in hand to examine the mineral chemistry of magnesia refractories, involving the analysis of large numbers of grains of periclase, forsterite, merwinite, monticellite, di- and tri-calcium silicate and lime, all or some of which are present in any sample of a magnesia refractory.

In another project, Critchley (1983) has examined the glass, merwinite, mellilite, oldhamite and native iron compositions in cementitious water-cooled slag. Finally, Dunham and Wilkinson (1980) have examined the homogeneity and inclusions in various samples of austenitic stainless steels which are used as X-ray fluorescence standards. The work showed that on the micro-scale the steels are inhomogeneous, and therefore could not be used as microprobe standards (see Table 8). There are also discrete inclusions of Mn-sulphide and Mn-chromite present.

(h) *Fused basalt.* If natural basalt is melted in a furnace then cast into tiles, it makes a very tough material with a resistance to abrasion in hoppers, for example, superior to steel. Microprobe analyses of olivine, pyroxene and glass from such a material are shown in Table 8. The excellent properties of the fused basalt are the result of careful control of the cooling and annealing part of the thermal cycle.

TABLE 8

A comparison between the mean and standard deviation of 10 analyses of stainless steel, with its bulk composition, and analyses of sulphides and chromite inclusions in the same steel

	Bulk	EMPA		Inclusions		
	Composition	Mean*	St. Devn.	Sulphide	Chromite	
Si						
Cr	0.44	0.47	0.06	—	SiO_2	—
Mn	12.80	12.59	0.36	8.57	Cr_2O_3	41.84
Fe	0.80	0.71	0.07	45.64	MnO	31.48
Ni	73.50	73.54	1.07	11.46	Fe_2O_3	0.83
S	12.40	12.69	0.78	1.25	FeO	1.93
				30.93	NiO	—
					Al_2O_3	21.24
					TiO_2	1.45

* Mean of 10 analyses.
Data from Dunham and Wilkinson (1980).

Analysts : A. C. Dunham and F. C. F. Wilkinson.

TABLE 9

Analyses of minerals and glass in a fused basalt

	Bulk Analysis	Glass	Pyroxene 1*	Olivine*	Pyroxene 2
SiO_2	45.15	48.73	53.22	39.11	43.82
TiO_2	2.28	2.63	0.29	—	2.72
Al_2O_3	12.43	17.24	1.42	—	9.10
Fe_2O_3	12.54*	—	—	—	—
FeO		16.82	8.00	20.49	9.71
MnO	0.20	—	0.34	0.58	0.30
MgO	12.96	1.20	13.90	39.04	13.38
CaO	10.90	3.33	21.31	0.50	19.89
Na_2O	2.21	5.23	1.63	—	0.86
K_2O	1.07	3.10	—	—	
P_2O_5	0.67	0.88	—	—	—
SO_3	0.04	—	—	—	—
Cr_2O_3	—	—	0.47	—	—

*** Pyroxene 1 and Olivine are probably unmelted remnants. Pyroxene 2 is the new phase.**
Analysts : A. C. Dunham and F. C. F. Wilkinson.

CONCLUSIONS

The purpose of this paper was to present some of the uses of EMPA in the minerals and metals industry. The range of materials reported here gives an idea of the potential of the method, whether the analyses are made with an electron microprobe or on an SEM.

Energy dispersive spectrometers have proved to be very suitable for our work : all the work described here was done using such a system. EDS has two advantages ; once the system is set up it is fast (around 50 analyses for up to 14 elements in an 8 hour shift), as accurate and precise for major elements as WDS (see Dunham and Wilkinson, 1978), and is 'user friendly'. In addition, because all the analytical data is collected at once then it is certain that it has come from the same spot. The disadvantages to such systems are the need to keep the detector permanently cooled (at liquid nitrogen temperature), and the rather poor detection limits, unless the analyst is willing to use very long counting times with one of the most recent windowless detectors. Even so, the detection limits still do not match wavelength dispersive spectrometers. An EDS system on a microprobe is not the way to determine trace element contents.

The success of any quantitative analytical investigation is dependent on the excellence of the standard materials available. These must be of the highest quality. Fortunately, pure metals can be used for many elements. Other elements (e.g. Na, Hg) must be found in a stable, homogeneous solid, whose composition is accurately known. Such materials are available commercially, but must always be treated with caution, and tested for their homogeneity by the user under the conditions under which his analyses will be made.

The final point to be made concerns the operation of such machines. They are not yet like a transistor radio, which you can turn on and expect to hear the programme of your choice ! Electron beam analytical devices need a skilled operator for each machine, who can maintain the machine as well as providing analyses and training users to obtain their own. It cannot be emphasised strongly enough that the success of any laboratory is entirely dependent on that person.

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The quartz mica schist the Agglomeratic Slate, the Panjal Formation and the Malakandi Formation represent the Kashmir sequence in the Balakot area. The Balakot gneisses and the biotite and garnet mica schists further west of Balakot apparently represent the Tanol Formation of Hazara sequence.

For the sake of convenience the stratigraphy of Balakot has been discussed below under two headings, the stratigraphy east of river Kunhar (comprising sedimentary rocks) and the stratigraphy west of river Kunhar (comprising metamorphosed rocks).

Stratigraphic Sequence East of River Kunhar

The stratigraphic units exposed in the Balakot Anticline and the Muzaffarabad Anticline further south constitute the Muzaffarabad Sequence. It is outlined below in Table 1. At Balakot these units occur mainly to the east of river Kunhar.

TABLE 1
Muzaffarabad Sequence Exposed at Balakot

Tentative Age*	Unit
Miocene	Murree Formation
Eocene	Margala Hill Limestone
Early Eocene to Palaeocene	Patala Formation
Palaeocene	Lockhart Formation
Palaeocene	Hangu Formation
Cambrian	Abbottabad Formation (base not exposed)

* These ages have been given on the basis of correlation with units further south in the Hazara basin.

Abbottabad Formation

The Abbottabad Formation occurs in the form of a broad band of outcrop extending southward from Garlat, a suburb of Balakot, just east of River Kunhar. Within the mapped area it is widest at Naukot in south where the outcrop width is over 6000 ft. Northwards its width gradually decreases being partly faulted and partly concealed under the alluvium. Apart from the main outcrop a number of fault slices occur sandwiched within the Tertiary sequence on the slopes east of River Kunhar. The most prominent of these fault slices occurs on the Kaghan road about 2 km from Balakot. Both north and south this squarish patch is abruptly truncated by faults. The eastern contact of this patch is marked by a squeezed band of Hangu Formation, marking an unconformity at the latter's base. The main outcrop underlies the villages of Khokhan Bud, Kanoch, Sohbarian, Chhappar, Naukot and others further south. The western contact of this main outcrop towards the riverside is faulted throughout. This fault is known as the Muzaffarabad Fault.

Lithology and Stratigraphic Characters

The Abbottabad Formation in the Balakot area is mainly a dolomite with cherty bands in the upper part and a siliceous variety of dolomite with banded chert in the lower part. The colour of the formation is medium grey and sometimes greyish brown on the fresh surface and generally light to pale grey and sometimes brown to dark grey on the weathered surface. The chert bands are mostly dark grey and occur either in the form of thin dark and light grey mottled laminae, planer patches, lenses or sometimes in the form of boudins. They are generally much harder than the surrounding dolomite and may stand up on the weathered surface. The dolomitic part shows a chopboard weathering style due to the presence of a large numbers of incipient fractures.

The formation is well jointed, the joint blocks being larger in the upper dolomitic part and being smaller in the lower siliceous part. The rock is fairly competent and shows a lot of brittle deformation. Minor folding, at places, is well developed and is of concentric type. The lower siliceous part has been intensively sheared and crushed leading to rapid erosion at many places. This has resulted in the formation of large gravel fans at the mouths of major streams on the eastern bank of River Kunhar especially between Balakot and Garhi-Habib-Ullah. Lithologically the following rock types are seen in this formation.

Cherty Dolomite. This is the uppermost part occurring below the Hangu Formation. It is thick bedded, shows development of chert bands, is composed of relatively pure dolomite and on the weathered surface shows chopboard weathering. The cherty dolomite, can be further subdivided into two parts. The uppermost part is generally light grey on fresh surface as well as on the weathered surface. It contains thin dark grey and white banded layers which where siliceous, stand out prominently on the weathered surface. The lower part of the cherty dolomite is dark grey to light brown on the fresh surface and brown to dark brownish grey on the weathered surface. It generally contains thicker patches and lenses of grey chert which may stand out prominently on the weathered surface.

Banded Quartzite. The lowermost part of the formation is quartzitic and banded. The whitish or light grey bands alternate with dark coloured bands. The lithology shows effects of shearing and crushing.

Banded Grey Limestone. Calkins et al. (1975) reported and mapped a 400 to 450 ft. thick black limestone unit near the top of the Abbottabad Formation in the Muzaffarabad area. This black limestone band is generally absent in the Balakot area. However, in the south of the presently mapped area on the Kummi spur near Chhappar a banded grey limestone is present within the Abbottabad Formation. Most probably it is the same black limestone noted by Calkins et al., in the Muzaffarabad area. Its outcrop, however, does not extend much further northwards towards Balakot. The limestone band near Chappar is nearly 150 ft. thick. It comprises a fine grained dark grey limestone with yellowish grey bands. It is overlain by a white band of quartzite and dark grey shales.

Intraformational Breccias. One or more horizons of intraformational breccias showing white and grey banded angular quartzite/chert pieces in a quartzitic/dolomite matrix are found in the Abbottabad Formation. These breccias appear most striking due to the random alignment of banded pieces. There is no regular alignment or visible shearing effect.

The lowermost part of the Abbottabad Formation exposed in the Khwas Katha is a black graphitic shale. Argillaceous partings are also present elsewhere in the Abbottabad Formation.

Calkins et al. (1975), called the Abbottabad Formation the Kingriali Formation and described it as follows :

"In the outcrop belts between Abbottabad and Garhi Habib-Ullah and between Muzaffarabad and Balakot, the Kingriali Formation consists primarily of cherty dolomite with quartzite and conglomerates at the base of the formation. The dolomite is grey to white on the weathered surface and dark grey to black on the fresh surface. Some layers are distinctly pink, possibly owing to the presence of manganese carbonate. Beds range in thickness from thin lamination to 2 feet. Locally beds of intraformational conglomerate and quartzose sandstones are found..............Chert, which stands out in relief on the weathered surface, is distributed in layers, lenses and irregular patches. The chert layers are as much as 100 feet long. Because of its silica content, the dolomite is extremely brittle and is traversed by many closely spaced joints. For hundreds of feet away from a fault, this dolomite is shattered into small joint blocks which collect into huge talus cones at the base of steep slopes."

Hangu Formation

The Hangu formation in the Balakot area is generally poorly exposed and at many places has been faulted away. The Hangu Formation is a relatively thin and occurs in patches along the northwestern contact of Abbottabad Formation extending from Bala Pir Ziart near Balakot through Ackhan Bud to Kanoch and further south. Better exposures, however, are present at Jabba and Nakka below Bhangian and east of Kanoch village. It is also seen as a poorly preserved patch on the Kaghan Valley roadside about two and a half kilometre from Balakot.

The formation consists of quartzite, sandstone, claystone, shale and conglomerate. The quartzite is white to greyish white in colour and weathers rusty bown. It occurs at the base as a thick layer and at the top in the form of thin bands within shales. The sandstone is generally grey with rusty weathering and in some parts is conglomeratic. The claystones are dark grey or cream coloured and at places show poor development of pisolites.

The shales which occur towards the top are best exposed at Jabba and below and east of Bhangian. They are also well developed at Nakka southeast of Bhangian. South of the Bhangian spur, however, they were not seen in the Balakot area. These shales are steel grey and yellowish grey on the fresh surface and light grey (ash grey) and grey mottled with rusty orange patches on the weathered surface. They resemble parts of Patala shales but are differentiated from the latter and characterized by the presence of thin quartzite bands and by the absence of limestone bands. The quartzite bands are light grey, greenish grey and at times dark grey on fresh surface and grey, brown, and rusty on the weathered surface. This quartzite is mostly pure and coarse grained.

At places some flaggy siltstones are also present.

At the Kaghan Valley roadside exposure the claystone is dark grey on fresh surface and orange to rusty yellow on the weathered surface. It shows few poorly developed pisolites. The arenaceous part, here, occurs as light grey grit and as dark grey, coarse grained quartzite, conglomerate and breccia. There are some calcareous layers as well.

At Ackhan Bud the formation is represented by rusty weathering whitish quartzite, oolitic and haematitic claystone, and rusty brown weathering dark grey shales.

At Knoch the lower part of Hangu Formation is well developed and occurs as an outcrop patch on the left bank of Knoch Katha where the Kanshian—Knoch road crosses it. Here a medium grey sandstone with conglomeratic layers overlies the cherty dolomite of Abbottabad Formation with a disconformable contact. This sandstone is overlain by black shales. The upper contact with Lockhart limestone, where preserved, is sharp.

Lokhart Formation

In the Balakot area the formation mainly consists of grey limestone. The limestone is thinly bedded with shaly interclations in the lower part and medium bedded in the upper part. The nodularity is not clearly seen in the lower part but in the upper part it is poorly developed. Very thin marly parts are sandwiched between nodules. The marly parts are particularly fossiliferous. The fossils in the marly part are seen as small black dots but are best identifiable in white outline on the weathered surface of limestone nodules. Compared to Eocene Margala Hill limestone micro-fossils in the Lokhart limestone are fewer and their size is small, 1 to 3 mm. The limestone is fine to medium grained and the upper part generally breaks with an irregular surface. In this upper part irregular joints and incipient fractures are present. Also present are numerous irregular thin calcite veins. The upper part is dark grey on the fresh surface and light to medium grey and bluish grey on the weathered surfaces.

The lower contact with Hangu Formation is sharp to gradational ; the upper contact with Patala shales is transitional.

Patala Formation

The Patala shales occur in the form of a number of thin bands within the structure of the Balakot anticline on the eastern slopes of River Kunhar. The outcrops are well developed and fairly extensive on the Bhangian and Jusach (Magra) spurs and further south at Kummi and Batangi but are generally reduced southwards.

Predominantly the rock consists of shales and claystones and minor siltstones, thinly laminated and with well-developed fissility. The claystones as exposed at Bhangian and Jusach occur towards the top ; are splintery or flaggy, breaking into slabs like slates ; olive green, greenish grey and dark grey on fresh surface with occasional thin purple bands. They weather greenish grey with patches of rusty brown and orange.

The calcareous shales which occur mostly in the lower part are splintery and flaggy. On the fresh surface they are greenish grey or dark grey and weather greeish grey and whitish grey.

At Bhangian the Patala shales have, in their upper part, two thin bands of algal limestone. The algal limestone is medium to dark grey, medium to fine grained and has yellow dolomitic patches which in some parts are yellowish grey. This limestone in its lower part shows dark brownish grey colour on the weathered surface and some chopboard weathering. Here it is also somewhat coarse grained. With the algal bands a few micro-conglomerates (angular whitish 2—4 mm pieces in grey or purple matrix) are also associated.

The lower part of the Patala shales have a transitional contact with Lockhart limestone and have numerous bands of fossiliferous fine grained limestone. These limestone bands are dark grey on fresh surface and medium grey to yellowish grey on the weathered surface.

Fossils in shales and claystone are generally not visible to the naked eye.

The upper contact of Patala shales with the Margalla Hill limestone is sharp.

Margala Hill Limestone

The formation mainly consists of grey limestone. This limestone, in many ways, is similar to Lockhart limestone, but it contains fewer shaly interclations and the bedding and nodularity is better developed. Some marly parts are squeezed between the nodules. The limestone is dark grey on fresh surface and light to medium grey or dark brownish grey on the weathered surface. It contains more abundant and larger (4—10 mm) microfossils. Numerous species of Assilinas and Nummulites are seen. The foraminifers are seen in the field asdark grey specks in the marly part or in white outline on the medium grey weathered part of the limestone nodules. The lower contact with Patala shales is sharp but the upper contact with Murree Formation is gradational, where preserved.

Murree Formation

The Murree Formation in the Balakot area consists mainly of maroon coloured shales with green patches and bands, greenish grey sandstones and generally maroon siltstone. There are subordinate conglomerates and rare bands of limestone.

The shales are maroon, generally, and at places purple or bright red. The colour sometimes changes laterally into patches and bands of green. They are characterized by a splintry nature, presence of fracture cleavage, lineation and tension gashes. Numerous veins of calcite and quartz are also present. At some places the shales contain few disseminated small size pebbles.

The sandstone is greenish grey to grey on the fresh surface and brownish on the weathered surface. It is coarse grained, impure, calcareous and with minute rock pieces. The weathering is generally penetrative and a nearly one or more than one centimetre thick brown weathered layer may surround a greyish fresh core. The rock is well jointed and has quartz veins and tension gashes.

The conglomerates are intraformational and contain clasts of Murree.

The siltstones are very similar to shales except for the coarser grain size.

The occasional to rare grey fossiliferous Eocene limestone bands within Murree Formationmay be inliers of Margala Hill limestone but at other times they may represent olistostromes i.e. syndepositional patches and slices of Margala Hill limestone detached from the parent and emplaced within the Murrees during deposition.

The lower contact of Murree outcrop in the overthrust limb of Balakot anticline is generally faulted in the area but the throw of this fault gradually decreases to the south and on the Kummi spur there appears to be some reworked material at the base of Murree formation. A few boulders containing reworked Eocene fossils were also found above Batkarar but the outcrop could not be traced.

Presence of Kuldana Formation between Eocene Margala Hill limestone and Murree Formation has been reported from the Muzaffarabad area but its presence in the Balakot area could not be ascertained.

The upper contact of Murree Formation is not exposed in the area.

STRATIGRAPHY WEST OF BALAKOT

West of River Kunhar and Jalora Katha up to the Kund Bangalow ridgetop two main stratigraphic units are exposed in an inverted sequence. From Balakot westwards these are, respectively, Agglomeratic Slate (Chushal Formation) and Tanol Formation. The latter is intruded by Mansehra Granite. These two however, have been considered to belongs to two basinal affinites. The Agglomeratic Slate belongs to the Kashmir basin and the Tanol Formation to the Hazara basin. Apart from the Agglomeratic Slate some other units belonging to the Kashmir basin are also present in the Balakot area. These are the Panjal formation and Malakandi Formation (Triassic limestone) both of which outcrop as fault slivers at Batkarar. Fault slivers of thinly laminated limestone bands so characteristically associated with volcanics of Panjal formation in the Kaghan Valley are also seen north of Khet Sarash, though not described here.

West of Balakot, therefore, it is useful to realize that there is no stratigraphic continuity between the lowermost Tanol Formation and the upper three, Agglomeratic Slate, Panjal Formation and Malkandi Formation.

TABLE 2
Stratigraphic Sequence West* of Balakot

Tentative Age	Unit Name
Triassic	Malkandi Formation
Permian	Panjal Formation
Carboniferous	Agglomeratic Slate
———Fault———	
Precambrian	Tanol Formation

* Outcrops of Panjal and Malkandi Formation occur southeast of Balakot and east of river Kunhar.

The Tanol Formation

What is being described here as a single Tanol Formation sequence was considered as part Salkhala (eastwards near Balakot) and part Tanol (westwards near Kund ridge top) by Calkins et al., (1975). The Tanol Formation in the Balakot area outcrops between graphitic schist of the Agglomeratic Slates and the Mansehra granite (at kund ridge top). Trending more or less east-west it occurs under the villages of Khanda, Mittikot, Satbanni, Sarbori, Dandar, Barna, Rin and further north it extends under Ban, Madhar, Bagar, Sukki, Guchh, Rori and Shahidpani.

The Tanol Formation in this area consists predominently of two lithologies, a pelite-psammite unit to the east and a pelitic lithology (Satbanni pelites) occurring further west on the higher slopes of the Kund ridge. The pelite-psammite unit has been extensively feldspathised and will be, herein, referred to as the Balakot Gneiss.

Balakot Mylonite Gneiss

This quartzo-feldspathic unit is exposed to the west of Balakot between the graphitic part of Agglomeratic slates and the Satbanni pelites. The outcrop extends in more or less north-south direction passing through the villages of Khanda, Sarbori, Dandar etc. north of Balakot and through Bauli, Basut, and Tranna south of Balakot.

The Balakot Gneiss is tough, competent, well bedded, and breaks into relatively large joint blocks. The quartzo-feldspathic bands are light and the biotite rich pelitic bands are dark. Overall the rock is light greenish grey or sometimes dark grey on fresh surface and brown and rusty brown on the weathered surface. It is traversed by quartz veins and few dolerite dykes.

In cross section the rock shows a gneissic structure. The felsic layers (generally 5 to 10 mm thick) make small augen structures. The individual augens may be 5 to 15 mm long.

Apart from the gneissose feldspathised parts there are fairly thick non-feldspathised pelitic zones as well as dominantly psammatic bands which have been little affected by granitization. Rare bands of marble are also seen.

Calkins, et al. (1975), called these rocks the quartzo-feldspathic unit and considered them part of the Salkhala sequence. They described it as follows, "The quartzo-feldspathic unit consists, of medium to coarse grained somewhat gneissic rock made up of quartz, feldspar (microcline and oligoclase), biotite, muscovite, and chlorite. In places it is pegmatitic. The rock has a layered structure and a granitic texture, this being modified by foliation and cataclasis. Augens of feldspar are characteristic. Some augen are subhedral crystals as much as 1½ inches long but most are less than half an inch long and are rounded and crushed by shearing movements. At Balakot the quartzo-feldspathic unit includes layers or lenses of pure white fine grained sugary quartzose sandstone and layers of fine grained grey muscovite-biotite quartz schist, which probably represent argillaceous siltstones. These layers invariably feather out as tenuous stringers in to the quartzo-feldspathic gneiss, suggesting that original beds have been largely replaced (granitized) by the quartzo-feldspathic material. In other places the quartzo-feldspathic rocks resemble an arkosic sediment. Perhaps some of the unit represents an original arkosic sandstone."

Bossart et al. (1984) have described the Balakot gneiss as mylonites as follows :

"Mylonites are found in a 1—5 km wide zone of ductile deformation along the western border of the syntaxis. This zone disappears towards the SW under the alluvium of the Mansehra Valley. The mylonites can be followed towards the northeast into Kohistan. The unit consists of granitic mylonites, cataclasites and calcite mylonites. The granites mylonites can be subdivided in two groups.

(1) Mylonites with alternations of dark mica rich layers and quartz layers. The quartz layers consist of quartz ribbons with a crystallograhhic preferred orientation.

(2) Mylonites with feldspar clasts (microcline, potassium feldspar, plagioclase) in a quartz matrix. This matrix consists also of quartz ribbons, the quartz grains showing subgrain structures and recrystalised borders.

Both rock types show a well developed cleavage steeply inclined towards the WSW, W and WNW. The quartz ribbons are parallel to cleavage".

Agglomeratic Slate (Chushal Formation)

The Agglomeratic Slate which is best exposed in the Pir Panjal area of Kashmir moves north through the Neelum Valley and Kaghan Valley and then turns around the apex of the Hazara Kashmir Syntaxis and follows the western limb of the syntaxis to Balakot. In the Balakot area it is exposed west of Jalora Katha and west of River Kunhar. Here it comprises two main rock types, quartz mica schist and graphitic schist.

Quartz Mica Schist. The quartz mica schist is greenish grey and greyish on the fresh surface and brownish grey on the weathered surface. A few graphitic bands are also present. The rock is characterised by its pelitic nature and the ubiquitous presence of folded quartz viens and boudins.

Graphitic Schist. The graphitic schist is exposed on the spurs west of Balakot and Jalora Katha as a marker horizon which can be seen from far off, as from Bhangian on the opposite side of the river.

Coming from Kashmir the outcrop runs almost without interruption around the Hazara Kashmir syntaxis passing through Jigan, Dandar, Satbanni, Mittikot and Pauri Katha until it truncates in Sangal-Bhor Katha near Bamphora village about one km south of Balakot by the Murree fault and a younger transverse fault.

This is essentially a fine grained quartz mica schist with disseminated graphite but some pelitic bands are particularly rich in sooty graphite and act incompetently. The colour is steel grey to black with rusty brown patches on the weathered surface. At places cubic crystals of pyrite are present which may be washed out leaving squarish cavities behind. Folded quartz veins and boudins are common. The outcrop at Dandar is 400 to 500 ft. wide and has more than one few feet thick bands of coarse limestone marble. The limestone is medium to dark grey in colour and slightly metamorphosed. At places there are thin layers of calc-schist in the limestone/marble which mark flow folding in the rock. Veins of quartz and calcite at places have accumulated as nodules within the limestone/marble.

On the left bank slopes of Pauri Katha a few feet thick yellowish white siliceous band is also present within the graphitic schist.

The lower contact of graphitic schist with quartz mica schist is gradational but the upper contact with Balakot Gneisses is sharp and faulted.

The Panjal Formation

The volcanics of Panjal Formation so extensively exposed in the Kaghan Valley are seen near Batkarar south of Balakot, in the form of nearly a kilometer long fault slice.

The rock is greenish grey to green while a few horizons are dark red and purple in colour. Large dark green porphyroblasts of chlorite are fairly characteristic. At places the rock shows epidotization in the form of yellowish green patches. One or two thin creamish claystone like horizons were also noticed.

Apart from this outcrop thin slices of Panjal Formation are also seen on the spurs of Jalora Katha north of Balakot outside the presently mapped and described area. Further north, however, near Hangrai the exposures widen markedly.

The upper contact of the overturned Panjal Formation with a thin band of chert and quartzite at Batkarar appears to be normal to slightly disturbed. The other contact of this outcrop at Chhapper is faulted against a thin slice of Murree Formation and dolomite of Abbottabad Formation by the combined Murree and Muzaffarabad faults that pass through this area.

This outcrop of Panjal Formation occurs on the eastern bank of River Kunhar but must be considered stratigraphically a part of the metamorphic sequence mainly exposed on the west bank.

Malkandi Formation

A faulted slice of an oolitic limestone outcrops near Batkarar in close proximity with Panjal Formation.

This limestone is medium to coarse grained, medium grey on fresh surface and yellowish grey on weathered surface. The limestone has yellow dolomitic patches, a few yellowish bands and some minor calcareous sandstone horizons. The oolites are stretched. The rock is apparently clastic and has clear cross bedding at places. Some parts show reworking and presence of limestone clasts.

The limestone patch is overlain by a 50 ft. thick band of whitish quartzite which itself is overlain by a layer of metachert and then a slice of greenstones of Panjal Formation. This whole sequence is apparently upside down.

This Oolitic limestone of Malakandi Formation appears to be different from any other limestone seen in the Balakot anticline. It neither resembles the Tertiary limestones nor the dolomite or limestone of Abbottabad Formation. To a certain extent it resembles the Samana-Suk limestone of the Hazara stratigraphic province to the south. It represests the limestone horizon outcropping opposite Chore Banda near Malkandi in the Kaghan valley. It, therefore, belongs to the Kaghan stratigraphic province just like the greenstones of Panjal Formation.

MAJOR STRUCTURES

The Balakot Anticline

The rocks of the Balakot area east of River Kunhar have been folded in the form of a major anticline, which has been overfolded and thrust to the southwest, along the Muzaffarabad Fault (Calkins et al. 1975). The steep overturned southeastern limb of the anticline has been completely overridden by the more gently inclined northwestern limb which comprises the entire stratigraphic sequence now exposed in the anticline. The thrusting has generally brought the oldest exposed unit, the Abbottabad Formation, in juxtaposition against thin slices of Murree Formation exposed at places but generally burried under the alluvium of River Kunhar. These thin remnants of the Murree Formation are now the only exposed traces of the western limb of the Balakot Anticline. Further to the west, these Murree rocks have been truncated by the Murree fault.

The Balakot Anticline is a double plunging fold. In the northwest it narrows and disappears as well as is partially truncated against the Muzaffarabad fault between Garlat and Jabra near Patlang. In the southeast it plunges and disappears near Lari east of Shohal Mazula. Here it partially overlaps the Muzaffarabad anticline and has a fault disturbed en echelon relationship with the latter. Calkins et al. (1975) called the entire structure extending from Muzaffarabad to Balakot on the western margin of the axial zone of the syntaxis as the Muzaffarabad anticline. The northern part of this large structure has been called here the Balakot Anticline.

A number of sketch sections in Fig. 1 & 2 illustrate the structure of the Balakot Anticline. As can be seen from these figures the Balakot Anticline now basically comprises the overthrust northeastern limb. However, structures relating to the core can, at places, be seen in the main outcrop of Abbottabad formation. The overthrust limb itself has been reduced to a series of slices separated by medium to high angle imbricate faults. A number of asymmetric, inverted to isoclinal folds involving mostly the Lockhart limestone and Patala shales occur within the overall structure in the vicinity of Bhangian, Jusach and Magra.

Tectonic Significance of Murree and Panjal Fault

To understand the regional tectonic framework of the Murree and the Panjal faults, which have been described below, it would be appropriate to quote Wadia.

"Two more or less parallel and persistent planes of thrust have been traced at the Pir Panjal range along its whole length from the Jhelum to the Beas in Kulu. The outer of these (the Murree Thrust) has thrust the autochthonous Carboniferous-Eocene Belt of rocks over the mid-Tertiary Murree series, while the inner thrust (the Panjal thrust) has driven the older purana schists and slates of the central mountains over the autochthonous Carboniferous—Eocene rocks along an almost horizontal plane of thrust (Kashmir nappe)." (Wadia 1975, p. 392). Again he writes "The most important tectonic feature of this region is the occurrence of two great concurrent thrusts on the southern front of the Himalayas, delimiting the autochthonous belt which have been traced round the syntaxial angle from Hazara to Dalhousie, a distance of 400 km. Of these two thrusts, the inner (Panjal thrust) is the more significant, involving large scale horizontal displacements. The outer the Murree thrust, shows greater vertical displacement and is steeper in inclination but has an equal persistance over the whole region. In its geological constitution, the autochthonous zone between the two thrusts consists of a series of inverted folds of the Eocene (Nummulitic) rocks enclosing cores of Permo-Carboniferous Panjal Volcanics, and Triassic all closely plicated but with the roots in situ."

The Murree Fault

So named by Wadia in 1931 this fault has also been called the Main Boundary Fault, MBF, or the Main Boundary Thrust, MBT.

The Murree Fault at Balakot represents a thrust between the metamorphosed sequence west of River Kunhar and the sedimentary sequence of the axial zone of the Hazara Kashmir Syntaxis occurring east of River Kunhar. In the Balakot area this fault is generally vertical or inclined steeply to the

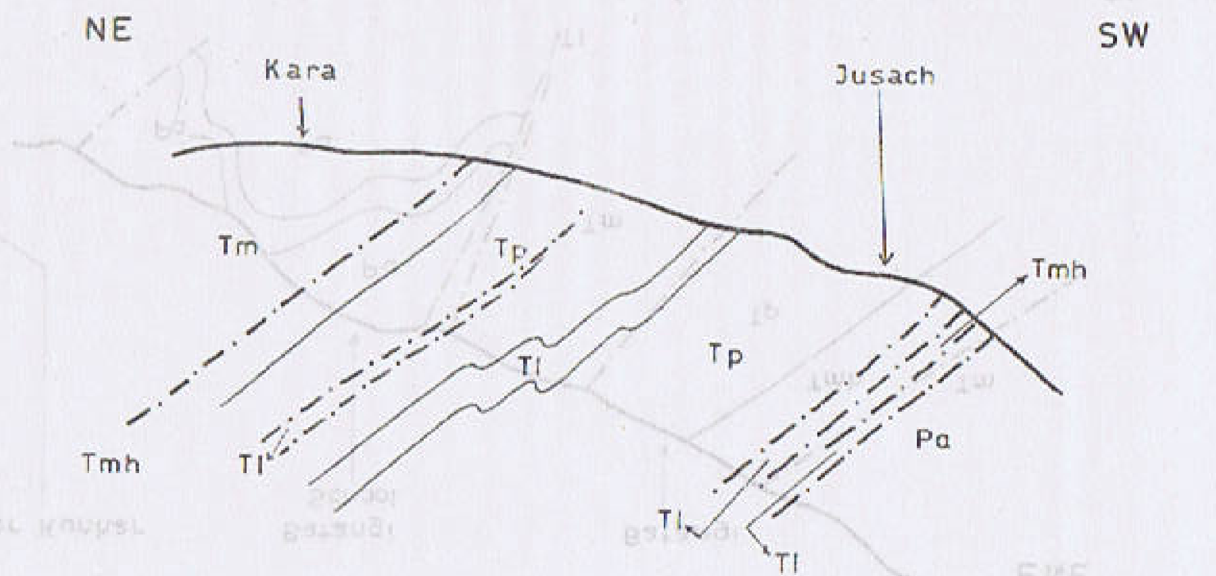


Fig 1a Sketch section left bank of Beran Katha (Pehran Katha)

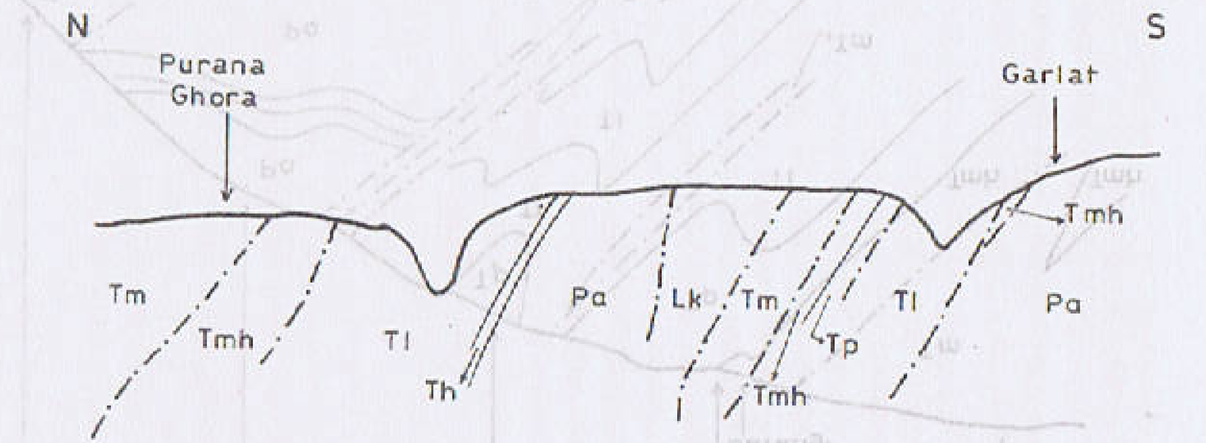
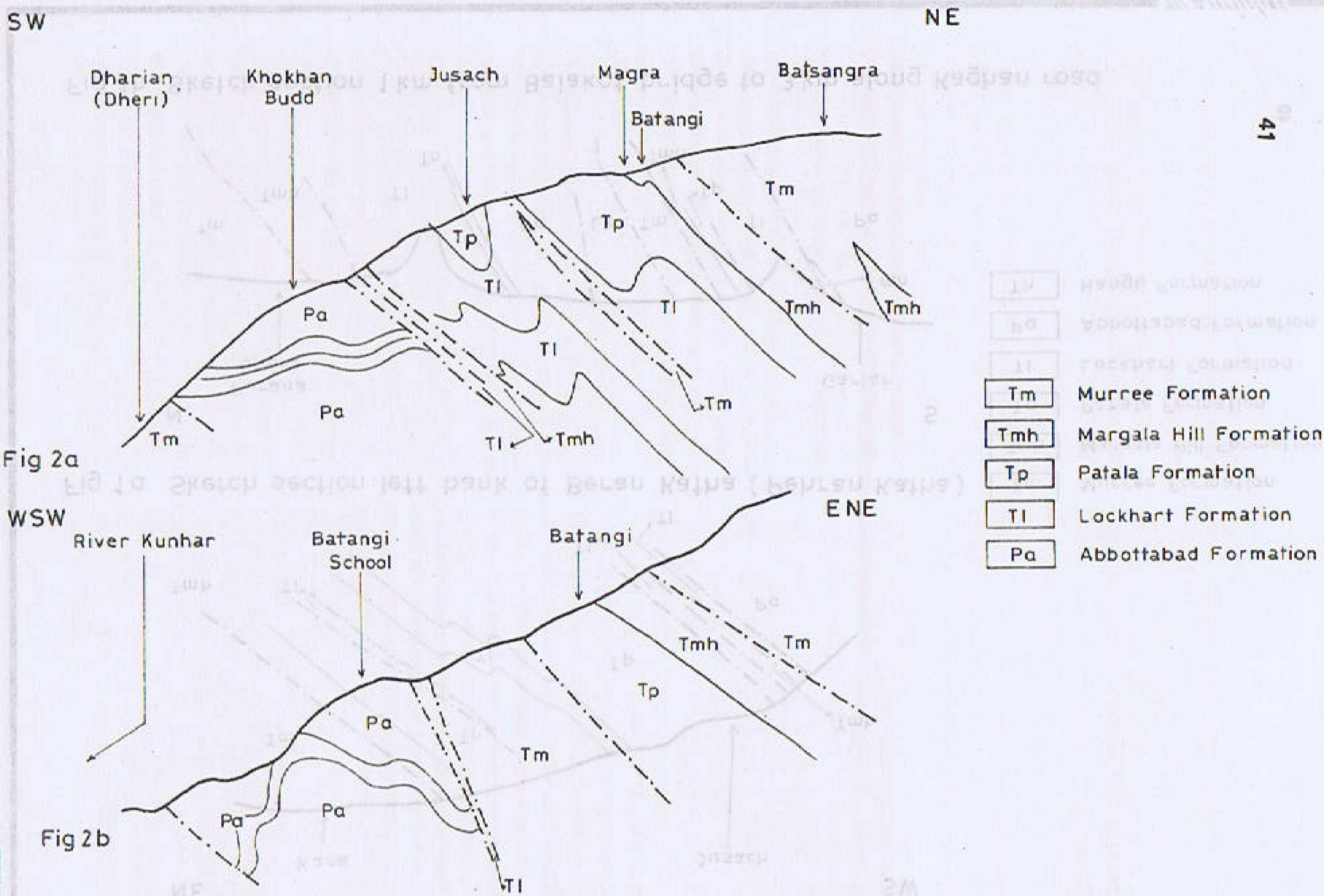


Fig.1b Sketch section 1 km from Balakot bridge to 3 km along Kaghan road

Tm	Murree Formation
Tmh	Margala Hill Formation
Tp	Patala Formation
Tl	Lockhart Formation
Pa	Abbottabad Formation
Th	Hangu Formation



Geologic sketch section east of river Kunhar between Dharian & Batsangra (above) and Batkarar & Batangi (below) west. Trending north from Nauseri in the Neelum Valley in Azad Kashmir the Murree thrust crosses the high Kaghan ridge and traversing the slopes of Bhunja Katha it appears near Malkandi on the roadside in Kaghan Valley. From here it is folded into a hairpin bend alongwith the rest of the structures and geologic sequence on the limbs of the Hazara Kashmir Syntaxis passing around the east-west trending apical part of the syntaxis and bending south along the western limb of the syntaxis.

Running north-south along the Jalora Katha it turns NW-SE north of Balakot and then runs along the Barna Katha. Further south it passes under the town of Balakot and continues to Naugran for a distance of about 4 miles concealed under the alluvial fill of Kunhar Valley. In the area of Naugran and Batkarar the Murree Fault separates a slice of Panjal Formation from dolomite of Abbottabad Formation. Further south it passes west of Muzaffarabad and then onwards along River Jhelum.

According to Calkins, et al. (1975) north of Balakot the Punjal Fault merges with the Murree Fault, the combined faults continuing southwards under the valley alluvium. However, since the so-called Salkhala Formation mapped by Calkins, et al. (1975) west of Balakot is in fact Chushal Formation (Agglomeratic Slate) the two faults do not merge north of Balakot. The Panjal Fault runs west of and separately from the Murree Fault in the Balakot area down to Bamphora, about one kilometre south of Balakot. However, from Bamphora south to Hassa and Batkarar the Murree and the Panjal faults do combine and run as a single fault zone though they diverge again further south. Calkins et al. (1975) gave dips of 50 to 70° E northwest of Muzaffarabad and 80° E to vertical south of Muzaffarabad. Apart from a strike slip movement these writers also gave a vertical displacement of about 10,000 ft. for the Murree fault on the western limb of the syntaxis.

The Panjal Fault

The Panjal Fault (Wadia, 1931) coming from Kashmir at the base of Pir Panjal Range like the Murree Fault bends round the Hazara Kashmir Syntaxis and trends in a northwest southeast direction west of Balakot separating graphitic schists of the Agglomeratic Slate sequence from the Balakot Gneiss of the Tanol Formation. On the western limb of the syntaxis from north to south it passes through the villages of Makhan Mohri, Tungli, Bajanbaura, Dandar and Khanda. Further south of Bamphora for some distance till Hassa and Batkarar it combines with the Murree Fault.

In the Balakot area especially north of Balakot it dips generally west at 25° to 65°. South of Balakot the dips range from 25° to 35° west. Calkins et al. (1975) called it a combination reverse strike slip fault which dips from 59° E to vertical.

The Muzaffarabad Fault

The Muzaffarabad Fault (Calkins et al., 1975) runs as a single fault zone from south of Muzaffarabad to north of Balakot along the western, southeastern margin of the Balakot and Muzaffarabad anticlines. It is along this fault that the Balakot anticline has been overthrust to be west. North of Batkarar this fault is more or less concealed under debris and river alluvium but south of Batkarar to south of Muzaffarabad it is exposed and presents a most striking structural feature.

The fault is a high angle thrust which dips 25° to over 50° northeast. In the Balakot area this thrust has juxtaposed the dolomite of Abbottabad Formation against Murree Formation ; though the Murree Formation is concealed under the river alluvium at places. For some distance south of Batkarar the Muzaffarabad and Murree Faults join together bringing the Panjal volcanics against the dolomite of Abbottabad Formation. Further south of Shohal Mazula again for some distance the dolomite is in faulted contact against metamorphics or Hazara Slates and here, too, the Muzaffarabad and Murree Faults have combined together. North of Balakot the Muzaffarabad fault trending northeast crosses the River Kunhar and merges into the Murree Fault which north of this point runs north-south along Jalora Katha.

Gouge and fault breccia are the two most common shear features throughout the length of this fault. The gouge zone is generally 5—20 feet thick. The cherty dolomite shows extensive brittle deformation.

Calkins et al. (1975) describe the Muzaffarabad Fault as follows: "The Muzaffarabad anticline on the western edge of the axial zone trends southeast, is sharply overturned southwest and is cross folded. Within the overturned southeastern limb of this anticline a second fault, the Muzaffarabad fault, separates Carboniferous to Triassic rocks (Kingriali Formation) from the younger rocks. This fault dips 25°—50° E, and along this slanting surface the Carboniferous to Triassic rocks have moved westward over the Eocene limestone and Murree rocks. The Eocene limestone and Murree rocks of the overturned southwestern limb of the Muzaffarabad anticline are sandwhiched between the Murree and Muzaffarabad faults and in places are cut out altogether. North of Garhi Habibullah, the Muzaffarabad Fault joins the Murree fault; southeastward it decreases in displacement and disappears". The above statement must now be read with quite a few changes in the stratigraphic nomenclature.

Bomphora Structure

About 2 km south of Balakot along the roadside a small but very interesting exposure of the tectonic relationship between Murree and Muzaffarabad faults is seen. The section is best exhibited along the branch road that goes to Bomphora and Sangal villages just above the main road.

The entire rock sequence especially the small rather isolated patch of reddish coloured Murrees here is strongly sheared. Westward this patch of Murrees is in tectonic contact with the mylonitic Balakot Gneiss along the Murree and Panjal faults that combine here into a single west dipping fault. However, the fault gouge present on the place also contains sheared pieces of dolomite of Abbottabad Formation. More clear are some sheared slices of dolomite that rest on the fault gouge and dip east, toward the river. A structural interpretation of this relationship is given in figure 3. The figure suggests that the Muzaffarabad fault being younger has brought the dolomite of Abbottabad Formation to rest on the Murree/Balakot Gneiss contact. The dolomite shears with their eastward dip therefore, constitute a klippe and lie directly above the eastward dipping Muzaffarabad fault zone which forms the base of the overthrust limb of the Balakot anticline. One could thus expect a zone of Murrees under the alluvium of river Kunhar separating the two east and west banks traces of Mazaffarabad fault. In between these two traces the Abbottabad dolomite overlying the Muzaffarabad fault has been removed by River Kunhar.

DISCUSSION

Stratigraphy

The above described stratigraphy of Balakot area brings into light the fact that more than one type of stratigraphic sequences have been tectonically juxtaposed in the Balakot area. These sequences belong to what may be called the stratigraphic provinces of Muzaffarabad, Hazara and Kashmir (Ghazanfar, Chaudhry

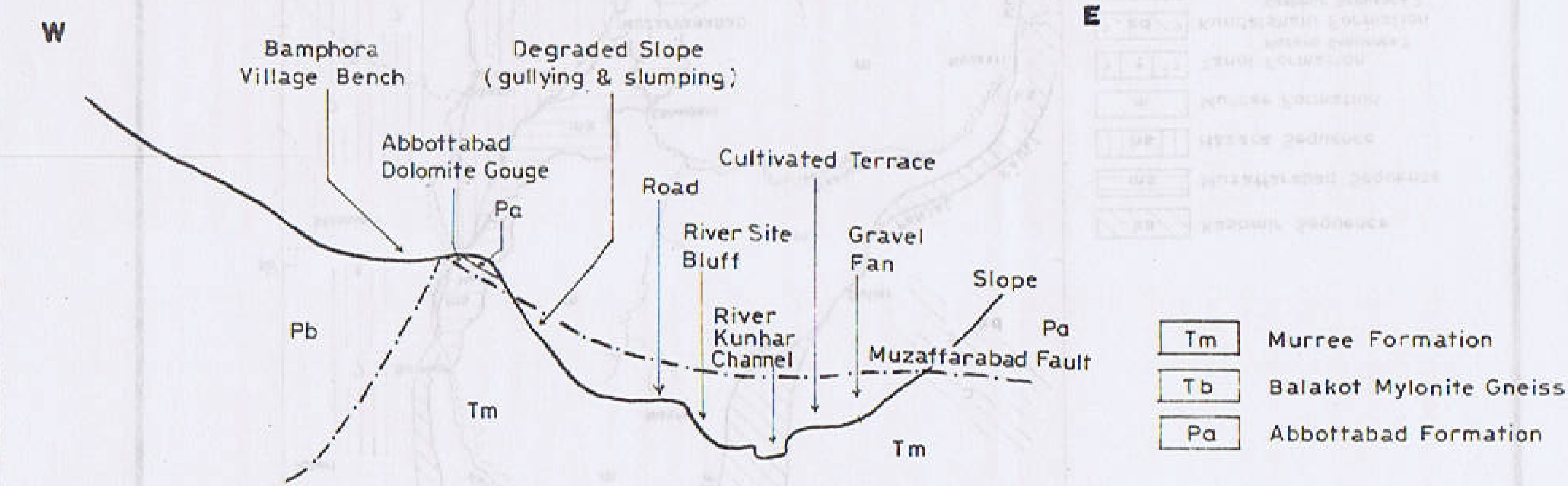
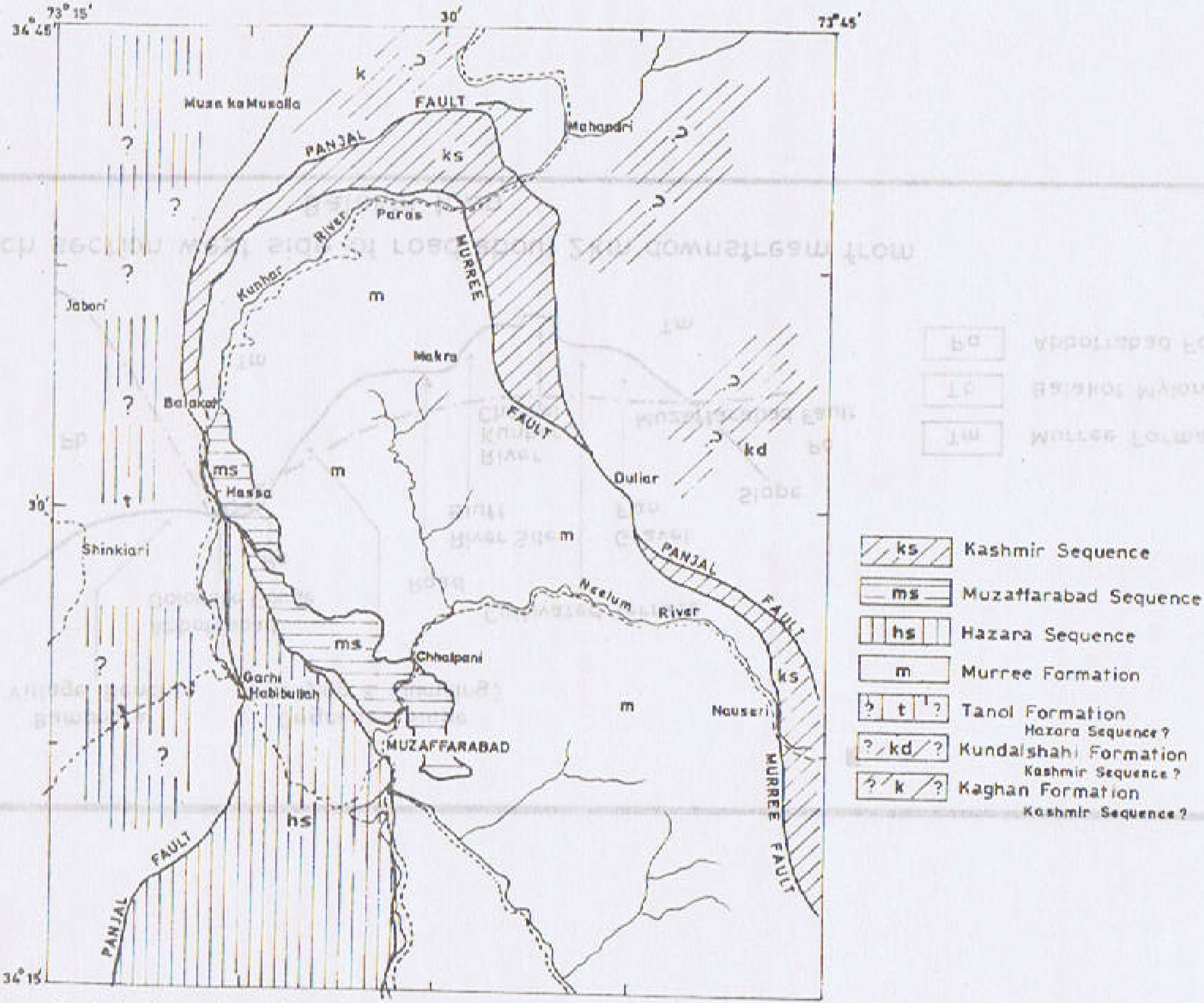


Fig 3 Sketch section west side of road about 2 km downstream from Balakot town

Fig. 4. Three Stratigraphic Sequences at Hazara Kashmir Boundary with possible areas of extension



Geologic base adapted from Calkins J. A., Offield, T.W., Abdullah, S.K.M. and Ali, S.T., 1975.

and Latif, 1987). The relative location of the stratigraphic provinces in Balakot is shown in Fig. No. 4 while table No. 3 shows a classification of the *outcropping* units of Balakot area according to their stratigraphic basinal affinities.

East of River Kunhar the rocks of the Balakot anticline belong to the Muzaffarabad stratigraphic province (table 3). These are all sedimentary rocks. After the Abbottabad Formation as the oldest exposed, there is a long gap in deposition with lasted from Cambrian through the entire Mesozoic era until Palaeocene time when Hangu Formation and younger Cenozoic sequence was deposited. The western limit of the Muzaffarabad Sequence is marked by the Murree Fault which juxtaposes the sedimentaries, mainly Murree Formation, against the metamorphics.

West of River Kunhar metamorphic rocks extend all along the Batrasi-Kund ridge. Stratigraphically, however, the metamorphics occurring on the lower slopes in the vicinity of Khet Sarash, Satbanni, Balakot and Bamphora belong to the Kashmir/Kaghan affinity (table 3). These rocks are mainly Chushal Formation (Agglomeratic Slates) and slices of Panjal Formation along with a minor patch of oolitic limestone of Malkandi Formation.

TABLE 3
Showing classification of outcropping units of Balakot area according to their stratigrapic basinal affinities

	Muzaffarabad Sequence	Kashmir Sequence	Hazara Sequence
Miocene	Murree Formation	Murree Formation	
Eocene	Margala Hill Formation		
Palaeocene	Patala Formation	Paleogene rocks of sequence faulted away in Balakot area.	
Palaeocene	Lockhart Formation		Remaining sequence outcrops outside and south of the Balakot area.
Palaeocene	Hangu Formation		
Triassic		Malkandi Formation (exposed at Batkarar)	
Permo-Carboniferous	Unconformity between Cambrian and Palaeocene	Panjal formation Agglomeratic Slate	
Cambrian	Abbottabad Formation (Base not exposed)		
Cambrian/ Precambrian			Tanol Formation

Further west of Balakot on the middle and upper slopes of the Kund ridge start the Tanols, comprising mainly a huge thickness of quartz mica schists and quartzites converted in part to mylonitic genisses and still further west intruded by Mansehra Granite. This stratigraphic formation belongs to what we may call the Hazara stratigraphic province (table 3) which is much more fully developed further south.

The Tanols, also called Tanawals (Shah, 1977) are a controversial formation of the Himalayas. Their exact stratigraphic relations are still being debated. However, we regard these Tanols of Hazara to be different from the Tanawals of Kashmir which coming through the Neelum Vallev possibly have a narrow outcrop at Jared in Kaghan Valley. The Kaghan Tanawals are part of the Kashmir basin and Middle Palaeozoic in age whereas the Hazara Tanols (or Tanawals) are more likely to be Precambrian in age and are intruded by the Mansehra Granite which is now regarded as Cambrian in age. So there are two Tanols/Tanawals (Ghazanfar, Chaudhry, Latif, 1986) which were confused as a single formation in the past. Those belonging to the Hazara stratigraphic province may be called Tanols and those belonging to Kashmir may be called Tanawals.

Structure

The Kashmir Boundary Thrust, *K B* T. A belt of foredeeps filled with red coloured molassic Miocene-Pleistocene sediments continuously borders the Pakistani platform on the north and the west. The northern part of this belt comprises what may be called the sub Himalayan foredeep (Sokolov and Shah 197(). It consists of two separate troughs (Voskresensky, et. al., 1965), the Potwar Foredeep in the west and what we may call the Azad Kashmir Foredeep in the east. Both the Potwar foredeep and the Azad Kashmir foredeep are traversed longitudinally by a zone of thrusts which have brought the older sediments up from place to place.

A look at the tectonic map of Pakistan (Kazmi et al. 1982) shows that the Balakot Muzaffarabad anticlines are only two of such a series of structures exposed along a fault zone extending southeast from Balakot. Southeast of Muzaffarabad other such structures are exposed at Kotli and at Riasi. This fault zone which in the Balakot-Muzaffarabad has been called the Muzaffarabad fault continues southeastwards to Riasi fault. It is considered to have overthrust the folded flank of the sub Himalayan foredeep southwestward over the platform flank of the same.

Analogous to the Balakot-Muzaffarabad anticlinal structure of the Azad Kashmir foredeep we have the Khairi-Murat anticlinal structure in the Potwar foredeep. The Khairi Murat structure in the Potwar is located along a system of ruptures which have been called the Big Boundary Fault. Here this thrust zone is traced as a narrow strip along the boundary of Siwalik and Murree sediments.

The Balakot, Muzaffarabad, Kotli and Riasi structures indicate a stratigraphic throw of over 1000 ft. along this fault. Since it cuts through the Murree Formation and has thrust Murrees over Siwaliks in Potwar this fault is at least Pleistocene in age.

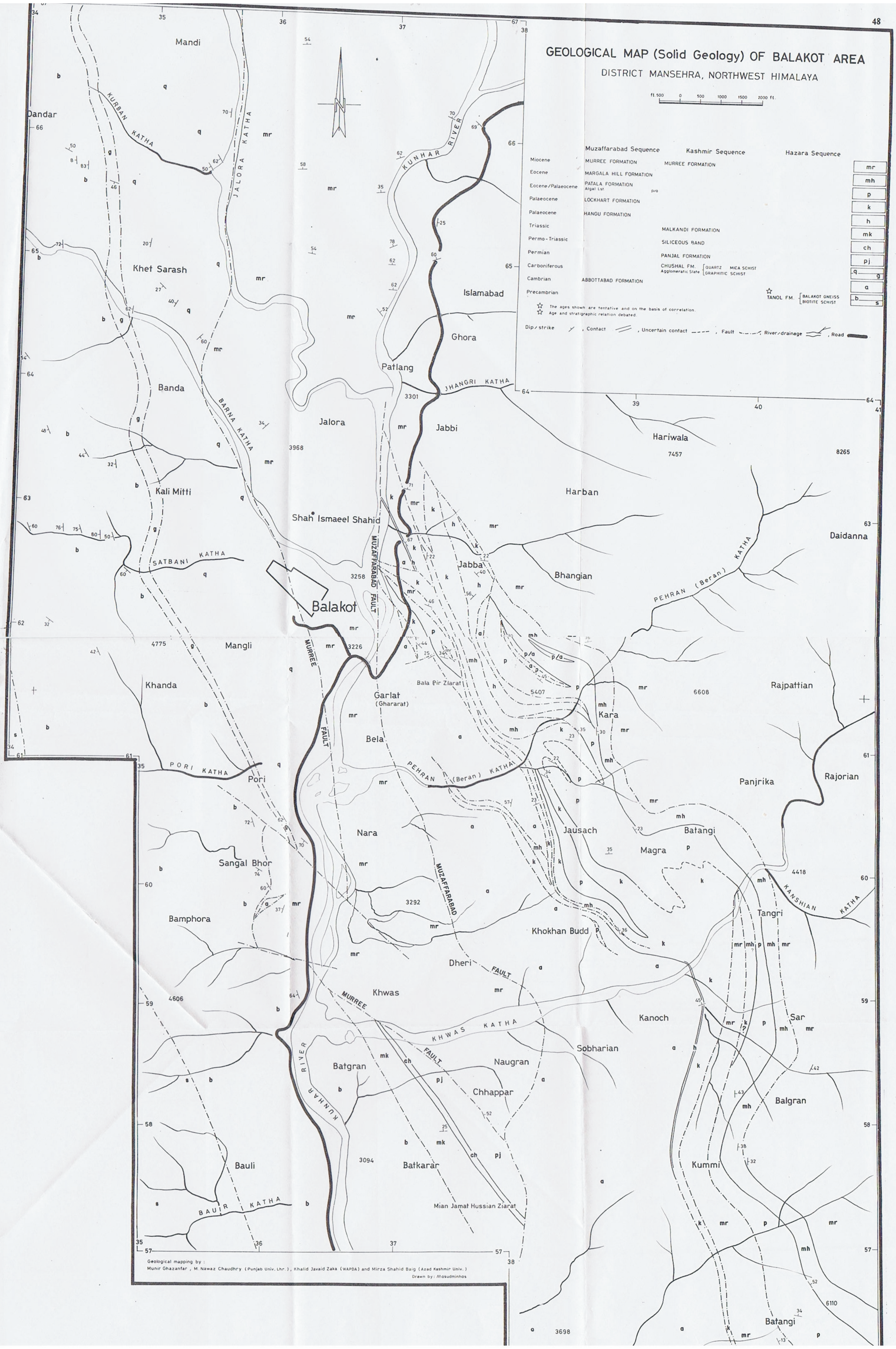
The Muzaffarabad—Riasi fault south of Kashmir and Khairi Murat or the Big Boundary Fault in Potwar together constitute what we may call the Kashmir Boundary Thrust, KBT. However, between the Muzaffarabad—Riasi segment and the Khairi Murat segment of this fault there appears to be a sinistral offset of many kilometers caused in main by the Jhelum Fault.

The Jhelum Fault

A large, left lateral displacement is involved between the eastern segment of the

Kashmir Boundary Thrust, KBT, at Balakot and the western segment of the KBT in the Potwar plateau. The fault causing this displacement extends from north of Balakot for miles further south along the river Jhelum and has been called Jhelum Fault (Kazmi, 1979) Northwards from Balakot the seismically detected Indus Kohistan Seismic Zone (IKSZ), (Seeber et al, 1980) is possibly also an active underground continuation of this fault. The numerous ramp faults of southern Hazara converge and truncate against the Jhelum Fault which has thus displaced the whole of the western limb of the HKS. The NNW to SSE trend of Jhelum Fault is followed by other similar faults to the west like the Shinkiari Fault Zone and the Tarbela Fault (Kazmi, 1979). The Shinkiari Fault Zone and the Jhelum Fault in its southern part is known to cut through alluvium. A number of earthquake epicentres have also been detected along the Tarbela Fault Zone and, a much bigger concentration is present along the IKSZ.

At the Hazara Kashmir Syntaxis, HKS, all the major structures including the Main Boundary Thrust, MBT, (the Murree Fault) and the Panjal Fault locally go through a bend of nearly 180°. Since the MBT is considered a basement fault so it is presumed that although the surface trace of MBT has undergone a bend due to superficial sliding the subsurface geosutural trace continued unbent in the form of IKSZ. It is, in fact, more likely that the Indus Kohistan Seismic Zone, IKSZ, represents a continuation of the Jhelum Fault for many kilometres northwards beyond Balakot. The sinistral Jhelum Fault at Balakot is marked by a major shear zone represented by a 1—5 km. wide belt of mylonites (Bossart et al., 1984) or Balakot Gneiss.


GEOLOGICAL MAP (Solid Geology) OF BALAKOT AREA
DISTRICT MANSEHRA, NORTHWEST HIMALAYA
ft. 500 0 500 1000 1500 2000 ft.
Muzaffarabad Sequence
Kashmir Sequence
Hazara Sequence
Miocene
MURREE FORMATION
MURREE FORMATION
mr
Eocene
MARGALA HILL FORMATION
mh
Eocene/Palaeocene
PATALA FORMATION
Algal Lst.
p/a
p
Palaeocene
LOCKHART FORMATION
k
Palaeocene
HANGU FORMATION
h
Triassic
MALKANDI FORMATION
mk
Permo-Triassic
SILICEOUS BAND
ch
Permian
PANJAL FORMATION
pj
Carboniferous
CHUSHAL FM.
Agglomeratic Slate
QUARTZ MICA SCHIST
GRAPHITIC SCHIST
q
g
Cambrian
ABBOTTABAD FORMATION
a
Precambrian
TANOL FM.
BALAKOT GNEISS
BIOTITE SCHIST
b
s
The ages shown are tentative and on the basis of correlation.
Age and stratigraphic relation debated.
Dip/strike
, Contact
, Uncertain contact
, Fault
, River/drainage
, Road
Mandi
Dandar
KURBAN KATHA
JALORA KATHA
KUNHAR RIVER
Khet Sarash
Islamabad
Ghora
Patlang
JHANGRI KATHA
Banda
BARNA KATHA
Jalora
Jabbi
Hariwala
Kali Mitti
Harban
Shah Ismaeel Shahid
SATBANI KATHA
MUZAFFARABAD FAULT
Jabba
Bhangian
Daidanna
PEHRAN (Beran) KATHA
Balakot
Mangli
MURREE
Khanda
Garlat
(Ghararat)
Bala Pir Ziarat
Kara
Rajpattian
Bela
FAULT
PORI KATHA
Pori
PEHRAN (Beran) KATHA
Panjrika
Rajorian
Nara
Jausach
Batangi
Magra
Sangal Bhor
MUZAFFARABAD
KANSHIAN KATHA
Tangri
Bamphora
Khokhan Budd
Dheri
FAULT
Khwas
MURREE
Kanoch
Sar
KHWAS KATHA
FAULT
Sobharian
Naugran
Batgran
KUNHAR RIVER
Chhappar
Balgran
Bauli
Batkarar
Kummi
BAUIR KATHA
Mian Jamat Hussian Ziarat
Batangi
Geological mapping by :
Munir Ghazanfar, M. Nawaz Chaudhry (Punjab Univ. Lhr.), Khalid Javaid Zaka (WAPDA) and Mirza Shahid Baig (Azad Kashmir Univ.)
Drawn by: Masudminhas

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A NEW LAMELLIBRANCH FROM THE UPPER SIWALIKS OF PABBI HILLS, PANJAB, PAKISTAN

BY

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Abstract : *An internal cast of a unionid has been described from the Pinjorian of Pabbi Hills of district Gujrat. A carefull examination has revealed that it is a new species of the genus Trapezoideus Simpson. This new species, Trapezoideus sardhokensis as it is named, was a large trapezoid, extremely compressed laterally and with extremely compressed umbones.*

INTRODUCTION

Siwaliks are very famous for fossil treasures. However, uptil now, emphasis has been given to the vertebrates only. A number of foreigners have been visiting the Siwalik Series since Falconer & Cautleys' (1846) time, but none has tried to explore the invertebrate fauna of the Siwaliks. There is no report of the Siwalik fresh water lamellibranchs by any known invertebrate palaeontologist such as Dall (1895), Moore et al (1952), Shrock and Twenhofel (1953), Murray (1985) Easton (1960), Wood (1961), Stanley (1970) and Yonge and Thomson (1978). The present work, thus makes the first description of the fossil fresh water lamellibranchs. It is based upon an internal cast of a lamellibranch collected by one of us from south-east of village Sardhok, district Gujrat, Panjab, Pakistan.

Since the Siwalik invertebrates are hitherto unknown, the present material has been compared mostly with the living lamellibranchs found in the Sub-continent of Pakistan and India. The morphological features of the specimen under study have indicated that it is congeneric with the genus *Trapezoideus* Simpson but represents a new species, *Trapezoideus sardhokensis.*

SYSTEMATIC ACCOUNT

Phylum	MOLLUSCA
Class	LAMELLIBRANCHIATA
Order	EULAMELLIBRANCHIATA
Superfamily	UNIONACEA
Family	UNIONIDAE
Genus	*Trapezoideus* Simpson

Trapezoideus sardhokensis new species

Holotype :

P. U. P. C. M.* No. 2, an internal cast.

Hypodigm :

Type only.

Locality :

South-east of Sardhok, district Gujrat, Panjab, Pakistan.

Age :

Pinjorian (Lower Pleistocene).

Diagnosis :

Test very much compressed. Somewhat thicker posteriorly than anteriorly. Anterior end rounded, but posterior biangular. Umbones highly compressed. Post dorsal wing fairly elevated but thin and sharp at the apex. Radial lines present.

DESCRIPTION (Figs : 1-2)

The specimen is a finely preserved internal cast of the animal shell. It is fairly elevated but highly compressed transversely. Its diameter or thickness is comparatively more posteriorly than anteriorly. Height of the specimen remains uniform for most of the length of the specimen. The anteriormost end is somewhat damaged but the contours indicate that most probably it was rounded. The posterior end is vertically linear. The umbones are forwardly placed. Thus the test was prosogyre and prosocline. The umbones are highly compressed. A prominent ridge runs posteriorly from the umbones on each side. Prosopon is poorly preserved. The right side is almost smooth. The upper half of the left surface is almost smooth. However, close to the ventral margin, radiating grooves and ridges can be observed. These grooves and ridges are less prominent at the anterior half than at the posterior half. Lunule is a shallow pit. Escutcheon is missing. The hinge-line is short. The post dorsal wing is much elevated but very thin and sharp.

DISCUSSION

In general contours, the specimen under study resembles with the genera *Lithophaga, Solecurtus, Nodularia, Parreysia, Lamellidens,* and *Tropezoideus.* The genera *Lithophaga* and *Solecurtus* are the marine lamellibranchs (Barnes, 1980 ; Murray, 1985). A deailed study indicates that it can also be differentiated from the freshwater genera except the last one. In the genus Nodularia, the posterior half is larger vertically than the anterior one and also the posterior end is very much rounded (Preston, 1915). In P. U. P. C. M. No. 2, the anterior and posterior halves are almost equally thicker and the posterior end is not rounded. In the genus *Parreysia,* the shell is inflated and oval to rhomboidal in shape. Cavity of the beaks is deep and not compressed (Simpson, 1900). The specimen under study is neither inflated nor oval, rather it is highly compressed with rounded or subrounded ends. In the genus *Lamellidens,* the shell is pointed behind with comparatively thick pre-umbonal area (Preston, 1915). The shell in P. U. P. C. M. No. 2 is not pointed behind and is not comparatively thin in the pre-umbonal region. In the genus *Trapezoideus,* the shell is much compressed and trapezoid with radial ridges on the posterior slope (Preston, op. cit.). The specimen uuder study is also highly compressed, trapezoid with radial ridges and grooves on the posterior slope. It is therefore justified to include the specimen under study in the genus *Trapezoideus.* In this genus, a single species have so far been described from the subcontinent of India and Pakistan. This is an extant species, *Trapezoideus theca* described from Bundelkhund, India. In this

* Punjab University palaeontological collection of Mollusca.

TABLE I

Comparative measurements (in mm) of the samples in various Sub-continental and Burmese species of the genus *Trapezoideus*

	Length (L)	Width (W)	Diameter (D)	W/L index	D/L index
Trapezoideus foliaceous	42	22	13	52	31
T. misellus	61	28	16	46	26
T. theca	40	20	10	50	25
T. exolescens	70	32	15	46	21
P. U. P. C. M. No. 2	65	34	17	52	26

species, the anterior and posterior ends are rounded (Preston, 1915). In the specimen under study, it is true for the anterior end but not for the posterior end. Moreover, the measurements of the adult sample of *Trapezoideus theca* shows that it is comparatively much smaller specimen (table I). In various measurements, the specimen under study differs from the known species (table I) except the species, *Trapezoideus exolescens* which is known from Burma. It is very close to the adult samples of the species, *Trapezoideus exolescens* in length, width and diameter. However, it can be differentiated from this Burmese species in morphological characters. In *Trapezoideus exolescens*, the umbones are subelevated (Preston, 1915) whereas in the specimen under study the umbones are highly compressed.

Keeping in view the dissimilarities found in the morphology of the specimen under study and the compared material, it is advisable to erect a new species for the P. U. P. C. M. No. 2. The name *Trapezoideus sardhokensis* is being proposed for this new species which is after the name of the type locality.

Fig. 1. ***Trapezoidens sardhokensis*** **n. sp. Dorsal view of the type specimen, P.U.P.C.M. No. 2 (Natural size).**

Fig. 2. ***Trapezoidens sardhokensis*** **n. sp. Lateral view of the type specimen, P.U.P.C.M. No. 2 (Natural size).**

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GEOLOGICAL EVOLUTION OF SOUTHERN PAKISTAN THROUGH PLATFORM AND RIFT STAGES

BY

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Abstract : *Southern Pakistan is a typical example of folded-platform basins. It is postulated that from Vend (Precambrian) to the end of Palaeozoic it experienced two stages of development——platform and rift. The latter provides a tvpical examp'e of triple junction construction in the area under study. Further more, such an interpretation manifests that Sukkur region is an ancient rift.*

INTRODUCTION

The geological evolution of Southern Pakistan (Fig. I) is being described for the first time keeping in view the modern concepts of development of folded-platform basins. It, therefore, provides a fresh approach for the appraisal of structural peculiarities and economic potential of the area in terms of geology.

The fundamental principles of various stages of development of folded-platform basins were forwarded by B.A. Sokolov (1975) and have received acceptance on a wide scale. These are briefly described for a better appreciation of the present work.

Since the geological evaluation of Pakistan is closely associated with the adjoining regions, it was therefore inevitable to discuss these areas, as well.

The study of platform and rift stages of development of Southern Pakistan was undertaken, because these are the major missing links, yet to attract attention.

PRINCIPAL STAGES OF DEVELOPMENT OF FOLDED-PLATFORM BASINS

Development of the basins of folded-platform or laterally heterogeneous type is closely associated with the evolution of the adjacent geosynclinal folded regions. According to B.A. Sokolov (1975), in the history of folded-platform basins, three stages can be distinguished, rift, pericraton and foredeep. The last two stages may be subdivided into two sub-stages ; early and late.

Development of basins at rift stage depends upon splitting up of margins of seaward sinking platform. As a result of displacement of individual blocks, graben type depressions are formed, where marine-shelf, deltaic and evaporite rock facies are deposited. Terrigenous-carbonate sediments thus deposited at a later stage turn out to be deeply submerged and catagenetically transformed.

Rift stage is succeeded by the pericratonic stage. It is characterised by the existence of wide platform monoclinal zone submerging towards the geosynclinal depression. Platform may be formed of zones of different ages of consolidation. At this stage rift type depressions, parallel to the main axis of the geosynclinal trough or oriented at an angle to it, may form on the submerged platform slope.

Pericratonic stage can be subdivided into two substages; at early substage of development of the basin, sediments are transported from platform side only. In the marginal areas, shallow water terrigenous sediments are accumulated. Towards the geosyclinal depression they are substituted by clay and carbonate deep water sediments. From the sea side basinal limits are still demarcated by buried folded-block elements. During the late substage of development, island cordillera are formed in the geosynclinal trough. At this stage, material is supplied by both dry land masses of platform and newly uplifted internal parts of the geosynclinal depression. Within the conjugated zones of compensated and uncompensated sedimentary deposition, reef building may take place. Evaporites may form in the shelf areas. At the pericratonic stage maximum thickness of sediments in the basin is generally confined to the perigeosynclinal regions.

The succeeding development stage is marked by the beginning of epigeosynclinal orogen and formation of conjugated foredeep. The foredeep stage is subdivided into two substages ; early and late.

At early substage orogen structure is not yet distinct. During this substage principally shallow water, fine carbonate clay sediments are deposited. Platform areas are the principal source regions. At late substage of development, due to increasing intensity of uplifting movements, orogenic structure is distinctly expressed in relief. Simultaneously, the quantity of transported terrigenous sediments is increased giving rise to thick molasse formation. Distribution of these rocks clearly outlines the position of foredeep. At this stage rising structure is the principal source of terrigenous material. Even foredeeps are included in the uplift. This leads to the shifting of troughs and their displacement towards the platform flanks.

DISCUSSION

Geological evolution of Southern Pakistan, a typical example of folded-platform basin, is intimately associated with the development of adjoining regions. Keeping in view the available theoretical ideas, two independent stages of development, embracing Vend (Precambrian) and whole of the Palaeozoic era, can be distinguished in the geological history of Pakistan.

Vend (Precambrian)—Early Palaeozoic Platform Stage

Analyzing available materials on Central Iran (Stocklin, 1968, Auden, 1974) Afghanistan (Slavin, 1977) and stratigraphic sections of Western India, Salt Range of Pakistan and Persian Gulf (Sokolov, 1977) it is possible to say that during Vend-Early Palaeozoic time Indian platform and Baluchistan-Iran areas existed as a singular closed basin. Terrigenous rocks and evaporites were laid down in the western parts of this vast region from Vend to Cambrian times (Fig. 2). In the beginning terrigenous sediments were deposited in shallow water environments. These were succeeded by evaporites, which were formed, most probably, in a sea basin with high salinity. Evaporites were followed by the deposition of carbonate sediments. Finally purple coloured sandstones, as witnessed by their rosy tinge, were laid down in oxidising environments.

Palaeozoic Rift Stage

Rift stage is distinguished by the author somewhat conditionally, out coming from the available theoretical ideas, supported to a certain extent by inhand factual material and geological analogies. Possibly during Middle Palaeozoic tensional forces led to the splitting apart of above mentioned vast platform region. Thus, between separate blocks of platform, along major fault zones-lineaments, was laid down the system of rifts, two branches of which at a later stage, developed into Sulaiman-

Kirthar depression and the third one was inherited by the Sukkur rift (Fig. 3). V. E. Popov, et al. (1978) include Sulaiman-Kirthar rift into Trans Asian system of rifts, established by V.D. Nalivkin.

The rift stage of development of the Indus basin has significant resemblance with the evolution of other basins of similar type, in particular Leno-Vilui basin of USSR (Sokolov, Larchenkov, 1978).

CONCLUSIONS

From the foregoing discussion it is evident, that the platform stage of evolution of Southern Pakistan provides a solution to the stratigraphic correlation of sporadic exposures of Precambrian-Early Palaeozoic rocks existing over a vast region.

After a platform stage of development, as evidenced by the platform rock facies, the formation of Sulaiman-Kirthar alpine geosynclinal depressions can only be explained through rift stage of development.

The development of deep Sulaiman-Kirthar troughs, through rift stage, manifests submergence of these trough zones along major faults-lineaments.

Sukkur region, previously treated as a high, in fact is a rift zone and serves as a classical example of the triple junction in Southern Pakistan.

Various interpreted stages of development, supplemented with further geological and geophysical studies will be of direct assistance in establishing the potential of the area in terms of minerals and mineral fuels.

ACKNOWLEDGEMENT

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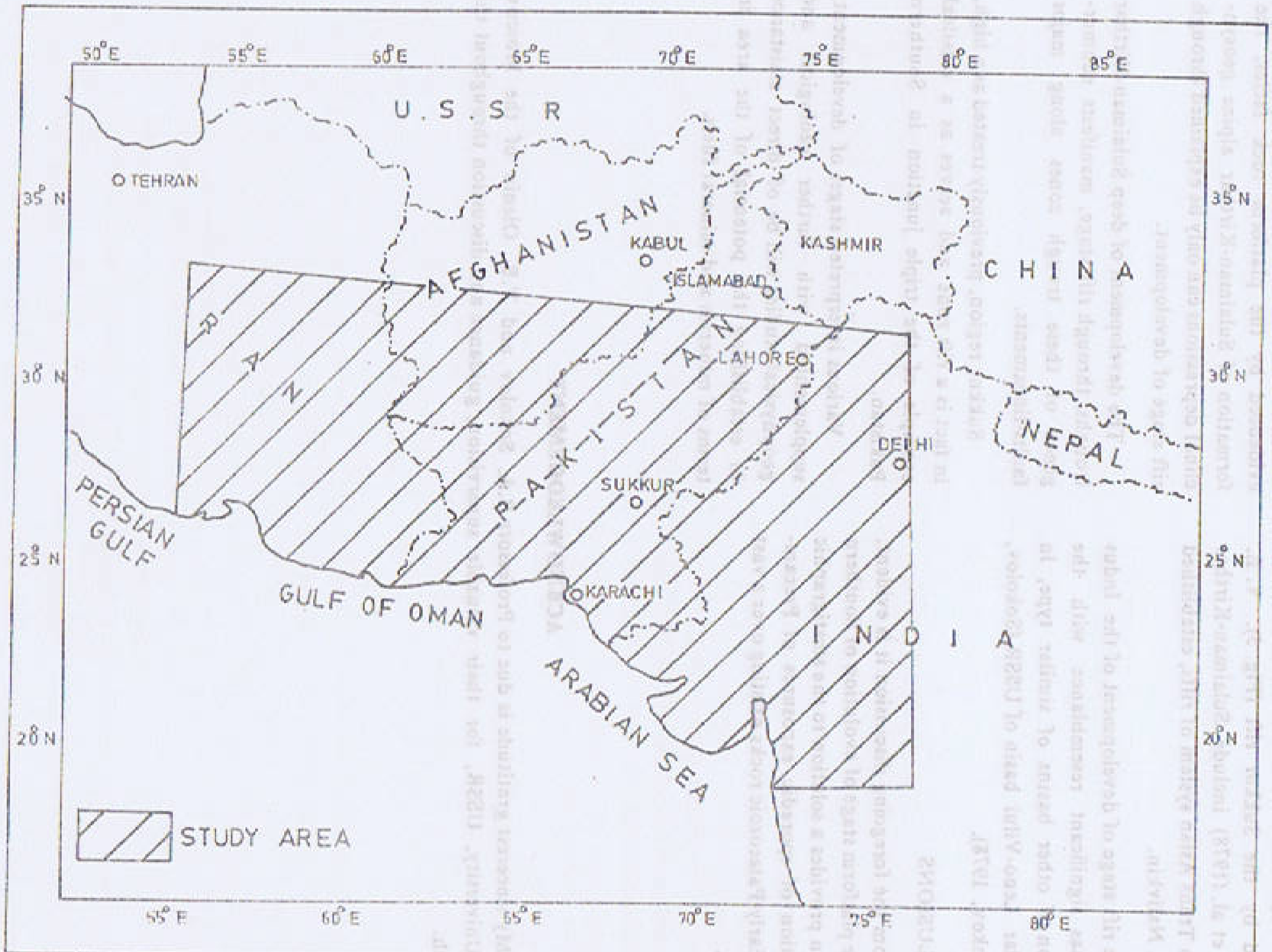
MAP OF PAKISTAN AND ADJOINING REGIONS



SCALE

1 : 19,000,000

500 Km 0 Km 500 Km 1000 Km

Fig. 1

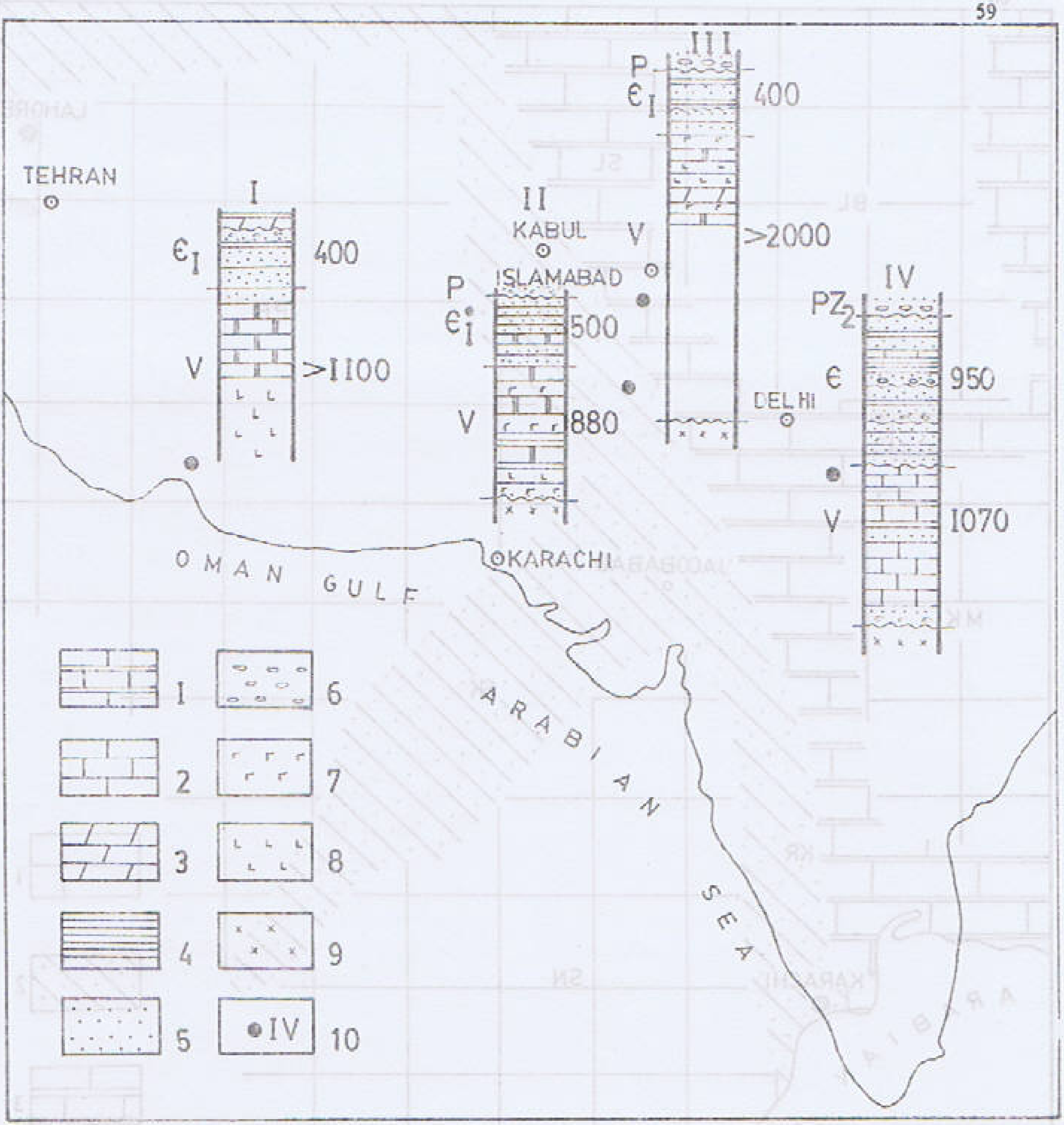


Fig. 2 Conditions of deposition during Vend (Pre-camberian)-Early Paleozoic, Platform stage by Mahmood H.Chaudhry, 1978.

1. Dolomite. 2. Limestone. 3. Marl. 4. Clay. 5. Sandstone. 6. Conglomerate. 7. Anhydrite. 8. Salt. 9. Basement. 10. Location of stratigraphic columns: I. Hormuz; II. Karampur. III. Salt Range. IV. Vindhyan Depression.

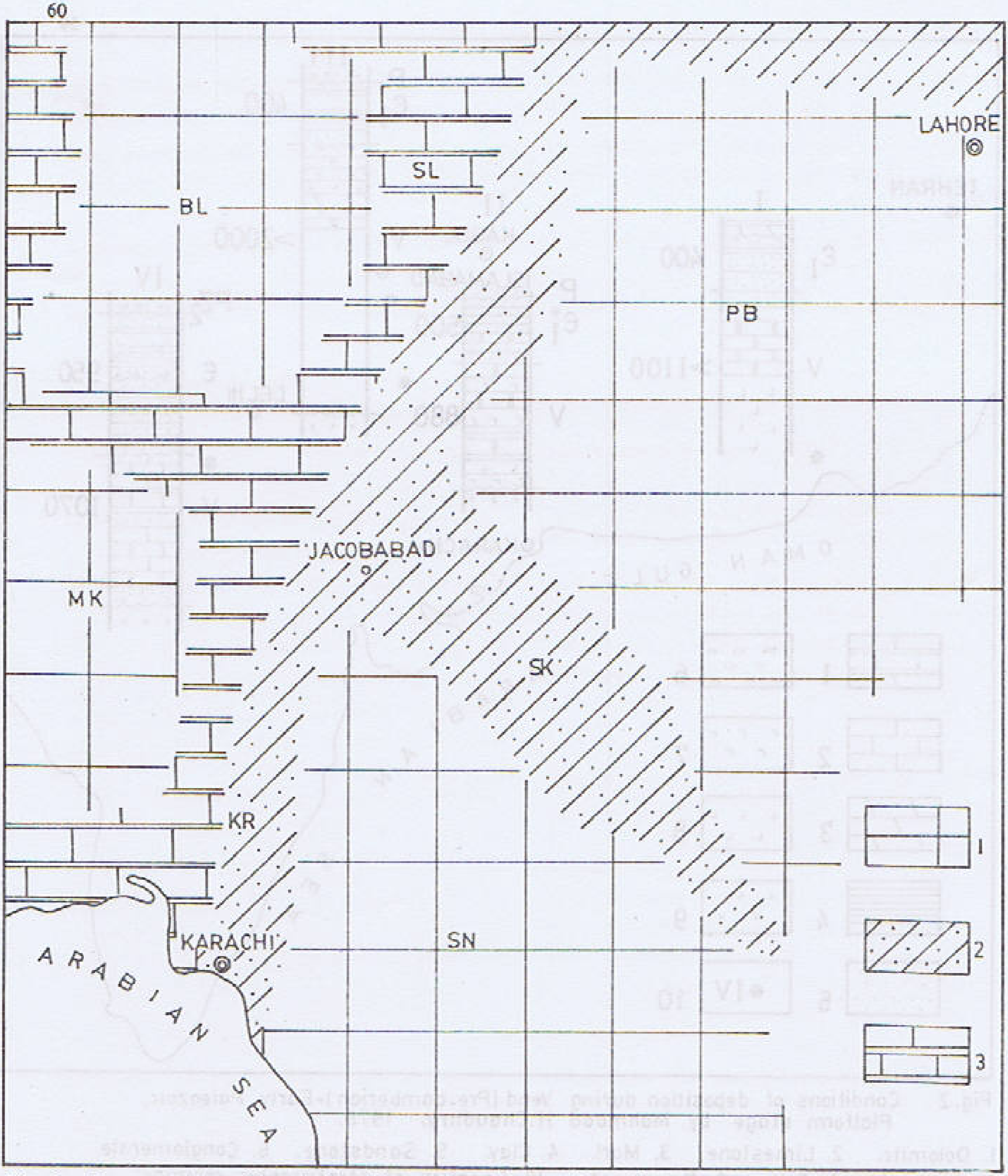


Fig. 3 Proposed depositional situation during Paleozoic Rift stage by Mahmood H.Chaudhry, 1978.

1. Dry land masses ; PB _ Punjab ; SN_Sind : BL _ Baluchistan : MK_ Makran.
2. Marine terrigenous shelf sediments. 3. Marine terrigenous _ carbonate sediments. SL _ KR _ Sulaiman _ Kirthar depression SK _ Sukkur rift

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METAMORPHISM AT THE INDO-PAK PLATE MARGIN, KAGHAN VALLEY, DISTRICT MANSEHRA, PAKISTAN

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Abstract : *This paper presents for the first time mineral assemblages, textures, structures, index mineral zones, metamorphic facies and metamorphic grades of the rocks lying between Paras and Babusar Pass, Kaghan Valley. The metamorphic rocks are regionally metamorphosed and belong to medium pressure type metamorphic series. The rocks range from unmetamorphosed units to high grade metamorphic units e.g. from greenschist facies to high amphibolite facies. In terms of index minerals, they range from biotite to sillimanite zones and in terms of metamorphic grades the rocks range from very low grade to high grade metamorphism.*

INTRODUCTION

Wadia (1931), Calkins et al. (1975) and Bossart et al. (1984) studied rocks and structures of Kaghan Valley down stream of (Khannian) Mahandri. Ghazanfar and Chaudhry (1985) mapped, at the scale 1 : 17000, the middle Kaghan Valley area between Paras and Batakundi. The area between Mahandri (Khannian) and Batakundi was mapped by these authors for the first time while mapping of the units to the south of Khannian was revised. The upper Kaghan Valley between Batakundi and Babusar Pass (MMT) was also mapped for the first time by Chaudhry and Ghazanfar in 1987. They worked out the stratigraphy, structure and geomorphology of the area. The area around Balakot at the mouth of Kaghan Valley has been mapped and described in detail by Ghazanfar, Chaudhry, Zaka and Baig (1986).

This paper presents for the first time petrography, mineral assemblages, textures and structures, index mineral grades, facies and metamorphic grades (after Winkler 1979) of the area between Paras and Babusar.

REGIONAL GEOLOGY

The Kaghan Valley provides a N-S transverse section through the middle part of NW Himalaya lying in Pakistan. It is drained by the river Kunhar. To its east lies the more or less parallel valley of river Neelum(Kishanganga) in Azad Kashmir. To its west lies the valley of river Indus draining the so-called Kohistan Himalaya. Tectonically the lower part of Kaghan Valley comprises the Hazara Kashmir Syntaxis, an acute bend of strike at the western end of the Himalayan chain. This syntaxis is beautifully outlined by the Main Boundary

Fault (MBF/MBT). As we move from Balakot up the Kaghan Valley to Paras, for about 16 miles along the road, we pass through a sequence of Murree formation forming the core of Hazara Kashmir Syntaxis. Further between Paras and Jared one passes through the eastern limb of the syntaxis formed by the so-called Carboniferous to Eocene sequence enclosed between the Panjal and the Murree faults. From Tutan near Jared right across Babusar, a very extensive and long section of rocks or its parts were termed as the Salkhalas by Wadia (1931) and later writers Calkins et al. (1975), Bossart et al. (1984). Detailed geological mapping has revealed that this sequence, in fact consists of a large number of lithologic units which have now been mapped by us and grouped into broader units. Thus it is possible to subdivide the entire so-called Salkhala sequence, into the following broad units :

1. A rather small Jared unit.
2. A very large Kaghan group.
3. An equally large Sharda group.

The Sharda group which forms the western or the upper Kaghan Valley is truncated by the Southern Suture Zone or Main Mantle Thrust (MMT) of the northwest Himalayas, just north of Babusar. Further north of Babusar across the MMT we have a sequence of low grade schists, amphibolites, diorites and norites with some ultrabasic shreds. The bulk of the sequence of Kaghan Valley between Jared and Babusar, therefore, comprises Cambrian and Precambrian rocks and is sandwhiched between Panjal Fault in the south and MMT in the north. Thus from the point of view of stratigraphy, from south to north, the Kaghan valley comprises the Miocene Murree formation, the so-called Carboniferous to Eocene sequence and the very wide Cambrian and Precambrian sequence.

We may term the sequence between Balakot and Malkandi (near Paras) as sedimentary although Bossart et al., (1984) placed it in the Prehnite-Pumpellyite facies. Up from Malkandi the entire sequence is metamorphosed in a progressive manner upto Silliminite grade or Upper Amphibolite facies. There is however, a break in this progression near Batal. Finally the grade of metamorphism suddenly decreases as we cross the Main Mantle Thrust near Babusar.

DESCRIPTION OF ROCK UNITS

Stratigraphic sequence along with the main lithologies of the area is presented in Table 1. For detailed field description of the rock units, stratigraphy, structure and geomorphology the reader is referred to Ghazanfar and Chaudhry (1984, 1985, 1987) and Chaudary and Ghazanfar (1987).

SHARDA GROUP

The various component lithologies of Sharda group of rocks seen on the roadside from Batal to Babusar along with their petrographic summaries are briefly described below :

Dumri Calc-Pelites

West of Sobhai Mahli between Bans and Batakundi it occurs as a distinctively calcareous sequence on the right bank of river Kunhar. It also extends on the left bank under Dumri Maidan at Batakundi and mainly comprises white pale yellow marbles intercalated with light grey to greyish brown pelites.

Dabukan Marble

A distinctive white massive thick band of marble with subordinate layers of calc-pelites. Dabukan marble passes through Dunga Katha, Dabukan Katha and Dadar Nar north of Reori. In the area of Khaba Nar it appears to be intruded by a number of amphibolite bands.

TABLE No. 1

Stratigraphic Sequence

Group	Formation	Lithology
	Murree Formation (Miocene)	
	Paras Formation (Paleocene to Eocene)	
	Rosachcha Formation (Paleocene)	
	Malkandi Limestone (Triassic)	Dark grey Oolitic limestone with shale partings.
	Panjal Formation (Permian)	Panjal basic volcanics and associated Ling, Bhunja and Shino bands of limestone/marble.
	Chushal Formation (Agglomerate Slate Series) (Carboniferous)	Graphitic schist, limestone/marble, metaconglomerates and tuffs.
	Tanawal Formation (Silurian to Carboniferous)	Jared quartzites and quartz mica schists.
Kaghan Group (Precambrian)	Mahandri Formotion	Biari quartzites, metaconglomerates, quartz mica schist, calc-schist and pegmatites. Doga schists, marbles, quartzites and metaconglomerates. Phagal quartz mica schists and quartzites Lohar Banda, marble. Kamalban quartz mica schists, quartzites, calc-schists and marbles.
	Kaghan Formarion	Kaghan pelites
	Rajwal Formation	Rajwal quartzites, quartz mica schists/gneisses pegmatites, aplites and granite/gneiss. Paludaran graphitic schist. Batal quartzites and quartz mica schist/gneiss.
Sharda Group* (Precambrian)	Amphibolites.	
	Migmatites and Granite Gneisses including :	:— Saif-ul-Maluk granite gneiss. :— Dadar migmatites. :— Babun granite gneiss. :— Jalkhad granite gneiss. :— Gittidas granite gneiss.
	Lulu Sar Feldspathised Porphyroblastic Gneies.	
	Mixed unit including :	:— Purbinar mixed unit. :— Besal mixed unit.
	Garnetiferous Calc-pelitic Gneisses including :	:— Naran garnetiferous calc-pelites. :— Burawai garnetiferous calc-pelites.
	Dhak Graphitic Gneisses (In Jalkhad Nar). Bans pelitic Gneisses. Dabukan Marble. Dumri Calc-pelites.	

* Includes garnetiferous calc-pelitic gneisses, pelitic gneisses. graphitic gneisses, marbles, porphyroblastic gneisses. sheet granites, migmatites, younger garnet-tourmaline granites and amphibolites. The above listed subdivisions of Sharda group represent an approximate stratigraphic order with geographic names (not strictly stratigraphic) after place of best development is given.

Bans Pelitic Gneisses

This lithology occurs in the area of Dharir (near Rakhan), Bans, and Dila. It comprises pelitic gneisses with subordinate psammites and occasional bands of marble. Petrographic summary is as follows :

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

1. **Pelite**

CGQ 1. Kyanite—Garnet—Quartz—Biotite—Muscovite—Magnetite—Sillimanite.

Texture :—Porphyroblastic and hypidioblastic.

2. **Amphibolite**

CGQ 2. Garnet—Amphibole—Quartz—Plagioclase—Sphene—Magnetite — Apatite.

Texture :—Porphyroblastic and poikiloblastic.

Dhak Graphitic Gneisses

Dark grey to black graphitic gneiss associated with feldspathised pelitic gneiss showing tourmaline needles and at places, kyanite lathes. It occurs as a small band on both sides of Jalkhad Nar near Dhak village.

Garnetiferous Calc-pelitic Gneisses

This is the principal lithology among the metamorphosed sedimentary rocks between Naran and Babusar. There are two main out crops, one around Naran and the other around Burawai. Other lithologies like pelitic gneiss, calc-pelites and marbles are relatively minor and have been described separately.

Naran Garnetiferous Calc-Pelites. The calc-pelitic gneisses are generally light grey and light brownish grey on fresh surface and dark brownish grey or yellowish brown on the weathered surface. They are banded and show differential weathering with the micaceous and schistose layers appearing as positive ribs on the weathered surface. Their texture is gneissic and porphyroblastic, and they are composed of calcite, garnet, biotite, muscovite and quartz. The garnets are mainly subidioblastic. Accessory to trace amounts of pyrite and graphite may also be present. The garnet is generally very prominent, the size varying usually between 1 mm to 10 mm but, at times, the garnet reaches 30 mm., as at Danna above Danna da Katha at the back of Naran. At times more than 50% of the rock is comprised of garnet.

The calc-pelitic gneisses are interbedded generally with impure bands of marble. The impure marble bands are porphyroblastic and poikiloblastic. There are some few metres thick pure marble bands also. These are typically granoblastic.

1. *Amphibolites.* The amphibolites are fine to medium grained, well foliated, dark greenish with shining fresh faces and are also garnetiferous.

The amphibolite bands generally range from one cm. to 3 m. in thickness although a few bodies are much thicker like the one above Leda Gali and the other above Mohri leading into Hans Dhar Katha. This variation in thickness is possibly related to two types of origin. The amphibolites are fine to medium grained, well foliated dark greenish grey with shining fresh faces and garnetiferous. At places they are subporphyroblastic to porphyroblastic and even poikiloblastic. They are invariably garnetiferous. Chlorite and epidote are retrograde products. The garnetiferous calc-pelites are generally more prone to chemical weathering. Occasional graphitic bands are also found.

2. *Marbles.* The interbedded marble bands constitute a subordinate lithology. They are white, light grey, or yellowish and yellowish grey on fresh surface and greyish brown or yellowish brown, mustard or brown on weathered surface. They are generally medium bedded and medium grained.

Following is the petrographic summary of various lithologies.

Upper Middle to Upper
Amphibolite Facies
Kyanite Grade
Sillimanite (?)
High Grade Metamorphism.

1. Pelite

CGQ 22. Garnet—Quartz—Biotite—*Chlorite**—Muscovite—Magnetite — Plagioclase —Sphene—Apatite.

CGQ 23. Quartz—Muscovite—Garnet—Biotite —Kyanite—Andalusite (?)—Tourmaline—Sphene—Magnetite.

CGQ. 24. Quartz—Muscovite—Garnet — Biotite—*Chlorite*—Plagioclase — Magnetite—Apatite—*Epidote*—Zircon.

CGQ 25. Quartz—Plagioclase—Garnet — Biotite—*Chlorite* — Magnetite— *Epidote* —Tourmaline—Zircon.

Texture. Generally poikiloblastic and porphyroblastic, occasionally sub-porphyroblastic.

2. Psammite

CGQ 26. Quartz—Muscovite—Kyanite— Microcline.

Texture. Granoblastic.

3 Calcareous

CGQ 27. Calcite—Quartz— *Epidote* — Amphibole—Zircon.

Texture. Granoblastic.

4. Graphitic Pelite

CGQ 28. Quartz — Graphite — Muscovite — Pyrite—Plagioclase — Tourmaline — Biotite.

Texture. Lepidoblastic.

5. Amphibolites

CGQ 29. Plagioclase—Amphibole — Garnet — Biotite, *Chlorite*—*Epidote*— Quartz—Sphene—Magnetite

* Retrograde mineral names are given in italics.

Texture. Mostly hypidioblastic but at places subporphyroblastic to porphyroblastic and poikiloblastic.

Burawai Garnetiferous Calc-pelites. Pelitic gneiss and calc-pelitic gneiss with large sized garnet. This may show alternation of pelites with thin bands of marbles or with thin laminae of quartzofeldspathic type. There are numerous quartz veins which contain tourmaline needles. At places thin bands of para-amphibolite are developing. Generally the rock resembles the description of Naran garnetiferous calc-pelites. The Burawai garnetiferous calc-pelites occur in the form of an elliptical outcrop, in the vicinity of Burawai.

1. Amphibolite

CGQ 3. Amphibole—Labradorite—Sphene—Ore—Quartz—Apatite.

CGQ 4. Amphibole—Labradorite—Biotite — Sphene—Quartz — Magnetite—Apatite.

CGQ 5. Amphibole — *Epidote* — *Chlorite* — Quartz—Magnetite — Sphene— Apatite.

CGQ 6. Amphibole—Plagioclase — Biotite—Sphene—Quartz—Apatite — Magnetite.

Texture. Hypidioblastic to porphyroblastic, and poikiloblastic to sub-poikiloblastic.

Mixed Unit

The mixed unit in main accupies the Ratti Gali Nar, the Purbi Nar, and a part of the Gittidas Nala. For the sake of convenience it has been divided into following two parts :

Purbi Nar Mixed Unit. This unit occurs in the upper reaches of Purbi Nar, Ratti Gali and Dadar Nar. It is in main a mixture of granite, gneiss and granitized feldspathised gneiss. These lithologies can sometimes be mapped as separate units but mostly interfinger and intertwine. The granites are generally light grey and the gneiss shows shades of brown.

Following is the petrographic summary of pelites.

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

1. Pelite

CGQ 9. Garnet—Biotite—Muscovite—Quartz —Sillimanite—Plagioclase — Magnetite—Zircon.

CGQ 10. Kyanite—Garnet—Sillimanite — Biotite — Plagioclase —Quartz—Muscovite—Tourmaline—Magnetite.

Texture. Porphyroblastic — poikiloblastic, sometimes xenoblastic.

Besal Mixed Unit. The mixed unit at Kutawai in Purbi Nar is about 1000m thick but on the road side between Besal and Lulu Sar it is about 200m thick. On the roadside it consists of a mixture of marbles, calc-biotite gneisses, pegmatites, granitized gneisses and amphibolites. Following is the petrographic summary of pelites.

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

1. Pelite

CGQ 8. Garnet—Biotite—Muscovite—Quartz —Magnetite—Zircon—Plagioclase.

Texture. Xenoblastic.

Lulu Sar Feldspathised Porphyroblastic Gneiss

This unit is exposed on the road side around Lulu Sar Lake and its outcrop is present in Khote Nar and Putha Nar. It is a pelitic gneiss which at most places shows development of feldspar porphyroblasts along with small sized garnets. The general colour is light brown. Following is the petrographic summary of pelites.

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

1. Pelite

CGQ 7. Garnet—Plagioclase— Quartz — Biotite—Muscovite—Sillimanite— Magnetite.

Texture. Porphyroblastic and poikiloblastic.

Migmatites and Granite Gneisses

A number of granite bodies occur mostly associated with the metamorphic sequence. These bodies are sheet like and conformable as well as folded with the metamorphic rocks. Nearly all of them may be termed garnet tourmaline granite gneisses and especially near the contacts may show variable degree of migmatization. There are some leucocratic younger garnet-tourmaline granite bodies also. These are generally small in size and occur associated with granite gneisses and migmatite horizons.

Gittidas Granite Gneiss. Biotite granite and gneisses with amphibolite bands and patches is the principal lithology. The granite is fine grained and leucocratic, light grey to white on fresh surface. The gneisses are garnetiferous and high grade. They may contain sillimanite. Following is the petrographic summary of amphibolites and pelite.

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

1. Amphibolites

CGQ 14. Amphibole—Garnet—Labradorite — Quartz—Sphene — Magnetite—Apatite.

CGQ 15. Amphibole—Quartz—*Chlorite—Epidote*—Sphene—Apatite,

Texture. Sub-porphyroblastic and poikiloblastic, sometimes hypidioblastic.

2. Pelite

CGQ 16. Garnet—Biotite—Muscovite—Quartz —Magnetite.

Texture. Porphyroblastic, poikiloblastic and hypidioblastic to xenoblastic.

Jalkhad Granite Gneiss. These foliated, nonporphyritic granites are exposed on the roadside opposite Jalkhad Nar. The unit, where gneissic, contains abundant biotite rich layers. It also contains amphibolites. Following is the petrographic summary of amphibolites.

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

1. Amphibolite

CGQ 11. Amphibole—Garnet—Quartz—Magnetite—Sphene—Apatite.

CGQ 11a. Garnet—Quartz—Amphibole —*Epidote*—Sphene—Apatite.

CGQ 12. Amphibole — Garnet — Biotite — Quartz — Labradorite — Sphene — Magnetite—Apatite.

CGQ 13. Garnet—Amphibole—Biotite—Quartz —*Epidote*—Sphene—Apatite — Magnetite.

Texture. Generally porphyroblastic and poikiloblastic, sometimes hypidioblastic.

Babun Granite Gneiss. Leucocratic microgranite gneiss and granite occurs near the contact with Lulu Sar feldspathised porphyroblastic gneiss. The unit has a gradational relationship, away from the contact however it is more massive. It occurs in the vicinity of Babun, Wetar and Jora, however, from north and south it joins with other granite gneiss bodies.

Dadar Migmatites. These occur in Dadar Nar and near Dharir. These are migmatites formed by anatexis of meta-pelites, meta-arkoses, acid meta-tuffs (?) and meta-feldspathic psammites. They show a wide variety of structures within leucosomes. They show stromatic, phelabitic and neubilitic structures. The palaeosome and neosomes show a particularly complex relationship. Agmites and restites are also common. Schilleren, ghost structures and stratigraphy can be seen in the neubilites. The restites are orthoquartzites, calc-pelites, amphibolites and marbles. The pelites with minor carbonate contents also tend to survive anatexis.

Saif-ul-Maluk Granite Gneiss. The Saif-ul-Maluk Granite/Gneiss is a non-porphyritic, fine to medium grained strongly foliated biotite granite gneiss/migmatites with thin pegmatite veins. The granite gneiss at many places contains abundant relics of transformed (granitised) metasediments and screens.

It is extremely well foliated dark coloured biotite granite gneiss/migmatites with irregular leucocratic bands. It appears to be a transformed granitised paragneiss. The modified metamorphic element appears to be considerable, especially in the dark granite gneiss. The gneiss is granitised and aplitised frequently.

Following is the petrographic summary of pelitic and feldspathic gneisses of this unit.

Upper Amphibolite Facies
Sillimanite Grade
High Grade Metamorphism

CGQ 17. Quartz—Biotite— Muscovite — Kyanite — Garnet—Plagioclase — Microcline—Sillimanite—Magnetite.

CGQ 18. Quartz—Muscovite—Biotite —Garnet —Plagioclase—Tourmaline—Magnetite—*Epidote*—Apatite.

CGQ 19. Muscovite — Quartz — Staurolite — Calcite — Magnetite—Tourmaline — *Epidote*.

CGQ 20. Quartz—Biotite—Muscovite—Sillimanite — Plagioclase — Magnetite — Zircon.

CGQ 21. Quartz — Microcline — Plagioclase—Muscovite — Andalusite—Magnetite—Zircon—Sphene.

Texture. The rocks are gneissic. Hypidioblastic to xenoblastic and porphyroblastic to subporphyroblastic textures are common.

KAGHAN GROUP

The various component lithologies of Kaghan Group of rocks seen on the roadside from Mahandri to Batal (near Naran) alongwith their petrographic summaries are briefly described below :

Batal quartzites and quartz mica schist/gneiss

Dominantly quartz mica schist and quartzites with thin sheet granites, subordinate marble and some thin amphibolite bands and a few retrograde chlorite schist patches. Most rocks are light grey to brownish grey on the fresh surface and grey to dull brownish grey on the weathered surface. Quartz mica gneiss is the main lithology of the unit. It is brownish grey on the weathered surface. At some places garnet has developed while at others it cannot be seen with the naked eye. The pelites have numerous interbeds of grey coloured micaceous quartzites. This interbedded rock (especially where in the form of isolated boulders) shows differential weathering. When differentially weathered the quartzite shows light grey positive flat faced ribs and the pelites (with granet and biotite) appear as dark grey negative ribs.

The quartz mica schist shows segregated quartz bands stretched into boudins and at times, these boudins appear just like pebbles of a conglomerate.

Within the quartz mica schist some distinctive green chlorite schist patches are found which represent retrogressive metamorphism. Following is the petrographic summary of various lithologies within the Batal quartzites and quartz mica schist.

Lower Amphibolite Facies
(Epidote-Amphibolite Facies)
Garnet Grade
Medium Grade Metamorphism

1. Pelite :

CGQ 30. Quartz—Biotite—*Chlorite* — Muscovite — Garnet — Magnetite — Tourmaline—Apatite—Zircon.

CGQ 31. Quartz — Garnet — Biotite — Muscovite—*Chlorite*—Magnetite — Epidote—Apatite—Tourmaline—Zircon.

CGQ 32. Quartz— Biotite — Garnet — Muscovite—*Chlorite*—Magnetite—Zircon.

Texture. Generally porphyroblastic and poikiloblastic. Occasionally sub-porphyroblastic.

2. Psammite :

CGQ 33. Quartz—Muscovite—*Chlorite* — Biotite—Magnetite—Zircon—Epidote—Apatite.

CGQ 34. Quartz—Muscovite—Pyrite—Plagioclase—Calcite — Tourmaline — Epidote—Apatite.

CGQ 35. Quartz—Muscovite — Tourmaline — Magnetite—Epidote—Zircon.

Texture. Granoblastic and somewhat foliated.

3. Calcareous :

CGQ 36. Calcite—Quartz—Muscovite—Wollastonite (?)—Epidote—Magnetite.

Texture. Sub-porphyroblastic and somewhat foliated.

Paludaran Graphitic Schist

This unit is mainly composed of graphitic schist, quartz mica schists and gneisses with some calc-schists and occasional marbles.

Graphitic Schist. It is dark grey on fresh surface and dark grey to dark brownish grey, at times rusty brown, on weathered surface. Pyrite crystals are present which weather out leaving square cavities behind. Quartz veins and boudins are also present which are usually stained rusty brown.

Quartz Mica Schist and Gneisses. It is the subordinate lithology in the unit. Its weathering colour is brownish grey, while fresh colour is grey. Generally segregation of quartz and micaceous material is seen. Sometimes the quartzitic part of these gneisses completly dominates over the schistose part. Some graphitic intercalations along with a few pegmatites are also present. It is generally granitized.

Occasionally garnetiferous meta-dolerite sills are also present.

Calc-Schists and Marbles. Subordinate bands of calc-schists and well foliated marbles are present intercalated with graphitic schist. The marbles are white and cream coloured on fresh surface and weather yellowish brown to dark brown. Partings of biotite schist may be present which in general give the rock a slightly darker shade. The calc-schists are generally medium grey.

Following is the summary of various lithologies of this unit.

Lower Amphibolite Facies
(Epidote-Amphibolite Facies)
Garnet Grade
Medium Grade Metamorphism

1. Pelite :

CGQ 37. Quartz—*Chlorite* — Biotite — Muscovite—Garnet—Magnetite — Tourmaline—Epidote.

Texture. Sub-gneissic.

2. Calc Pelite :

CGQ 38. Quartz—Calcite — Muscovite — Biotite—*Chlorite*—Epidote — Magnetite —Tourmaline—Zircon.

Texture. Schistose and lepidoblastic.

3. Calcareous :

CGQ 39. Calcite—Quartz—Muscovite— Magnetite.

CGQ 40. Calcite—Olivine (*Antigorite*) — Magnetite.

Texture. Granoblastic to sub-porphyroblastic.

4. Graphitic Pelite :

CGQ 41. Quartz — Graphite — Muscovite — Pyrite—Epidote—Apatite.

CGQ 42. Quartz—Graphite—Muscovite — Pyrite—Epidote.

Texture. Schistose.

Rajwal Quartzites, Quartz Mica Schist/Gneiss, Pegmatites, Aplites and Granite/Gneiss

The principal lithology of this unit is indicated by the title above. Where the lithology is pelitic the colour of the fresh surface is generally shining brownish grey and when it is psammitic the colour of the fresh surface is generally whitish grey with brownish schist partings and porphyroblasts of biotite and muscovite. The pegmatites are greyish brown. On the weathered surface the unit generally has a yellowish brown or rusty brown colour and is sometimes earthy grey.

This unit is composed of the following lithologies :

(i) Pelites
(ii) Psammites
(iii) Migmatites
(iv) Pegmatites/Aplites
(v) Granites
(vi) Marbles
(vii) Quartz Mica Gneisses

The above five lithologies are closely intermixed. In this complicated unit the pelites and psammites are affected by granitization especially in the lower part of the unit so that in some cases it becomes difficult to name the rock. Such complication reaches its maximum in the Bhimbal Katha northeast of Paludaran. Near Kundi Ka Maidan and in upper part of Por Katha (Chamber Katha of the map) granitisation is absent and pegmatites and aplites decrease and the unit consists mainly of garnetiferous quartz mica schist and micaceous quartzites with few thin bands of white sugary marbles which weather yellow. Occasional metadolerite dykes are also found.

Pelites. These generally comprise garnetiferous quartz mica schist and gneisses and make up the principal lithology of the Rajwal unit in the almandine grade. The pelites are composed mainly of quartz and micaceous minerals (muscovite, biotite and *chlorite*). Almandine garnet, tourmaline (schrolite) and magnetite are subordinate or accessory minerals. These rocks are at places, porphyroblastic. In some parts of the unit these are interbedded with quartzites and intruded by pegmatites/aplites while in others they contain some intercalations of marble. At still other places, this lithology is migmatised.

Metamorphic differentiation and migmatisation has produced biotite rich layers composed of biotite, chlorite, garnet, quartz and muscovite and light coloured layers composed mainly of quartz, feldspar, mica and a little tourmaline. Chlorite in this unit is secondary.

Psammites. The psammites are well developed in both pure and impure forms. The psammites comprise feldspathic quartzites. The feldspathic quartzites show xenoblastic to subporphyroblastic texture. They are composed mainly of quartz and feldspar. They contain subordinate to accessory amounts of mica, tourmaline, garnet and magnetite. They are arkosic to subarkosic, banded grey quartzites and feldspathic micaceous quartzites.

The banded grey quartzites are generally better developed in the middle part of this unit. They are white and greyish white on fresh surface while light to dark grey on weathered surface.

The micaceous quartzites are better developed towards the upper part of the Rajwal Unit. On the fresh surface they are whitish or creamish grey while on the weathered surface they are creamish grey to rusty brown. Sometimes the micaceous quartzites have creamish or rusty brown schist partings and occasionally they have bands of garnetiferous quartz mica schist. Quartz veins and boudins are present abundantly in the metapsammites.

Marbles. The marbles constitute a subordinate lithology and are present mainly in the upper part in the form of thin bands or intercalations. They are granoblastic and white on fresh surface while creamish grey or yellowish on the weathered surface.

Quartz Mica Gneisses. This lithology is exposed well at Kundi ka Maidan. This gneissic lithology is complicated and contains a number of variations including garnetiferous quartz mica gneiss, quartzofeldspathic microaugen gneiss, aplites and pegmatite. In the quartz mica gneiss the garnetiferous layers are intercalated with quartzofeldspathic layers containing porphyroblasts of feldspar. The garnetiferous layers contain occasional needles of amphibole.

A few porphyroblastic to hypidioblastic amphibolite bands also occur in this unit. These are composed mainly of plagioclase, biotite, amphibole and garnet. Magnetite, calcite, apatite, epidote and sphene are the accessories.

Following is the petrographic summary of some lithologies of the unit.

Lower Amphibolite Facies
(Epidote-Amphibolite Facies)
Garnet Grade
Medium Grade Metamorphism

1. Pelite

CGQ 43. Quartz—*Chlorite* — Biotite — Plagioclase—Garnet—Magnetite—Epidote—Apatite.

CGQ 44. Muscovite—Biotite—Quartz—Garnet—*Chlorite*—Magnetite—Apatite.

CGQ 45. Amphibole—Biotite—Quartz—Calcite—Plagioclase—*Chlorite*—Magnetite—Apatite—Zircon.

CGQ 46. Quartz—Biotite—Muscovite—*Chlorite*—Garnet—Epidote—Plagioclase—Magnetite—Apatite—Zircon.

CGQ 47. *Chlorite* — Plagioclase — Biotite — Quartz—Magnetite—Sphene—Calcite—Epidote—Apatite—Muscovite.

Texture. Granoblastic and hypidioblastic generally, sometimes porphyroblastic and poikiloblastic, occasionally lepidoblastic.

2. Psammite

CGQ 48. Quartz—Biotite—*Chlorite*—Muscovite.

Texture. Lepidoblastic.

3. Meta Basic

CGQ 49. Andesine — Biotite — Amphibole—Garnet—Magnetite—Calcite—Apatite—Epidote—Sphene.

Texture. Porphyroblastic and hypidioblastic.

Kaghan Pelites

This component unit of Kaghan group of rocks is distinctive by the great predominance of greenish grey garnetiferous schists. Although this unit comprises at least four different and distinct lithologies viz., quartz mica schist, graphitic schist, marble and gypsum, it is the great and monotonous predominance of greenish grey quartz mica schist by which it is distinguished. The subordinate lithologies of graphitic schist, marble and gypsum are present mainly towards the upper part of the unit.

Quartz Mica Schist. This is by far the dominant lithology in the unit constituting over 90% of the whole. The quartz mica schist has a distinctive silvery greenish grey colour on the fresh surface and is greenish grey to greenish brown or creamish on weathered surface. The rock is studded with white lenticular quartz boudinaged veins. At times very thin greenish grey micaceous layers can be distinguished from the white quartz layers in hand specimen in sections across the foliation. The quartz mica schist is garnetiferous (garnet occuring as brownish black protrusions) but the size of the garnet is small (1 to 3 mm) and decreases still further towards the upper side of the Kaghan Pelites until it becomes indistinctive at Khannian.

Graphitic Schist. Occasionally the quartz mica schist is graphitic. This change occurs simply by graphite assuming the status of an essential mineral and increase in the quantity of pyrite.

Marble and Gypsum. More than one bands of marble occur in the unit but the marble occurring in intimate association with gypsum towards the upper part of Kaghan Pelites is the most distinctive. It is generally yellowish on weathered surface and cream or white on fresh surface. This marble has thin micaceous partings of greenish or brownish schist and in part is thinly intercalated with gypsum.

Following is the petrographic summary of its lithologies.

Lower Amphibolite Facies
(Epidote—Amphibolite Facies)
Garnet Grade
Medium Grade Metamorphism

1. Pelite

CGQ 50. Muscovite — Biotite — *Chlorite* — Quartz—Garnet—Magnetite — Apatite.

CGQ 51. Quartz—Biotite — *Chlorite* — Garnet —Muscovite— Magnetite — Tourmaline—Zircon—Apatite.

Texture. Porphyroblastic and poikiloblastic, sometimes lepidoblastic.

2. Psammite

CGQ 52. Quartz—Biotite — *Chlorite* — Muscovite—Garnet—Magnetite— Tourmaline—Epidote.

Texture. Lepidoblastic.

3. Calcareous

CGQ 53. Calcite—Quartz—Muscovite— Magnetite—Apatite—Plagioclase.

CGQ 54. Calcite—Quartz—Muscovite — Magnetite—Apatite.

CGQ 55. Calcite—Muscovite—Quartz — Magnetite—Epidote—Sphene—Apatite.

Texture. Generally hypidioblastic and foliated, sometimes granoblastic also.

4. Graphitic Pelite

CGQ 56. Quartz—Graphite—Muscovite—Biotite—Pyrite—Magnetite.

Texture. Lepidoblastic.

5. Gypsum

CGQ 57. Gypsum — Calcite — Muscovite — Pyrite.

Texture. Granoblastic.

Kamalban Quartz Mica Schists, Quartzites, Calc-Schists and Marbles

The principal components of the rock unit are indicated by its title. On the fresh surface most components are whitish, light green, light brown and light grey and are generally banded. On the weathered surface the marbles are yellowish and greyish, the schists are dark greyish brown and the quartzites are rusty and creamish yellow.

Quartz Mica Schist. Proportionately this is the main lithology but quartzites, marbles and calc-schists are more striking and prominent. The quartz mica schist is shining greenish grey on fresh surface and brownish grey or brown and sometimes whitish on the weathered surface. It contains quartz boudins much like those in the Kaghan Pelites. Fracturing and jointing is common and may obscure foliation. Schistosity is well developed and generally a strain slip cleavage can be seen in addition to the bedding plane schistosity.

Quartzites. Alongwith the quartz mica schists there are a number of orthoquartzite bands. These bands are granoblastic. They are composed mainly of welded and sutured quartz grains. Muscovite, biotite, chlorite and pyrite are the accessories. These pure quartzites are white, cream or light green and grey and generally banded on the fresh surface while on the weathered surface they are creamish yellow, rusty brown and yellowish grey.

The quartz-mica schists and micaceous quartzites are schistose and from subporphyroblastic to porphyroblastic. The porphyroblasts are of micaceous minerals.

Calc-schist. The calc-schist is generally greenish grey on fresh surface and brownish grey, yellowish grey or dark grey on weathered surface. It may be banded in the form of schist and marble bands. Sometimes there is a gradation between calc-schist and marbles. It is common to find schist and thin bands of marble intercalated in varying proportions. The calcareous material itself can be white, grey, green or yellowish.

Marbles. Apart from the thick marble unit at Kandlan, Phagal and Lohar Banda which border the Kamalban unit a number of small marble horizons occur within the unit.

The marbles are either grey, brownish grey or yellowish on weathered surface and grey, white, light green or creamish white on fresh surface. The creamish coloured marbles are distinctly schistose, the schist laminae being of greenish colour. The white marbles are generally sugary with faint grey bands.

Following is the petrographic summary of psammite and calcareous lithologies.

Upper Part	Greenschist Facies Biotite Grade Low Grade Metamorphism
Lower Part	Lower Amphibolite Facies (Epidote-Amphibolite Facies) Garnet Grade Medium Grade Metamorphism

1. Psammite

CGQ 58. Quartz—Muscovite—Chlorite— Biotite—Magnetite.

CGQ 59. Quartz—Biotite—Tourmaline.

CGQ 60. Quartz—Muscovite—Biotite— Chlorite—Magnetite—Pyrite—Tourmaline.

CGQ 61. Quartz—Muscovite—Biotite — Tourmaline—Zircon—Magnetite.

CGQ 62. Quartz—Chlorite—Musovite — Biotite—Magnetite—Apatite—Sphene.

Texture. Generally xenoblastic and granoblastic, occasionally cataclastic.

2. Calcareous

CGQ 63. Calcite—Quartz—Muscovite— Pyrite —Epidote.

CGQ 64. Calcite—Quartz—Muscovite — Magnetite—Epidote.

Texture. Hypidioblastic, subporphyroblastic and sub-poikiloblastic.

Lohar Banda Marble

The Lohar Banda marble has been mapped as a separate rock unit because of its distinctive nature which enables it to act as a marker horizon for field mapping.

It is mainly white, light grey and light green banded marble with some calc-schists. On the weathered surface it is generally grey.

The marble is fine to medium grained, medium bedded and white with light green and light grey bands, on the fresh surface. On the weathered surface it is medium grey to dark grey and sometimes yellowish. Within the marble outcrop there are one or two bands of quartz mica schist. Both above and below the main marble band there is a gradation into the adjoining quartz mica schist through a sequence of calc-schist and thin marble bands. The calc-schist is cream to greenish grey. The micaceous parts are greenish and the calcareous parts are yellowish.

Following is the petrographic summary of calcareous lithology.

Greenschist Facies
Biotite Grade
Low Grade Metamorphism

1. Calcareous

CGQ 65. Calcite—Quartz—Muscovite— Chlorite — Pyrite — Sphene—Epidote — Zircon.

CGQ 66. Clacite—Muscovite—Quartz — Chlorite—Epidote—Magnetite.

CGQ 67. Calcite—Quartz — Muscovite — Epidote—Magnetite—Apatite.

Texture. Generally hypidioblastic, granular, sometimes sub-lepidoblastic.

Phagal Quartz Mica Schists and Quartzites

This unit comprises quartz mica schist and quartzites with subordinate calc-schists and marble. On the weathered surface it is generally dark brownish grey and rusty.

The quartzites are medium bedded, both ortho and micaceous types. They are grey, light brownish grey and white on the fresh surface while brownish grey to rusty brown on the weathered surface. They are medium grained and often granoblastic. The grains are welded and sutured.

Quartz Mica Schists. The quartz mica schist is greenish grey on fresh surface and dark brownish grey on the weathered surface. It contains veins and boudins of quartz. The quartz mica schists show poor to moderate schistosity.

The calc-schists are medium grained and poorly to moderately foliated. They are granoblastic to hypidioblastic.

Marbles. The marbles are medium grained and granoblastic.

Following is a petrographic summary of pelitic, psammitic and calcareous lithologies.

Greenschist Facies
Biotite Grade
Low Grade Metamorphism

1. Pelite

CGQ 68. Quartz—Muscovite—Chlorite— Biotite—Magnetite—Epidote.

Texture. Sub-lepidoblastic.

2. Psammite

CGQ 69. Quartz—Muscovite—Chlorite — Biotite—Magnetite—Zircon.

Texture. Granoblastic.

3. Calcareous

CGQ 70. Calcite—Quartz—Muscovite— Chlorite—Epidote—Magnetite.

Texture. Hypidioblastic.

Doga Schists, Marbles, Quartzites and Metaconglomerates

The principal lithologies in this unit are indicated by its title. The schists include both quartz mica schist and calc-schist. The main difference from the Kamalban unit is the presence of meta-conglomerates and quartzites with porphyroblasts of chlorite and biotite.

Quartzites. The Doga quartzites are banded, light greenish grey with green porphyroblasts and some intercalations of grey marble.

Marbles. The marbles are generally banded, light grey or white with schist partings and weather to light earthy brown, creamish and grey colours. Occasionally the marble bands may be greenish white. The micaceous marbles and calc-schists are intercalated with quartzite.

Following is a petrographic summary of various lithologies of this unit.

Greenschist Facies
Biotite Grade
Low Grade Metomorphism

1. Pelite

CGQ 71. Quartz—Biotite—Muscovite — Tourmaline — Chlorite — Plagioclase — Magnetite—Epidote—Apatite.

CGQ 72. Quartz—Biotite—Chlorite — Muscovite—Plagioclase—Sphene—Apatite—Magnetite—Tourmaline.

Texture. Lepidoblastic.

2. Meta Conglomerates

CGQ 73. Quartz—Biotite—Muscovite — Magnetite—Sphene.

Texture. Metaconglomeratic.

3. **Calcareous**

CGQ 74. Calcite — Quartz — Muscovite—Pyrite—Magnetite—Apatite.

Texture. Hypidioblastic to granoblastic.

4. **Meta Basic**

CGQ 75. Amphibole—Plagioclase—Microcline Perthite—Biotite—Sphene — Magnetite—Epidote—Quartz.

Texture. Hypidioblastic.

5. **Psammite**

CGQ 76. Quartz—Chlorite—Muscovite — Biotite—Magnetite—Tourmaline.

Texture. Granoblastic to sub-porphyroblastic.

Biari Quartzites, Metaconglomerates, Quartz Mica Schists, Calc Schists and Pegmatites

The principal lithology is indicated by the title of the unit. It contains ubiquitous pegmatites. Also the calc-schists are subordinate and the metaconglomerates are more prominent compared to those in Doga unit. A number of metadolerite bodies are also present.

Quartzites. The quartzites are generally banded grey, brownish grey, greenish grey and whitish on fresh surface and dark brownish grey and rusty brown on weathered surface. They are generally micaceous, containing porphyroblasts of green chlorite and sometimes of brown biotite and intercalations of quartz mica schist. The intercalations of schist are dark grey with prominent brown biotite. The banded quartzites with porphyroblasts of chlorite and intercalations of schist make the dominent lithology in the unit.

Metaconglomerates. The pebbles in the metaconglomerates stand out on the weathered surface. The pebbles are generally dark grey or dark greenish grey in colour while the ground mass is light grey to light greenish grey in colour.

Quartz Mica Schist. It is generally light grey, greenish grey and brownish grey on fresh surface while on the weathered surface it is dark brownish grey to dark grey. It is interbedded with quartzites, metaconglomerates and marbles and contains some quartz veins in the form of thin boudins. Chlorite and biotite are prominent flaky minerals.

Calc-schist and Marbles. A few thin grey and white marble bands are present, especially towards the Doga unit. The marbles have thin micaceous partings. The calc-schists are distinguished by differential weathering.

Following is a petrographic summary of various lithologies of this unit.

Greenschist Facies
Biotite Grade
Low Grade Metamorphism

1. **Pelite**

CGQ 77. Biotite—Quartz—Muscovite — Chlorite—Epidote—Plagioclase—Sphene—Apatite.

Texture. Lepidoblastic.

2. **Psammite**

CGQ 78. Quartz—Chlorite—Biotite — Muscovite—Tourmaline—Magnetite.

Texture. Porphyroblastic.

3. **Calc-Pelite**

CGQ 79. Calcite—Quartz—Biotite—Chlorite—Muscovite—Magnetite.

Texture. Sub-lepidoblastic to sub-porphyroblastic.

KASHMIR SEQUENCE

What has been described here as Kashmir sequence includes a stratigraphic sequence that represents the Kashmir Basin to the east. This sequence outcrops in the Kagban Valley between Paras and Jared and includes Tanawal Formation, Chushal Formation (Agglomerate Slate) Panjal Formation with associated limestones and Triassic to Eocene sedimentary rocks.

Jared Quartzite and Quartz Mica Schists (Tanawal Formation).

What has been considered Tanawal Formation is represented by a relatively minor out crop of quartzites and quartz mica schist around Jared faulted on the lower side against Mahandri formation of Kaghan group. The rocks between Jared and Tutan on the roadside are distinguished by their arenaceous/psammitic lithology represented by interbedded quartzites and quartz mica schists. There is marked absence of calcareous and graphitic material. On the fresh surface the general colour is light brownish grey for quartzites and greenish grey for schists. Occasional metadolerite sills are also present.

Quartzites. Most quartzites are banded, micaceous and relatively thinly bedded. They are generally light coloured on the fresh surface. They can be greenish grey, light grey or brownish grey and occasionally green and white banded. On the weathered surface they are earthy brown, brownish grey and dark brownish grey and at times rusty brown. Individual beds are generally from 5 cm. to 15 cm. thick.

Quartz Mica Schists. The other main lithology of Jared unit comprises quartz mica schists which are greenish grey, at times whitish to light brown on fresh surface and dark brownish grey on weathered surface. Some schists in cross section can be seen to comprise very thin green and white (quartz) layers.

These rocks are foliated but poorly to moderately schistose. They are fine to medium grained.

Following is a petrographic summary of psammite and metabasic units.

Greenschist Facies
Biotite Grade
Low Grade Metamorphism

1. **Psammite**

CGQ 80. Quartz—Biotite—Muscovite—Tourmaline—Sphene—Zircon—Epidote—Apatite.

Texture. Lepidoblastic.

2. **Meta Basic**

CGQ 81. Plagioclase—Amphibole—Quartz—Epidote—Magnetite—Sphene.

CGQ 82. Plagioclase—Amphibole—Sphene—Quartz—Muscovite—Magnetite—Epidote.

Texture. Hypidioblastic.

Chushal Graphitic Schist and Metaconglomerate

Between Shino marble and the Jared quartzites there is a relatively thin but very prominent sequence of graphitic schists, metaconglomerates with occasional thin bedded marble bands, calc-schist and quartzofeldspathic microgneisses. This represents the Agglomeratic Slate unit of Kashmir.

Graphitic Schists. The pelitic graphitic schist is silver grey to dark grey on fresh surface and dark grey to dark brownish grey with rusty patches on the weathered surface. It is fine grained, well cleaved and contains small pyrite cubes which leave square cavities when removed by weathering. There are also thin quartz veins which are folded and make prominent white boudins.

Marble. It is medium grey, thinly laminated with fine white partings and intercalated with calc-schist. The marble and calc-schist occur towards the contact of Chushal unit with Jared unit.

Metaconglomerates. The metaconglomerates are best exposed on the path from Chushal village to Kamil-di-Gali. It consists of rock pebbles of graphitic schist, quartzite, marble, calc-schist and of granite. The rock is poorly sorted but shows a degree of foliation. Most pebbles are subangular indicating short distance transportation. The matrix is coarse grained and gritty. A few quartzofeldspathic veins are present. The conglomerate shows two varieties, one is coarse grained and the other is relatively fine grained. The coarse variety contains boulders one foot or more across. The conglomerate is dark brownish grey on weathered surface and grey on fresh surface.

The conglomerate sequence also contains a band of impure quartzite, medium grey on fresh surface and brownish grey on the weathered surface. It is highly fractured.

Following is a petrographic summary of various lithologies of this unit.

Greenschist Facies
Biotite Grade
Low Grade Metamorhhism

1. Pelite

CGQ 83. Muscovite—Quartz—Chlorite—Graphite — Pyrite — Magnetite —Tourmaline.

CGQ 84. Quartz—Muscovite — Chlorite—Biotite—Magnetite—Tourmaline.

CGQ 85. Quartz—Chlorite—Muscovite — Biotite—Magnetite—Tourmaline.

CGQ 86. Muscovite—Quartz—Chlorite—Tourmaline—Epidote—Sphene—Zircon.

Texture. Phyllitic to sub-schistose. Lepidoblastic to sub-porphyroblastic.

2. Psammite

CGQ 87. Quartz—Muscovite — Tourmaline — Zircon.

Texture. Xenoblastic.

3. Calc-Pelite

CGQ 88. Quartz—Calcite—Chlorite—Albite—K-feldspar — Magnetite — Tourmaline—Graphite.

CGQ 89. Quartz—Calcite—Chlorite—Albite — Magnetite—K-feldspar.

CGQ 90. Quartz — Calcite — Chlorite — Muscovite — Cryptocrystalline matter — Albite—Zircon.

Texture. Lepidoblastic and sub-porphyroblastic.

4. Marbles

CGQ 91. Calcite—Quartz.

CGQ 92. Calcite—Quartz.

Texture. Granoblastic.

5. Graphitic Pelite

CGQ 93. Quartz — Graphite — Muscovite — Chlorite—Biotite—Pyrite—Sphene—Tourmaline.

Texture. Sub-lepidoblastic.

6. Feldspathic Unit

CGQ 94. Quartz— Albite/Oligoclase — Microcline/K-feldspar — Cryptocrystalline matter — Tourmaline — Graphitic matter.

CGQ 95. Quartz—Albite/Oligoclase — Cryptocrystalline matter — Microcline / K-fedspar—Muscovite — Tourmaline — Biotite—Zircon—Pyrite.

CGQ 96. Quartz—Albite / Oligoclase—Muscovite—Tourmaline.

CGQ 97. Quartz — Microcline / K-feldspar — Albite/Oligoclase—Muscovite — Cryptocrystalline matter.

CGQ 98. Quartz—Albite/Oligoclase — Muscovite—Microcline / K-feldspar — Biotite—Tourmaline.

Texture. Porphyroblastic and sub-gneissic.

Panjal Formation

Panjal Volcanics. On the roadside the Panjal Volcanics comprise a few thick bands of basic volcanics which alternate with a few thick laminated calcareous bands. The whole sequence has suffered low grade metamorphism.

The trap is the volcanic part of the Panjal series and occurs as two thick bands. The band in contact with the Shino marble extends on the roadside from near Shino Hatchery to close to the Bhunja Bazaar. The colour of the rock is dark greyish green. Large porphyroblasts of chlorite are commonly developed. At places the rock shows pillow like lenses which appear to be relics of pillow structure. Only a part of this thick series of rocks occurs within the mapped area. The Panjal outcrop becomes thinner towards the apical side of the syntaxial bend.

Shino Marble. The Shino Marble is best exposed on the roadside opposite the Shino Hatchery where it is making overhangs on the roadside. The unit consists of sugary arenaceous marbles and calcareous quartzites. Most of these are coarse grained light grey or yellowish grey. At the contact with Chushal unit the Shino unit comprises fine grained marble which is medium grey on fresh surface and creamish yellow or yellowish brown on weathered surface.

Ling and Bhunja Limestone/Marbles. The greenstones are inter-bedded and folded with sediments comprising three major bands including Shino Marble of crystalline, slightly metamorphosed limestone/marble.

The Ling and the Bhunja limestone/marble bands are fairly similar to each other. They comprise fine grained, thinly laminated, medium grey limestone/marble with thin white and yellow partings. Both outcrops also contain some thin greenish grey phyllite bands. The Bhunja outcrop in addition shows one or two quartzite bands.

Following is a petrographic summary of various lithologies of this unit.

Greenschist Facies
Biotite Grade
Low Grade Metamorphism

1. Panjal Volcanics

BK-4. Actinolite — Albite/Oligoclase — Epidote—Chlorite—K-feldspar—Sphene—Magnetite.

90. Actinolite — Albite/Oligoclase — Epidote—Chlorite—Quartz— K-feldspar—Calcite—Magnetite—Sphene.

N-6. Actinolite — Albite/Oligoclase — Epidote—Quartz—K-feldspar — Sphene — Magnetite.

N-24. Actinolite — Albite/Oligoclase — Epidote—Chlorite—Quartz— K-feldspar—Sphene—Magnetite—Calcite.

224. Actinolite — Albite/Oligoclase — Epidote—Chlorite—Quartz—Sphene.

N-11. Actinolite — Albite / Oligoclase — Epidote—Chlorite—Quartz—Sphene.

13. Actinolite—Albite—Oligoclase — Epidote—Chlorite—Quartz— K-feldspar—Calcite—Sphene—Magnetite.

BK1. Actinolite — Albite/Oligoclase — Epidote—Chlorite— Quartz—K-feldspar—Sphene—Magnetite.

91. Actinolite — Albite/Oligoclase — Epidote—Chlorite—Quartz—K-feldspar—Sphene—Calcite—Magnetite.

N-1. Actinolite / Albite—Oligoclase — Epidote—Chlorite— Quartz—K-feldspar—Sphene—Calcite—Magnetite.

Texture. Porphyroblastic to sub-porphyroblastic and sub-poikiloblastic. At places hypidioblastic to acicular. Some horizons are amygdaloidal.

2. Shino Band

1167. Calcite—Quartz—Chalcedony—Limonite/Haematite.

1164. Calcite—Limonite/Haematite.

453. Calcite—Quartz — Limonite/Haematite.

113. Calcite— Chlorite — Quartz — Limonite/ Haematite.

Texture. At many places it is microcrystalline to cryptocrystalline. At others it is granoblastic to xenoblastic.

Bhunja Band

465. Calcite—Quartz—Pyrite.
800. Calcite—Quartz—Chlorite—Pyrite.
469. Calcite—Quartz.
470. Calcite.

3-a. **Recrystallized Cherty Parts Associated with Bhunja Band.**

102. Chalcedony—Quartz—Calcite—Zeolite—Chlorite—Pyrite.
827. Chalcedony—Quartz—Calcite—Zeolite—Chlorite—Pyrite.
833. Chlorite—Quartz—Calcite — Chalcedony —Epidote.

Texture. Some parts are microcrystalline to cryptocrystalline, while others are sub-porphyroblastic to granoblastic.

4. **Ling Band**

1192-L1. Calcite—Dolomite—Quartz.
1194-L3. Calcite—Quartz.
1196-L7. Calcite—Chlorite—Quartz—Sphene.

Texture. The Limestone is generally fine grained and even microcrystalline to cryptocrystalline. At places it is coarser and even locally dolomitised.

DISCUSSION AND CONCLUSION

The rock units between Paras and Babusar top are regionally metamarphosed from biotite to sillimanite grades of regional metamorphism of Harker (1932). In terms of facies the metamorphics range from greenschist facies to upper amphibolite facies. In terms of four major divisions of metamorphism of Winkler (1979) these rocks range from very low grade to high grade metamorphism. The absence of cordierite and andalusite as regional metamorphic minerals and the presence of garnet, kyanite and sillimanite in the sequence show that the terrain belongs to the medium pressure metamorphic belts of Miyashiro (1972).

The status of various stratigraphic sequences of the area in terms of index minerals, metamorphic grade and facies series is presented in table No. 2. The area between Bhunja and Khannian was studied by Calkins et al. (1975) and Wadia (1931). The area around the syntaxial bend was studied structurally by Bossart et al. (1984). Ghazanfar and Chaudhry (1984, 1985, 1987) and Chaudhry and Ghazanfar (1987) revised the geology of the area and remapped the rock units lying between Bhunja and Khannian. They also mapped for the first time the rock units lying between Khannian and Batakundi and between Batakundi and Babusar. They have described the rock units and worked out the stratigraphy af the area (see table No. 1) and commented in general terms on the metamorphism of the areas studied. This paper presents a systematic account of the metamorphic rocks of the area between Paras and Babusar Pass or between MBF (Main Boundary Fault) and MMT (Main Mantle Trust).

The index mineral zones have been characterised by the first appearance of the index minerals e.g. biotite, garnet, kyanite and sillimanite.

Low grade metamorphism is characterised by the isograd band "Zoisite and clinozoisite in and pumpellyite-prehnite out" Winkler (1979). The Panjal volcanics and associated rocks lack lawsonite as well as pumpellyite-prehnite and contain zoisite and clinozoisite.

The Panjal formation, Chushal formation and Jared quartzite unit all fall in biotite grade and in low grade metamorphism. Biotite is present in these units and garnet is lacking. Also chlorite occurs in stable association with

TABLE 2

Metamorphic Grades and Facies in Relation to the Stratigraphic Sequence.

Metamorphic Grades and Facies	Group	Formation	Lithology
Prehnite — Pumpellyite (?) Facies.		Murree Formation (Miocene)	
		Paras Formation (Paleocene to Eocene)	
		Rosachcha Formation (Paleocene)	
		Malkandi Limestone (Triassic)	Dark grey oolitic limestone with shale partings.
		Panjal Formation (Permian).	Panjal basic volcanics and associated Ling, Bhunja and Shino bands of limestone/marble.
		Chushal Formation (Agglomerate Slate Series) (Carboniferous)	Graphitic schist, limestone/marble, metaconglomerate and tuffs.
		Tanawal Formation (Silurian to Carboniferous)	Jared quartzites and quartz mica schists.
Greenschists Facies. Biotite Grade. Low Grade Metamorphism.	KAGHAN GROUP	Mahandri Formation.	Biari quartzites, metaconglomerates, quartz mica schist. calc-schist and pegmatites. Doga schists, marbles, quartzites and metaconglomerates. Phagal quartz mica schists and quartzites Lohar Banda marble. Kamalban quartz mica schists, quartzite, calc-schists and marbles.
	KAGHAN GROUP	Kaghan Formatiom.	Kaghan Pelites.
Lower Amphibolite Facies. (Epidote-Amphibolite Facies) Garnet Grade. Medium Grade Metamorphism.	KAGHAN GROUP	Rajwal Formation.	Rajwal quartzites, quartz mica schist/gneiss, pegmatites, aplites and granite/gneiss. Paludaran graphitic schist. Batal quartzites and quartz mica schist/gneiss.
	SHARDA GROUP	Amphibolites Migmatites and Granite Gneisses including :	:— Saif-ul-Maluk granite gneiss. :— Dadar migmatite. :— Babun granite gneiss. :— Jalkhad granite gneiss. :— Gittidas granite gneiss.
Upper Middle to Upper Amphibolite Facies. Kyanite and Sillimanite Grade High Grade Metamorphism.	SHARDA GROUP	Lulu Sar Feldspathised Porphyroblastic Gneiss.	
	SHARDA GROUP	Mixed Unit including :	:— Purbinar mixed unit. :— Besal mixed unit.
	SHARDA GROUP	Garnetiferous Calc-pelitic Gneisses including :	:— Naran garnetiferous calc-pelites. :— Burawai garnetiferous calc-pelites.
	SHARDA GROUP	Dhak Graphitic Gneisses (In Jalkhad Nar). Bans Pelitic Gneisses. Dabukan Marble. Dumri Calc-pelites.	

muscovite. In addition the metadolerites in these units contain albite to low oligoclase. All these characters justify the grouping of these units into low grade metamorphism. Ubiquitous presence of chlorite, stable association of chlorite with muscovite and the characteristic assemblage albite-epidote-actinolite-chlorite-quartz and albite to low oligoclase composition of feldspar in metadolerites justify placing these units in greenschist facies.

The top of Kaghan formation marks important changes. Almandine garnet appears for the first time in pelites. Muscovite disappears in the presence of chlorite. Although retrograde chlorite is present yet stable association was not found. The criteria "formation of staurolite and disappearance of chloritoid" (Winkler 1979) could not be used since chloritoid was not found in lower grade rocks and staurolite was not found. However, the metabasites (amphibolites) studied show the anorthite jump (Winkler 1979). So the top of Kaghan pelites (Kaghan Formation) marks the beginning of medium grade metamorphism. On the basis of above observations it may be concluded that the top of Kaghan formation also marks the onset of lower amphibolite facies (Epidote—Amphibolite Facies).

Lower part of Rajwal unit (of Rajwal formation, see table 1) shows good development of migmatites. Earlier (Ghazanfar and Chaudhry, 198?) regarded this part of the unit as rather high grade. But this observation is questionable. This tectonic slice falls in overall lower amphibolite facies (Epidote — Amphibolite Facies).

The Kaghan formation contains ubiquitous almandine garnet. Chlorite in stable association with muscovite was not found. The plagioclase of amphibolites ranges from oligoclase (> An 17) to low andesine. The lower part of Mahandri formation, Kaghan formation and parts of the Rajwal unit of Rajwal formation undoubtedly fall in the garnet grade. They belong to lower amphibolite facies(epidote—amphibolite facies).

From lower part of Rajwal unit to Batal unit of Rajwal formation upto Batal fault the rocks do present some difficulties. Pseudomorphs of olivine (now antigorite) were found in metacarbonate of Paludaran unit of Rajwal formation and wollastonite (?) was found in the lower part of Batal unit of Rajwal formation. These rocks are often gneissic. Although it can be said with certainty that these units fall in the medium grade of Winkler (1979) yet it is difficult to say weather they have already reached upto staurolite grade. Staurolite or kyanite could not be found despite thorough search. The absence of kyanite is significant but lack of staurolite may be due to unsuitable composition of the pelites since chloritoid is also absent in the lower grade pelites.

The Sharda group beyond the Batal fault represents a jump in metamorphic grade kyanite and sillimanite appear in the metapelites. It is difficult to separate the kyanite from the sillimanite grade in this block. A significant part of the kyanite grade appears to have been faulted out. Sillimanite soon makes its first appearance some distance north of the Batal fault. The exact boundary between sillimanite and kyanite grades is difficult to mark.

The area between Batal fault (south of Naran) and MMT (near Babusar Pass) falls in kyanite-sillimanite grades. The amphibolites are invariably garnetiferous. Plagioclase is very often a labradorite. Extensive migmatisation near Dharir, in Dadar Nar, Khote Nar and Jora Nala (near Burawai) etc. is significant. Presence of kyanite and sillimanite, partial anatexis and high grade amphibolites show that the rocks belong to upper amphibolite facies.

There is no general breakdown of muscovite in presence of quartz in these rocks. However, lower down in the sequence in certain horizons partial resorption of muscovite was observed, specially where plagioclase was present. But complete breakdown of muscovite was not observed. The criteria laid down by Winkler (1979) "We choose the breakdown of muscovite in the presence of quartz and plagioclase to define the change from medium grade to high grade metamorphism" cannot be applied usefully. This is because many pelite psammite horizons lack plagioclase. It has been observed by Winkler (1979) that muscovite + quartz is stable upto a much higher temperature than was previously thought. So presence of kyanite and sillimanite, high grade amphibolites and formation of migmatites along suitable horizons justify placing these rocks in high grade metamorphism.

Retrograde Metamorphism

The rocks lying between MBT and MMT have suffered a superimposed retrograde metamorphism. This metamorphism is marked by the development of secondary chlorite, actinolite and epidote. Biotite and garnet are replaced partially by chlorite. Plagioclase is replaced partially by epidote and hornblende is replaced partially by epidote and chlorite. Development of secondary actinolite is also common. These changes in general are sporadic. However, in the vicinity of major faults (thrusts) like, Shino fault, Tutan fault, Jared fault, Khannian fault, Rajwal fault, Batal fault and MMT, the retrograde effects are particularly well marked These faults are generally marked by crush zones, fault gouges, mylonites, etc. It is here that retrograde effects become very much pronounced. The retrograde metamorphism belongs to the greenschist facies.

Break in Metamorphic Grade

There are a number of breaks of varying degrees in P-T continuum in the area. The Murree fault brings the sedimentary sequence against the metamorphics. Bossart et al. (1984) and Greco (1986) place the Murree formation in the prehnite—pumpellyite facies. Petrographic study of a large number of samples did not show the presence of characteristic minerals of this facies. However, due to thrusting along MBT such facies may have developed locally. But there is no regional prehnite—pumpellyite facies. These authors also show a big break in P-T along the Panjal fault. Following the previous workers they called the Jared quartzites, etc. Salkhala formation. They further showed this so-called Salkhalas (actually Tanawals) as falling in almandine-amphibolite facies. In fact, both Panjals as well as the Tanawals (Salkhalas of Bossart et al.) fall in the greenschist facies. At places where the contact between Panjals and Tanawals is normal there is no P-T break, elsewhere, where the contact is faulted, the break is much smaller than shown by Bossart et al. (1984).

The Shino fault and Tutan fault, mark small breaks in P-T continuum. However, the Batal fault shows quite a significant break. The Batal unit belongs to the lower amphibolite facies (epidote—amphibolite facies) or at best lower part of the amphibolite facies and garnet grade. The Naran unit of Sharda group represents upper amphibolite facies. Possibly staurolite grade and a part of the kyanite grade is faulted out. The Naran unit falls, at least, in kyanite grade and a part of this unit falls in sillimanite grade.

The MMT near Babusar Pass similarly marks a big break in P-T. The rocks lying to the south of MMT belong to the sillimanite grade or upper amphibolite facies while the rocks lying to the north of MMT at most represent greenschist and epidote-amphibolite facies.

CONCLUSION

Detailed geological mapping and a study of mineral assemblages of the large variety of rock units exposed between Paras and Babusar Pass in the Kaghan Valley reveals the following preliminary picture of metamorphism in the area :

1. In main, the metamorphism increases up-valley towards north and varies from greenschist facies, biotite grade, at Mahandri and Bhunja to Upper amphibolite facies, sillimanite grade between Naran and Babusar.

2. The Murree sandstone, shales and older Cenozoic-Mesozoic rocks exposed downstream of Paras and upstream to Malkandi were classed under Prehnite-pumpellyite facies by Bossart et al. (1984). We are inclined to consider this sequence as unmetamorphosed sedimentary though locally, possible presence of this facies may not be ruled out.

3. Within the limits of the mapped area the metamorphic isograds appear to follow major tectonic lines. This indicates the post metamorphic nature of these tectonic lines.

4. There is a widespread greenschist facies metamorphism superimposed on an earlier metamorphism ranging from upper amphibolite facies to greenschist facies.

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A NEW GENUS OF THE FAMILY HYAENIDAE GRAY FROM THE UPPER SIWALIK BEDS OF THE PUNJAB

BY

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Abstract : *Two fragments of an anterior half a hyaenid skull from Neogene Upper Siwaliks of district Attock, Pakistan are described here as a new genus,* Romeria. *The conclusion is based on the overall morphology of cheek teeth, location of the first molar and the size of the third incisor.*

INTRODUCTION

Scientific description of the Siwalik hyaenids is known since 1868 when Murchison edited Falconer's "Fauna Antiqua Sivalensis". Since Falconer's time, these Siwalik carnivores have been worked out by a number of workers such as Lydekker, Bose, Pilgrim, Matthew and Abubakr. The material worked out by these workers comprises isolated teeth, fragments of mandible, maxillary portions and few skulls, The present material comprises two fragments of an anterior half of a skull collected by one of the authors from Jassian, about 10 K.M. Southeast of Attock city. The material is unique in the sense that the 3rd incisive alveolus is even larger than that into which canine is inserted. Due to this and other morphological features of the teeth, a new genus has been erected for the present material.

The abbreviations used are as follows :

L.	Anteroposterior diameter.
l.	Left.
P.U.P.C.	Punjab University Palaeontological collection stored in Zoology Department at Lahore, Pakistan.
r.	Right.
W.	Transverse diameter

SYSTEMATIC ACCOUNT

Order	CARNIVORA Bowdich
Suborder	FISSIPEDIA Blumenbach
Superfamily	FELOIDEA Simpson
Family	HYAENIDAE Gray
Subfamily	HYAENINAE Mivart
	ROMERIA New Genus

Generic type : *Romeria jassianensis* new species

Diagnosis :

In general similar to *Crocuta* but different from the latter in having the third upper incisor larger in diameter than the canine. Canine with anterior and posterior keels as in *Crocuta carnifex*. P^1 reduced, P^{2-3} with strong posterior and slight anterior cingula. P^4 transversely narrow but long anteroposteriorly with pronounced protocone. M^1 reduced and transversely elongated lying anterior and internal to the posterior end of P^4 on the palate.

ROMERIA JASSIANENSIS, new species

Type :

P U P C. No. 87/4, two fragments of an anterior half of the skull with canine, P^3 and alveoli of P[1], P[2] and partially those of third incisor and P[4] on the lef side ; and P2-3, M[1] and alveolus of P[4] on the right side.

Type Locality :

Jassian, about 10 K. M. South-East of Attock city, Punjab, Pakistan.

Horizon :

Tatrotian of the Upper Siwaliks.

Hypodigm :

Type only.

Diagnosis :

As for the genus.

DESCRIPTION (Figs. 1—6).

The skull under study is broken up longitudinally into almost two equal halves. On the left side, canine and P[3] are preserved and the alveoli of I[3], P1-2 and protocone of P[4] are distinct. The right half has P2-3, complete alveolus of P[4] and complete M[1].

Third incisor, which is represented by its alveolus, was evidently more stout than the canine. In crocuta, I[3] is always more stout than I1-2 but less so than the canine. Although I[3] is not preserved in this specimen, yet the alveolus, without doubt, clearly shows its thickness. The canine is stout with greater longitudinal than transverse diameter, as is generally the case. It has distinct keels on the anterior and posterior sides like that of *Crocuta carnifex*. The alveolus of P[1] indicates its small size and its outer boundary internal to that of P[2] as in *Crocuta*. P2-3 are very thick and stout teeth with conical crowns and with anterior and posterior cingula of which the posterior one is more prominent. P[4], which is represented by its complete alveolus on right side, was decidedly longer and thinner than in *Crocuta*. Moreover, it had very prominent protocone more so than in *Crocuta*. It extends inwards beyond the inner border of P[4]. Its alveolus clearly indicates a sharp, thin and long crown. Pilgrim (1931) states about *Crocuta*, "P[4] gradually lengthening, with protocone either larger or much reduced". In the specimen under study the protocone was definitely prominent. However, one feature which distinguishes it from *Crocuta*, is that it is much thinner and longer tooth.

M[1] is complete. It is much reduced in size. It is shorter longitudinally but its transverse dimension is greater. Anterior to it, there is a prominent depression on the palate. The posterior border of the palate shows concavity on the left and right side because medial part of the palatine and external part of maxilla are longer than their counter parts.

TABLE 1

Dental measurements (in mm) in *Romeria jassiarensis* new genus & new species

Anteroposterior diameter of l.I^3 alveolus	19
Antero-posterior diameter of canine at base	23
Transverse diameter of canine at base	17
Height of canine	37
Antero-posterior diameter of P^1 alveolus	5
Reconstructed antero-posterior diameter of P^1	6.5
Transverse diameter of P^1 alveolus	5
Reconstructed transverse diameter of P^1	6.5
Antero-posterior diameter of r. P^2	21.5
Antero-posterior diameter of l.P^2 alveolus	21.5
Transverse diameter of r.P^2	15.5
Transverse diameter of l.P^2 alveolus	15.5
Crown height of r.P^2	15
Antero-posterior diameter of r.P^3	28
Antero-posterior diameter of l.P^3	28
Transverse diameter of r.P^3	20
Transverse diameter of l.P^3	20
Crown height of r.P^3	22
Antero-posterior diameter of r.P^4 alveolus	40
Reconstructed antero-posterior diameter of r.P^4	42
Transverse diameter of r.P^4 alveolus at protocone	22
Reconstructed transverse diameter of r.P^1 at protocone	24
Antero-posterior diameter of r.M^1	4.5
Transverse diameter of r.M^1	13

DISCUSSION

In having heavy and blunt premolars, powerful carnassials and highly reduced postcarnassial tooth, the skull under study is referable to the family hyaenidae.

According to Simpson (1945), there are 4 genera in the subfamily hyaeninae. These are *Hvaenictis*, *Lvcyaena*, *Crocuta* and *Hyaena*. Of these, the first three are known from the various faunal stages of the Siwalik Series (Pilgrim, 1932 ; Abubakr & Akhtar, 1983 ; Abubakr, 1986).

The skull fragments under study needs no comparison with the relevant material of the genus *Ictitherium* of the subfamily Ictitherinae because the latter was a primitive hyaenid with low and comparative lightly built teeth (Colbert, 1935 ; Piveteau, 1958). Actually, it presents a transition between viverrids and the modern hyaenids (Zittel, 1925 ; Romer, 1966). In the genus *Hvaenictis*, M^1 is large and triangular with much greater antero-posterior diameter than that of any known species of *Hyaena* or *Crocuta* (Pilgrim, 1932). M^1 is situated posteriorly to P^4 in the genus *Hyaenictis* (Matthew, 1929). Thus, the skull under study cannot be referred to the genus *Hvaenictis*. The specimen under study is sharply differentiated from the narrow and elongated skull of the genus *Lycyaena* (Pilgrim, 1931.) In P.U.P.C. No. 87/4, M^1 is highly reduced and is placed anterior to the posterior end of the P^4 whereas it is situated slightly behind the P^4 in the genus *Lycvaena* (Pilgrim, 1931). The complete alveolus of P^4 indicates that the tooth was decidedly longer and thinner with sharp, thin and long crown than that of the genus *Crocuta*. The alveolus also indicates that its protocone was much prominent than that found in the P^4 of the genus *Crocuta*. In the skull under study, the posterior border of the palate ends comparatively far more anteriorly than that of the genus *Crocuta*.

There is no doubt that the specimen under study is a hyaenid but differs from the known genera in having a very large I^3, structure of M^1 and P^4 and their location and the posterior border of the palate. It is therefore, referred to a new genus *Romeria* which is in recognition of the great palaeontological contributions of the late Professor Alfred Sherwood Romer. The new species, *Romeria jassianensis* is named after the type locality Jassian.

TABLE II

Comparative measurements (in mm) of teeth in various genera of the subfamily Hyaenodontinae and Ictitheriinae

	C	p^1		p^2		p^3		p^4		Length of Upper pre-molar series	M^1	
	L	L	W	L	W	L	W	L	W		L	W
Ictitherium Roth & Wanger												
British Museum Collection (from Pilgrim, 1931)	9	4-5	—	12-13	6	13.5-15	8	20-21.5	13	53-53.5	—	—
Collection in Palaeontological Museum in Munich (from Pilgrim, 1931)	—	—	—	—	—	—	—	—	—	55	—	—
Lycyaena Hensel												
British Museum Collection (from Pilgrim, 1931)	16	—	—	16.5	9	19.8	12	31.5	17	80	7	14
Indian Museum Collection (from Pilgrim, 1932)	—	—	—	16	—	23.4	12.5	33.6	17	86	8	16.8
P.U.P.C. Collection (from Abubakr, 1986)	—	8	6	17	11	—	—	32	17.5	—	—	—
Florence Museum Collection (from Pilgrim, 1931)	16.7	—	—	21	12	25.4	12.7	33	—	—	4.5	10
Ramrria new genus												
P.U.P.C. Collection (from Table I)	23	6.5	6.5	21.5	15.5	28	20	42	24	95	4.5	13
Crocuta Kaup												
American Museum Collection (from Colbert, 1935)	—	—	—	—	—	26	18	41	21	—	—	—
Collection in Palaeontological Museum in Munich (from Pilgrim, 1931)	20	—	—	17	15	22	16	40	21	—	7	13
British Museum Collection (from Pilgrim, 1931)	16-17	8	8	17-19	12-14	21-25	15-16	36-38	17-19	86	6	13
Hyaena Brisson												
Indian Museum Collection (from Pilgrim, 1931)	16.5	—	—	17	10.5	21-5	14	30	18.5	—	6	14

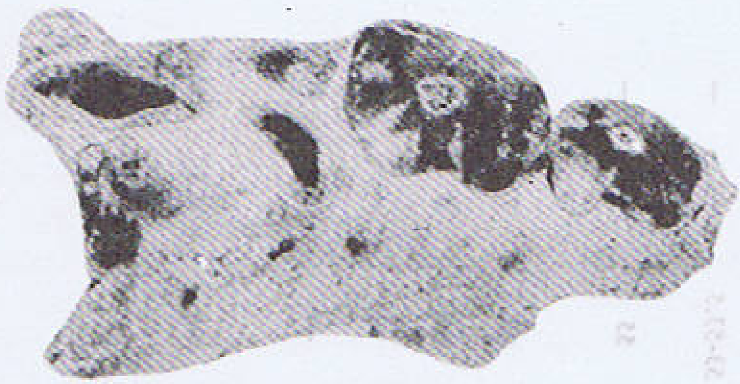

Fig. 1. *Romeria jassianensis* n. g. et n. sp. Ventral view of right fragment of the skull, P.U.P.C. 87/4.

Fig. 2. *Romeria jassianensis* n. g. et n. sp. Outer view of right fragment of the skull, P.U.P.C. 87/4.

Fig. 3. *Romeria jassianensis* n. g. et n. sp. Inner view of right fragment of the skull, P.U.P.C. 87/4.

Fig. 4. *Romeria jassianensis* n. g. et n. sp. Ventral view of left fragment of the skull, P.U.P.C. 87/4.

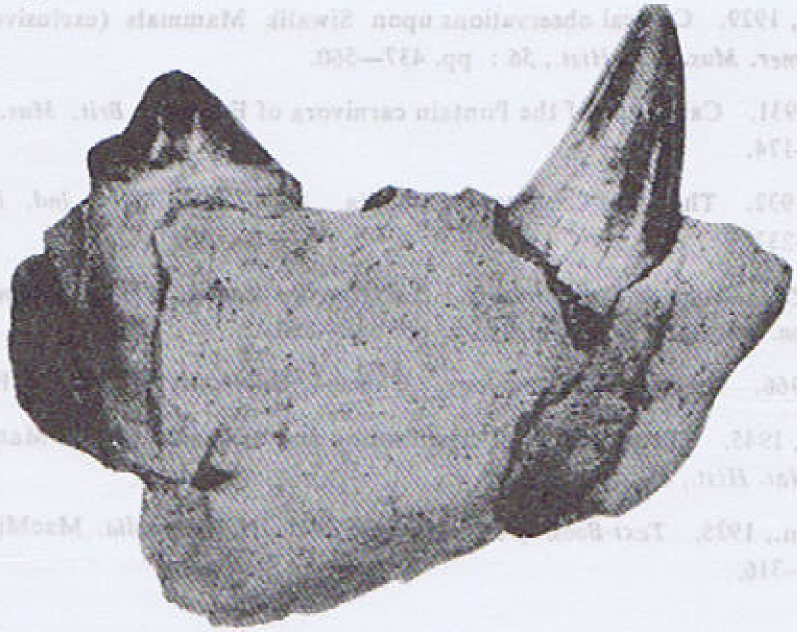

Fig. 5. *Romeria jassianensis* n.g. et n. sp. Outer view of left fragment of the skull, P.U.P.C. 87/4.

Fig. 6. *Romeria jassianensis* n. g. et n. sp. Inner view of left fragment of the skull, P.U.P.C. 87/4.

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NANGA PARBAT : A STUDY OF GEOGRAPHICAL INFLUENCE

BY

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Abstract : *Nanga Parbat is under active investigations in the field of geology. On the other hand there does not exist any notable geographical investigation to elaborate the geographical factors of the area. Here an attempt has been made to elaborate geographical factors at work and their associations. Here a probe has been made to ascertion the commanding position of Nanga Parbat and its influence in shapping the regional geomorphology and the resultant topography.*

INTRODUCTION

The study region lies between 74° — 15′ to 75° E and 35° to 35° 30′N. It is situated in the Diamir district of Northern Area, in the N-W mountainous region, between the Indus valley in the N and Great Himalayan system bordering the S-Wn and Sn side. In this region is situated the most dominating feature of Nanga Parbat (naked range) (Fig. I). The mountain is more than 30 miles long and its axis is positioned in the S-W and N-E direction. Towards N-E it advances as a 'low spur' above 12,000' to the Indus Valley where it ends in a cliff. The steep dipping of this section is disturbed at a place where it shoots up to above 16,000' above sea level.

Geologically speaking, the Nanga Parbat area, between Chilas mountains to the W and Astor mountains to the E consists of :—

(a) Nanga Parbat Massif, (b) Precambrian Series covering the area to the S upto latitude 35° 13′, (c) Crystalline complex showing an association of gneiss and Precambrian series surrounding the central massif, (d) Massive black basic igneous rocks occupying extensive ground to the E of Indus Valley and (e) the Indus Valley fluvial terraces (See Fig. 2).

(a) Nanga Parbat is a gneiss occupied area and extends to the eastern slopes of Bunar Valley. The Nanga Parbat mass alongwith its other peaks is composed of gaeiss and Precambrian rocks which show metamorphosed forms of marble, graphitic and mica schists. The whole mass of different kinds of formations is excellently and uniformly consolidated. The region possesses a regular dip to the N-W. The general strike of the foliation is consistently in the N-E and S-W direction. The gneiss and schist are extensively traversed by acid and basic igneous intrusions. The intrusions are of considerably large dimensions. They belong to the 'Central Gneiss' of Himalaya interspersed by a finergrained granite of later intrusive phase. As a matter of fact, the higher portion of Nanga Parbat shows foliated granite which intruded into the gneiss dome.

(b) Precambrian sediments (Salkhala Formation) are found in the southern area of Nanga Parbat. Here the series of rocks consist of highly metamorphosed corbonaceous and graphite bands in the form of schists. These rocks prevail upto a level of 1,000', but at higher level become scare and gneiss give way to mica and marble schists.

On the SE from Trashing, (Fig. I), metamorphism decreases and Precambrian formations emerge from the monotonous gneiss complex. The occurrence of acid and basic intrusions steadily decrease SE wards.

(c) This type of formations surround Nanga Parbat elliptically (See Fig. 2). The rim of the ellipse continues in a NE direction beyond Astor towards Gilgit. It is more exclusively constituted by schists.

(d) This whole area is characterised by widespread injections of plutonic and acid plutonic formations. Dolerite type of igneous rock intrusions in the Astor mountains and east of Nanga Parbat, occupy an extensive area and at places are of mountainous dimentions. Smaller intrusions are in the form of dykes and stocks which exist everywhere.

(e) These are Quarternary deposits of coarse deposits in the form of river terraces. They are a narrow belt in the N and becomes of sizeable extent on the southern side, extending southwards along the valley of Bunar river for a small distance.

Physiographically this region is directly related to the dominating influence of Nanga Parbat. This is made further clear by a cros-section of the range from Indus Valley in Chilas in the NW to Rupa Valley in the SE (Fig. 3).

Techtonic Influence of Nanga Parbat : The Nanga Parbat and its twin orogen-Haramosh in the NE direction, makes a tectonic axis which runs almost perpendicular to the main Himalayan range. Previously it was considered that the Nanga Parbat is the culmination of Himalayan range. Recently, it has been extended across the Nanga Parbat towards SW direction into the Hazara, Swat and Dir areas. Therefore, the status of Nanga Parbat is of enigmatic position.

According to Misch (1949), the Nanga Parbat is composed of granites and gneiss with high grade rock constituting the central dome and decreasing grades symmetrically disposed outwardly. The rocks are found to have undergone high pressure-temperature changes involving addition of material from depths, as a result the composition of the original rocks has been transformed in what we find at present. This change in composition has caused decrease in the density of rocks so that orogen is in a state of gravity imbalance as compared with the surrounding formations. This is believed to have happened even if there was only a redistribution of chemical material within the mountain system without involving additions, as claimed by Gansser (1964). The only chemical investigation so far carried out by Shams and Shafiq (1979) support addition of material.

According to Desio (1960) the Nanga Parbat constitutes a remobilised prism of the basement rocks which has also involved the cover rocks. In both cases, the Nanga Parbat is known to be siesmically active and still rising. According to Zitler ———— the rate of rise of Nanga Parbat is 21 to 03 cms per year which is very high in geological terms. Due to this unique behaviour, the Nanga Parbat region constitutes an extraordinary geomorphic phenomenon such that there is a drop of, as explained below, slope which is very steep. Due to this reason the Nanga Parbat is suffering from abnormal rate of weathering and erosion. On the E side weathering is both due to ice and water while the western side suffer mostly from ice action and temperature variations. As a result the river Indus which flows mostly on the West side receive excessive sediments. An other influence of Nanga Parbat techtonics is siesmic activity related to Nanga Parbat and influencing other regions as well at considerable distance.

The Nanga Parbat is the most massive feature of Western Himalayan system. Its topography is fascinating. It has a height of 26,6c0′ above the sea-levelel. The range has 16 other pinacles of which 11 are above 20,000′ and other five above 16,000′ (Fig. I).

The Nanga Parbat is the central one and most commanding in the whole region. On the Northern side the range dips down to below 3,500′ at Indus Valley bed in only approximately 14 miles, to the West it falls 20,000′ in 17 miles, to the South 20,000′ in 31 miles and to the East within 14 miles the slope dips from 19,600′ to the Astor river gorge to less than 10,000′ above Sea level. This gives an idea of the gradient of the slope of the area. On all sides there are also numurous abrupt scarps, and deep gorges and basins from 5,000′ to 10,000′ level which again and again interrupt the mainfall.

The Nanga Parbat has wall-like precipices on the South side, rising sharply 12,000 to 13,000′ from the Rupal valley beneath. The ledges and recesses all along the slope carry several small glaciers and dangerous avalanches. (Fig. I). The range breaks into two points in its Souther length which is Mazeno Gali, 17,640′ and Toshi Gali, 16,820′. The former provides a passage to the Bunar Valley in the Chilas mountainous region. Both the galies are covered under the mantle of talus and moraine deposits. The eastern and south-eastern side of the mountain is surrounded by enormous stretches of morains, consisting of angular blocks of sizes upto 100′ diameter. These boulders, alongwith fresh frost-broken debris, is regularly shed from higher crags. This is the only loose material available to provide evidence of the character of the rocks in the higher region, because most of the top of the range above 16,000′ remain under snow cover. There are also found discontinuous patches of bare rocks along Rupal valley upto Toshe Gali. North-wards naked cliffs hang over various parts of the stream tributaries which join the Indus Valley. The region, to the NW and NE falls precipitously to the valley of the Indus and on the other side rises again steeply in the Shinaki mountains. Similar is the case with the area to the S and E of the main massiff. Here the relief, generally, is high.

The NW slope of Nanga Parbat is also precipitous but more regularly as compared to the southern slope. Here the landscape shows spur-ridges first extending to the NW and then turning N-wards to end up in the river bank cliffs. The main feature of the valley is that it is flanked by cliffs and spurs. The whole region is occupied by Chilas mountains.

It is clear from the Map (Fig. I) that Nanga Parbat is very well covered with snow from where originate several glaciers on both sides. On the south-eastern side glaciers slip down in large numbers from a very steep slope. They push down from the edge in the form of avalanches and extensive snow-slips. On the other hand north-western side of the ridge is fairly wide and, therefore, possesses stable ice-field. Only some gaps and craveces are favourable for ice flows. On this side develops only 4 or 5 glaciers. Anyhow, on both sides glaciers reach the level of 10,000 above Sea-level.

Topographically, the region shows many abutting pinacles with elevations above 11,000′ while above 16,000′ are only a few. On the other-hand in the north-eastern and eastern section there are plenty of isolated hillocks with heights above 13,000 and above 18,000′.

The southern and south-eastern sections of Nanga Parbat have a good number of pinacles. As said before, all of them are above 16,000′. If southern, south-eastern and central Nanga Parbat are considered together, the region possesses the highest concentration of peaks in a single mountain range. In short this knot of high ground has shaped the terrain trend of this region.

Again the drainage pattern development seems clearly due to the positional control of Nanga Parbat. It acts as a watershed. As discussed earlier, the north-western slope is gradual. The ice-field above snow line is stable and here glaciers do not tumble down erratically. Therefore, the regular snow-melts have assured water supply, due to which a profuse stream system has come into existence, though rainfall is scarce. The largest of the stream system on this side is Bunar Gali. The streams possess dendritic pattern. The paucity of cliffs, spurs and plugs provide favourable physiograghy for development of streams, as well as numerous secondary and tertiary order tributories. This form of drainage also extends to the north-eastern section of the area.

The eastern, south-eastern and southern sides of the range are different as compared to the north-western side. Here the slope, as explained before, is extremely steep and rises abruptly. It is due to this fact that there are plenty of glaciers. This is drained by only one stream named Rupa Gali. It is joined by a few streams only. The streams here possess linear form, though the water supply here is sufficient due to glacial melts and sufficient rainfall. This side of the area does not favour the development of extensive drainage system as the whole area is elevated mass of hard rocks.

The dendritic form of drainage reappears in the N-E. This is due the south-western slopes of Deosai mountains which also remain covered with snows.

Climatically, the whole region belongs to the central Asian desert. It is an expense of rock desert, devoid of any soil, but covered by a drab blanket of scree material. This region lies on the back of Great Himalayas and therefore is in the rain-shadow area. Summer temperature becomes fairly high as the bare rocks becomes hot during the day-time. The nights become frosty due to altitude. This temperature variation results in dreadful denudation. The region presents the vista of shingle desert landscape. The north-western side of Nanga Parbat is more so as it experiences much more extremes of temperature. The eastern and S-eastern area, having higher over all altitude, is less extreme in the day temperature, but nights become even extremer than the NW side of the Nanga Parbat range.

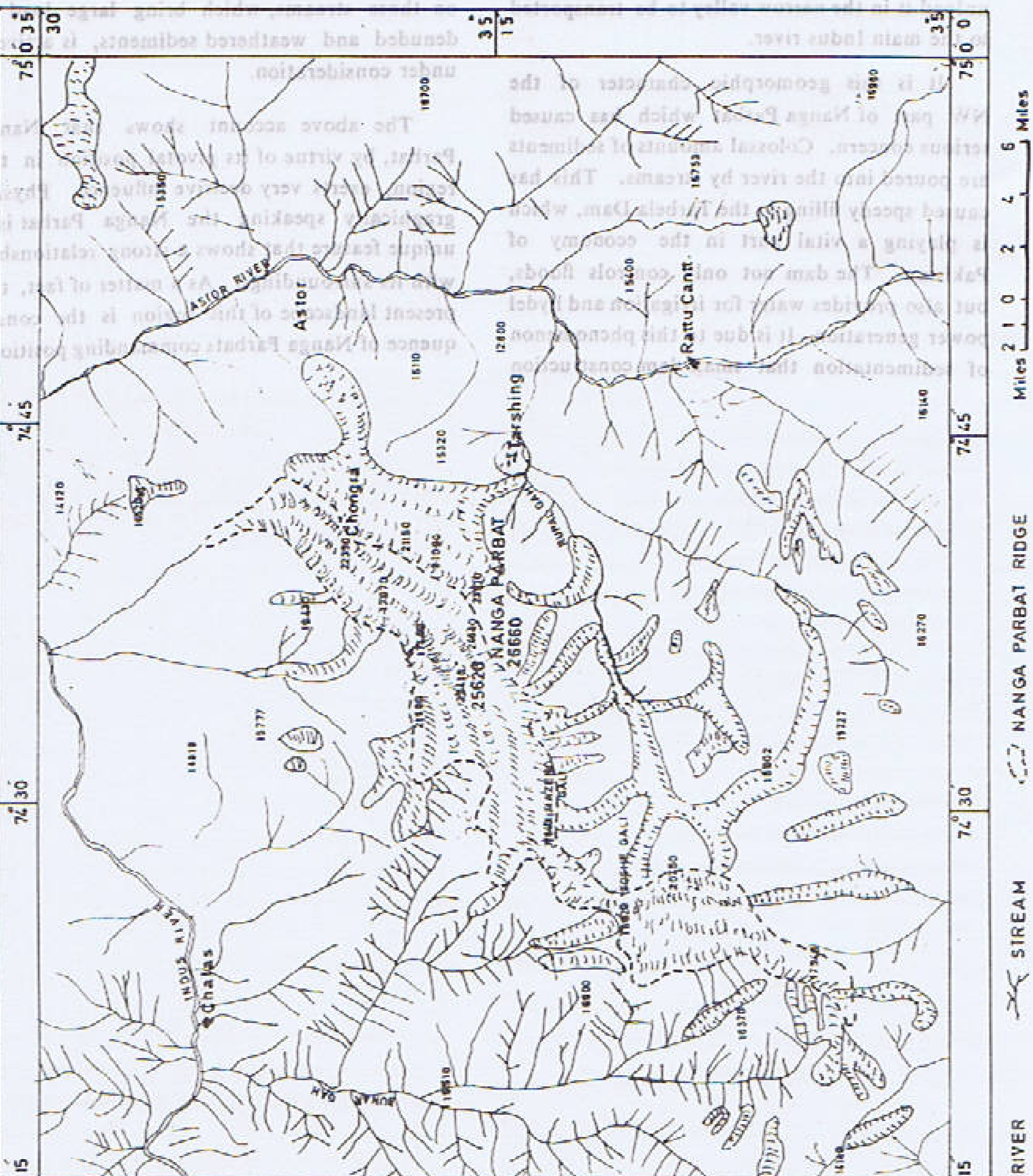
As far as precipitation is concerned, it is due to Indus Valley depression. The direction of the valley is suitable only to provide moist winds to advance in the eastern direction. The depression between the Deosai and Nanga Parbat provides physiographic position. Therefore the area to the E and SE of Nanga Parbat gets much of the precipitation. The higher parts of the Nanga Parbat and other peaks remain covered with snow. The precipitation even becomes more abundant still further North On the other hand, western side gets some stormy rainfall which pulls down the slope whatever denuded rock material exist and unload it in the narrow valley to be transported to the main Indus river.

It is this geomorphic character of the NW part of Nanga Parbat which has caused serious concern. Colossal amounts of sediments are poured into the river by streams. This has caused speedy filling in the Tarbela Dam, which is playing a vital part in the economy of Pakistan. The dam not only controls floods, but also provides water for irrigation and hydel power generation. It is due to this phenomenon of sedimentation that small dam construction on those streams, which bring large load of denuded and weathered sediments, is actively under consideration.

The above account shows that Nanga Parbat, by virtue of its pivotal position in the region, exerts very decisive influence. Physio-graghically speaking the Nanga Parbat is a unique feature that shows a strong relationship with its surroundings. As a matter of fact, the present landscape of this region is the consequence of Nanga Parbats commanding position.

FIG _1

PHYSICAL MAP OF NANGA PARBAT



GEOLOGICAL DIVISIONS OF NANGA PARBAT

FIG_2

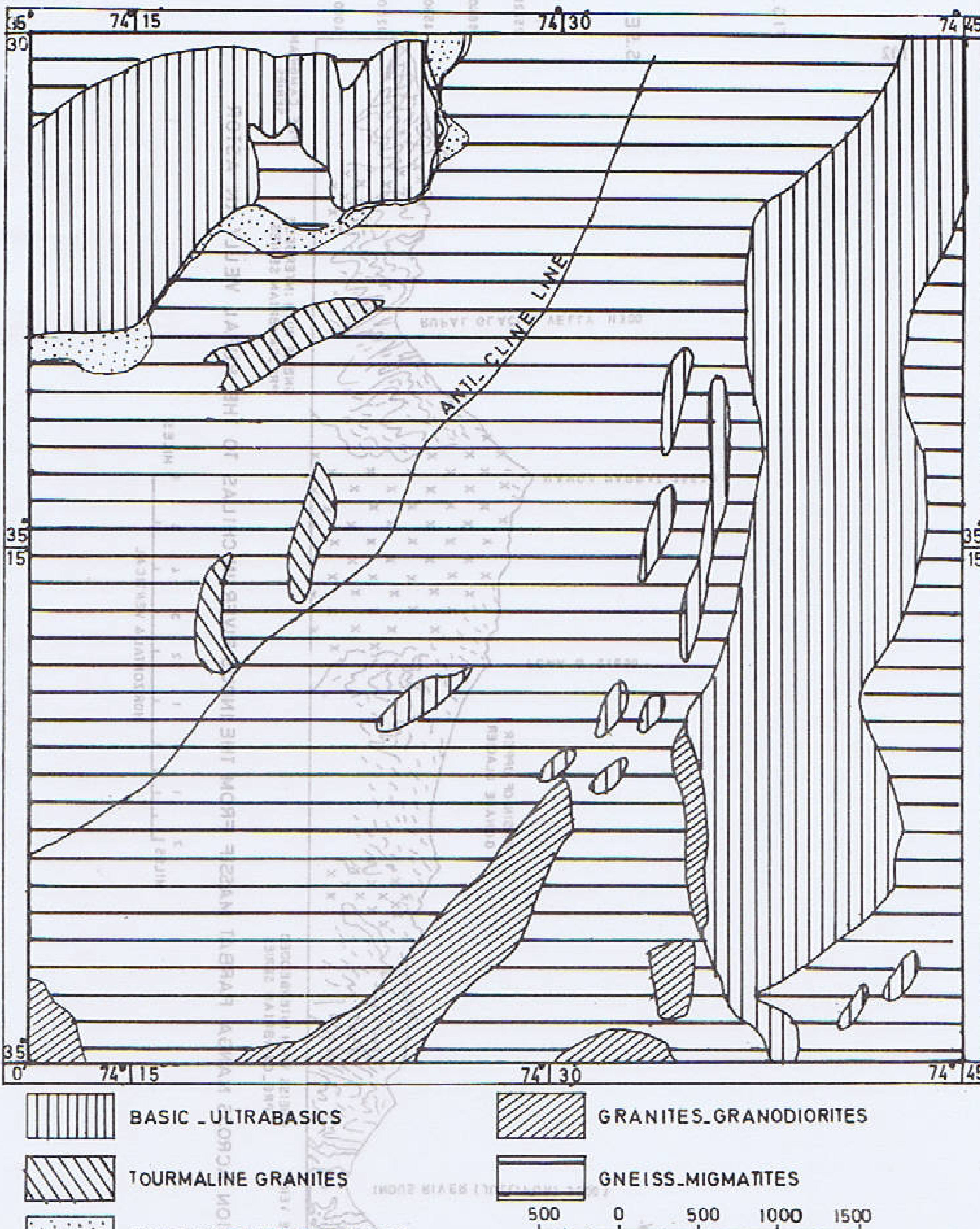
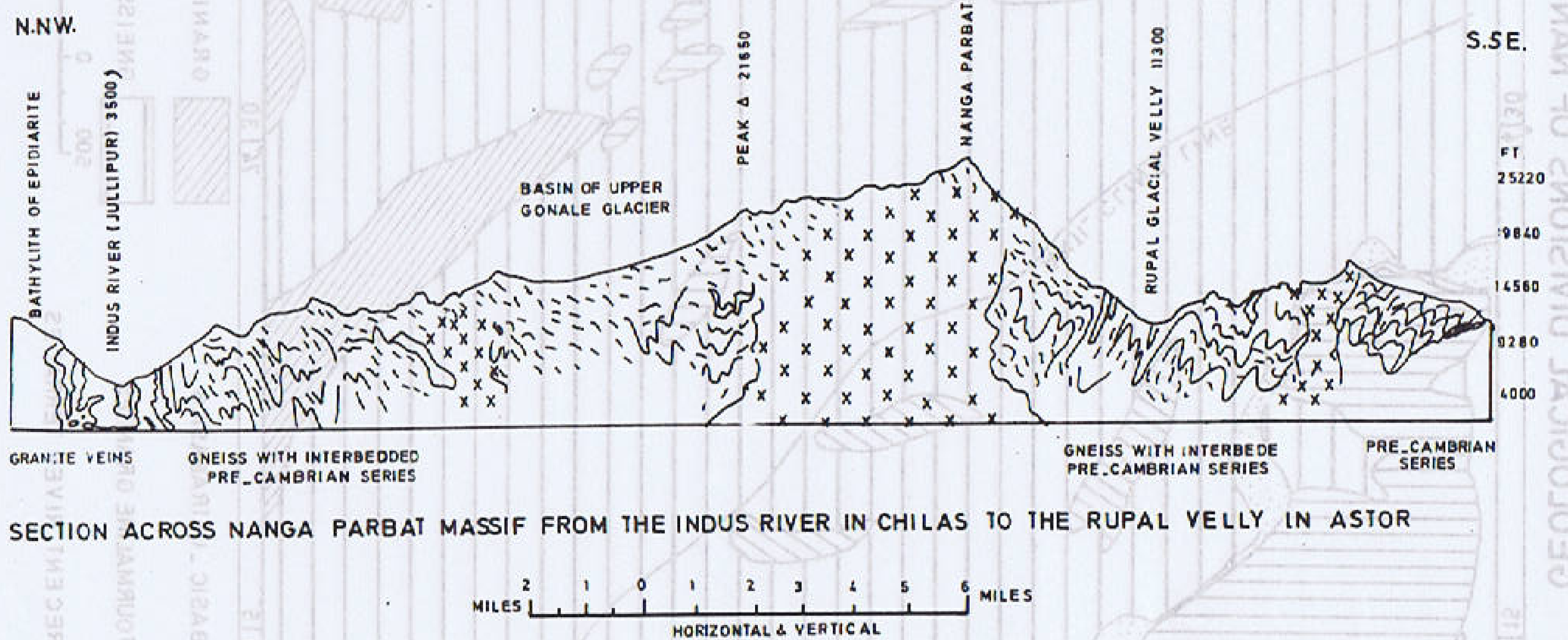


FIG_3



SECTION ACROSS NANGA PARBAT MASSIF FROM THE INDUS RIVER IN CHILAS TO THE RUPAL VELLY IN ASTOR

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STRATIGRAPHICAL DATES ON THE TRIASSIC ROCKS OF LANDU NALA, SURGHAR RANGE

BY

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Abstract : *The stratigraphy and microfacies of some of the Triassic rocks of Landu Nala are described. Within the pisolitic horizon on top of the Mianwali formation a few species of conodonts namely Gondolella timorensis, Neospathodus homeri and Ozardina tortilis are recorded. Within the Kingriali succession some brachiopod species of Spiriferinoides and some pelecypods have also been identified. An Anisian and Carnian age is proposed on the basis of fossil contents.*

1. INTRODUCTION

The Salt Range and Trans Indus Ranges have attracted attention of many geologists since the middle of the 19th century. The Triassic rocks mainly the ammonoid-bearing strata have already been subject of intensive research by different workers including Wynne (1878), Waagen (1895), Mojsisovics (1895) and Noetling (1900, 1901). Gee (1945) made a detailed study of the Triassic rocks and named the uppermost part as "Kingriali Dolomite", the middle one as "Kingriali Sandstone". He introduced the term "Mianwali series" in a time stratigraphic sense for all sediments believed to be of Triassic age. Kummel (1966) considered the Mianwali Formation as the lowermost lithostratigraphic unit of the period. Gee (in Kummel, 1966) renamed in part his earlier name "Kingriali Sandstone" as Tredian Formation. The Stratigraphic Committee of Pakistan (Fatmi, 1974) formalized the lithological succession from bottom to top as Mianwali, Tredian and Kingriali Formation. Gee (1979) in his Salt Range maps placed them all together in the Musakhel Group. Shah (1977, 1980) and Iqbal & Shah (1980) adopted it.

The Mianwali Formation has been investigated by different paleontologists. Generally a Scythian age has been established :

Kummel (1966) recorded the uppermost ammonoid bearing horizon with *Isculitoides* sp. and *Subvishnuites* sp. 61 feet below the Tredian Formation. Within the pisolitic bed he found *Spiriferina* and other brachiopods. On the basis of fauna he considered a Late Scythian age for this part of the Narmia Member of Mianwali Formation in the Surghar and Salt Range.

Guex (1978) described *Tozericeras pakistanum, pakistanum* zone, Middle Spathian about 16 meters below the Tredian Formation and he compared it to the *Subcolumbites* beds of USA. The Upper Spathian was not identified by ammonoids.

Sweet (1970) established 9 subsequent conodont zones, one straddling the Permian-Triassic

Boundary, the others within the Lower Triassic. The youngest fauna from the top of the Narmia Member yielded *Neospathodus timorensis*, which he thought to be of Anisian age.

Balme (1970) analysed various palynomorphs of the Permian and of both Mianwali and Tredian Formations. In the Surghar Range he recorded from Landa Member about 5 feet above its base a Middle Triassic assemblage.

The Pakistani-Japanese Research Group (1985) found *Nordophiceras* sp. at the Nammal which occurred on top of the Narmia Member. They correlated it to parts of the conodont-zones of *homeritriangularis* and *timorensis*.

Marine fossils have not yet been reported by any worker from the Tredian Formation. Kingriali Dolomite yielded a few poorly preserved specimens of unidentifiable bivalves and crinoids.

Ashraf (1977) looked at the mineral composition of the dolomite. Mensink *et al.* (1985) divided the formation on the base of its microfacies. They described 4 units in ascending order: Clastic Dolomite Unit, Limestone Interval, Dolosparite and Dolomicrite Unit. 11 microfacies types were observed. Fatmi (in preparation) introduced the term "Doja Member" for the lowermost 2 units and the term "Vanjori Member" for the dolomitic upper part. Recently Haq and Hardenbol (1987) worked on Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. They presented on fig. 13, Lithostratigraphic Paleontologic, and sequence—stratigraphic data of the Scythian (Lower Triassic) section at Nammal Gorge Salt Range. This figure was actually based on the work of Pakistani-Japanese Research Group (1985).

The Kingriali Formation is doubtfully assigned to the Late Triassic (Fatmi, 1974; Shah, 1977). Iqbal & Shah (1980) placed it probably into the Middle Triassic. The contact to the overlying Datta Formation is disconformable.

2. STRATIGRAPHIC SEQUENCE OF LANDU NALA

The section under investigation is located lat. 32°58'N and long. 71°11' 17'E on Topo-Sheet No. 38 $P/_1$ of survey of Pakistan (fig. 2). During a field trip in spring 1987 a detailed study of the top of Mianwali-Formation and Kingriali-Formation was initiated. The rocks of Triassic age are well-exposed along Landu Nala.

Lithology and Facies

The measured sequence starts with the topmost part of the Mianwali-Formation consisting of an inter-calation of marls, sandy marls and thinly bedded limestones. The brownish weathering pisolite overlies a hardground which bear features of animal borings. The discontinuity is covered by pelecypods. The pisolitic horizon is also thinly bedded having cross-stratification and it contains some marine fossils, e.g. brachiopods, echinoids and crinoids.

The Tredian-Formation is composed of sandstones, siltstones and claystones, with some conglomeratic and coaly horizons. The thickness is about 96 m.

The Kingriali-Formation has been studied with more detail. In its basal part dolomitic sandstones and sandy bioclastic dolomites are alternating. Some of these horizons are intensively reworked. Followed by bioclastic and oncolitic limestones there is a thick bedded part of coarse grained dolomites. Towards top dolomicrites are the most frequent rock type. These dolomicrites are weathered, at places, into yellow-brownish to white-grey in colour.

From the Kingriali-Formation and from the topmost limestones of Mianwali-Formation a total of 12 microfacies types are established (from top to bottom, fig. 3) :

(1) *Dolomicrites-Facies.* It is an extremely fine-grained micrite consisting of pure dolomite and it is without any fossils or carbonatic components. Just a few authigenic quartz-cristalls badly shaped are scattered within the micrite. Sometimes irregular or planar lamination occur.

(2) *Intraclastic Dolomicrite-Facies.* The groundmass is finely crystalline and dolomitic. Up to 10% angular to rounded interclasts are present. Crinoids and shells (together up to 3%) are present.

(3) *Dolosparite-Facies* fig. 4). This facies is composed of coarse grained dolomitic crystalls of sub- to anhedral shape. Due to the late diagenetical development of these dolomites a relatively high amount of irregular distributed pore space is present in this facies type. Crinoidal fragments are scattered in the sparitic fabric.

(4) *Oncolitic Dolosparite-Facies* (fig. 4). Oncoids up to 2 cm in size are the most important feature of this facies ranging up to 35% of the total material. Crinoids and shells presumably of brachiopods are present up to 5%. Some other fossils are surrounded by micritic envelops. Groundmass is a dolomitic sparite.

(5) *Intraclastic Biosparite-Facies* (fig. 4). Shells (30%), crinoids (10%) and bryozans (1%) are the main bioclasts. Coated grains, micritic intraclasts and detrital quartz (3%) are the other components in the calci-sparitic groundmass.

(6) *Oncolitic Biosparite-Facies* (fig. 5). Oncoids are present up to 30%, coated grains and intraclasts are accessory which are up to 10%. Most of the bioclasts are crinoids (about 15%), the shells of brachiopods range up to 5%. The groundmass is a coarse calcitic sparite.

(7) *Oncolitic Biomicrite-Facies.* The groundmass is a calcitic micrite. In it crinoids 10 %), shells of pelecypods and brachiopods (15%) and shells of gastropods (5%) are distribured. Oncoids are present up to 10%.

(8) *Biosparite-Facies* fig. 5). Crinoids (15—30%), shells of brachiopods (up to 10%) are the bioclastic components. Coated grains are present up to 5%. The groundmass is a calcitic sparite.

(9) *Sandy Dolosparite to dolomitic Sandstone-Facies* (fig. 5). Detrital, singular to subangular quartz grains are the main components. Percentages varies between 35 to 60%. Plagioclas might reach about 5%. Crinoids are present up to 15%. The groundmass consist of dolomitic sparite.

(10) *Sandy bioclastic Dolosparite-Facies.* Detrital quartz is angular to subangular and ranges in size from 50 to 750 um, about 10 to 20% are distributed within the dolomitic groundmass. Crinoids and shells are frequent (20%).

(11) *Sandy pelloidal Biomicrite-Facies* (fig. 5). The groundmass is calcitic micrite, slightly washed. Detrital quartz is present up to 10%. Shells of different lamellibranchias are frequent (25%). Crinoids and peloids each have a percentage of 10%. Micritic intraclasts about 5%. The facies is highly bioturbated.

(12) *Oosparite-Facies* (fig. 5). Up to 30% of both ooids (smaller than 2 mm) and pisoids (bigger than 2 mm) are the most important component of this facies. According to their shape single ooids can be differentiated from a lot of compound ooids. The latter ones are developed as multiple ooids since these are intergrowths of two or more ooids and polyooids are developed as several complete ooids which

serve as a nuclei for a larger new one. The ooids are densely packed, only a few are broken. Nuclei of both ooids and pisoids are mostly shells or crinoids. Sometimes two or more ooids are agglutinated and form a grapestone type of aggregate grains. Less frequent are oncoids formed by a biogenous coating of an ooid nuclei. Fossils of crinoids, echinoids and shells of pelecypods, gastropods and brachiopods are frequent. The groundmass is a calcitic sparite.

Faunal Contents

Within the uppermost part of the Mianwali-Formation (fig. 3) conodonts have been identified.

Gondolella timorensis (*Nogami*) (fig. 6). Skeletal elements of this species are laterally compressed, blade shaped units with a crest of some erect, sharp pointed denticles of almost the same width and length. Sweet (1970) included it into *Neospathodus* group and described it from Narmia section of the Narmia Member. His Zone of "*Neospathodus timorensis*" was based on the occurence of this particular species within the pisolite. Vrielynck (1987) placed it again back into *Gondolella* group. *Gondolella timorensis* is thought to be of basal Anisian age (Gupta and Chhabra 1985).

Neospathodus homeri (*Bender*) (fig. 6). Skeletal elements of *Neospathodus homeri* are bowed, bladelike units with a midlateral ridge. The anterior process bears 5 to 11 denticles that decline in length toward the distal end. Sweet (1970) recorded it from Narmia Member at Landa, Narmia and Nammal. A Lower Triassic age is attributed to this form of conodonts (Kozur, 1980b).

Ozarkodina cf. tortilis (*Tatge*) (fig. 6). Elements attributed to this species have laterally compressed blades. One denticle is rather high and distinct. The other anterior denticles decline in length towards the distal end of the process. The posterior process is surmounted by shorter denticles. Sweet (1970) decribed the identical form as *Xaniognathus elongatus* from Landa, Narmia and Nammal out of the Narmia Member. Recently Vrielynck (1987) recorded it as a synonym of *Pseudozarkodina tortilis*. He discussed its presences from all faunal provinces of the world ranging from Middle Permian to Upper Triassic, Sevat.

The limestone Interval of Kingriali-Formation contains some fossiliferous horizons. One of them which is situated about 19 m above the base of the formation yielded internal casts and shells of the pelecypod genus *Halobia* and even more important two identifiable species of *Spiriferinoides* which allow a stratigraphical dating of the bed.

Spiriferinoides yeharai (Kobayashi) and Tokuyama (fig. 7). Their shells are almost plano-convex, 1.5 times wider than long ; the largest width slightly anterior to hinge line. Median sinus of pedicle valve well marked ; nearly in all cases 7 lateral costae rounded and widely spaced, narrowing and weakening laterally ; beak, if present, pointed and gibbous. Brachial valve more or less subcircular; 7 costae strong and rounded. Complete specimens are not observed, however, brachial valves and in some cases pedicle valves indicate that the material under consideration is similar to what have been recorded from the *Ha'obia-Tosapecten* Bed of Tosa area, Japan (Tokuyama, 1957) out of Carnian horizons.

Spiriferinoides nasai (*Tokuyama*) (fig. 7.) Shell small, more or less conical and plano-convex. Median sinus of pedicle valve wide and very shallow ; 4 to 6 lateral costae covering the lateral slope, costae subangular, narrow and widely spaced. Brachial valve slightly convex and rounded with 4 to 5 lateral costae. Judged by general outline and shell structure the representatives of this species belong decidedly to

Spiriferinoides. The features of both pedicle and brachial valves indicate that the material present is almost similar to the species recorded again from the *Halobia-Tosapecten* Beds of the Tosa province, Japan. The deposits bearing this species have been attributed to a Carnian age, too.

3. DISCUSSION

This study presents litho- and biostratigraphical dates of the topmost part of the Mianwali-Formation (a) and secondly that of the Kingriali-Formation (b).

(a) Within the topmost limestone-beds of the Narmia-Member three species of conodonts have been identified namely *Gondolella timorensis*, *Neospathodus homeri* and *Ozarkodina cf. tortilis*. The first one is the most typical element of the oldest Anisian conodont-zone as considered by Kozur (1970a/b) and Gupta and Chhabra (1985). The other two species are accessory elements. They occur also in assemblages underlying and overlying the *timorensis*-zone. The precise age has been discussed variously (Gupta and Chhabra, 1985). A Late Spathian up to an Early Anisian age has been considered. According to recent investigations (Chios, Nevada and Himayala) the species *Gondolella timorensis* makes its appearance at the base of the Anisian. This is coinciding with the opinion expressed by sweet (1970) concerning the Anisian age of the pisolitic rocks of Narmia section. The Pakistani-Japanese Research Group (1985) attributed the uppermost part of Narmia Member to the *Nordophiceras*-zone which covering even the Late Spathian.

(b) The brachiopod-beds belongs to the second unit of the Kingriali-Formation. It is divided into a total of four units. These are very similar to those described from the adjacent Gulakhel area (Mensink *et al.*, 1985) and are mentioned here in order of their superposition.

Clastic Dolomite-Unit

This zone is transitional between the underlying Tredian-Formation and the higher part of the purely carbonaceous Kingriali-Formation. Rocks were deposited in a shallow marine environment, nearshore. Dolomitazation happened almost late diagenetically.

Limestone-Internal

Four facies types namely intraclastic biosparites, oncolitic biosparites, biomicrites and biosparites have been attributed to this unit. All of these developed in a shallow subtidal sea. Sometimes water agitation had been rather high so that the ground mass is predominantly a sparite. Oncolites had been washed in. The micritic facies type represents an area of calm water, oncolites were preserved *in situ*. Generally the fossil diversity is relatively high in comparison to that of the overlying sediments.

Dolosparite-Unit

This unit consists of dolosparites and oncolitic dolosparites with a more or less high amount of crinoids. The environment had been a shallow marine realm. Dolomitazation took place late giagenetically.

Dolomicrite-Unit

It builds up the uppermost part of the Kingriali-Formation. Mainly pure dolomicrites and intraclastic dolomicrites are involved. Lamination seems to be relict structures of algal mats. The environment might have been a tidal flat area.

About 19 m above the base of the Kingriali-Formation a horizon with identifiable brachiopods has been discovered. Its genus *Spiriferinoides* is distributed throughout Europe and Asia with different species appearing in the Middle and Upper Triassic. The species identified as *Sp. nasai* and *Sp. yeharai* are recorded exclusively from the Carnian. Therefore, we propose a Carnian age for this part of the Limestone-Interval of Kingriali-Formation.

In conclusion sediments of the Scythian, Anisian and Carnian had been verified faunistically in the Surghar and Salt Range. Parts of all three Triassic formations, now, had been stratigraphically determined.

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Fig. 1. Position of Gulakhel area (■) within Surghar Range, Pakistan.

Fig. 2. Locality map of Landu Nala (X) northwest of Gulakhel.

Fig. 3. The investigated part of the Triassic section of Landu Nala. Microfacies and fossil horizons are indicated.

- x position of ammonite horizon described by Kummel (1966)
- xx position of ammonoid horizon described by Guex (1978)
- xxx palynomorph horizon examined by Balme (1970)

1 Dolomicrite-Facies
2 Intraclastic Dolomicrite-Facies
3 Dolosparite-Facies
4 Oncolitic Dolosparite-Facies
5 Intraclastic Biosparite-Facies
6 Oncolitic Biosparite-Facies
7 Oncolitic Biomicrite-Facies
8 Biosparite-Facies
9 Sandy Dolosparite to dolomitic Sandstone-Facies
10 Sandy bioclastic Dolosparite-Facies
11 Sandy pelloidal Biomicrite-Facies
12 Oosparite-Facies

I Sandy Dolosparite Unit
II Limestone Interval
III Dolosparite Unit
IV Dolomicrite Unit

Fig. 4. Facies types of Kingriali-Formation, Landu Nala.

1 Oncolitic Dolosparite-Facies, Dolosparite Unit (X 2.5)
2-4 Dolosparite-Facies, Dolosparite Unit (X 2,5)
5 Intraclastic Biosparite-Facies, Limestone Interval (X 2.5)
6 Biosparite-Facies, Limestone Interval (X 2.5)

Fig. 5. Faciestypes of Kingriali- and Mianwali-Formations, Landu Nala.

1 Intraclastic Biosparite-Facies, Limestone Interval (X 2.5)
2-3 Oncolitic Biosparite-Facies, Limestone Interval (X 2.5)
4 Sandy Dolosparite-Facies, Clastic Dolomite Unit (X 2.5)
5 Oosparite-Facies, Mianwali-Formation (X 2.5)
6 Sandy pelloidal Biomicrite-Facies, Mianwali-Formation (X 2.5)

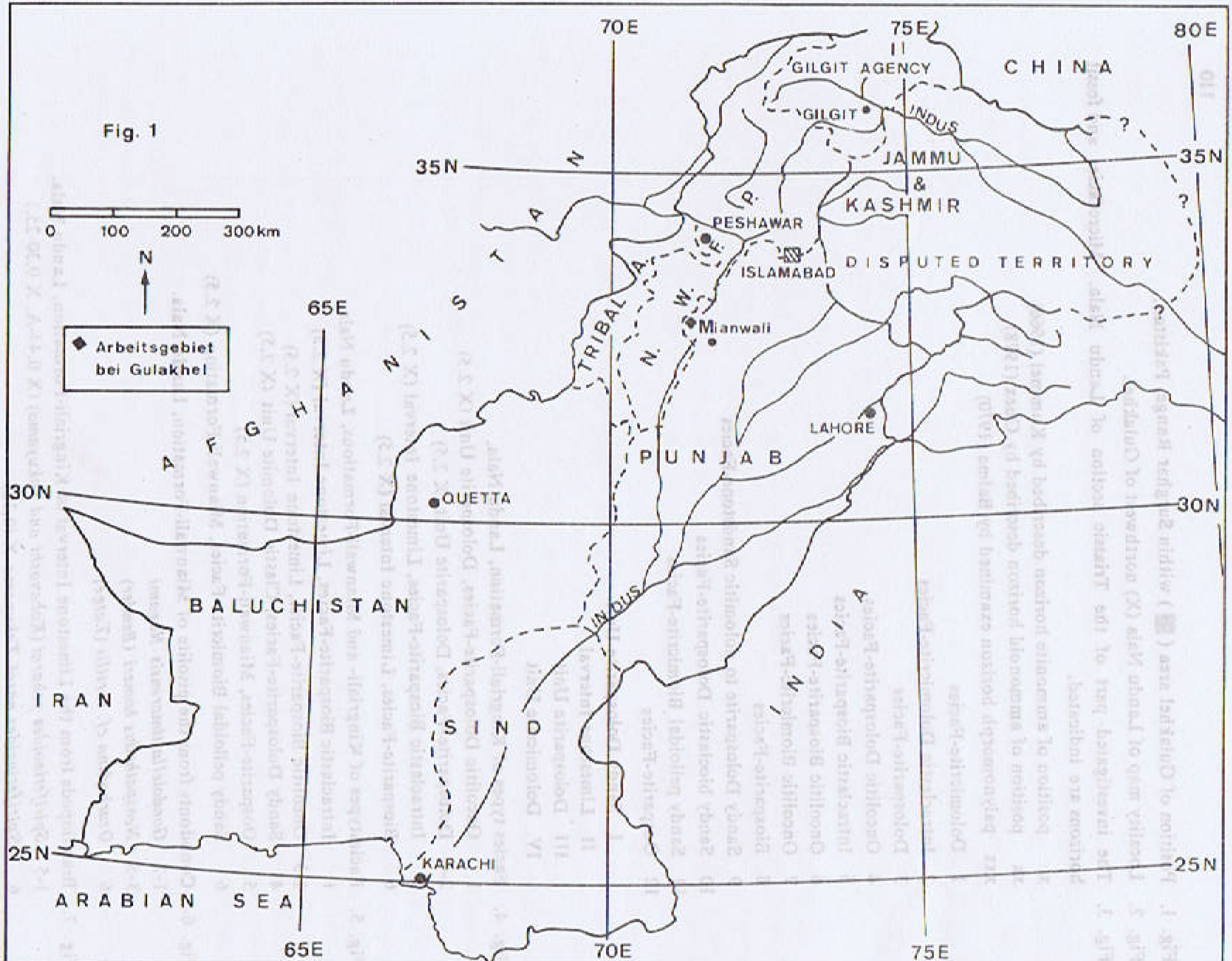
Fig. 6. Conodonts from the pisolite of Mianwali-Formation, Landu Nala.

1-2 *Gondolella timorensis Nogami*
3-5 *Neospathodus homeri (Bender)*
6 *Ozarkodina cf. tortilis (Tatge)*

Fig. 7. Brachiopods from the Limestone Interval of Kingriali-Formation, Landu Nala.

1-5 *Spiriferinoides yeharai (Kobayashi and Tokuyama)* (X 0,44-A. X 0.30-25.)
6 *Spiriferinoides nasai Tokuyama* X (0,32)

Fig. 1



18424-18-3/11.8.87 Ma.


3520
Shogai
3545
2882
2361
2000
3000
2500
1500
1250
1000
Lundu
Punnu
1299
1329
Mastuwala
Gulakhel
Banda Karak
Malla Khel
Zarifwala
Dag Banda
Banda Karki
Banda Girdhari

Fig. 2

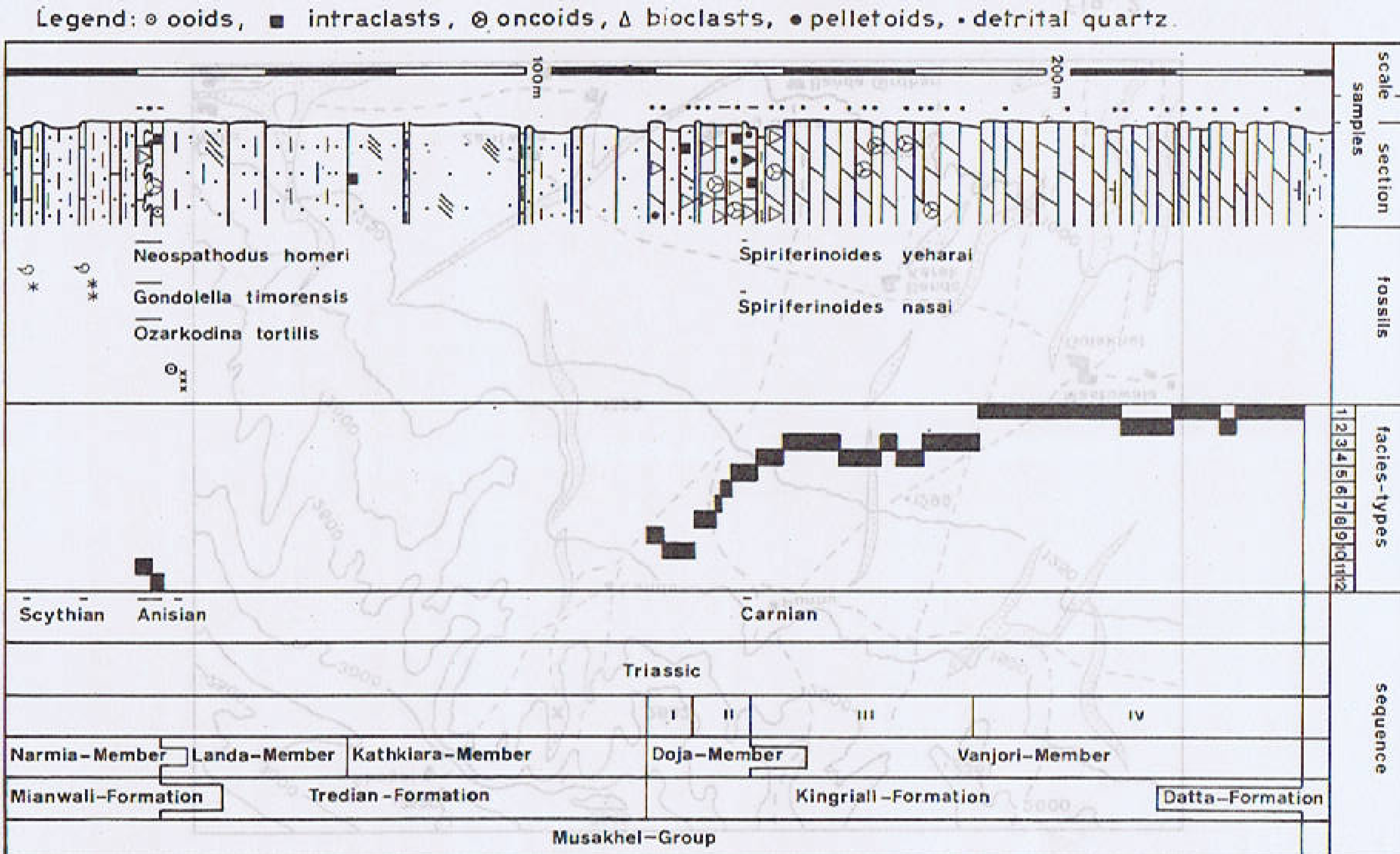


Fig. 3

18425-18-3/14.8.87 Ma.

Fig. 4

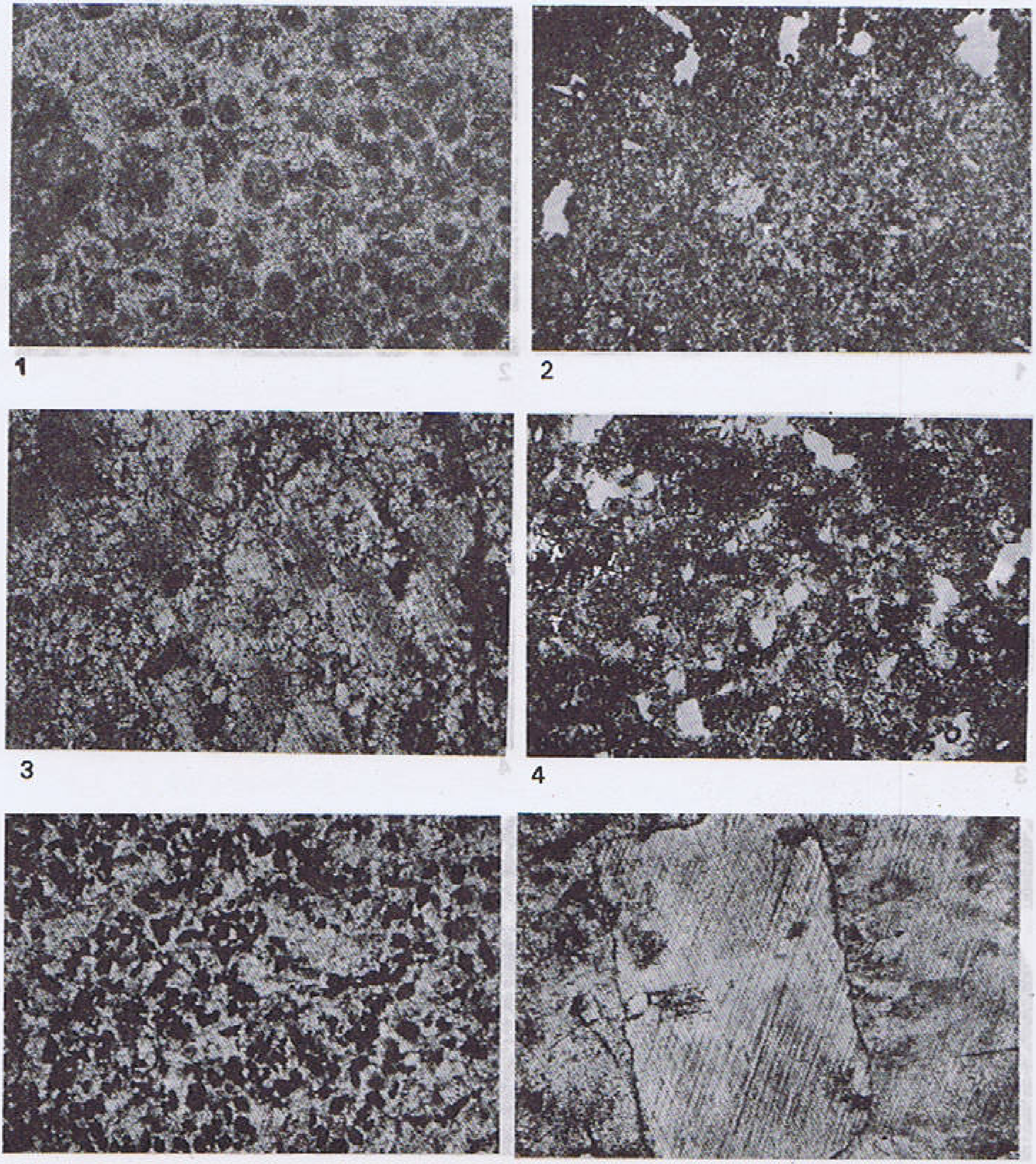


Fig. 5

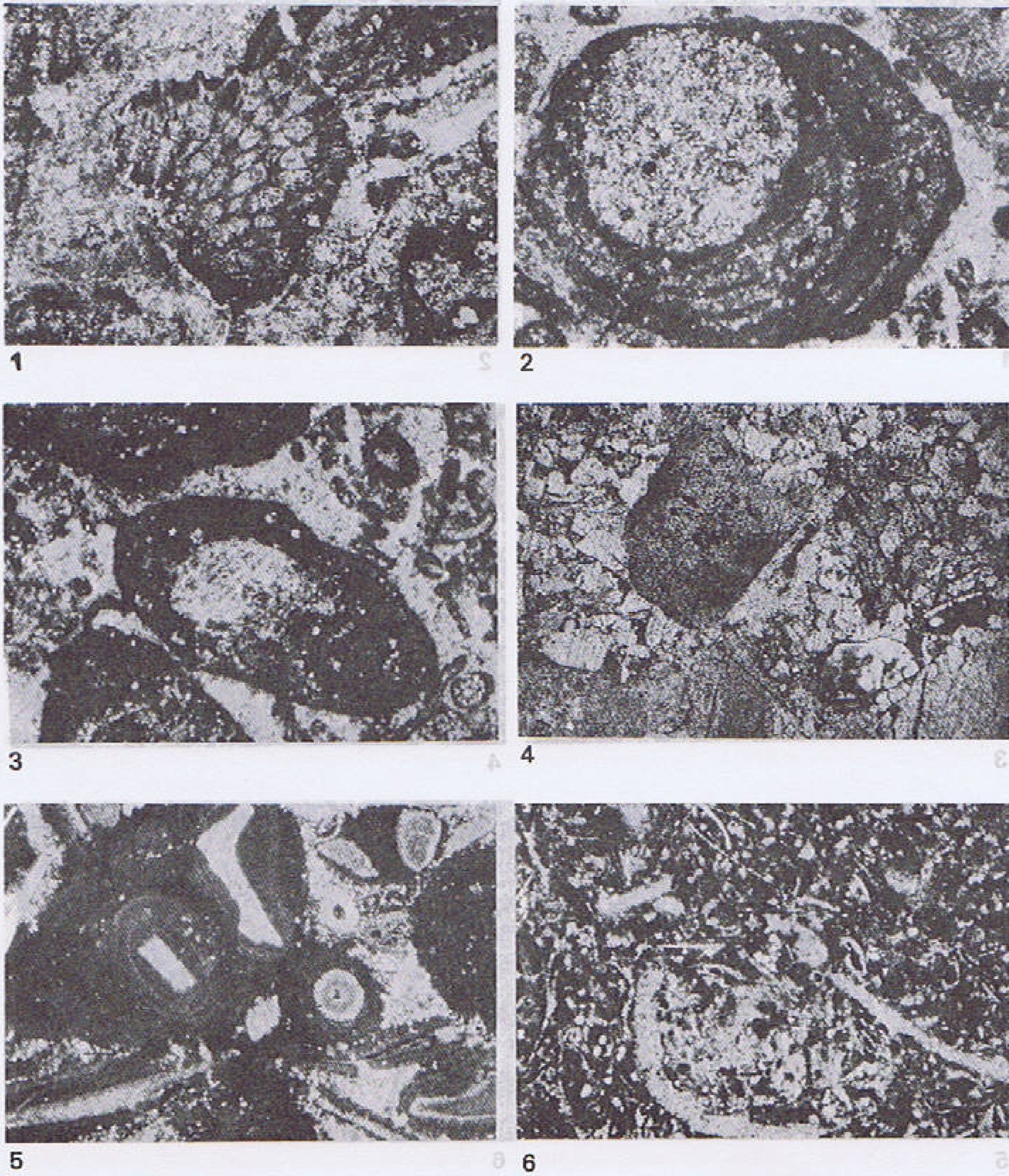


Fig. 6

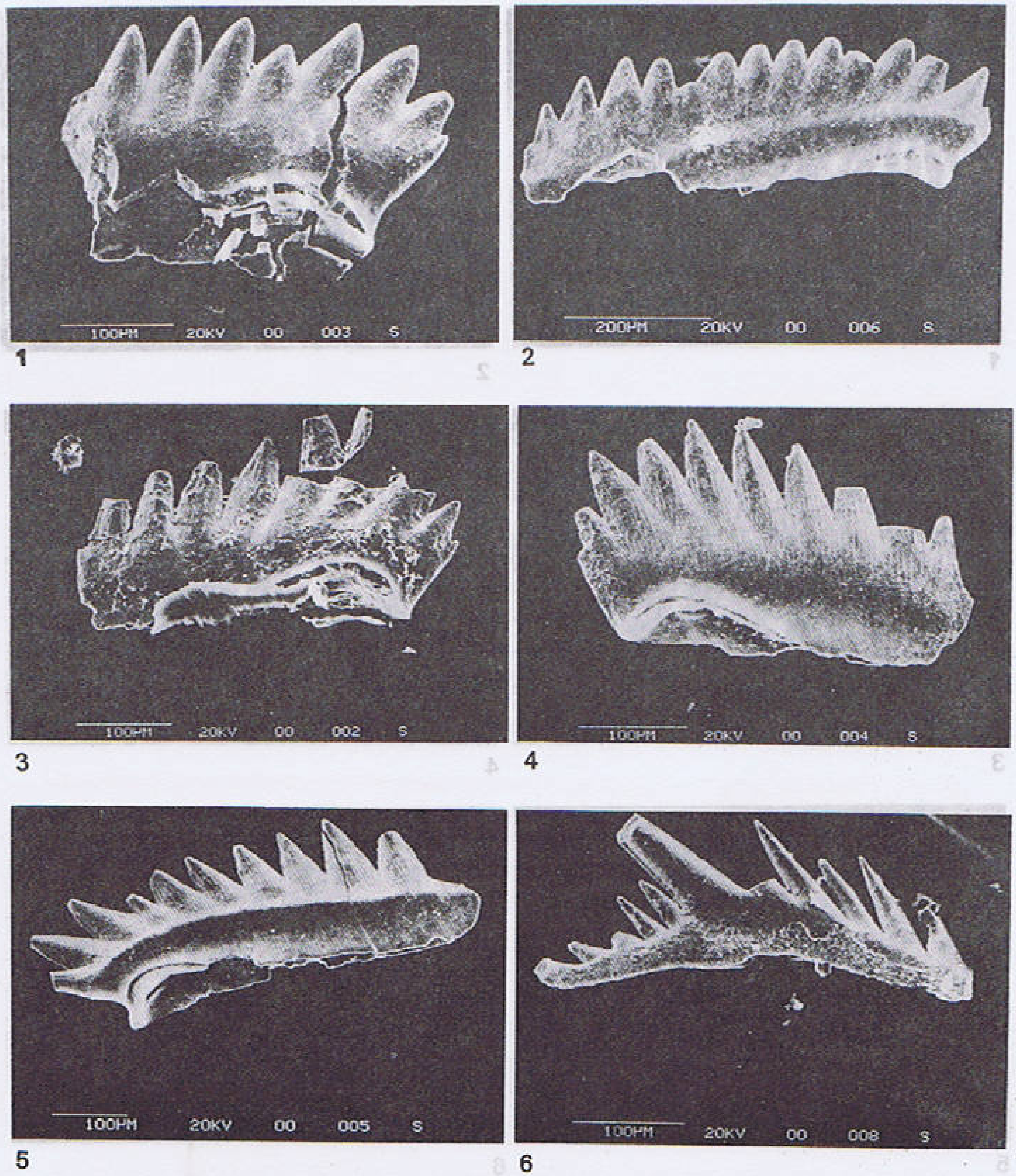

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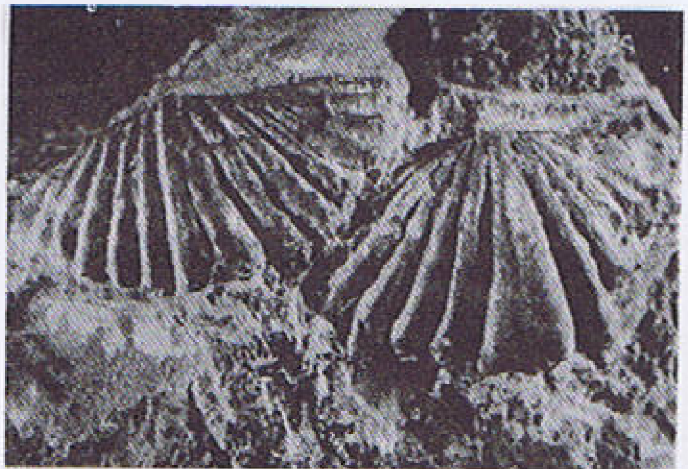
Fig. 7



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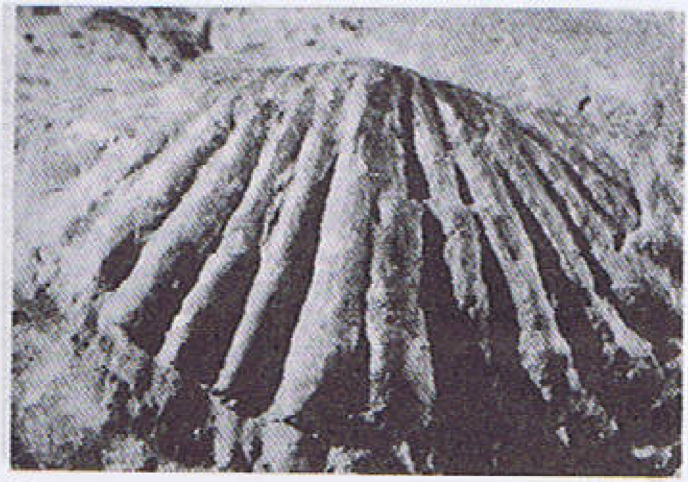

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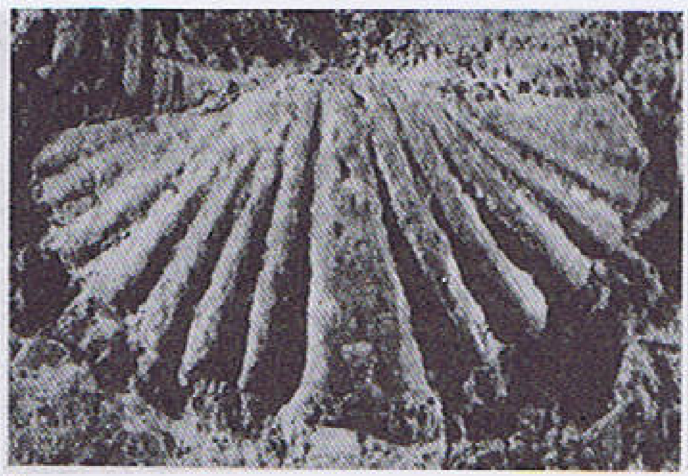

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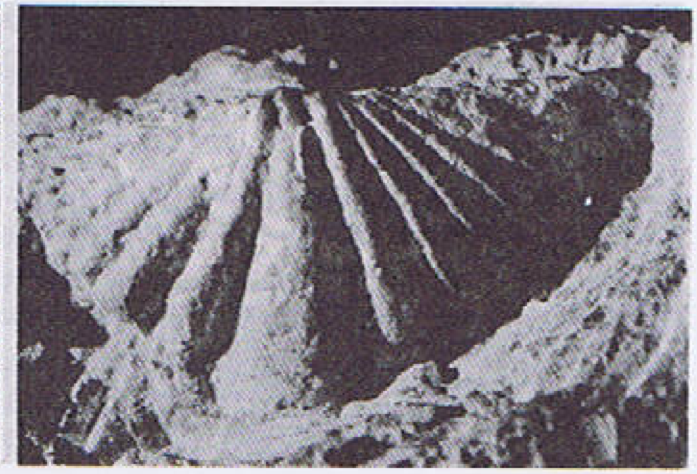

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COMPARISON OF PARADA LIMESTONE AND BONANSA FORMATION IN CENTRAL PYRENEES AS CONCRETE AGGREGATE NEAR PONT-DE-SUERT VILLAGE, PROVINCE LERIDA, SPAIN

BY

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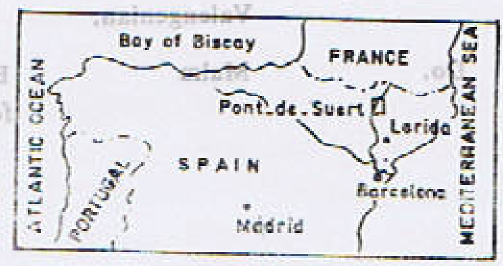
Abstract : *Comparative studies have been made on Bonansa Formation of Jurassic age and Parada Limestone of Cretaceous age to establish a quarry for concrete aggregate. In some North-east parts of Spain traditional sources of aggregate for use in concrete will become increasingly unable to keep up with demand. Physical properties and Petrographical studies have been made with additional geo-technical properties on cores and crushed samples to evaluate the behaviour of rocks which will be very useful in quarry designing in future in pont-de-suert area.*

INTRODUCTION

Pont-de-Suert is situated in Ribogozana Valley in North-east of Spain which is quite close to southern boundary of France. The highest mountains are found in this area. Barcelona city is about 200 km down to south and a lot of construction material is supplied from here for houses and multistoreyed buildings. Also few hydroelectric projects are under investigation and in construction phases in the vicinity of the area.

Generally very adequate quality control is exercised in European Countries in the selection of concrete aggregate for vital projects, but here the authority used different types of limestones, as aggregate in ESTANY GENTO DAM (Repumping Storage Project) without investigating and considering the geotechnical properties of the aggregates. In 1985, I.T.C. Delft and Minning Institute of Technical University Delft Netherlands assigned the jobs to their students in Spain to identify the various sites for concrete aggregates. Quarry area for limestone is lying on right side of the river Ribogozana. Access is through metalled road. Proposed site has enough place to install the crushers and to stack the quarry products.

LOCATION MAP



CONCRETE AGGREGATE

The American Society for testing materials defines the term "Aggregate" as in the case of material of construction, designates inert material which when bound together into a conglomerated mass by a matrix forms concrete. It is a man made composite, the major constituent of which is natural aggregate such as gravel and sand or crushed rock. About 70% of concrete consists of aggregate, therefore, aggregate's properties have significant influence on concrete after setting. This is very first investigations for concrete aggregate in the area. Also terrace deposits, alluvial fans and colluvial deposits are found along the valley and streams. These deposits can also be investigated in detail. In this paper only a comparative study of two limestones namely Bonansa Formation and Parada Limestone belonging to Jurassic and Cretaceous ages is presented.

TABLE 1

Geological Formations of Jurassic and Lower Cretaceous in Project Area

PERIOD	Time Strati-graghic Unit EPOCH	Litho-Strati-graphic Unit	General Lithology	Thickness variations, in project in maters (m)
CRETACEOUS	Albian	Lrusa Marl	Mainly marls and nodular marly lime-stone.	20—50
Do.	Aptain Barre-mian Hauterivian Valengenian.	Parada Limestone.	Massive, mic-ritic fossilife-rous limestone.	30—100
Do.	Malm	Bonansa formation	(Upper member) Massive dolomitic limestone gradually changing to pure limestone.	30—120
JURASSIC	Dogger		(Middle member) Very fossiliferous dark shales/marls.	50—100
Do.	Liassic		(Lower member) Finely stratified marl (dolomitic) & limestone/dolomite.	60—80

In Bonansa formations, lower and middle members are not suitable for concrete aggregate and totally rejected due to presence of shales and dominating dolomite. Carbonate rock aggregates, usually, dolomitic in composition have been found to be reactive in concrete structures in Canada (Ontario) and U.S.A. This reaction causes the undesirable expansion and as a result of this reaction, Brucite is formed.

The presence of Dolomite was therefore sufficient enough to think about the discredibility of the aggregate. That is why only the upper portion of Bonansa Formation is selected for study. In Parada Limestone, a major portion consists of fine grained, massive and micritic fossiliferous limestone.

SAMPLING TECHNIQUES

The author tried to collect samples from an area which is not dolomitized. Colour of dolomitic limestone is relatively dark grey and shows blackish appearance in general. Then upper member of Bonansa Formation and Parada limestone are present. Parada limestone does not show any sign of dolomitization from where samples have been taken. Reasonable quantity of samples from both limestones have been collected, whenever change in physical appearance occurred in the rock unit, in the site for petrographic analysis.

The laboratory studies have been performed on both types of limestones from different locations all along the road side to compare their properties. 40 mm x 80 mm cores have been prepared in the laboratory from big sized samples. The samples were reasonably representative for the whole quarry.

PHYSICAL PROPERTIES OF AGGREGATES

Properties have been observed after crushing the rock in the form of aggregates.

TABLE 2

Physical Properties of Aggregate after crushing

Type	Colour	Texture	Lamination	Coating	Shape of aggregate	Cleaning by washing
Parada Limestone.	Grey to light grey.	Fine grained.	Visible in some some pieces.	No	Sub-angular Sub-rounded	No
Bonansa Formation	Grey	Fined to medium grained.	No	No	Angular Sub-rounded	Required (some time)
	Dark grey	Oolitic texture			10% shows flaky aggregates	

CEMENT AGGREGATE REACTION

Hydration of cement takes place and alkalies are released during the setting and hardening of concrete. All silicates and silica minerals if any are attacked by these alkalies. The results become very serious if minerals like opal, chalcedony, chert glass or tridymite are present in the aggregate. Five thin sections of each limestone i.e. BONANSA FORMATION AND PARADA LIMESTONE from different locations were examined petrographically to study the mineral variations.

In Bonansa Formation, the texture is fine to coarse grained. Oolites are also observed in some thin sections. Mostly more than 90% is carbonate. Crystalline calcite is noted in the veinlets with some quartz (less than 5%) and some authigenic feldspar decaying to clay. No reactive mineral is observed.

Parada Limestone exhibits very fine grained texture. The limestone consists of carbonate mostly showing homogeneity in all thin sections. Calcite is not well-crystallized. Less veinlets and fractures as compared to Bonansa Formation are present. Iron oxides and clay contents are about 10%. No reactive mineral is present.

RESULTS OF LABORTORY TESTS

The laboratory tests for determination of engineering properties of rocks have been divided into two categories.

(a) Tests carried out on core samples.
(b) Tests carried out on crushed samples.

A. Tests carried out on core samples (See table 3)

All the cores were obtained from the big samples of Bonansa Formation and Parada Limestone, by coring in labaratory which, were brought from the field. Results have been based on 8 cores, 4 of Bonansa formation and 4 of Parada Limestone which are denoted as BF1, and PL1 etc. Size of core was 40 mm x 80 mm. The ends were fully polished and levelled.

B. Tests carried out on crushed samples

To find out the mechanical properties of crushed stones and the behaviour of rocks while crushing, jaw type of crusher of mining department of Technical University of Delft was used. It was a small unit and only accepts the broken pieces of rock of different sizes ranging from 8 cm × 10 cm to 10 cm × 12 cm.

TABLE 3

A. Tests on Core Samples

No. of Test	Type of rock	Porosity in %	Specific gravity	Bulk Density $Kg\ m^{-3}$	Dry Density $Kg\ m^{-3}$	U.G.S. KNm^{-2}	Ultrasonic velocity $m\ sec^{-1}$
PL1	Parada	0.4	2.68	2673	2669	114	8121
PL2	Limestone	0.5	2.67	2663	2658	132	8400
PL3	(Cretaceous)	0.4	2.71	2664	2660	88	7403
PL4		0.3	2.68	3648	2652	85	X
BF1	Bonansa	2.1	2.69	2732	2711	116	5576
BF2	Formation	2.0	2.68	2729	2709	64	5804
BF3	(Jurassic)	1.9	2.58	2738	2719	88	5595
BF4		1.98	2 69	2735	2710	90	5910

Note :—These tests have been carried out on core samples 4 cm × 8 cm. The sides of cores were fully levelled and polished to minimise the side effects.

About 2800 g rock pieces of each limestone separately belonging to Bonansa formation and Parada limestone are put in the crusher. The product produced in one shot was mechanically analyzed to see the crushing behaviour of the rocks. About 65% of coarse aggregate of Bonansa Formation (jurassic age) and 70% coarse aggregate of Parada Limestone (Cretaceous age) respectively are retained on sieve 4.75 mm.

TABLE 4

Sieve analysis of Bonansa formation and Parada limestone and their retaining on 4.75 mm.

Sieve m.m.	Bonansa Formation		Parada Limestone	
	Wt. Retained (g)	% Retained	Wt. Retained (g)	% Retaindd
25.00	47.1	1.6	38.1	1.3
19.00	74.1	2.6	68.5	2.4
12.50	583.7	20.8	637.1	22.7
9.50	488.3	17.4	531.2	19.0
4.75	645.1	23.0	687.3	24.6
Total Retained as Coarse aggregate.	1838.3	65.4	1942.2	70.0

Total Wt. of samples 2800 g for each limestone.

Also Los-angeles abrassion test and slake durability tests are performed on the crushed agregates of both type of limestones.

TABLE 5

Results of Abrassion and Slake durability tests

Crushed Rock	Abrassion %	Slake durability Index after 3 cycle %
Parada Limestone	20	99.2
Bonansa Formation	23	99.4

CONCLUSION

As we see from the physical, chemical and laboratory tests of the Bonansa Formation and Parada Limestone, both the limestones as aggregate, are quite good. Parada Limestone better than Bonansa Formation because it does not have any indication of dolomite in it. Also less washing will be required in Parada Limestone as it is less fractured less filled by clays as indicated by ultrasonic velocity test in Table 3. Generally in a quarry we are mainly interested in the production of the required size material, Parada Limestone will provide more coarse aggregate than the other limestone. Also other properties like abrassion, slake durability, unconfined compressive strength are relatively better and porosity is relatively less in Parada limestone as compared to Bonansa formation's limestone. As both the limestones are in abundance, so we will select the best one that is Parada Limestone.

ACKNOWLEDGEMENT

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A NOTE ON LAKHRA COAL

BY

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INTRODUCTION

In 1885 Baluch Namdar, while digging a well for water at Lakhra, reported the presence of a seam of coal about 2.43 m (8 ft.) thick. However, actual surveying was performed in 1870. The Geological Survey of Pakistan (GSP) and the United State Geological Survey (USGS) investigated the area in 1960. Further investigations were carried out by West Pakistan Industrial Development Corporation (WPIDC), LURGI, a Polish consultant, Japan international Cooperation Agency (JICA) and Stone and Webster Engineering Corporation (SWEC). The recent work was commissioned by the United State Agency for international development and Pakistan Water and Power Development Authority, (USAID/WAPDA) conducted by J T. Bayd Company concerning mining and Gilbert Common Wealth international Inc. (GCII) Concerning Power Plant design consideration.

LOCATION

The Lakhra Coal field lies at about 48 km to the north of Metting (25° 07, 30′ N : 68° 08′E) and at about 16 km to the west of Khanot railway station on the Kotri-Dadu section of the Pakistan Railways.

GENERAL GEOLOGY

Lakhra coal is lignite to sub-interminous and occurs in the Ranikot formation of paleocene age. The beds have been gently folded in to an anticline which is 64 km long for north to south and 16 km wide from east to west. The beds on the flanks dip at less than 2°. The Anticline is dissected by a member of north-trending normal folds. The coal is dull black in colour.

STRATIGRAPHY

Lakhra coal deposit, found in the Bara formation of Paleocene age. The origin of formation is fluviatile where accumulation of vegetation was favoured to produce coal. This is overlaid by Lakhra formation (Paleocene) of Esturine origin. The Hyderabad arch preceded this deposition and an unconformity was raised on the top of the formation. After this stage, coastal swamps were developed on the arch flanks by the Eocene Transgression. Here swamp vegetation frew and formed the source of coal in the Sonhari member (Hunting Survey Corporation).

The name Bara formation was given by Ahmad and Ghani for the "Lower Ranikot (Sandstone)" of Vrodenburg (1906) and "Lower Ranikot" of later workers. Bara formation consist of mostly sandstone with lesser shale and minor volcanic debris. This sandstone is multi-coloured, soft, crumbly and fine to coarse grained. It is calcarcous, ferruginous, cross-stratified and ripple-marked. These massive looking beds ranged in thickness from a few centimetre to 3 m are common. Dark shades of colour are found in the inter-bedded shale which are similar to those of sandstone. This is soft, earthy and gypsiferous. Shale and sandstone both are sometimes carbonaceous but at some places the shale is highly carbonaceous and possesses coal seams locally. Volcanic debris varying from greenish grey to black are present, ferruginous nodules are also frequently met with.

Bara formation is overlain conformably by Khadro formation and underlain by the Lakhra formation. When the overlying Lakhra formation is not present (Ranikot area). This is unconformably overlain by the Laki formation. We take Bara formation as Middle Paleocene. Bara formation correlated with the Hangu formation of Kohat-Potwar and the lower part of the Rakhshani formation in Baluchistan Basin. It is stratigraphically equivalent to lower part of the Dungan formation situated in The Indus Basin.

RESERVES

The total available reserves in Lakhra are 240 million tonnes, out of which PMDC is holding 230 million tonnes as per details given below :

Measured reserves = 60.00 Million Tonnes
Indicated reserves = 170.00 " "

Historical production (Metric Ton)

1978-79	1979-80	1980-81	1981-82	1982-83
195159	153909	236089	287620	331885

Exploration Summary

Source	No. of Dril Hole	Aggregate Meterage Drilled	Date
Geological Survey of Pakistan	3	343	mid-1960 Sep
PMDC	19	1,845	Dec. 1975 June 1976
JICA	50	5,203	June 1979 Nov. 1976
USAID Interim	10	1,111	Oct. 1984 Dec. 1984
USAID/Boyp	55	5,877	Jan. 1985 May 1985
	137	14,379	

Quality of Coal

Average chemical composition of Lakhra coal as provided by PMDC is given as under.

Moisture		25.0%
Volatile matter	...	28.8%
Ash	...	19.3%
Fixed Carbon	...	26.9%
Sulpher	...	5.95%
Calorific Value	...	6300—10550 BTU/LB

CHEMICAL COMPOSITION

On, a moisture free basis, coal consists of an organic fraction and an inorganic (or mineral) fraction and the proper characterization of coal requires the analysis of both fractions. The ultimate analysis consist of the determination of the carbon, hydrogen, oxygen, and sulpher and in generally thought of as referring to the organic fraction, although all of the elements listed above also occur in minerals found in coal.

Ash Test

Coal ash is the inorganic residue remaining after the combustion of the organic matter and should not be confused with mineral matter. Ash test of 17 samples from 3 coal mines of Lakhra coal field was carried out. The amount of ash in different samples of different seam varied between 9.8766—37.381. Data of ash analysis is given in table No. 1.

Sulpher Test

Sulpher in coal exists primary in two forms-Pyritic and Organic ; a third form, sulphate sulpher, occurs in minor concentrations. In some coal fields in Pakistan (including the Lakhra coal field) weathering of the coal has increased the amount of sulphate sulpher even at overburden depth greater than 100 metres. Knowledge of the forms-of-sulpher is particularly important for predicting the efficiency of coal benefication plants. Organic sulpher, which is chemically combined with organic matter, cannot be removed by the Physical methods used in most benefication plants.

The amount of total sulpher, Pyritic sulpher, sulphate sulpher and organic sulpher in all the 17 coal sample collected from the 3 mines of Lakhra coalfield is given in the Table 2.

X-RAY DIFFRACTION ANALYSIS

X-Ray diffraction of inorganic mineral separted from coal by heavy liquid separation technique was taken. Minerals identified by X-Ray diffraction analysis are given below :

(1) Pyrite
(2) Marcasite
(3) Gypsum
(4) Kaolinite
(5) Halite
(6) Calcite

TABLE 1

Ash on Lakhra Coal
Weight Percentage of Ash after buring for 8 hours at 800°C

1.	KH/B 0-14″	9.877
2.	KH/B 14-28″	12.209, 11.924
3.	KH/B 28-42″	14.128
4.	IN-2-B/1 0-3′	25.456
5.	IN-2-B/2 3-6′	37.381
6.	IN-2-B/3 6-8½′	21.315
7.	IN-2-B/4 0-8½′	23.445
8.	PMDC 0-2′	22.494
9.	PMDC 2-4′	25.395
10.	PMDC 4-6′	27.242
11.	PMDC-6-8½′	29.745
12.	PMDC-0-8½′	26.661

TABLE 2

Total Sulpher

No.	Name	Sample No.	Total Sulpher
1	Habib Mine	A-1 0-14″	2.2025
2		A-2 14″-28″	3.3759
3		A-3 28″-42″	2.4292
4	PMDC Mine	PMDC-6-1 0-2′	3.2082
5		PMDC-6-2 2-4′	2.9087
6		PMDC-6-3 4-6′	7.3412 7.6545
7		PMDC-6-4 6-8′	6.0720
8		PMDC-6-5 0-8′	3.5284
9	Indus Mine A-Face	A-1 0-2′	4.1632
10		A-2 2-4′	2.4168
11		A-3 4-6′	3.1615
12		A-4 6-8½′	2.4663 2.6174 2.3371
13		A-5 0-8½′	4.1755
14	B-Face	B-1	2.3795
15		B-2	3.2357
16		B-3	3.5009
17		B-4	4.3500

TABLE 2.1
Habib Mine

No.	Sample No.	Total Sulpher	Sulfate Sulpher	Pyritic Sulpher	Organic Sulpher
1	A/1 0-14′	2.2025	0.1394	0.6003	1.4628
2	A/2 14-28′	3.3759	0.1744	0.8433	2.3582
3	A/3 28-42′	2.4292	0.1888	0.4886	1.7518

TABLE 2.2
Indus Mine No. 2

No.	Sample No.	Total Sulpher	Sulfate Sulpher	Pyritic Sulpher	Organic Sulpher
1	A/1 0.2′	4.1632	0.2836	0.9913	2.8883
2	A/2 2-4′	2.4168	0.2424	0.9773	1.2197
3	A/3 4-6′	3.1615	0.2664	0.9773	1.9178
4	A/4 6-8½′	{ 2.4663 2.6174, 2.3371	0.2472	1.0471	1.1720
5	A/5 0-8½′	4.1755	0.5590	1.1868	2.4297

TABLE 2.3
Indus Mine No. 2-B. Face

No.	Sample No.	Total Sulpher	Sulphate Sulpher	Pyritic Sulpher	Organic Sulpher
1	IN-2-B/1 0-3′	2.3797	0.2795	0.7751	1.3251
2	IN-2-B/2 3-6′	3.2357	0.1778	1.1992	1.8587
3	IN-2-B/3 6-8½′	3.5009	0.3893	1.0822	2.0294
4	IN-2-B/4 0-8½′	4.3500	0.4237	0.9798	1.4035

TABLE 2.4
PMDC—MINE No. 6

No.	Sample No.	Total Sulpher	Sulphate Sulpher	Pyritic Sulpher	Organic Sulpher
1	PMDC-6/1 0-2′	3.2082	0.2389	0.9213	2.0408
2	PMDC-6/2 2-4′	2.9087	0.4903	1.1261	1.2923
3	PMDC-6/3 4-6′	7.6545	1.3769	0.9213	5.3563
4	PMDC-6/4 6-8½′	6.0720	0.3859	1.4332	4.2529
5	PMDC-6/5 0-8½′	3.5284	0.5700	1.2723	1.6861

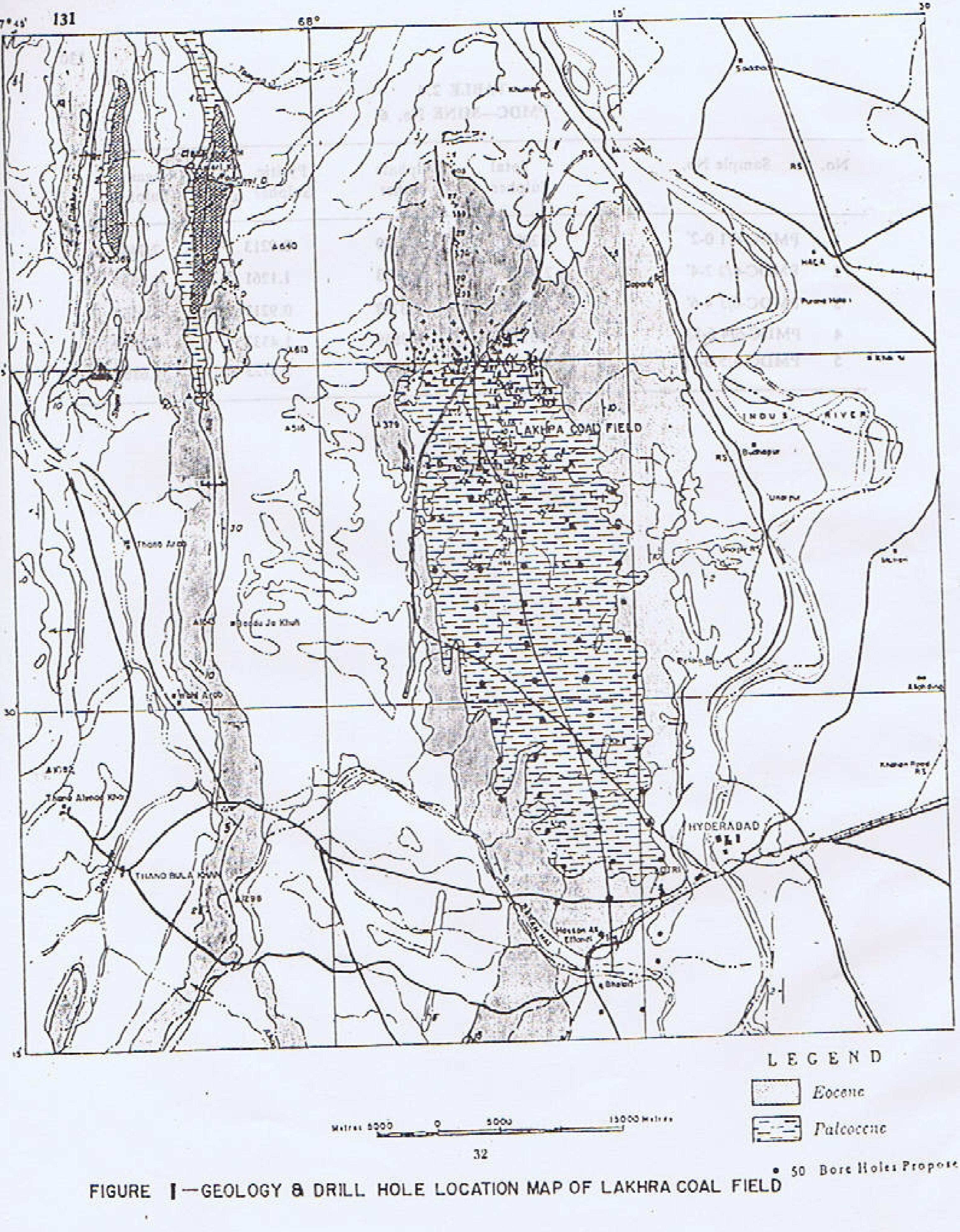

FIGURE 1—GEOLOGY & DRILL HOLE LOCATION MAP OF LAKHRA COAL FIELD

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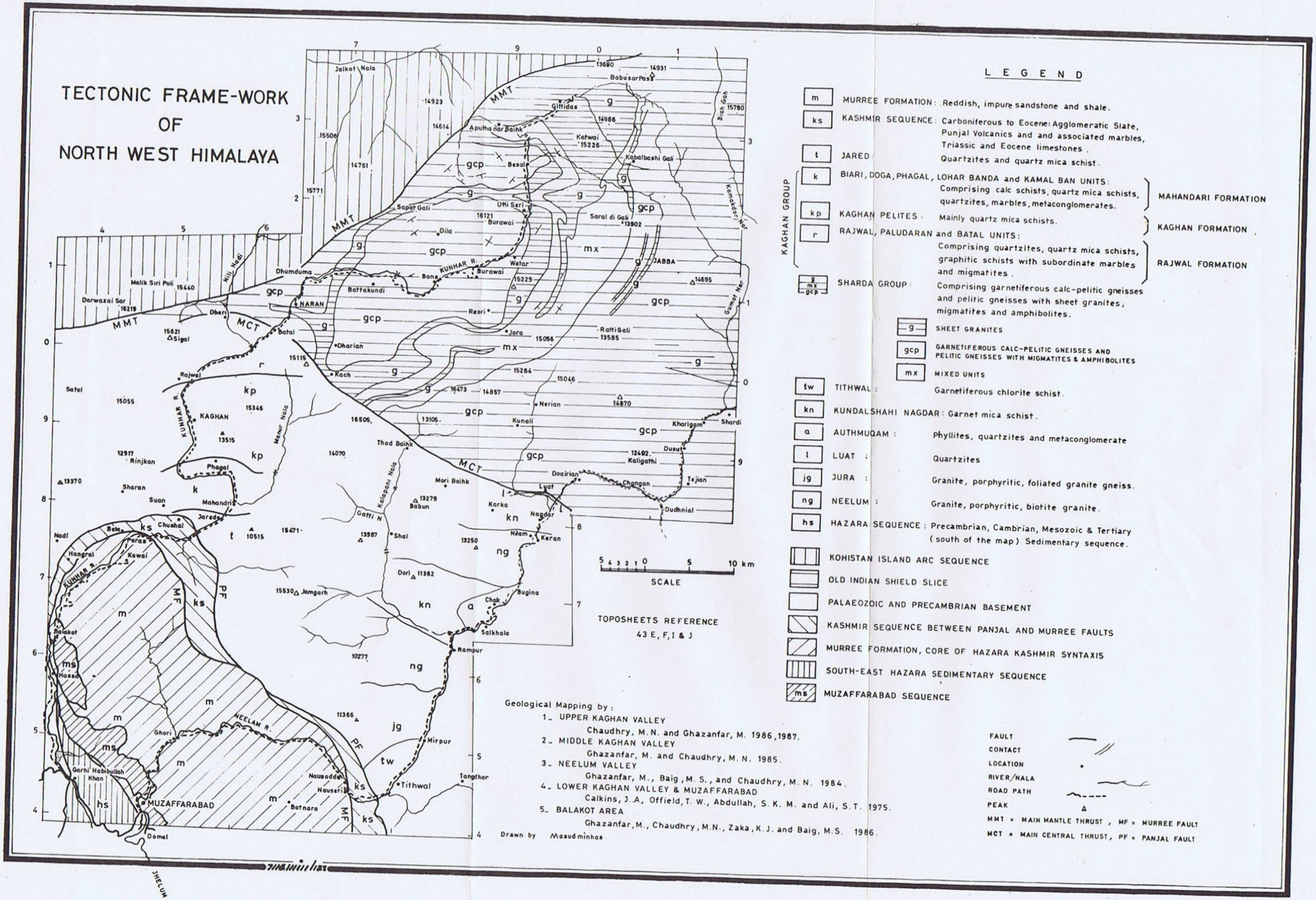
TECTONIC FRAME-WORK OF NORTH WEST HIMALAYA
LEGEND
m MURREE FORMATION: Reddish, impure sandstone and shale.
ks KASHMIR SEQUENCE: Carboniferous to Eocene: Agglomeratic Slate, Punjal Volcanics and and associated marbles, Triassic and Eocene limestones.
t JARED Quartzites and quartz mica schist.
KAGHAN GROUP
k BIARI, DOGA, PHAGAL, LOHAR BANDA and KAMAL BAN UNITS: Comprising calc schists, quartz mica schists, quartzites, marbles, metaconglomerates. MAHANDARI FORMATION
kp KAGHAN PELITES: Mainly quartz mica schists. KAGHAN FORMATION
r RAJWAL, PALUDARAN and BATAL UNITS: Comprising quartzites, quartz mica schists, graphitic schists with subordinate marbles and migmatites. RAJWAL FORMATION
SHARDA GROUP: Comprising garnetiferous calc-pelitic gneisses and pelitic gneisses with sheet granites, migmatites and amphibolites.
g SHEET GRANITES
gcp GARNETIFEROUS CALC-PELITIC GNEISSES AND PELITIC GNEISSES WITH MIGMATITES & AMPHIBOLITES
mx MIXED UNITS
tw TITHWAL: Garnetiferous chlorite schist.
kn KUNDALSHAHI NAGDAR: Garnet mica schist.
a AUTHMUQAM: Phyllites, quartzites and metaconglomerate
l LUAT: Quartzites
jg JURA: Granite, porphyritic, foliated granite gneiss.
ng NEELUM: Granite, porphyritic, biotite granite.
hs HAZARA SEQUENCE: Precambrian, Cambrian, Mesozoic & Tertiary (south of the map) Sedimentary sequence.
KOHISTAN ISLAND ARC SEQUENCE
OLD INDIAN SHIELD SLICE
PALAEOZOIC AND PRECAMBRIAN BASEMENT
KASHMIR SEQUENCE BETWEEN PANJAL AND MURREE FAULTS
MURREE FORMATION, CORE OF HAZARA KASHMIR SYNTAXIS
SOUTH-EAST HAZARA SEDIMENTARY SEQUENCE
ms MUZAFFARABAD SEQUENCE
FAULT
CONTACT
LOCATION
RIVER/NALA
ROAD PATH
PEAK
MMT = MAIN MANTLE THRUST, MF = MURREE FAULT
MCT = MAIN CENTRAL THRUST, PF = PANJAL FAULT
SCALE
5 4 3 2 1 0 5 10 km
TOPOSHEETS REFERENCE
43 E, F, I & J
Geological Mapping by:
1. UPPER KAGHAN VALLEY
Chaudhry, M.N. and Ghazanfar, M. 1986, 1987.
2. MIDDLE KAGHAN VALLEY
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5. BALAKOT AREA
Ghazanfar, M., Chaudhry, M.N., Zaka, K.J. and Baig, M.S. 1986.
Drawn by Masud minhas
MMT
MCT
MF
PF
KUNHAR R.
NEELAM R.
JHELUM R.
Babusar Pass
Naran
Batal
Kach
Kaghan
Rajwal
Phagal
Mahandri
Jared
Paras
Balakot
Garhi Habibullah Khan
MUZAFFARABAD
Domel
Sharda
Kharigam
Dudhnial
Luat
Nagdar
Keran
Salkhala
Rampur
Mirpur
Tithwal
Tangdhar
Nauseri
Batal
Dhumduma
Battakundi
Burawai
Besal
Jora
Reori
Sapat Gali
Dila
Jabba