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CONTENTS

GEOCHEMISTRY OF GARNET GRAINS FROM MURREE AND SIWALIK FORMATIONS, RAWALPINDI AND JHELUM DISTRICTS, PUNJAB, PAKISTAN

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Abstract : *More than 300 garnet grains of Murree and Siwalik Formations of Miocene to Pleistocene age from Rawalpindi and Jhelum districts were analysed under Electron Probe Micro Analyser (EPMA) and data plotted on Mn-Fe-Mg and Ca-(Fe+Mn)-Mg triangles. The distribution patterns of garnets, based on Mn-Fe-Mg and Ca-(Fe+Mn)-Mg molecular percentage ratios, in both the triangles showed a marked difference between Murree and Siwalik Formations. Some difference in the chemical trends of the garnet grains from the Lower, Middle and Upper Siwalik Formations can be observed in the Mn-Fe-Mg triangles, but no such difference can be noted in the second type of triangles. It is evident that most of the garnets of Murree Formation have been distributed in the high Fe, high Mn zone as compared with that of Middle and Upper Siwaliks, which have taken positions in the high Fe and Mg areas. Whereas, the data of Lower Siwaliks are distributed almost equally in the zone of high Fe and low Mg and low Mn zone, but the trend toward Mn is a little higher. However, some scattered data are also present in all the Siwalik horizons. The evidences suggest that the garnets of Murree Formation have been derived from low grade schists, that of Lower Siwaliks from medium and high grade rocks and that of Middle and Upper Siwaliks from high grade gneisses and amphibolites.*

INTRODUCTION

The paper is based on the first geochemical study of the detrital garnets of Murree and Siwalik formations. Field data was collected by the author 1, from the Rawalpindi and Jhelum districts.

Nearly 350 garnet grains of Murree and Siwalik sandstones were analyzed under the electron probe micro analyser (EPMA), at the Department of Geology & Mineralogy, Kyoto University, and Department of Earth Sciences, Kyoto Education University. The former consists of an energy-dispersive analytical system (Kevex Corporation EDS) and Hitachi S-550 scanning electron microscope (SEM), and the latter, EDAX analytical system. The analytical procedure followed was that of Mori-DYO, 1984.

This paper is the first geochemical study of its kind on the sandstones of Murree and Siwaliks, from Potwar Plateau, Pakistan. Wynne (1877) mapped the Potwar region on

1 : 50,900 scale. Pilgrim (1910) classified the Miocene-Pliocene sediments of Potwar region. Anderson (1927) grouped these deposits in the Nimadric system and classified them. Wadia (1928) described geology of Poonch State and adjacent areas of Punjab and published a map on 1 : 250,000 scale. Lawis (1937) proposed a classification for the Siwalik Group, following Ashley and others (1937) Gee (1945) mapped Siwaliks of Salt Range and Trans-Indus Range. Gill (1951) described the stratigraphy of Siwalik series in the Northern Potwar. Martin (1962) discussed the tectonic style of Potwar. Stratigraphic Committee of Pakistan (1967) approved geographic names of rocks of the Kohat-Potwar Province and Indus Basin of Pakistan. Among recent workers, Akhtar and Bajwa (1975) mapped Jatli area (43 G/4) of Jhelum district on 1 : 50,000 scale. Akhtar and Bajwa (1976) mapped Riwat area (43 G/3) of Rawalpindi district on 1 : 50,000 scale. Naeem and Bajwa (1978) maped Papin area (43 C/15) on 1 : 50,000 scale. Waheeduddin, Akhtar and others (1974) mapped Sohawa area (43 G/8) on the 1 : 50,000 scale. Ahhtar and Bajwa (1976) mapped Dina area (43 G/12) on 1 : 50,000 scale. All information was utilized during the present study.

GEOLOGICAL SETTING

Marine and non-marine sedimentary rocks of Eocene to Pleistocene age occur in the investigated area. The major part of the area is underlain by Siwalik sediments, covered at most of the places by a thick mantle of alluvium. However, Murree Formation is exposed near Riwat and Sohawa villages, whereas marine rocks of Eocene age are present at the north-western corner of the area. The prominent physiographic features of the area are: hilly ranges in the north-west and south-east, the dissected terraces and flat terrain in the central part. Khairi Murat and Bakrala ranges, exposed in the north-west and south-east corners of the study area, are the prominent hills. Highest point is about 950 metres above the mean sea level (AMSL), and is located in the north-western part. In general the relief ranges between 300 to 900 metres AMSL (Bajwa, 1983, 1984).

Generally, the strata is folded into north east-south west trending anticlines and synclines, which are dissected by faults at places. On the lithological basis, the non-marine rocks of the area have been divided into six units. Murree Formation ; Kamlial and Chinji Formation (Lower Siwaliks) ; Nagri and Dhok Pathan formations (Middle Siwaliks) ; Soan and Boulder Conglomerates (Upper Siwaliks) ; total thickness averages 3200 metres. Fig. 1 & 2 ; Tab. 1 & 2 (Bajwa, 1983, 1984).

Murree and Siwalik formations of the study area comprise sandstones, siltstones, claystones, mudstones, and conglomerates. Sandstones are grey to greenish-gray, fine to medium grained, medium to thick bedded, medium hard to soft, calcareous and argillaceous at places. Interbedded siltstones and claystones are reddish brown and yellowish brown and friable. Generally, the sandstones are tough and compacted rocks, forming strike ridges, whereas the silt/claystones are comparatively loose and soft, resulting in strike valleys. The conglomerates are mainly yellowish in colour and comprise of pebbles and cobbles of quartzite, sandstone, some igneous and metamorphic rocks (Bajwa 1983, 1984 ; Fatmi, 1973 ; Shah, 1977).

The sandstone beds are 2-25 metres thick, and contain concretions and coarse pebbles at some places. On the mineralogical basis, the sandstones of the study area are classified as subgreywakes (Bajwa, 1985, 1987 a, b ; Chaudhry R.S. 1970, 1971 a,b ; Chaudhry and Ashraf, 1981 ; Farshori, 1966 ; Johnson & Tahirkheli, 1985 ; Waheeduddin and Akhtar, 1984).

LABORATORY PROCEDURES

25 sandstone samples were disaggregated, passed through the 60 and 80 mesh sieves, washed with water and heavy mineral fraction separated by using 2.8 specific gravity bromoform. EPMA thin sections were prepared from the heavy mineral specimens, and carbon-coated for making good conductors to the electricity. All the thin sections were identified, and encircled, using the diamond point microscope. Identification diagrams were prepared to locate the garnets on the scanning electron microscope, as the grain margins were only visible on the screen. Chemical analysis of the garnet grains were carried out using a stable beam current, and 4,000 magnification. Analytical procedure followed was that of Mori-DYO, 84, (Auto-Garnet computer programme). The data were printed and the data points were plotted on Mn-Fe-Mg and Ca-(Fe+Mn)-Mg triangles, after some necessary calculations, following the method of Banno, Sakai and Higashino (1986).

RESULTS

Out of 350 total number of analysis, 275 data points were plotted on Mn-Fe-Mg and Ca-(Fe+Mn)-Mg, A and B type of triangles, respectively. The rest of the analyses were cancelled, because of very low or very high cation-totals, may be because of the non-stability of the beam-current intensity. Cation-totals of the selected data range between 97 to 103, and include 51 analyses of Murree, 88 Lower Siwalik, 70 of Middle Siwalik, and 66 of Upper Siwalik.

The data-points of the Murree Formation (Early to Middle-Miocene), belonging to three different routes, are distributed in the zone on high almandite-high spessartite, having Fe up to 95%, Mn 42%, and Mg 19% (Fig. 3). Fig. 7, shows that most of the grains are gathering in the almandite-grossularite zone, having (Fe-Mn) up to 96%, Ca 34% and Mg 26%.

The garnets of Lower Siwalik (Middle to Late Miocene), from five routes of the investigated area, got concentrated in the area of high Fe, low Mg and low Mn. But, trend towards Mn is a little higher as compared to Mg, having Fe up to 96%, Mn 24% and Mg 20%. But some grains have taken positions in the area of low Fe, and high Mg, having Mg up to 41% and Mn about 03%. However, one exceptional grain has appeared in the high spessartite zone, with Mn 52% and Mg 01% (Fig. 4). Fig. 8 shows that the grains are scattered in the area, with (Fe+Mn) up to 91%, Ca 37% and Mg 31%.

The data-points of Middle Siwalik (Early to Middle Pliocene), belonging to four routes, show main concentration in the zone of high almandite-high pyrope, in the type A triangle, and have Fe up to 95%, Mg 42% and 22%. Some scattered grains, have appeared in high spessartite zone, having Mn up to 37%, and Mg 05% (Fig. 5). Triangle B of the Middle Siwalik grains also show scattered data with garnets having (Fe+Mn) up to 92%, Ca 34% and Mg 25% (Fig. 9).

The plottings of the data of Upper Siwalik (Early Pleistocene) belonging to four routes, show their concentration in the high almandite, high pyrope zone, having Fe up to 94%, Mg 40% and Mn 15%, but one grain has Mn 20%. However, one lonely grain is also seen with Fe 61%, Mn 25% and Mg 14% (Fig. 6). Data are very much scattered in the B type triangle. The garnets have (Fe+Mn) up to 87%, Ca up to 38% and Mg. up to 33% (Fig. 10).

DISCUSSION

It is notable that Murree Formation does not have any grain in the high pyrope area (Fig. 3). Lack of pyrope in Murree Formation, may be because of the fact that at the time of its deposition, the erosion level in the source area was not so deep as to touch the pyrope-bearing high grade schist, situated deep-seated. At the time of deposition of Lower Siwalik sandstone, the high grade rocks were partly eroded for supplying some of the pyropes. The presence of some scattered high spessartite garnets in the Middle Siwalik triangle, leads to two possibilities. Firstly, the re-working of the Murree sandstone. Secondly, the low grade schist, which provided high spessartite garnets to the Murree Formation, was again brought to the erosion site, by process of glaciation or tectonic movements. The presence of one scattered garnet in the type A triangle of Upper Siwalik (Fig. 6), supports the view that re-working of Lower and Middle Siwaliks also contributed to the formation of Soan sandstone. The brown sandstone of the Soan Formation is also an evidence of re-working.

The distribution pattern of data-points in the B type triangles, show a striking difference between that of Murree and the Siwalik Formations towards high almandite and high grossularite, whereas the data of the Siwalik Formations are just scattered, and this scattering trend is a little higher towards the upper part. The chemical trend of the garnets of Murree Formation, towards high Fe and high Mn shows that the sediments were derived from low grade schists and phyllites of the North and north-eastern part. The garnet positions in the Lower Siwalik triangles, concentration in high Fe, low Mg and low Mn, and in the high Mg, low Mn areas indicate that its constituents were supplied by the medium and high grade rocks. The distribution pattern of the garnets of Middle Siwalik, occupying the zones of high Fe and high Mg, and high Mn, low Mg, leads us to the conclusion that the particles of the Middle Siwalik sandstones were supplied by the high grade gniesses and amphibolites and partly by the re-working of the Murree Formation. The chemical trend of the garnet-grains of the Upper Siwalik gives an indication that the Soan Formation was formed by the erosion of high grade gneisses and amphibolites and the re-working of Lower and Middle Siwaliks.

A similar idea of different erosion levels was also given by Chaudhry (1970, 1971) while discussing petrogenesis of the Siwalik formations of the NW Himalyas, India.

CONCLUSIONS

1. The most remarkable result of the chemical analyses is the difference of distribution pattern of the garnets, between the Murree and the Siwalik formations. This difference is very much clear in both the A as well as the B type of triangles.

2. The garnets of the Murree Formation have been concentrated in the zone of high almandite and high spressartite molecule, having not a single grain in the area of high pyrope molecule. This shows that all the garnets were supplied by the low grade schists and phyllites and the erosion level was not so deep to touch the underlying high grade pyrope-bearing schist, at the time of deposition of Murree sandstone.

3. The concentration of the garnet grains in the area of high Fe, low Mg and low Mn, in the A type triangle of the Lower Siwalik, indicate that most of the garnets originated from medium grade rocks, but some high Mg garnets were also supplied by the partial erosion of the high grade rocks, as shown by the presence of some grains in the high Mg area.

4. The A type triangle of the Middle Siwalik shows that most of the garnets are gathered in the zone of high almandite and high pyrope, but a few also come in the area of high Mn and low Mg. This suggests that most of the garnets were supplied by the deep seated pyrope-bearing high grade

gneisses and amphibolites but some spessartites were provided by the erosion of the Murree Formation.

5. The distribution pattern of the grains in the A type triangle of the Upper Siwalik, indicates that major part of the garnets came from erosion of high grade schists and gneisses, but some also joined, due to re-working of the Lower and Middle Siwaliks.

6. The difference of the grain distribution pattern, between the Murree and Siwalik formations in the B type triangle is also very striking. The garnets of the Murree Formation are mainly gathered in the area of high-almandite and high-gossularite, and are less scattered as compared with those of the Siwaliks formations. The data-points of the Lower, Middle and Upper Siwaliks are very much scattered, and this scattering trend is a little higher towards the upper side.

7. The A and B type triangles (Figs. 3-10) also show that high almandite-high spessartite garnets have been supplied by the schists, high pyrope-low grossularite grains by the gneisses, and high pyrope-high grossularite grains by the amphibolites, from North-eastern parts of the investigated area.

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TABLE 1
Stratigraphic Sequence of Area

		Alluvium	Recent
		Unconformity & Loessic clay & sand unconformity	Sub Recent
		Lei conglomerate	Upper Pleistocene
Upper Siwaliks	RAWALPINDI GROUP / SIWALIK GROUP	Soan Formation	Early Pleistocene
		Dhok Pathan Formation	Middle Pliocene
Middle Siwaliks		Nagri Formation	Early Pliocene
		Chinji Formation	Late Miocene
Lower Siwaliks		Kamlial Formation	Middle to Late Miocene
		Murree Formation	Early to Middle Miocene
Chharat Group		Kuldana Formation	Middle Eocene
		Chorgali Formation	Early Eocene
		Margala Hill Limestone	Early Eocene
		(Base not Exposed)	

TABLE 2
Thickness of Rock Units Measured in various Stratigraphic Sections of the Investigated Area

Section No.	Location of Stratigraghic Sections	Murree Formation	Lower Kamlial Formation	Thickness in Metres Siwaliks Chinji Formation	Nagri Formation	Middle Siwaliks Dhok-Pathan Formation	Late Siwaliks Soan Formation
1	S.E. of Papin Village (Investigated Area)	1000 b	600 (Measured of Ranial)	650	1050	850	500 b
2	S.W. of Riwat Village.	110	695	728	325	430	490
3	S.E. of Sukho Village.			40 b	586	325	300 b
4	N. of Sohawa	385	138	435	545	960	170

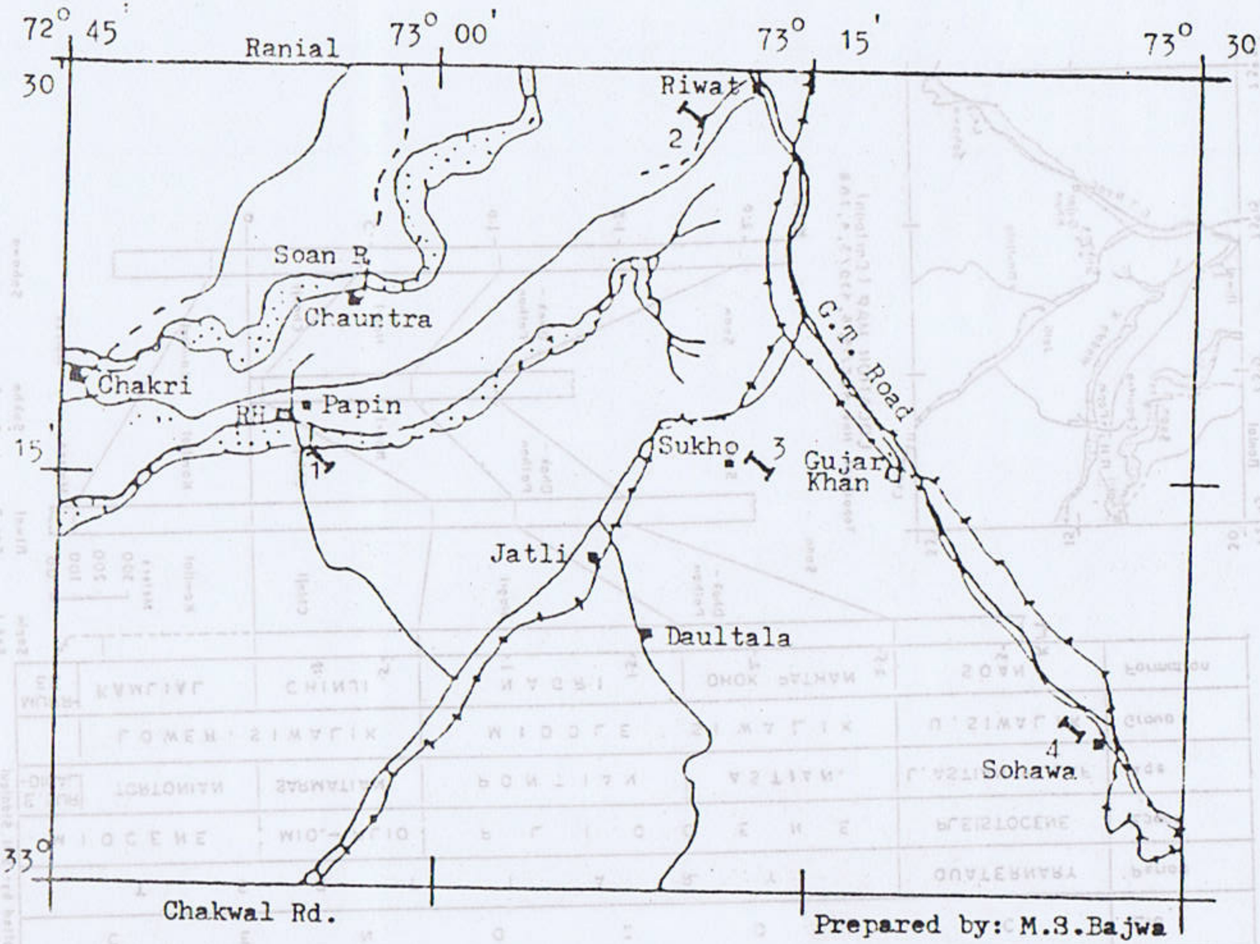

Fig. 1 : LOCATION MAP OF THE INVESTIGATED AREA (Cartoon)

Consisting of toposheet Nos. 43 C/15,16; 43 G/3,4,7,8

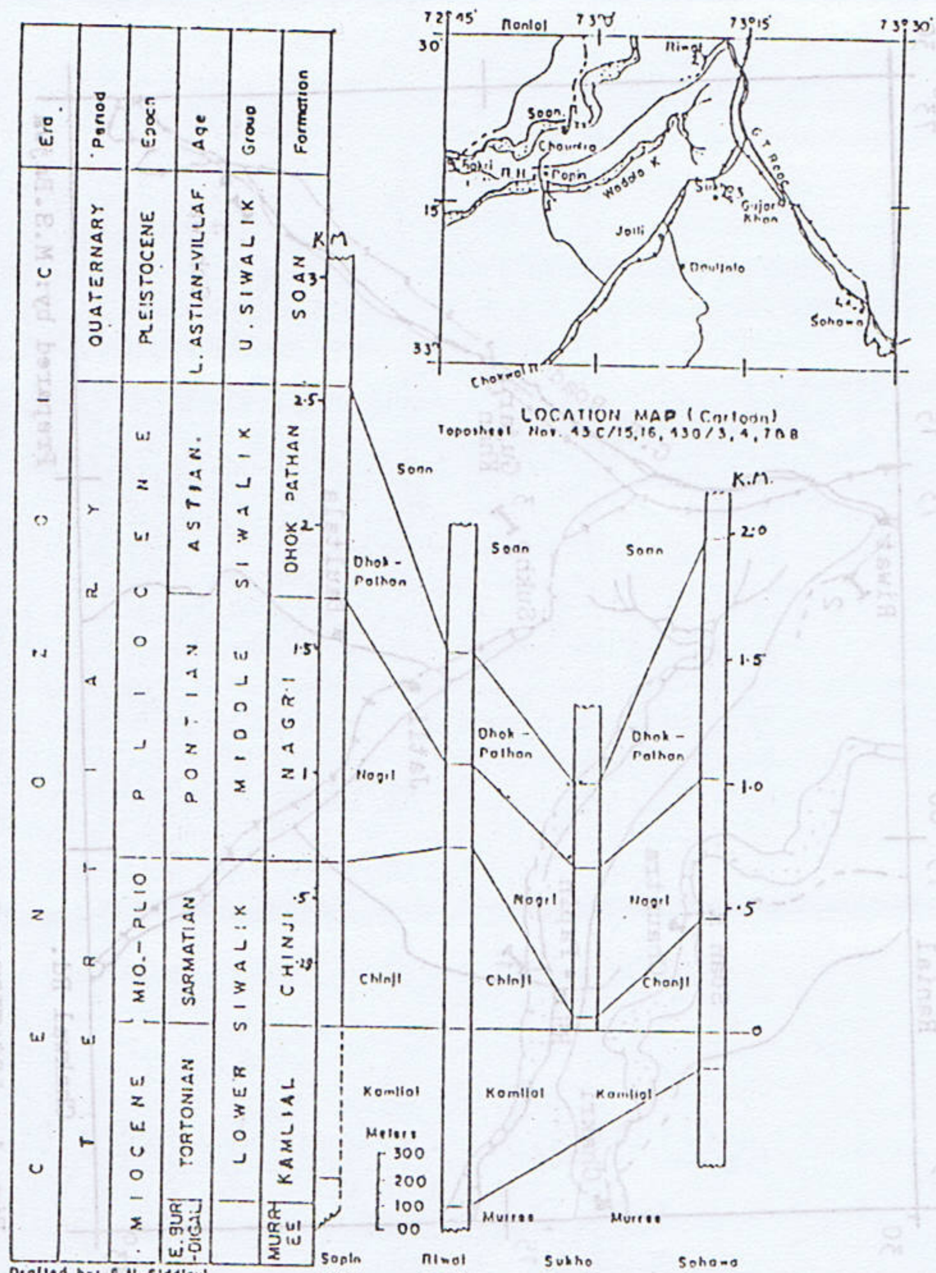

FIG.2 CORRELATION OF MEASURED STRATIGRAPHIC SECTION OF INVESTIGATED AREA AND ADJOINING AREAS OF ATTOCK, RAWALPINDI AND JHELUM DISTRICTS, PUNJAB.

Prepared by : M.S. Bajwa

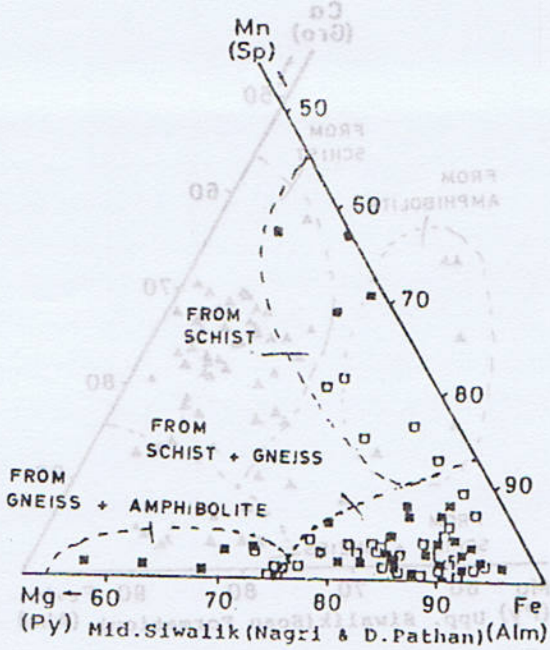

FIG.5

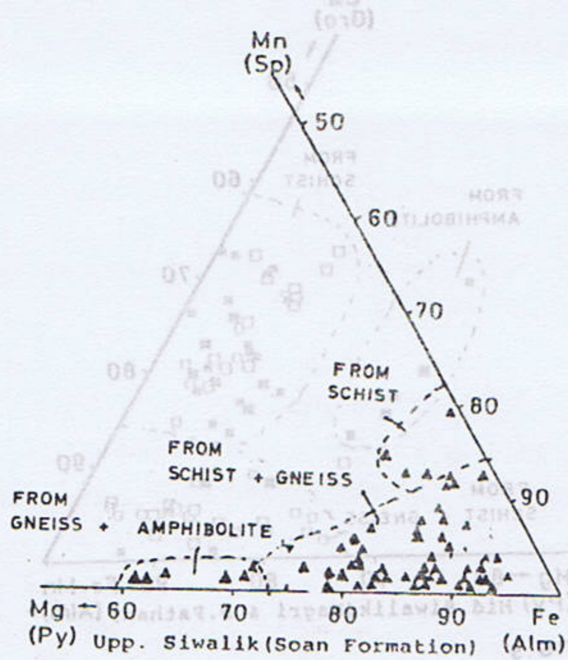

FIG.6

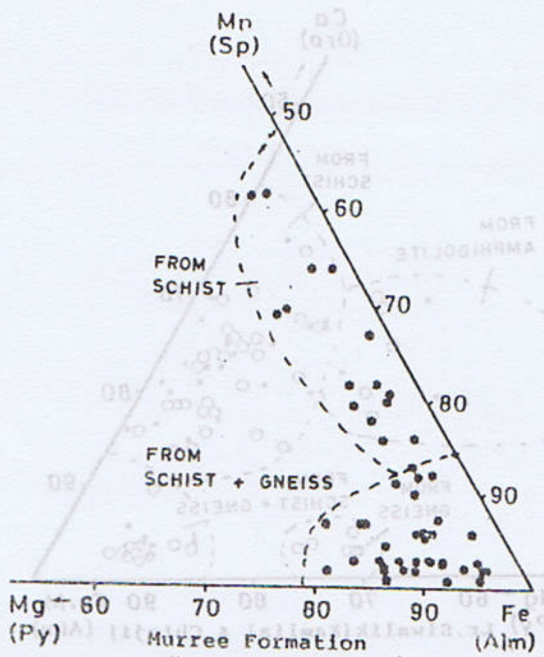

FIG.3

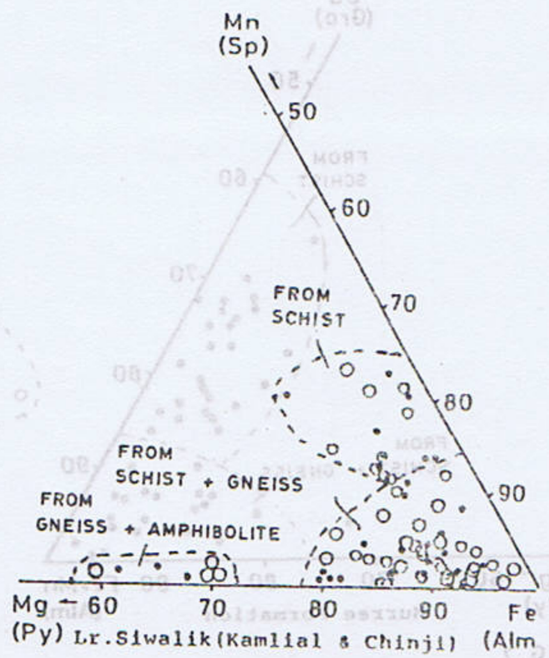

FIG.4

Figs. 3-6. Type A triangles (Mn-Fe-Mg) of garnets based on EMPA data.

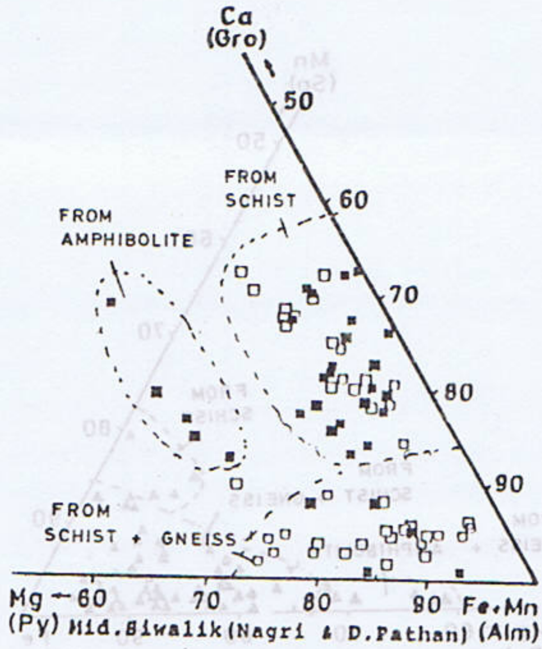

FIG.9

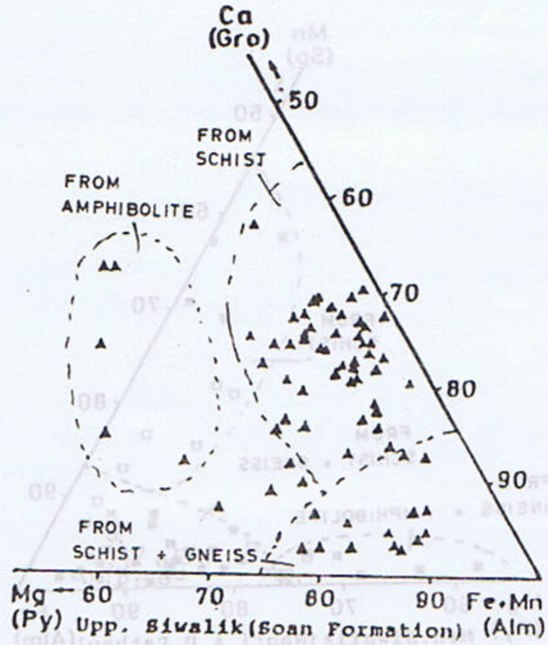

FIG. 10

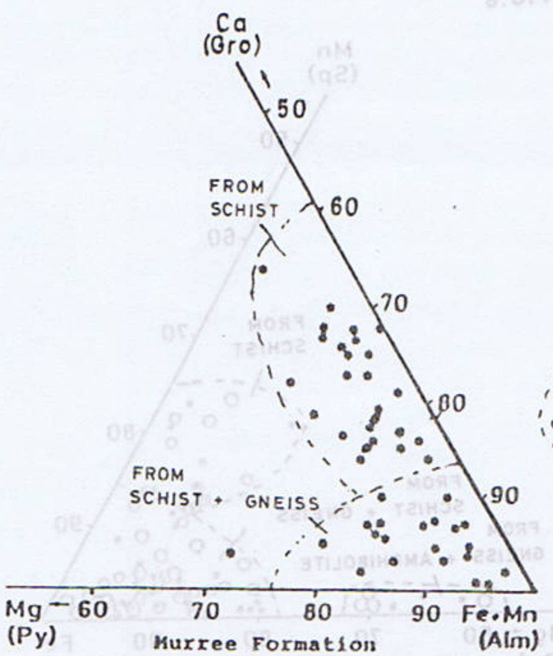

FIG.7

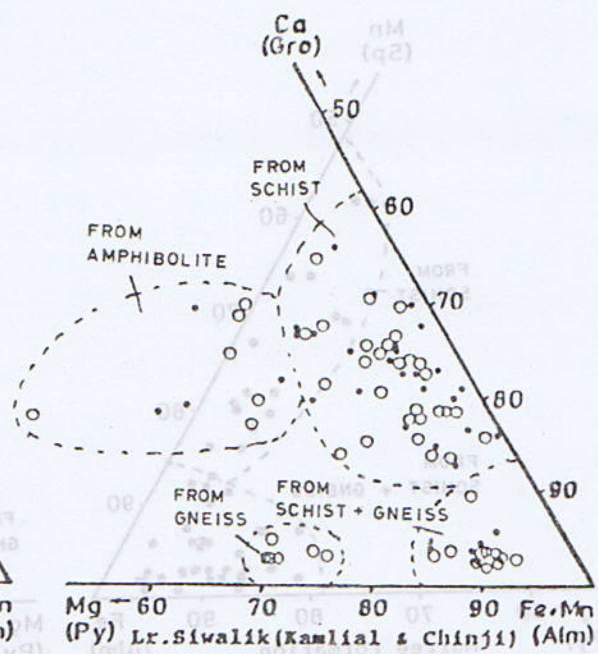

FIG. 8

Figs. 7-10. Type B triangles (Ca-(Fe+Mn)-Mg) of garnets based on EMPA data.

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Kaghan Group (Proterozoic to Lower Palaeozoic)	Mahandri Formation Kaghan Formation Rajwal Formation
Sharda Group (Archean to Proterozoic)	Including Naran, Gorian Katha, Besal, Lulu Sar, Burawai gneisses, sheet granites and amphibolites.

The whole of the Upper Kaghan Valley between Naran and Babusar Pass comprises nothing but the Sharda Group of rocks except near the Kohistan watershed in the north-east where rocks associated with the Southern Suture and the Kohistan Sequence cover high reaches of some tributary valleys.

Outline Lithostratigraphy of Sharda Group

Sharda Group (Mid Proterozic Archean)	Granite Gneisses and Migmatites	Granite gneisses comprise non-porphyritic foliated biotite granite gneiss, micro-granite gneiss and leucocratic granite. Migmatites show various structures and levels of development in feldspathic psammites, pelites and meta-tuffs (?).
	Amphibolites	Generally foliated, garnetiferous and melanocratic bedded bodies.
	Metasediments	These include Naran and Gorian Katha Gneisses, Burawai Gneisses, Besal Gneisses and Lulu Sar Gneiss and are mainly garnetiferous calc-pelitic gneisses with marbles and pelites. Pelitic horizons may contain kyanite/sillimanite.

The Sharda Group was first described from Sharda, Neelum Valley (Valley of River Kishanganga) by Ghazanfar et al., (1983). The rocks of Upper Kaghan are in physical continuation of the same. The stratigraphic sequence of Sharda Group in Kaghan Valley has been worked out by structural interpretation based on geologic mapping. An outline of this is given below.

Stratigraphic Order in Sharda Group in Upper Kaghan Valley.

SHARDA GROUP	Burawai* Gneisses	Burawai Garnetiferous Calc-pelites Bans Pelites Dabukan Marble Dumri Calc-pelites	Gorian Katha gneisses in the South and the Babusar Pass garnetiferous graphitic gneiss/schist and mylonites in the north correlate with parts of this sequence.
	Dadar Granite Migmatite Complex (also includes the Jora Migmatite zone).		
	Saiful Muluk Granite Gneiss (also includes the Gittidas and Babun Granite gneiss outcrops).		
	Lulu Sar Gneisses*		
	Besal di Khari Granite Gneiss (also includes the Duck Granite Gneiss outcrop).		
	Besal Gneisses*		Naran Gneisses* (in Naran area, south)

* also includes amphibolites.

The Sharda Group in Upper Kaghan comprises the following rock types :

1. Granites. Most of the granitic complex comprises S-type granite gneisses which are genetically similar and structurally continuous. As will be seen from the Section on the description of rock units, below, the granites and the gneisses have been described from a number of outcrops. Stratigraphically, however, there are only two main horizons of metasedimentary gneiss. Structurally it appears that the outcrops of Saiful Muluk Granite Gneiss, Babun Granite and Gittidas Granite Gneiss are not only continuous but also represent a more or less equal/comparable level within the stratigraphic sequence. This level has been called the Saiful Muluk Granite Gneiss. Similarly Besal di Khari and Duck Granites are structurally continuous and structurally belong to lower granite level. This level has been called Besal di Khari Granite Gneiss.

2. Metasediments. The much more extensive metasedimentary rocks comprise garnetiferous calc-pelites, pelites and marbles with only occasional psammatic and graphitic parts. The level of these metasediments can be described relative to the concordant granite sheets. The Saiful Muluk Granite Gneiss is overlain by Burawai metasedimentary Gneisses and the Gori Katha Gneisses in two separate troughs and is underlain by the Naran Gneisses which outcrop between Naran and Sohch. In the northern part of Upper Kaghan, however, metasediments equivalent to Naran Gneisses have been split into two parts, the upper Lulu Sar Gneisses, and the lower Besal Gneisses. Between these two levels has been introduced the Lower granite level marked by the Duck and Besal di Khari Granite gneisses.

3. Amphibolites. These are bedded horizons continuous over long distances and occur at numerous levels in the metasedimentary sequence. They will be discussed as a single catagory, the Sharda Group Amphibolites.

4. Migmatites. Excellent migmatites have developed along a fairly large horizon in Upper Kaghan. Genetically they are a part of the metasediments and the granite complex.

The Sharda Group in Upper Kaghan Valley occurs in the form of a wedge Shaped slab of Indian Sheild which has two tectonic boundaries. The northern boundary is with the Kohistan Sequence across the southern Suture or the MMT and its associated ophiolitic melange. The southern contact near Naran is with the younger Kaghan Group of rocks across the Main Central Thrust, MCT (Ghazanfar and Chaudhry, 1986). We may here point out some stratigraphic characteristics of the Sharda Group that differentiate it from the Kaghan Group :

1. It mainly comprises a sequence of calc-pelites, pelites and marbles and is marked by the near absence of quartzites which are fairly abundant in the Kaghan Group. The graphitic material at least in Kaghan Valley also cannot be rated more than minor.

2. It has extensive bedded layers of amphibolites.

3. It shows a jump in the metamorphic grade from lower amphibolite facies to upper amphibolite facies and almost throughout shows kyantite-sillimanite grades. This metamorphism has led to the formation of S-type granitic bodies.

4. The whole group shows a uniformity of tectonic style. The metamorphics, amphibolites and the granitic complex all show plastic deformation and are folded into large structural synforms and antiforms.

DESCRIPTION OF ROCK UNITS

Naran Gneisses

The Naran Gneisses may be described as garnetiferous calc-pelitic gneisses and pelitic gneisses with marbles, thin bands/streaks of granite and amphibolites. Here we shall describe only the calc-pelites and the marbles for further details the reader may refer to Ghazanfar and Chaudhry (1985).

Calc-pelites. These underlie Leda Gali, Dhumduma and part of Naran. On the roadside the outcrop extends between Naran and Sohch. 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 subidioblastic and, at times, may constitute over 30% of the rock. Accessory to trace amounts of pyrite and graphite may also be present.

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 and rarely coarse grained, sugary. The thin intercalated bands are impure but the relatively thicker bands are pure and massive. Some impure marbles are garnetiferous. They, in addition, may contain small quantities of quartz, biotite or fuchsite or phlogopite. The close association of some intercalated amphibolites with some marble bands indicate that some of the thin amphibolite bodies might be metamorphosed impure marbles.

Structurally we may correlate the Naran Gneisses with the Besal and Lulu Sar gneisses. The last two are separated by the intervening Besal di Khari Granite Gneiss. These units occur in the northern part of Upper Kaghan upwards of Jalkhad.

Besal Gneisses

This unit lies between the village Kutawai opposite Besal di Khari to just south of Duck village at the outlet of Lulu Sar Lake and forms the core of the Besal antiform. The Lower part of Purbi Nar and most of Saadullah Nar passes through it. It is a very heterogeneous unit and lies between two outcrops of Besal di Khari gneiss (one at Besal di Khari and the other at Duck). This unit may represent the lower part of Naran Gneisses in the northern upper Kaghan. This unit is composed of the following elements :

(1) Feldspathised gneisses

(2) Calc-pelites

(3) Amphibolites

(4) Marbles

(5) Orthoquartzites

(6) Pelites

(7) Granite/pegmatite/aplite bodies

(8) Biotite rich gneiss bands and vermiculite horizons.

In the following each of the above is described.

1. Feldspathised gneisses are distinctly porphyroblastic and poikiloblastic to subpoikiloblastic. The feldspar porphyroblasts are from 5 mm to 25 mm. The rock is very distinctly gneissic and layered. It is composed of quartz, feldspar, mica (muscovite+biotite) and garnet as essential minerals. Tourmaline, magnetite and garnet are the accessories. The garnet is an almandine garnet and is generally fine grained. It ranges in size from 0.2 to 0.8 mm. If feldspar is removed, what is left is merely a garnetiferous gneiss. Aluminosilicates are rare.

2. *Calc-pelites.* The calc-pelite horizons are composed of typically banded rocks. The alternate bands are rich in carbonates and pelitic matter. The bands are generally centimetric. The carbonate bands are composed mainly of carbonates with subordinate to accessory quartz, muscovite, biotite and prominent garnet. The pelitic bands are composed of quartz, micas(muscovite + biotite)and almandine. The accessories are magnetite, tourmaline and calcite. The calc-pelites, at places, contain layers rich in amphibole. These layers are composed of amphibole, quartz, a little feldspar and calcite. There are also accessory micas and, at places, garnet.

3. *Amphibolite.* They occur mainly as concordant bodies. If traced along strike they may occasionally split and inter-finger with enclosing units. They are medium grained and foliated. At places they may show excellent crenulation. They are hypidioblastic to subporphyroblastic. They are composed of amphibole and plagioclase. Garnet, epidote, biotite and quartz are generally accessories, but at places these may individually assume the status of essential minerals. Just to the south of Duck bridge (outlet of Lulu Sar) occur banded amphibolites. The alternate layers are rich in epidote and amphibole. They also contain garnet and are associated with calcareous bands here.

4. *Marbles.* Although thin marble beds are exposed in this unit they are particularly abundant and exposed around the mouth of Purbi Nar and Saadullah Nar. Marble beds are also exposed south of Duck. They are associated with amphibolites and calc-pelites. The marbles are from off white to snow white. Some beds are pure and granular to granoblastic. They are massive looking, medium grained and composed essentially of carbonates. Quartz and micas are accessories.

The associated calc-gneisses and micaceous marbles are gneissic to layered and in addition to carbonates contain variable amounts of muscovite, biotite and quartz.

5. *Quartzites.* Off white to snow white hard and massive quartzites are well-exposed at the mouth of both Saadullah Nar and Purbi Nar. They are granoblastic and composed of quartz. Muscovite, biotite and tourmaline occur as traces to accessories. Some bands are, however, composed almost entirely of quartz.

6. *Pelite gneisses.* They are subordinate. They are porphyroblastic to subporphyroblastic and poikiloblastic. They are composed of quartz, micas (muscovite+biotite) and garnet. Tourmaline, aluminosilicates and magnetite are accessories.

7. *Granite, pegmatite and aplites.* The unit being described is bounded on the south by Besal di Khari Granite Gneiss and to the north by the Duck Granite Gneiss outcrops and near the contacts on either side, contains granite, pegmatites and aplite bodies. Feldspathisation and tourmalinisation of associated pelites is common.

Minor biotite rich gneisses and vermiculite bearing horizons are present just south of Duck village in a mixed zone composed of marbles, calc-pelites, amphibolites, biotite gneisses and minor granite/pegmatite intrusions.

Lulu Sar Gneisses

The Lulu Sar Gneisses occur in the form of two outcrops one that passes through the Lulu Sar Lake east to Purbi Nar and west to Putha Nar and the other that passes through Jalkhad Nar and then through Khotey Nar to Ratti Gali. Structurally this unit appears to correlate with the upper part of Naran Gneisses to the south.

The Lulu Sar Gneisses show the following varieties :

Feldspathised pelitic gneiss. These are mica rich gneisses. They are porphyroblastic and poikiloblastic. They are medium grained. They are composed of quartz, biotite, muscovite and thin patches (upto 6 × 5 cm) of feldspar, quartz and garnet. Tourmaline needles upto 2 cm. long and magnetite are ubiquitous accessories. At places aluminosilicates are also present.

Quartz rich pelitic acicular gneiss. These are foliated gneisses. They are composed mainly of quartz, biotite and muscovite. Garnet, tourmaline, magnetite and aluminosilicates are ubiquitous accessories.

Silvery grey mica rich gneiss. This occurs inter-bedded with the above gneisses. These are silvery grey and muscovite rich gneisses. They are composed of quartz and abundant muscovite. Biotite is generally small in amount. Garnets are fine grained. Tourmaline and magnetite are the accessories.

Kyanite bearing garnet gneisses. These rocks are strongly gneissic and rich in quartz. They are medium to coarse grained and subporphyroblastic to porphyroblastic. The rock is composed of abundant quartz, micas (muscovite+biotite) garnet and kyanite. Feldspar, magnetite and tourmaline are common accessories. In this unit pegmatitic veins, pods and patches composed of feldspar, mica, quartz and tourmaline are common. Microgranite bands and patches are also present. There are also plenty of quartz veins. This unit is well-exposed around Kalawan-da-Maidan.

Acicular granitised gneiss. It occurs as distinct horizons. It is gneissic, acicular, mica rich and porphyroblastic. It is composed of feldspar, quartz and abundant micas. The distribution of feldspar is, however, very uneven. Tourmaline garnet and apatite occur as accessories. It has developed mainly around Ratti Gali village and around Khotey Nar Gali, sides of Lulu Sar Lake and Purbi Nar Gali.

Garnetiferous calc-pelites. This variety occurs as bands on the roadside on both sides of the pelitic outcrop of Lulu Sar gneiss opposite Jalkhad Nar and as patches further south. On the roadside thin bands of amphibolite and offshoots of Babun Granite can be seen mixed with the granetiferous calc-pelites of Lulu Sar Gneisses.

Burawai Gneisses

This unit shows following varieties which have been mapped separately :

(1) Burawai garnetiferous calc-pelitic gneisses.

(2) Bans pelites.

(3) Dabukan marbles.

(4) Dumri calc-pelites.

Burawai garnetiferous calc-pelitic gneisses. This unit occurs in the core of the Burawai Syn-form occupying the areas of Wenjtar, Seri, Gattian (in Jora Nala) Burawai, Rakhan and Dunga Katha. On the roadside it extends between Bans Bandi and Utli Seri/Jalkhad.

This unit is composed of the following lithologies.

(1) Banded calc-pelites

(2) Marble beds

(3) Layers, bands and thick beds of amphibolite

(4) Pelite beds

(5) Psammite beds

The banded calc-pelites and marble beds and bands are predominant. Pelite beds and amphibolites are subordinate. The psammite beds are rare/minor.

The banded calc-pelites are composed of alternating carbonate rich and pelite rich bands. The calcareous bands are medium grained and from granular to granoblastic. However, they are generally impure and contain muscovite and biotite which impart them a weak planer structure. Where garnet develops the texture becomes porphyroblastic to subporphyroblastic. The garnet crystals are poikiloblastic and generally range in size from 3-10 mm. The pelitic beds are subgneissic to gneissic and from subporphyroblastic to porphyroblastic and are composed of abundant micas (muscovite + biotite), quartz, garnet and some magnetite. The impure pelitic bands contain prophyroblasts of grossularitic garnet while the muscovite rich pelites contain smaller almandine crystals. Some pure thick bands of pelites, at places, contain kyanite/sillimanite.

The marble beds are medium grained and granoblastic. They are composed mainly of calcite. Accessory minerals are muscovite, biotite, garnet, and pyrite. Graphite and magnetite are relatively uncommon accessories. *Some impure marble bands develop layers of amphibole.* The pelitic beds are sub-gneissic to gneissic. They are porphyroblastic and lepidoblastic. They are composed of quartz, muscovite, biotite and almandine garnet as essential minerals. Feldspar, magnetite and tourmaline are the accessory minerals. Kyanite/sillimanite may be occasionally encountered. Tourmaline, andalusite and kyanite are often from subidioblastic to idioblastic.

Amphibolites occur as layers, thin bands as well as thick beds. The amphibolite is most commonly a medium grained garnet amphibolite, composed essentially of amphibole and plagioclase Garnet is a distinct ubiquitous accessory which, at places, assumes the status of an essential mineral. Epidote, quartz and sphene are other accessory minerals.

The psammites are rare. These are either orthoquartzites closely associated with marble bands or impure quartzites. The orthoquartzites are medium grained and composed mainly of quartz. Feldspar, magnetite, muscovite and biotite are the accessories. The impure quartzites in addition to quartz also contain subordinate muscovite and biotite. Rarely kyanite/sillimanite may also occur. Magnetite, feldspar and tourmaline are the other accessories.

In the region between Burawai and Jalkhad the unit is composed mostly of banded calc-pelites with occasional marble bands. This part throughout contains abundant quartz veins. These veins in size commonly range between 1-5 cm although they can be as thick as 30 cm. These veins are often folded alongwith the enclosing strata and commonly show pinch and swell structure. There are also irregular patches of quartz. These veins may rarely contain muscovite flakes. Some veins also contain carbonate patches. Some joints are lined with films and coatings of carbonate. Kyanite is rare and is restricted to pelitic horizons around Jabba Wenjtar (Wetar) and on roadside opposite Wenjtar Jabba.

Around the Burawai Nala there are some layers composed of hornblende, garnet, quartz and calcite. These amphibolite layers are generally broken or discontinuous. The associated marble bands are upto 15 cm thick and light to medium green in colour. Thicker, upto 7 m, marble bands may occur at the contact with amphibolite sills. Garnet amphibolite bands are also present in this section.

The Burawai Gneisses are correlatable with Gorian Katha Gneisses which occur downstream of Naran between Naran and Batal.

Bans pelites. The Bans pelitic gneisses are present on both sides of the Bans Katha almost throughout its length. This is a very extensive unit of pelitic gneisses. The rocks are medium to coarse grained and porphyroblastic. Overall these gneisses are either quartz rich pelites or pelites i.e. relatively poor in quartz. At some places like near Chechian and Bans the gneisses show banding. The alternate bands are quartz rich (or relatively quartz rich) or relatively quartz poor pelites.

The pelite (mica rich) bands are silver to silver grey and show well-developed foliation. The size of garnet in these bands is generally small (1-5 mm). These bands are often rich in muscovite. The colour of garnet is reddish and brownish.

The quartz rich pelites are massive looking compact and coarser grained. They are prophyroblastic. The colour of garnet is dark brown to dark grey. It forms crystals upto 12 mm and exceptionally 15 mm size. This unit shows extensive exsolution of quartz. Quartz veins and patches are common. These very often bear blue kyanite crystals which may at places, reach up to 10 cm. in length.

The unit as a whole may be characterised as medium to coarse grained, porphyroblastic and poikiloblastic gneisses. The prophyroblasts are of garnet, kyanite (mainly in associated quartz veins) and rarely prismatic to acicular sillimanite.

The rocks are composed of quartz, muscovite, biotite, kyanite/sillimanite and garnet as essential minerals and tourmaline and magnetite as ubiquitous accessories. Graphite may occur as traces.

Kyanite bearing quartz veins are very common in this unit. These veins range from a cm upto 50 cm. Rarely 2 m thick veins are also present. These exsolved veins contain bladed subradial to sheaf like or individual crystals of kyanite. The kyanite ranges in size from 1 cm to 10 cm. Some veins contain upto 30% kyanite. Smaller crystals of kyanite may occur within the mass of pelites. *The Kyanite mineralisation here* (*Bans-Dila—Sobhai Mahli area is so common and widespread that it certainly merits economic evaluation.*

A comparison with pelitic gneisses of Kalawan-da-Maidan and Khotey Nar shows there are some similarities between this unit (i.e. Bans-Dila-Sobhai Mahli) and the pelitic Lulu Sar gneisses of Kalawan-da-Maidan and Khotey Nar. However. this unit is very rich is quartz-kyanite veins and contains much less aplite-pegmatite-granite metatects/anatects than at Kalawan-da-Maidan and Khotey Nar area. The Kalawan-da-Maidan and Khotey Nar area, on the other hand, contains widespread small kyanite crystals within the pelitic gneiss unit.

Dabukan Marbles. A distinct white and banded massive marble with subordinate calc-pelites. The Dumri calc-pelites have a band of marble on the southeast. This band passes through the mouth of Dunga Katha through Dabukan Katha and Dadar north of Reori from where it extends further south-west. It is a distinctive white massive thick band of marble. At places it is grey and at other places it is banded with grey layers.

The colour of the weathering surface varies from off white to light yellow and brown. Subordinate layers of calc-pelite are present. Veins of quartz and calcite are both present. The rock is well-jointed and shows plenty of minor-folds.

The Dubukan marble is also associated with garnetiferous amphibolites. Some of these amphibolites occur and are folded within the main body of the marble.

Dumri calc-pelites. Following the very thick band of pelite gneisses unit, below Sobhai, towards Batakundi starts a thick and extensive marble-calc-pelite unit (with amphibolite bands). The Dumri calc-pelites contain typical calc-pelite banded gneisses and thin to medium marble beds alongwith amphibolites. The marbles are from white to off-white granoblastic and medium grained. The marbles form shear cliff faces on the right bank of river Kunhar on Battakundi-Dila path in the Sobhai Mahli-Battakundi section. At Battakundi itself, though, there are migmatites. Some bands are neutral green to light green. They are predominantly composed of carbonate with accessory quartz, pyrite and mica. Impure bands contain some garnet too. The marbles are interbedded with calc-pelites and amphibolites. A few pelitic bands and beds are present as well.

Light green marble bands up to 8 m. thick are present where marble beds come in contact with thick amphibolite bands.

The Babusar Pass Garnetiferous Graphitic Gneiss/ Schist and Mylonites

The outcrop of this unit extends NE-SW from north of Gittidas through Lohya Lul (Lohlul) to Ledi and Chhalayyan. It is well-exposed between Kinari and Ledi in Ledi Nar. In the Lohlul Nar it starts after crossing the Saleh Baihk. On the Babusar road it occurs mainly on the Kaghan Valley side close to the Babusar Pass.

These rocks are generally gneissic with good schistosity and subporphyroblastic to often distinctly porphyroblastic. The porphyroblasts are mainly of garnet and very often are poikiloblastic. The unit contains a few subordinate intercalations of non-graphitic pelites and horizons of fine grained calc-pelites and thin marble bands. The marbles are granular and composed essentially of calcite with minor to accessory amounts of quartz, muscovite and chlorite. The calc-schist is similar to marble but contains more musovite, chlorite and biotite. The texture, structures and mineralogy of associated calc-pelites and thin marble bands is much like the similar horizons occurring elsewhere.

Mylonite zones occur within this unit specially close to the Main Mantle Thrust, MMT. The garnets generally range in size from 4 mm to 8 mm. However, in the carbonate bearing parts of the garnetiferous graphitic gneiss the garnet porphyroblasts may reach a size of 12 mm. Wherever needles of amphibole and/or tourmaline develop they give an acicular look. The content of graphite is generally low, seldom exceeding 5% but most often ranging between 1 and 4%.

The rock is composed mainly of quartz, garnet and micas (muscovite + biotite). Graphite, pyrite, tourmaline, amphibole and sillimanite may occur as accessories. Chlorite is an ubiquitous retrograde mineral.

Quartz veins from 0.5 to 2 cm, quartz patches and boudins are characteristic of this unit. They are often tinged brown.

On the fresh surface the rock is dull dark grey, grey and light grey while on the weathered surface it is commonly dirty grey, dirty brownish grey and dark grey.

Sharda Group Amphibolites

These occur in calc-pelites as well as in the pelite units. They are extensive bodies from one to few tens of metres thick. They are folded alongwith the enclosing metasediments. They are generally concordant but split and interfinger specially where associated with marbles and calc-schists. They show well developed foliation, a number of cleavages and crenulation. In short they share the tectonic history of the enclosing gneisses. They have been strongly metamorphosed. They are medium grained and composed of plagioclase, amphibole and garnet. Quartz, biotite, magnetite, sphene and epidote are accessories. They are generally melanocratic but show rare intermediate facies and acidic differentiates. At places, they also contain secondary quartz veins.

The Granties of Sharda Group

The granite gneisses/granites of the Sharda Group in Kaghan are quite similar to each other almost throughout the slab between MCT and MMT. Not only there is a genetic and physical similarly but also many outcrops of granite gneisses appear to be interconnected with each other over antiforms and under synforms. Stratigraphically, therefore, the granite gneisses may be considered to belong to fewer horizons than the number of outcrops.

The granite gneisses and granites have been described below with reference to the following main outcrops :

1. Saif-ul-Muluk Granite Gneiss
2. Babun Granite Gneiss
3. Besal di Khari Granite Gneiss
4. Duck Granite Gniess
5. Gittidas Granite Gneiss

It is suggested that Duck and Besal di Khari Granite gneisses stratigraphically represent a single granite horizon while the Saif-ul-Muluk Gneiss, Babun and Gittidas outcrops may represent another and an upper stratigraphic horizon.

As mentioned above although the granite gneisses and granites have been described separately from various outcrops they are essentially similar in nature.

Saiful Muluk Granite Gneiss and Granite

The outcrops are in the form of one major sheet-like body, the Saiful Muluk Granite Gneiss and granite, and a number of thin sheet-like bodies folded concordantly with the major structure in the Naran unit.

It extends NE-SW from Sohch Danna through Sohch above Leda Gali to the right bank upper slopes of Saiful Muluk Katha and Saiful Muluk Lake. From Saiful Muluk it extends NW passing through Naran on the right bank slopes of river Kunhar.

Generally speaking the Saiful Muluk Granite Gneiss is a non-porphyritic fine to medium grained strongly foliated biotite granite gneiss with minor granite and thin pegmatite veins. The granite gneiss at many places contains abundant relics of transformed (granitised) metasediments and shows effects of metamorphism. The granite gneiss is composed of albite/oligoclase, quartz, microcline, muscovite, biotite, garnet tourmaline apatite and magnetite.

The Saiful Muluk granite gneiss, as seen on the slopes of Saiful Muluk Lake, is extremely well-foliated dark coloured biotite granite gneiss with irregular leucocratic bands(less biotite) It appears to be a transformed granitised paragneiss. The modified metamorphic element appears to be considerable, especially in the dark granite gneisses. The gneiss is granitised and aplitised frequently i.e. contains minor acid bodies. The pegmatite veins are generally thin, ranging in thickness from 0.5 cm to 30 cm. These bands are unzoned simple and only slightly coarser than the gneiss with which they are associated. They are composed of quartz, feldspar, mica, tourmaline and eumorphic, translucent to transparent, sheared pink garnet. At places they contain prophyroblasts of potash feldspar of a later period of formation as they often cut across the fabric of the rock. The pegmatite veins are generally parallel to the structure and foliation of the surrounding rock and may make similar type folds alongwith the gneiss. The pegmatite veins sometimes contain boudins with occasional light greenish grey porphyroblasts of potash feldspar. One such porphyroblast measured 8 cm × 5 cm.

Babun Granite Gneiss/Granite

This is a banded and layered hypidioblastic to granoblastic microgranite gneiss. The bands and layers are marked by micas, specially biotite. It is composed of feldspar, quartz, muscovite and biotite. Garnet, magnetite, tourmaline and apatite may occur as accessories. Partially digested and feldspathised pelitic layers yield a subporphyroblastic to prophyroblastic facies. The porphyroblasts are of feldspar.

In addition to granite gneiss and subporphyroblastic to porphyroblastic feldspathised gneiss a non-porphyritic microgranite facies is also present. It is leucoratic and composed of quartz and feldspar. Muscovite, biotite, iron oxides and garnet may occur as accessories.

North of Seri the massive granite facies comes in contact with metasediment at places. Here it may cause some hornfelsing. Here the contact near roadside is under debris but pieces of andalusite hornfelse are found in the scree.

There are also veins of aplite and simple pegmatite. Behind Jalkhad hotel, on the upper slopes, the leucogranite interfingers with metasediments. Thin bands of granite are found within the Lulu Sar Gneiss especially within its calc-pelitic part near Jalkhad.

To the east of Jalkhad hotel and Seri, the contact between Babun microgranite gneiss and the pelitic Khotey Nar part of Lalu Sar gneiss is well-exposed on the west bank slopes of Khotey Nar 2 Km south of the peak 12888 of Babun. The contact zone is 200 m to 500 m wide. Here microgranite interacts with the metasediments. The contact zone has been variably feldspathised resulting in the development of porphyroblastic feldspathic gneisses. Within the contact zone no visible hornfelsing was observed. The contact zone contains a number of microgranite sills, aplite and migmatitite veins (cross cutting relationships within the contact metasediments may also be seen).

Besal di-Khari Granite Gneiss

Some distance to the north and upstream of the Babun Granite outcrop at Jalkhad another outcrop of granite is met with, on the roadside near Besal di Khari. Around Besal-di-Khari the granite gneiss is intimately associated with metasediments and a number of amphibolite sheets.

The granite gneiss is strongly foliated and contains abundant layers rich in mica. It also contains darker schlieren and streaks.

The gneiss also contains strongly to moderately feldspathised metasediments. These are rich in mica. specially biotite, garnet and tourmaline. They may rarely contain aluminosilicates. The granite gneiss is composed of feldspar, quartz and mica, specially biotite. Garnet, tourmaline, magnetite, apatite and rarely aluminosilicates may occur as accessories.

The feldspathised gneiss horizons merge with the granite gneiss. These horizons look, similar to the micro-granite gneiss but are relatively richer in micas, garnet, tourmaline and aluminosilicate.

The leucogranite facies of this outcrop may cut the amphibolite sheets. Here they may contain patches and pieces of garnet amphibolite They may also contain hornblende, garnet and chlorite digested from amphibolites.

The contact zones of Besal di Khari Garnite Gneiss are generally transitional. The lower contact of granite on left bank of river Kunhar opposite Besal di Khari is, however, faulted. The contact zone is 200-300 m wide and contains a number of granite, aplite and pegmatite veins. In this zone considerable intermixing of metasediments and amphibolites with granitic facies of the outcrop is seen.

Duck Granite

A relatively narrow band of granite especially mixed with amphibolites towards its margins crosses the roadside near Duck village close to the outlet of Lake Lulu Sar. Westwards the outcrop extends on the upper right bank slopes of the Putha Nar while east of road it bends south-east crosses the Purbi Nar and then joins with another outcrop of granite moving south-east from Besal di Khari, a point on the roadside between Besal and Jalkhad. The two bands dip away from each other north-east and south-east and together form two limbs of the Besal Antiform. The Duck granite south of Besal di Khari appears to join the Babun Granite outcrop across the river Kunhar near Jalkhad. This is distinct unit and shows a variety of petrographic types. These are as follows :

Pure leucocratic granite. It is very leucocratic and occurs as very fine grained and almost aplitic facies. It is hypidiomorphic to saccharoidal. It is composed of quartz and feldspar. Muscovite, biotite, tourmaline, garnet, magnetite and apatite are accessory minerals.

Banded and layered tourmaline microgranite gneiss. It is fine grained and hypidioblastic. It contains layers and thin bands of mafics. These bands may be rich in biotite and muscovite. In addition they often contain garnet and tourmaline. Rarely aluminosilicates may also occur. At places xenoliths, screens and layers of pelitic matter occur in various stages of granitisation. Overall such gneisses are layered and banded. They are hypidioblastic and, at places, subporphyroblastic and composed of feldspar, quartz and micas (muscovite+biotite). Tourmaline, garnet, magnetite and apatite are common accessories. Aluminosilicates are rare accessories.

Amphibole bearing banded and layered gneisses. Such gneisses are closely associated with the amphibolite bearing horizons. Such rocks are fine to medium grained and hypidioblastic. They are composed of quartz, feldspar, amphibole, micas and tourmaline. Apatite may occur as an accessary.

Porphyroblastic granitised gneisses. These rocks occur in close association with pelitic horizens. The rocks are gneissic and porphyroblastic. The porphyroblasts are of feldspar. These rocks are also mica rich. They are composed of feldspar, quartz and micas (muscovite+biotite) as essential minerals. Tourmaline, garnet and magnetite occur as accessories. Rarely aluminosilicates may also occur.

Simple pegmatites. Simple pegmatites are associated with all types of granites as well as associated gneisses. These range in thickness from a few cm. to a few metres (10 m), are coarse grained and show an uneven segregation of minerals. They are composed of feldspar, quartz, mica and tourmaline. These pegmatites are common but they are particularly abundant below Bans Gali near the head of Putha Nar. Lesser concentrations are in upper reaches of Saadullah Nar. Some pegmatites contain Beryl and Amazonite. Garnet also occurs occasionally.

Aplite veins. The granite is itself fine grained. The aplitic veins are still finer grained. They are not very common. They are saccharoidal and composed of quartz, feldspar, mica and tourmaline. These can be seen developed specially at or close to the contact between pelitic gneiss and granite on Babun slopes towards Karawali Basti (also called Khotey Nar-di-Basti).

The Contact Relations of Duck Garnite Near Duck Village. The northern part of the Besal gneisses comes in contact with the Duck granite at Duck. The Besal unit near the contact is composed of amphibolites, calc-pelites, marbles, quartzites and some pelites. The amphibolite screens and xenoliths are very common in the garnite. The calc-pelites and granite/pegmatite veins are involved in lit-par-lit injection relationship. The granite becomes rich in mafics and contains abundant biotite, some garnet and amphibole. Pegmatitic veins in the mixed zone are common. They range in thickness from 2 cm to 7 cm. These are simple pegmatites which are composed of feldspar, quartz, muscovite and tourmaline. Some pegmatites contain garnet, biotite, vermiculite and even amphibole. The garnite in the mixed zone itself becomes very heterogeneous and minerals like garnet, biotite (abundant), vermiculite (some), epidote and amphibole may develop in it. The pelitic horizons involved become porphyroblastic feldspathised gneisses. They contain quartz, feldspar, mica (muscovite + biotite) and garnet as essential minerals. Aluminosilicates, tourmaline and magnetite may occur as accessories. The contact zone is also well-developed near the mouth of Putha Nar. The Lulu Sar pelitic gneisses at the contact have been feldspathised and tourmalinised for almost 400 to 500 m. Feldspar and feldspar and quartz patches develop among the planes of foliation of the Lulu Sar pelitic gneisses. These gneisses are now porphyroblastic and poikiloblastic. The feldspar porphyroblasts and patches are strongly poikiloblastic. The gneisses are also acicular since they contain abundant tourmaline needles. They are composed of quartz, feldspar and mica (muscovite + biotite) and garnet as essential minerals. Tourmaline, magnetite and aluminosilicates may occur as accessories.

The southwestern contact of Duck Granite with Besal Gneisses is well-exposed near the village of Kutawai inside Purbi Nar. Here a wide mixed zone of up to 1 km is well-developed. There are abundant sills of granite (some dykes) and pegmatite veins also occur within the pelites. The pelites have been strongly feldspathised and become porphyroblastic feldspathised gneisses. They are now composed essentially of feldspar, quartz, and mica (mainly muscovite). Garnet, tourmaline, aluminosilicates and magnetite may occur as accessories. The amphibolites in the mixed zone have been feldspathised and develop local meta-dioritic facies. Intermediate pegmatites with biotite and vermiculite also develop in granitised amphibolites.

Gittidas Granite Gneiss

The Gittidas Granite Gneiss is exposed over a fairly long road stretch nearly two/three miles on either side of Gittadas. Northwest of the road the outcrop covers the lower part of Lohya Lul Nar and moves southwest on the right bank slopes of the Gittidas Nala and then on the left bank slopes of the Putha Nar. South and southeast of the roadside the Gittidas Granite Gneiss covers the area of Thanda Nar, Kamarbashi (Kabalbashi) Nar and Gittidas Nala. This outcrop then crosses the Purbi Nar between Kaar village and Maulaney-di-Baihk (Mulla-di-Basti). Further south the outcrop thins and moves in the form of a band successively crossing the Jalkhad Nar, Khotey Nar and then Ratti Gali Nar near Ratti Gali Baihk and Nazarewali Baihk.

The Gittidas Granite is mainly a microgranite gneiss. It is fine grained and hypidioblastic to xenoblastic. It is often banded and contains layers rich in mafics (mainly biotite). It is composed of quartz, feldspar and micas (muscovite + biotite). Garnet, tourmaline and magnetite are ubiquitous accessories. Apatite may also occur as an accessory. Tourmaline is often idioblastic. Some layers contain sillimanite, andalusite and rarely kyanite. Xenoliths and screens of feldspathised and tourmalinised garnetiferous aluminosilicate bearing gneisses are also found. Some porphyritic gneisses are also present around Gittidas. But these appear to be granitised pelites. Folding, flexuring, crenulations and mylonisation are very common features of the Gittidas Granite Gneiss, specially towards the MMT.

The Gittidas Granite also contains screens and xenoliths of amphibolite and ultrabasic garnet-amphibole pyroxene rocks. The latter ultrabasics look like garnet retrogranulite and retroeclogites.

Where amphibolite xenoliths or screens are present the granite becomes rich in biotite and garnet. Sometimes additionally some amphibole is also encountered. Some of these ultramafic slices can be seen near Kaar and Khan ka Dheri villages in Purbi Nar and between Lalıan di Baikh and Kamarbashi Nar on the slopes of Gittidas Nala. Near Kaar and Khan ka Dheri village the ultramafic garnet-amphibole-pyroxene rocks occur as xenoliths and small screens in granite. These rocks have a distinctly higher specific gravity than ordinary amphıbolites. They are multicoloured red, bright green and black. They are granoblastic to subporphyroblastic. The individual minerals may show segregation. At places the xenoliths are composed of almost 80% garnet. At other places pyroxene and amphibole show segregation. The screens and xenoliths, at places, along contacts with granite gain a little quartz, feldspar and even mica. While the surrounding granite becomes rich in garnet, amphibole and at places biotite. Garnet may typically occur as bunches in the granite.

Facies of Gittidas Granite

Banded, layered and foliated microgranite gneiss. This is predominant facies. The rock is fine grained hypidioblastic and gneissic. It contains thin bands and layers rıch in biotite and muscovite. The rock is composed of quartz, feldspar and micas (muscovite + biotite). Garnet, tourmaline and magnetite are ubiquitous accessories. Apatite may also occur as an accessory.

Porphyroblastic granite gneiss. This is a subordinate facies. It is distinctly porphyroblastic. The porphyroblasts are of K-feldspar. The rock is distinctly gneissic. It is composed of feldspar, quartz and micas (muscovite + biotite). Garnet, tourmaline and magnetite are ubiquitous accessories. Apatite may also uccur. This type is richer in micas and garnet than the microgranite gneiss.

Acicular porphyroblastic granitized gneiss. It is a minor facies. It is porphyroblastic and particularly rich is micas. It contains needles of tourmaline and aluminosilicates. It is composed mainly of quartz, feldspar and micas (muscovite + biotite). The accessories are garnet, tourmaline, aluminosilicates, magnetite and apatite.

Microgranite. It occurs as massive to poorly foliated leucocratic facies. It is hypidiomorphic and poor in micas. It is composed of feldspar and quartz. Muscovite, biotite, garnet, tourmaline and magnetite are common accessories. The microgranite occurs as areas, patches as well as distinct bodies within the microgranite gneiss.

Pegmatites. The pegmatites associated with the Gittidass microgranite gneiss are predominantly simple pegmatites. They are unzoned and composed principally of feldspar, quartz, tourmaline and muscovite. Some simple pegmatites contain mica books from 8 cm. to 20 cm. But due to shearing the books are often fractured.

A few beryl, amazonite and tourmaline bearing pegmatites occur on the upper slopes of Putha Nar at the back of Seita Baihk (Aputhanar Baihk).

Gittidas Granite Mylonites. The northern part of Gittidas Granite/Gneiss/Mixed Unit in the Lohya Lul-Gittidas—Babusar Pass area close to the MMT is represented by mylonites with some parts (Lohya Lul) strongly folded. These mylonites are well exposed on the Gittidas-Babusar road section. The rock here has become finer grained and developed a strongly planer structure. In addition to crushing and mylonisation it has sufferred low grade retrometamorphism. Biotite may often change to chlorite, garnet may be shattered and chloritised, feldspars are crushed and kaolinised. Muscovite is often shredded. All facies of Gittidas Granite Gneiss here apparently lose their distinctive character and change to similar looking mylonites.

South of the MMT in the Lohya Lul Nar the mylonite unit looks like a chlorite bearing microgranite gneiss. It is hypidioblastic and composed mainly of quartz and feldspar. Muscovite and chlorite are minor to accessory. It differs from the Gittidas Granite unit in having ubiquitous chlorite, being less micaceous and contains lesser garnet and tourmaline at most places. Where shearing is strong it looks schistose, stretching lineation, boudins and microfolding is common near the mouth of this Nala.

Southwestern Contact of Gittidas Granite with Lulu Sar. The Gittidas Granite in Purbi Nar starts near Ghulma (Kar). Here its southwestern contact comes in contact with the Lulu Sar gneisses. The contact zone is about 500 m wide. There is no hornfelsing. The contact is gradational. The Lulu Sar gneisses have been feldspathised. They are now porphyroblastic and subpoikiloblastic. They are composed of quartz, feldspar, and micas (muscovite + biotite). Accessory minerals are garnet, tourmaline, magnetite and aluminosilicates. The feldspathisation is, however, not uniform. Poorly feldspathised zones are also present. The contact zone contains simple unzoned pegmatite veins and microgranite sills and veins.

Northeastern Contact of Gittidas Granite. The northern contact of Gittidas Granite Gneiss in Purbi Nar is a very wide mixed zone. The mixed zone starts near Sadr in Purbi Nar. The host rocks are pelitic gneisses. The mixed zone is 2—5 km wide and contains sheets, sills, dykes and veins of granite, pegmatite swarms, aplite veins, feldspathised and strongly granitised gneisses, pelitic gneisses and amphibolites.

Between Purbi Nar Gali and Ishgah Gali the mixed zone contains a big swarm of simple pegmatites. These are invariably unzoned pegmatites which generally range in size from 0.5 m to 7 m. These are composed of quartz, feldspar, mica and tourmaline. Muscovite books up to 15 cm. across were observed. But they are often sheared. This area also contains granite patches and thin sheets. The following elements were seen in the mixed zone.

1. Acicular (needles up to 25 mm) mica garnetiferous pelitic gneisses. Poorly feldspathised.
2. Highly feldspathised, porphyroblasti and subpoikiloblastic acicular garnetiferou gneisses (common).
3. Muscovite rich silver white to silver grey garnetiferous (small garnets upto 2 mm only) gneisses (subordinate).
4. Dark grey porphyroblastic basic to intermediate gneisses (rare). The porphyroblasts are of feldspar.
5. Non-acicular prophyroblastic feldspathised gneisses (common).
6. Simple mica-tourmaline pegmatites (as swarms).
7. Microgranite veins, sills and dykes (common).

8. Microgranite gneiss (common).
9. Aplites (rare).

This mixed zone is wide, diverse and variably granitised. The northern part of the Gittidas granite gneisses/granite in Lohya Lul-Gittidas-Babu Sar Pass area is represented by mylonites.

Dadar Granite Migmatite Complex

Ghazanfar and Chaudhry (1985) described and discussed migmatites of Rajwal and Dharir units. They considered both these anatectic though they pointed out that the Rajwal unit unit did not contain staurolite, kyanite of sillimanite. Subsequent studies show that the Rajwal migmatite horizon is a localized phenomenon and closely associated with M.C.T. (Ghazanfar and Chaudhry, 1986).

The Dharair migmatites, on the other hand are regional in nature. They were considered by the above workers as the best developed migmatites outside those reported by Misch (1949) from the Nanga Parbat region. However, recent studies have shown that even better migmatisation has developed near Dadar in Dadar Nar. The Dadar migmatite zone in Dadar Nar, in fact, is a sort of continuation of the Dharair migmatites reported earlier. Beautiful exposures of migmatites are found on the left bank slopes of Dadar Nar between Dadar and Gatti. These hard and tough rocks show almost all varieties, forms and compositions. This extensive complex is composed of migmatites, paragneisses, granite gneiss patches and areas of microgranite, porphyritic granite, pegmatites and aplites. The Sharda Group rocks with which these migmatites are associated fall in the upper amphibolite facies, kyanite/sillimanite grades and high grade metamorphism (Chaudhry et al. 1986).

The migmatites show a very wide variety of textural and structural forms. The leucosomes show stromatic, phelabitic and neubilitic structures. The palaeosomes and neosomes show a very complex interrelationship. Agmites and resistites may be conspicuous at places. Schlieren and ghost structures are common. The resistites are amphibolites, calc-pelites, marbles and quartzites. The migmatite terminology preferred here is after Mehnert (1968) and not Ashworth (1985).

This migmatite zone contains quite a few pegmatite and aplite patches, veins and pods. Small patches, pods. veins and bodies of aplitic granite as well as porphyritic granite also occur as neosomes. The palaeosome patches are very often dark grey mica (specially biotite) and garnet rich. The patches may sometimes also contain aluminosilicates. Feldspathised biotite rich psammites may also occur as palaeosomes. These are, in a sense, mesosomes.

The Dadar Granite Migmatite Complex is composed of the following elements :

(1) Partially transformed relics of metapelites (palaeosome).
(2) Partially transformed relics of metapsammites (palaeosome).
(3) A few partially transformed relics of amphibolites (palaeosome).
(4) Patches, fragments and areas of barely transformed quartzites (resistites).
(5) Agmites.
(6) Neubilitic migmatites (abundant).
(7) Anatexites.
(8) Veins, patches and pods of granite (neosome).
(9) Porphyritic granite facies.
(10) Veins, patches and pods of pegmatites and aplites (neosome).

The first five types represent variable admixtures of palaeosome and neosome. The leucosomes and palaeosomes in these cases can be recognised as being in varying stages of reaction and transformation. The palaeosome is mostly a pelite or psammite in varying stages of transformation. It is generally feldspathised and granitized. The palaeosomes may survive either as feldspathised gneisses or as mere schlieren and biotite rich bands. In the latter case ghost structures can be seen. These rocks are composed of feldspar, quartz, abundant biotite, presistent garnet and muscovite. Tourmaline, magnetite and apatite occur as accessories. The individual constituents are very unevenly segregated. The darker minerals may form layers, clots, schlieren and patches. These layers are composed of biotite (rich), garnet, tourmaline, quartz and some feldspar. The light coloured areas are composed mainly of feldspar and quartz with accessory muscovite, garnet, tourmaline and sometimes apatite.

The neubilitic migmatites are much more uniform. But schlieren and ghost relics can still be distinguished. The anatexites are fairly uniform and hypidioblastic to xenoblastic. They are, however, gneissic and are composed of feldspar, quartz, muscovite, biotite, garnet and tourmaline. Rarely sillimanite and kyanite may also occur. However, ghost structures and some schlieren are still present.

Patches, veins and pods of granite. These are massive (non-gneissic) leucocratic and hypidiomorphic. They are composed of feldspar and quartz. Muscovite, biotite, garnet, tourmaline, magnetite and apatite are the accessory minerals. Schlieren and ghost structures are very rare.

The porphyritic granite facies are hypidiomorphic and porphyritic. The phenocrysts are euhedral and randomly oriented. They show a silky sheen. The ground mass is composed of small grains of feldspar, quartz, biotite, muscovite, garnet and tourmaline. This type contains more biotite than the type described above.

Veins, patches and pods of pegmatites and aplites. The pegmatites form veins, patches, pods and lenses. They are from a few cm. to 7 m thick. These are coarse grained, mainly unzoned and composed of feldspar, quartz, muscovite and a little tourmaline, garnet and ilmenite. Some pegmatites also contain beryl, specially at the watershed with Dabukan-da-Nar and left bank slopes of Dadar Nar between Dadar and Reori. Some pegmatites also contain amazonite. Aplites occur as small veins and patches. They show sacchroidal texture and are composed of feldspar, quartz, muscovite, garnet and tourmaline.

North of Reori upto opposite Gatti in Dadar outcrops, however, are predominantly of granite gneiss containing foliated, sheared and massive granite bodies. In this zone migmatites are subordinate.

Jora Migmatite Zone. The area between Reori (in Jora Nala) and around Jora is a migmatite zone, too. The horizon being migmatised and affected by thin granite sheets and intrusions was originally composed of pelites, amphibolites and subordinate calc-pelites. This migmatite zone is characterised by the fact that the amphibolite horizons have been strongly affected and have been strongly migmatised. The pelitic horizons have also been affected moderately but calc-pelites have been least affected. The amphibolite zones have been feldspathised So that now metadiorites and metagranodiorite gneisses have developed. Pegmatitic facies of intermediate composition are also present. The amphibolite zone also contains simple (quartz-feldspar-mica-tourmaline) pegmatites, normal microgranite gneiss patches and thin sheets as well as quartz veins.

Origin of Migmatites, Granite Gneisses and Granites

Origin of Migmatites

Presence of abundant mica and tourmaline in the migmatite complex shows that water and halogens were well-represented, during anatexis. The availability of these volatiles within upper amphibolite facies makes anatexis of suitable lithologies a distinct possibility. Why do some parts of the Shadra Group exhibit anatexis while others do not ? This question will be dealt with at some length. According to Winkler (1967, 1979) anatexis may start at around 650°C and pressures exceeding 2 kb under suitable conditions. Experimental work by Winkler (1974) shows that meta-arkoses and meta-acidic tuffs are first to melt while feldspathic metaquartzites and metapelites follow. The low temperature melting as described above requires water and halogens. The orthoquartzites, calc-pelites and amphibolites survive melting when arkoses, pelitic and meta-tuffaceous rocks reach a stage of advanced diatexis provided, of course, water and volatiles are present. Relevant experimental and geological data is discussed by Walton (1960), Tuttle and Bowen (1958), Tuttle (1955), Winkler (1954, 1967, 1979), Winkler and Platen (1958), Barth (1952) and Ashworth (1985). There are inconsistencies in data and difference of opinion regarding both field terminology and exact conditions of anatexis (for discussion see Ashworth, 1985). However, on the basis of worldwide field evidence and a general review of experimental data it can be said without much reservation that in the presence of water and volatiles, specially halogens anatexis of suitable lithologies takes place in the middle to upper amphibolite facies.

The Sharda Group rocks fall in kyanite/sillimanite grades, upper amphibolite facies, and high grade metamorphism. The lithologies are pelites, psammites, feldspathic psammites, metatuff (?), calc-pelites, marbles and graphite bearing gneisses. Calc-pelites, marbles, amphibolites and orthoquartzites are not involved in anatexis. But suitable pelite, psammite, feldspathic psammite and meta-tuff (?) horizons (wherever water and volatiles were available) appear to have been involved in anatexis. This anatexis has produced not only migmatites but also some granitic bodies. The graphitic gneisses are not significantly involved in anatexis. But presence of graphite is known to raise the temperature of anatexis (Winkler, 1974). Some pelitic horizons are also only slightly affected by anatexis. This may possibly be due to either poor availability of water and halogens or to some compositional characteristic or both. This needs further investigation.

Origin of Granite Gneisses and Granites

The following facts are important, indeed vital, to any discussion on the origin of the granite and granite gneiss bodies of this area.

(1) All the granitic rocks are broadly concordant with the regional structure. They have been folded in a complex fashion alongwith the enclosing metasediments and associated amphibolites. However, minor discordance and splitting and interfingering with the enclosing metasediments is present.

(2) Acid minor bodies of granite pegmatites and aplites within the enclosing rocks are predominantly concordant. However. some cross-cutting granite off-shoots and pegmatites are present.

(3) Hornfelsing at the contact with metasediments though present is very rare. Most contacts are clearly transitional and diffuse. Feldspathised and tourmalinised gneiss and migmatite zones alongwith sills of granites and pegmatites are common. The relatively thin sheet granites have developed from 200 m to

1 km wide feldspathised gneiss and migmatite zones.

(4) The granites are themselves emplaced in kyanite and sillimanite bearing rocks. Thus, appropriate lithologies of pelite-psammite, feldspathic psammites and metatuffs (?) themselves show variable development of partial melting and feldspathisation.

(5) All the granitic rocks are very heterogeneous and composed of the following components.

(i) Microgranite gneiss (banded and layered).

(ii) Migmatite zones.

(iii) Leucocratic massive to slightly foliated microgranites.

(vi) Pegmatites and some aplites.

(v) Feldspathised screens often tourmalinised in various stages of granitisation.

(vi) Garnet amphibolite screens in various stages of feldspathisation.

(vii) Resistites. These are little affected by granitisation and are xenoliths and screens of quartzites, silvery grey to silvery white garnetiferous muscovite rich gneisses, ultrabasic retrogranulite and retroeclogite (?) xenoliths and screens. The ultrabasic slices occur in parts of Gittidas Granite Complex.

6. Of the eight componet types described above microgranite gneiss is predominant with variable associates such as migmatites and feldspathised (often porphyroblastic) gneisses. The leucocratic, massive to poorly foliated microgranites are clearly subordinate to the gneissic facies.

7. The microgranite gneiss which is clearly predominant facies is banded and layered. Dark bands and layers are common. In addition dark coloured schlieren and ghost stratigraphy is also seen. These darker layers are rich in mica (biotite is generally much in excess of muscovite), garnet and tourmaline. They may also contain aluminosilicates. The lighter coloured layers though rich in quartz and feldspar, nevertheless, contain garnet and small amounts of muscovite, biotite and tourmaline. The darker layers and bands may more clearly show flexuring and folding.

8. The feldspathised porphyroblastic gneiss associates are well-foliated and often rich in mica and garnet They may contain sillimanite and sometimes kyanite. The prophyroblasts are of feldspar. If prophyroblasts are removed, these gneisses will look like somewhat feldspathised garnetiferous-alumino-silicate—bearing pelite-psammite gneisses.

9. Migmatite zones are associated with all the granite gneisses. But they are particularly abundant in Dadar Nar. They show phlebitic, stromatic, agmatic as well as neubilitic structures. The anatexites/metatexites are difficult to distinguish from the microgranite gneisses and microgranites.

10. The microgranitic facies are clearly younger than the microgranite gneiss. This facies often cuts across the farbic of the microgranite gneisses. It is often uniform, leucocratic, hypidiomorphic poorly foliated to massive It contains xenoliths and screens of the gneisses and even amphibolite.

11. Pegmatites belong to more than one generation. Some are older, concordant and strongly sheared, others are either concordant or discordant but less sheared to massive. Aplites are rare.

All the above characteristics in terms of P/T regimes (high grade metamorphism accompanied, at places, by anatexis/metatexis of suitable lithologies), mineral composition (presence of ubiquitous garnet, biotite-garnet rich layers and schlierens and relics of alumino-silicates), textures (schlieren, ghost stratigraphy agmites, stromites, neubilites, and phelibites a variety of textural forms), the ubiquitous, association of contact migatites, paucity of contact hornfelses, granitic sheets containing all forms and varieties of migmatites, all show a very intimate genetic association between the granitic bodies and the paragneisses. Slight discordances, splitting and interfingering, incipient and partial anatexis of select lithologies show that these massive leucocratic granite bodies have moved short though variable distance from the place of their origin.

Thus, the granite gneisses and associated minor granite bodies are all (except rarely such as an occurrence on the upper slopes of Besal-di-Khari) S-type (Chappel et al. 1974), and may look like migmatites and granitised/feldspathised paragneisses. Their petrographic and field characteristics have already been discussed. These granite gneiss bodies are mainly pre-tectonic (pre-Himalayan Orogeny) since they have been involved closely in folding along with the Sharda Group paragneisses and amphibolites. Although these S-type granite gneisses have themselves been derived from Sharda Group paragneisses through earlier anatexis.

Minor syntectonic to late-tectonic foliated granitic-granite gneiss bodies, pegmatites and aplites can also be distinguished, on the basis of field relations and fabric analysis. Further. work is required to determine the relative proportion of these bodies. The late-to post-tectonic anatectic garnet-tourmaline granite bodies, simple undeformed pegmatites and aplites are of particular interest. It appears that these bodies belong to two different anatectic phases i.e. anatexis associated with regional metamorphism of Himalayan age and anatexis associated with MCT. Evidence for anatexis associated with regional metamorphism has already been discussed at length. The evidence for anatexis associated with MCT has been discussed by Ghazanfar and Chaudhry (1986) under phenomena associated with MCT in Pakistan.

Correlation with Himalayan Granites

Debon et al. (1981) has divided the Himalayan intrusives in India into the four following types.

(*i*) *Trans-Himalayan Plutons*. These are intruded in an E-W belt north of Tsangpo Structure on the southern edge of the Eurasian plate. They pre-date India-Eurasian collision and are Cretaceous to Eocene in age (50-100 Ma).

(*ii*) *The High Himalayan Leucogranites*. These are emplaced between the Chiatsun Thrust to the north and MCT to the south on the Indian Plate. These are Eocene to Miocene in age (10-50 Ma) and intrude the Palaeozoic and Mesozoic metasediments of the higher Himalaya.

(*iii*) *The Lalogai Kangri granite belt* lies between the Chiatsun Thrust and the Tsangpo Suture, and therefore, between the Trans Himalayan Belt and the High Himalayan leucogranites. These are not related to the Himalayan collision. These may be lower Palaeozoic in age. Le Fort suggests that these granites may represent Palaeozoic gneiss domes which were reactivated during Himalayan collision event.

(*iv*) *The Lesser Himalayan Granites*. They constitute the southern-most granitoid belt. These are probably Cambrian (Le Fort et al. 1980).

The Sharda Group leucogranites (with some associated migmatites) belong to group II) above i.e. Higher Himalayan leucogranites.

The tectonic block in which the Sharda Group granite bodies occur in Pakistan is bounded by MCT to the south and MMT to the north (Ghazanfar and Chaudhry 1986). It is a distinct tectonic block. It is composed of high grade metamorphic gneiss (Middle to Upper Amphibolite Facies) migmatites and sheet granites/gneisses and amphibolites. The high grade gneisses, migmatite and granite gneisses/granites are genetically closely related. The origin of migmatites has already been discussed.

The granites have formed as a result of anatexis of the metasediments of suitable composition and accumulation of the anatectic melts from suitable surrounding rocks as well as from deeper levels.

These granites, and some granite gneisses and migmatites are similar to the garnet, tourmaline and muscovite bearing leucogranites, gneisses and migmatites of the Higher Himalayas described and discussed by Le Fort (1973), Andrieuse et al. (1977), Dietrich et al. (1981), and Searle et al. (1986).

The bulk of these granites, migmatites and granite gneisses are not related to MCT in Kaghan Valley. Small scale migmatisation and minor granite bodies which develop near MCT may be related to the MCT. This has already been discussed by Ghazanfar and Chaudhry (1986). Thus, the migmatites, granite gneisses and sheet granites discussed and described in this paper are not related to MCT frictional heat. These are the result of residual heat of Barrovian metamorphism. This metamorphism is a result of thickening of the crust. Searle et al. (1986) have expressed similar views about leucogranites, gneisses and migmatites of the Higher Himalayas from India. Ghazanfar and Chaudhry (1986) have already placed this block of Kaghan north of MCT in Higher Himalayas for the first time and correlated this with the Higher Himalayas of Kashmir and further east.

However, we do not agree with the above authors on the Tertiary age of all the granite gneisses, migmatites and granites. The undeformed granites and some remobilised migmatites and granite gneisses may belong to Tertiary age. But the fact that the granite gneiss—migmatite bodies have been intricately folded alongwith the paragneisses and amphibolites most of them must pre-date the Himalayan orogeny. What proportion of the granitic/migmatitic bodies is pre-Himalayan and what proportion is Himalayan or post Himalayan requires further work.

Age Relations of Calc-Pelites, Amphibolite and Granite.

Near Seri some sills of granite gneiss coming in contact with the amphibolite band are chilled against amphibolite and even cut it. Similarly near Besal-di-Khari the microgranite cuts amphibolite bands and incorporates small xenoliths of amphibolite. So, the granitic facies of (Besal-di-Khari) micro-granite gneiss is younger than amphibolites which in turn are either younger or contemporaneous with calc-pelites.

STRUCTURE

Two major fold structures have been described, the Burawai Synform and the Besal Antiform. These major features are secondarily deformed and have an irregular outline. Among the relatively smaller fold structures we may list Bans Aniform, Battakundi Antiform, Naran Antiform, Sobhai Synform and the Bela Synform. Two major tectonic scars, the Main Mantle Thrust, MMT, and the Main Central Thrust, MCT, separate the whole Upper Kaghan tectonic block in the north and south respectively. A relatively smaller tectonic scar is the

Sohch Fault which occurs within the Sharda Group lithostratigraphic slab.

Obviously the Precambrian Sharda Group lithostratigraphic slab has passed through a number of deformations. However, only the major structural trends in outline have been described below and no attempt has been made to trace the whole deformation history. The Sharda Group tectonostratigraphic slab has a somewhat wedge-shaped form pointing to the west. This wedge nearly closes in Nili Nadi near Chhalayyan. Even so slices of Sharda Group can be expected to occur further west. The upper Kaghan area comprises large, mainly open folds which have the appearance of structural basins and domes. Tectonically the terrain is a continuation of the Nanga Parbat structure (Misch, 1949) which occurs to the northeast. It is also a continuation of the Higher Himalayas of Kashmir which occur to the east.

Burawai Synform

The Burawai Synform is a very large structure and is best exhibited opposite Burawai at the back of Rakhan village on the right bank of River Kunhar where the dip reversal from SE to NW is prominent in its core.

The fold axis of this structure is curved and deformed but it broadly trends in a NE-SW direction making the structure from Jalkhad in the northeast to Dharian in the southwest nearly 17 miles long. The fold axis on its way passes through or close to Utli Seri, Burawi and the village of Kach (to the south of lake Saiful Muluk). At its widest the Burawai Synform extends for nearly 12 miles in a NW-SE direction from Sapat Gali to Kaghan watershed near East Jora Glacier. Since the Burawai Synform is a large (12×17 mi.) double plunging structure it has the shape of a deformed structural basin.

The northwestern segment of the synform may be called the Bans limb and southeastern segment may be called the Wenjtar (Wetar) limb. Generally speaking the Bans limb trends E-W in the region between Sapat Gali and Utli Seri and NE to SSW in the region between Sapat and Dharian. This limb generally dips to the SE at 35° to 70°. Near Bans Gali, however, the dips become very steep approaching vertical and near Battakundi towards the core the dips are gentle. The Wenjtar limb trends N-S between Jalkhad, Pari and Ratti Gali and ENE to WSW between Jora and Kach. This limb generally dips to the northwest. The dip of this limb generally varies between 40° and 75° but near Ratti Gali village it becomes nearly vertical.

The limbs of the Burawai Synform are themselves folded. One such flexure is prominent near Reori in Jora Nar. The axes of these secondary folds trend NW-SE and represent a later phase of folding.

Minor and parasitic folding in the limbs is common and is especially well-exhibited in calc-pelites and garnetiferous calc-pelitic lithologies. In the pelitic gneisses, on the other hand, crenulations and strainslip cleavage are common while in granite folds may be seen only in the more gneissic part.

The core of the Burawai Synform is comprised of Burawai Gneisses while its limbs are mainly comprised of bands of granite and pelitic gneisses. The last at places have been granitised and migmatized.

Besal Anitform

The Besal Antiform is well-exhibited to the east of Besal on the slopes of Purbinar. This major structure has been only partially mapped because to the west it extends accross the Kohistan watershed into Kohistan or is truncated by the Main Mantle Thrust, MMT. The axis of Besal Antiform appears to trend in an E-W direction but it tends to be arcuate on its two sides becoming SE further east and becoming SW in the west beyond the mapped area. The fold axis on its way passes through or close to Kutawai east of Besal and across the middle reaches of Saadullah Nar towards west.

The Besal Antiform is quite long. In the mapped area it appears to die out near Dudipat lake in the east and extends west to beyond Abumkatha (Bumgatta) Gali, a distance of nearly 12 miles. In a transverse sense the Besal Antiform is over 6 miles across between Thorewala ki Basti in the north and Bans Gali in its south. As against the basin like form of the Burawai Synform the Besal Antiform has a greater length to width ratio.

The northern limb of Besal Antiform may be called the Puthanar limb and the southern limb which is common with Burawai Synform may be called the Bans Gali limb. The Puthanar limb runs E-W between Lulu Sar lake and Thorewala ki Basti but it bends near Duck to trend southeast, obliquely cutting across the Purbinar. This limb generally shows medium to steep dip to the north between Lulu Sar lake and Puthanar Baihk and dips steeply over 60° where it trends southeast across Purbinar. The dip generally increases further northeast towards Babusar Pass and also reverses to the S or SW.

The southern or the Bans Gali limb extends between Bans Gali and Besal di Khari in an eastwest direction and from Besal di Khari it trends northeast towards Purbinar. West of Seri this limb dips steeply to the south but on the left bank of River Kunhar at Kutawai and the Jalkhad ridge it dips rather moderately to the SE.

The limbs of the Besal Antiform, too, are folded and the structures in the core are especially complicated. Generally speaking, however, the folds in the core appear to have NW-SE trending axes which is the same trend as that for the folds developed on the limbs of the Burawai Synform. These folds, too, therefore, indicate a later phase of folding.

The core of the Besal Antiform comprises Besal Gneisses (mainly garnetiferous calc-pelites) but the limbs are comprised of granite gneisses/granites and pelitic gneisses. The Puthanar limb near Duck shows a lot of mixing with granite towards the core and represents a mixed zone occurring to the north and northeast of Besal.

Bans Antiform

It is a relatively small structure in Bans pelites and garnetiferous calc-pelites which can be seen at Bans Bandi. The valley of Bans Katha near its mouth is cutting along it and the two limbs can be seen dipping NE and NW away from Ban Katha.

Sobhai Synform

Complimentary to Bans Antiform a synformal structure can be seen further west on the right bank of River Kunhar between Bans and Battakundi below Sobhai Mahli. It is an open synform with somewhat flat trough indicated by gentle dips. The structure has Bans pelites in the core and calc-pelites on its western limb.

Battakundi Antiform

This antiformal structure with SE plunge is well exhibited by a major band of amphibolite which generally strikes NE between Hans da Nar and Battakundi and NW between Kandore and Shanak.

Naran Antiform

The structure east of Naran is somewhat complicated by what appears to be the presence of a fault on the western contact of Saiful

Muluk Granite. There is need to reinterpret the so-called Naran antiform described as a single major structure by Ghazafar and Chaudhry (1985) and to investigate the structure around Naran further. North of Saiful Muluk Katha on the Leda ridge an antiformal relationship with NW and NE dips can clearly be discerned. The eastern limb of this antiform appears to be faulted at the base of Saiful Muluk Granite Gneiss.

Naran Synform

This is a larger structure and to some degree can be seen on the right bank slopes of River Kunhar opposite Naran township. It is also reflected in the outcrops of minor granite bodies at Leda and in the foliation measurements on the roadside between Naran and Sohch. The dips are NE or N between Batal to some distance north of Naran while they are steep NW from near Dhumduma to Sohch indicating on open asymmetric synform.

Sohch Fault

This fault extends NNE-SSW between Sohch and Ghulma. Near Ghulma it crosses the Saiful Muluk Katha and then moves further SSW along the watershed west of Saiful Muluk lake. The fault plane hades E or ESE and along most of its way marks the contact between Saiful Muluk Granite Gneiss and Naran Gneisses (mainly garnetiferous calc-pelites). Northeast of Sohch the fault enters the Sapat Katha and for some distance moves along it.

Tectonic Style of Upper Kaghan

As becomes quite apparent to a worker in Kaghan Valley the tectonic style in Upper Kaghan between Naran and Babusar Pass (a distance of nearly 40 miles by road) is quite different from that downstream of Batal i.e., Central and Lower Kaghan Valley. The Central and Lower Kaghan is marked by a number of steep dipping thrusts which have piled and stacked fault blocks one over the other leading to a sort of schuppen structure. The fault planes are marked by gouge and brecciation.

In Upper Kaghan the deformation is mainly plastic and faults, at least, are not so readily distinguished. Mylonites occur on both major faults MMT and MCT bounding the Upper Kaghan tectonic block on north and south.

Main Mantle Thrust or Southern Suture Zone

The Indus Tsangpo Suture Zone of the Himalayas splits into two branches in Northwest Himalaya i.e. the Southern and the Northern Sutures also called the Main Mantle Thrust, MMT, and Main Karakoram Thrust, MKT respectively.

The Southern Suture or MMT passes through the north and northwest of Upper Kaghan. From Babusar Pass it moves west along the Kohistan watershed passing through Lohya Lul Nar and then southwest through the uppermost reaches of Ledi Nar, Dhumduma Katha and Nili Nadi moving further southwest to Kohistan and then emerging at Jijal on the Karakorm Highway.

The MMT is characterized by the following features :

(i) a zone of shears and granite mylonites which in Upper Kaghan dips 45-55° to the north and northwest.

(ii) Presence of mantle slices of ultrabasics and slices of old oceanic crust amphibolites and greenstones. Ophiolites are well-known at Jijal and Patan on the Karakorum Highway while Zulfiqar and Chaudhry (1976) had reported some shreds of ultimafics from Babusar. The situation between Babusar and Nili Nadi has now revealed (Ghazanfar and Chaudhry 1986) prominent and major outcrops of dunites, peridotites and pyroxenites attacked and intruded by later acid volcanic and plutonic rocks, andesites, dacites, tuffs, agglomerates and diorites.

(iii) there is a sudden drop in metamorphic grade from the upper amphibolite facies to the south to the greenschist facies in the north as we move across the suture. A zone of low grade graphitic schists greenstone and limestones generally occurs at the base just above the mylonites and marks the beginning of the Kohistan Sequence.

Main Central Thrust

This tectonic scar of great significance had been known in India but not in Pakistan. Recent work in Neelum and Kaghan Valleys has shown it to pass through Upper Kaghan Valley at Batal (near Naran) and Chhalayyan in Nili Nadi (Ghazanfar and Chaudhry, 1986). The MCT in Kaghan Valley separates the Mid-to Early Precambrian basement block of Sharda Group comprising the Upper Kaghan tectonic slab from the Kaghan Group marked by a zone of thrusts, the Pakistani equivalent of Himalayan Schuppen Zone.

The MCT in Kaghan is marked by mylonites and is generally a high angle fault dipping 30° to 55° NE. The MCT in Kaghan Valley is associated with :

(i) a break between two different lithostratigraphic regimes. The Kaghan Group on the south is mainly pelites, calc-schists, marbles, graphitic schists and prominent quartzites. The Sharda Group on the north is mainly calc-pelites, marbles, pelites, amphibolites and granites.

(ii) a break between two different tectonic styles, a number of fold blocks separated by thrusts in the south as against the much larger structures without much brittle deformation in the north.

(iii) a P-T break represented by Lower Amphibolite facies (garnet grade) to the south and Upper Amphibolite facies (kyanite/sillimanite grade) to the north.

(iv) a zone of mylonites which, at places, is more than one km wide.

GEOMORPHOLOGY

Other than the geomorphic note accompanying the geology of Bhunja-Battakundi area, Central Kaghan Valley (Ghazanfar and Chaudhry, 1985), no previous work exists on the geomorphology of the region. The present work, therefore, is a continuation of the above mentioned. This first time report is, of necessity, regional and qualitative. A picture of structure, process and qualitative form emerges and the overall plan of the geomorphology of a vast tract is presented.

Geographically we may consider the Upper Kaghan area to extend between Naran and Babusar Pass, a stretch of valley nearly 40 miles long in a N-S direction. This part of Kaghan has its southeastern watershed (the Kaghan watershed) with Neelum Valley of Azad Kashmir and its north-western watershed (the Kohistan watershed) with Kohistan area. The northeastern watershed of Upper Kaghan adjoins parts of district Diamir and Azad Kashmir.

Upper Kaghan is a high relief mountainous region with altitudes varying between 7000 ft. at river level near Batal to over 17000 ft. at Mahli Ka Parbat. Peaks over 15000 ft. are common along the watersheds. The highest passes and peaks remain snow covered througout the year but fluvial processes are by far the dominant current geomorphic processes. It is obvious that in the glacial periods the cover of ice was far more extensive and permanent and the glacial imprint over the landforms of Upper Kaghan even today is charcteristic and distinctive.

In Pakistan within the Himalayas Upper Kaghan stands out as an area where glaciation has left its indelible mark outside the domain of Karakorams. Glacial features become markedly conspicuous above 10500 ft (3200 m) altitude. Most major tributary valleys along the long profile can be subdivided into two segments, the upper glaciated trough and the lower fluvially sculptured segment with a short transition knickpoint. Most of the landscape features can be studied with respect to these two segments. The zone of glacial troughs is the zone of alpine sculptures. Later fluvial sculpture has mostly erased glacial features below the level of glacial troughs. Some glacial features, however, appear at much lower altitude close to the main valley of River Kunhar, especially around its junction with major tributaries, in the form of large morainic deposits.

We begin our account with a description of the glacial trough and the features located along its floor. A description of the features related to the cross-profile of River Kunhar and its major tributaries, both in the fluvial and glacial segments then follows. This is mainly a qualitative account of deposits and of slopes and their surface features. Next we deal with lakes, prominent features of the alpine topography, separately. Finally a consolidated account of the depositional features, so prominent in the terrain, follows. There is also a section on discussion and conclusion at the end.

The Valleys

Almost all major valleys in the Upper Kaghan area have a lower fluvial segment and after an intervening knickpoint transition zone an upper glacial segment followed by a headwater zone. The knickpoint occurs at a variable altitude and in fact there may be more than one knickpoints between the altitudes of 10500 and 12500 ft. It is generally the upper knickpoint around 12000 ft. which marks the beginning of the glacial trough with all its characteristic cross-profile and landforms.

The knickpoints are generally not marked by waterfalls (except occasionally as in Dunga Katha) but by relatively steep segments of slope each extending over some 300 to 400 ft. of altitude.

Fluvial Segment

The long profile of fluvial segment below the transitional sections is relatively steep marked by frequent rapids, turbulent flow and coarse load. The cross-profile is marked by long streamside cliffs, for the population living up the valley generally one good path follows above this streamside cliff although another one may follow along the stream bed where possible. This steep V-shaped segment of the stream is filled with snow in winters and if the snowfall was heavy some snow bridges may persist through the summer over this lower section. At places this lower steep segment can be gorge like as in Bans Katha. The lower fluvial segment can cover nearly half the length of major tributaries.

Transition segment

The transitional segment which joins the lower fluvial part of valley with the upper glacial trough is marked by a noticeable steepening of the profile and rapids. As mentioned above, in fact, there are, commonly, more than one such knickpoints each extending over few hundred feet in altitude between 10500 and 12500 ft. Generally the first one around 10500 is more marked. The valley starts opening above it but the characteristic glacial trough with its broad open floor really becomes striking above about 12500 ft. altitude.

In the valley of River Kunhar itself the first major knickpoint occurs upstream of Besal and extends to the village Duck at the outlet of Lake Lulu Sar. The local word Duck in fact means an obstruction or narrowing of the valley creating a rapid. Thus, a village called Duck is also found in Jalkhad Nar where the transitional segment of the valley occurs.

Glacial Trough

After the knickpoints zone around 12000 ft. the valleys of the main tributaries of Kunhar in Upper Kaghan and of the valley of River Kunhar itself marked by Gittidas Nala upstream of Alaso Baihk almost abruptly open up and become noticeably gentle with a markedly wide valley floor through which a slow-moving stream proceeds in a meandering fashion. This segment can extend from 2 to 4 miles or more in length until we reach the headwater zone. This upper gentle segment of the valleys comprises the main "mahlies" or pasturelands of Upper Kaghan, being low-relief gentle, wide, and covered with lush green grass.

In the Putha Nar (Aputha Nar on map) the upper gentle segment occurs upstream of Thore wala ki Basti (village) at height above 12500 ft. In the Purbi Nar the upper gentle segment starts above 11800 ft. At 12000 ft. there is a second series of rapids after which the valley opens still further.

The stream in this segment not only becomes gentle and slow but also forms marshes and occasional meander cutoffs. Generally, however, this flat floor on the sides is bound by a low relief platform made by glaciofluvial fans, low transverse moraines, scree cones and aprons coming from sides and boulder cones.

The cross-profile of the upper flat segment or the glacial trough is markedly asymmetric with long slopes on one side and short on the other. In general the south facing slopes are short and cliffy and the north facing slope protected from sun is relatively gentler and longer. A cross-section taken through different (upper reaches, lower reaches) parts of the glacial trough is different as the various slope elements increase decrease or disappear. In general it may be likened to an asymmetric open U or an asymmetric V with a broad rounded bottom. The gentler side near its upper ends gets complicated developing a number of scoops or cirques.

Morainic Aprons. The morainic aprons are long, slightly convex middle slopes which flank the longer side of the asymmetric profile. This is the side relatively more protected from the Sun. The morainic aprons are characterised by a cover of morainic debris which is left in place when the snow cover recedes. This morainic debris has developed a thick soil which is poorly drained and humpy on surface. The slope is grassy though the grass is neither so thick nor so lush as on the lower slope segments. The morainic apron is characterised by numerous small shallow channels, seepages and depressions which are generally filled with a concentration of boulders—'Kaar'. Most of the 'Kaar' however, occurs at the lower boundary of the morainic apron, just above the morainic platform.

Where some big tributary valleys are closely spaced the morainic aprons between them develop the form of tent shaped truncated spurs as in Jalkhad Nar.

Scree Aprons and Cones. Generally the shorter and steeper side of the glacial trough is the one exposed to the Sun. This side may develop 3 or 4 slope segments each forming a distinct landform i.e. from top to bottom upper cliffs, scree aprons or cones, morainic platform or a concave footslope and, at places, even some floodplain. However, cliffs and the scree aprons and cones are the only well-developed landforms on this side. The other lower slope elements may be poorly developed or absent altogether.

The scree aprons of the glacial trough are the equivalent of the morainic aprons and represent fairly continuous stretches of loose debris. The gravity propelled loose debris of scree aprons is generally coarse but of a variable size. This scree shows a much greater mobility compared to that on morainic aprons. The size of the scree becomes coarser towards the lower end of the slope and concentrations of 'Kaar' may develop above the platform (if one is present as at Tato Butt (Chitta Watta Baihk). Elsewhere the scree aprons suffer sliding or undercutting by stream leading to a steep bluff.

Scree cones usually develop in the lower, now fluvial, reaches of the stream. Here scree cones from the lower part of the slope which comprises cliffs above. As we move in the glaciated segment the cliff tends to disappear and the scree cones (now aprons) become more continuous merging sideways and extending up right to the top of the ridge.

Morainic Platform. The morainic platform occurs below and is separated from the morainic aprons by a marked negative break of slope. Its morainic material is covered with a soil on which lush green grass grows in summer. This generally wide platform has gentle but marked slope towards the stream. This platform may have more than one levels and merges, with another concave break, into the floodplain below wherever the latter occurs. We may consider the morainic platform to represent a ground moraine and at places kame terraces.

The morainic platform especially in the lower reaches of the glacial trough where it directly bounds the stream (the floodplain being absent) stands above it with a bluff which increases in height downstream. In the Ratti Gali Nar near Nazarewali Baihk it is 20—30 ft. high. Near Deschali another bench can be seen at a still higher level.

The morainic platform generally shows a low relief created by small streams running across it. Many of these small streams originate at the concave break of slope above with the morainic apron and make the platform boggy at places.

Where the platform is continuous over a long distance it comprises more than one type of landforms including glacifluvial fans/cones at the mouth of streams. These latter are now raised and dissected alongwith the platform and to a lesser or greater degree merge into that part of platform which occurs in front of morainic aprons. The fans are distinguished by less grass or greater amount of scattered boulders.

Villages are generally located on the upper margin of the morainic platform where it is less boggy.

The morainic platform of the glacial trough probably correlates with the major ground moraine terrace at Tato Butt, Burawai and Battakundi as discussed under depositional landforms.

Glaciofluvial Fans. The glaciofluvial fans are found at the mouth of many tributary streams draining from the longer side slope into the glacial trough. Many of these old glaciofluvial fans are now being dissected by a network of narrow entrenched streamlets which flow radially outwards from the edge of the fan. The stream at the back of a glaciofluvial fan may lead up to a high level moraine with a cirque at its back.

The glaciofluvial fans generally coalesce into the morainic platform and the whole is dissected by shallow streams. This lends relief and irregularity to the surface of the sides of the glacial trough. Due to dissection the glaciofluvial fans, at places, develop a rib-like form with a relief that increases downslope and can vary locally between 5 and 20 ft. The dissected fan presents either a raised bluff to the stream or a gentle slope.

The smaller of these fans have angular boulders or cobbles scattered on the surface with the coarser material towards the top.

Trough Floodplain. Apart from the platforms bounding the stream there are, at places, some nearly flat and frequently boggy stretches of plain. These may be present on one or both sides of the stream and represent the flatest parts of the trough. In the Purbi Nar where present on both sides of the stream the flat stretch is some half a kilometer wide. When traversed parallel to the main stream the flat stretch has a gently undulating to nearly flat profile through which flows a freely meandering stream showing generally a laminar flow.

The material of the flat floodplain mainly comprises a layered sequence of fine sand and silt/clay and burried carbonaceous material (old grass). A section on the side of an entrentched stream in the Jalkhad shows the carbonaceous layers to be one 15 cm thick with thicker, 5 to 25 cm, intervening layers of silt. We may, therefore, treat the flat floodplain as post glacial fluvial floodplain.

In the Purbi Nar the flat portions of the grassy platform appear to occur in front of the spurs while the grassy or stony glaciofluvial fans/cones occur in front of the main tributaries to the glacial trough. Between Hamza Basti (village) and Sadr village the flat floodplain is flanked on the sides by grassy morainic platform partially covered with loose openly spread rock fragments.

In the Jalkhad Nar the flat boggy parts of the floodplain are traversed by meandering tributary streamlets which originate at the end of morainic platform or morainic aprons or a glaciofluvial fan/cone. These finally drain into main stream. Occasionally upto 200 metres wide shallow lakes are found on the boggy flat.

In the Jalkhad Nar a narrow strip of the floodplain besides the main stream is slightly raised like a riverside levee, drains better and backwards and is consequently shown by a greener and fresher strip of grass.

Kaar—The Boulder Cones. Kaar is the local term for concentration of boulders. Two types may be differentiated, the fossil Kaar and the active Kaar. Most of the fossil Kaar occurs on the longer, sun protected slopes and most of the active Kaar is related to scree aprons and fans.

Fan- or pear-shaped accumulations of large sized (1 to 6 ft.) angular boulders, generally joint blocks, are common in depression on the morainic aprons as well as at the foot of morainic aprons drained by shallow channels and seepages in the upper reaches of major tributaries like Gittidas Nala, Purbi Nar, Jalkhad Nar, Bans Katha, etc. These accumulations do not have any fine material between the boulders. Instead there are gaping spaces. These deposits must have been there for a long time and are not modified from year to year. This is evidenced by the stable relationship of these boulders which can be jumped over without moving them and also by the fact that some villages like Lalian di Bhaik in Jalkhad Nar are located very close to some major boulder accumulations. Some boulders on the upper surface show weathering and differential erosion, too.

The cliff faces, above the debris slope (morainic aprons) may also have accumulations of boulders in front of the cirques. Like the cirques themselves there may, at times, be more than one levels of these boulder accumulations, a lower Kaar and one or two upper Kaars. The boulder accumulations associated with cirques are, however, relatively fresher.

Accumulations of coarse material may also occur at the lower end of loose scree aprons especially where they form on granite as at Tato Butt and Alaso Baihk in Gittidas Nala. These accumulations, also called Kaar, in addition, contain smaller sized fragments.

The Kaar represents an accumulation of frost wedged boulders and their fossilized nature indicates they are a product of a past glacial time.

Frost wedging is one of the frozen ground phenomena and implies a climate in which the temperature fluctuates so as to freeze the ground at least once a year. Such a climate differs from one in which merely the air temperatures at the surface traverse the freezing point, (Flint, 1957). Frost wedging is one of the principal processes of weathering (mechanical) in Upper Kaghan Valley where a moist climate with frequent freezing and thawing helps it. The frost wedged boulders originate on upper cliffs and are then moved down by mass wasting assisted by glacial transport. The boulders are local and indicate movement from above and not from the side.

Push Moraines/Recessional Moraines. Another feature on the gentle floor of the glacial trough are occasional low spurs transverse to the main valleys which appear especially on the side, the valley slope is longer. These have been cut by the main stream to make a bluff besides it. Near the main stream these transverse spurs have a back slope (2.5° to 5° on one in Jalkhad Nar). In the Purbi Nar some villages are located at the back of these berm like features. These transverse low ridges apparently represent push moraines or recessional moraines.

Such features may, at times, assume the form of isolated low mounds with a gentle slope towards valley side-slope and steep bluff towards the stream. They then look like inverted half spoons. In the Putha Nar such smaller features closer to the side slope give the appearance of landslided material from the slope above.

Apart from the above features, at times, instead of a proper glaciofluvial fan one notices a gentle spur like feature on one or both sides of of a stream. Such a slope has a fair amount of open boulders and cobbles scattered over it. Between such features the mountain side is recessed and a low, flat, often boggy plain occurs through which the main stream meanders.

Headwater Zone

The upper gentle segment in the last one mile or more starts rising in slope and the landscape becomes irregular, hummocky and hilly, at times with a number of small cirque lakes as in Ishgah Nar, Kamarbashi Nar and Putha Nar, or one major lake like Dudipat Sar at the back of end-moraines. A number of cirques start forming in the side tributaries, too, in the headwater zone but the main passible gali (saddle or pass) may be free of a cirque, like the Ratti Gali at the head of Jora Nar and the Nuri Nar Gali at the head of Jalkhad Nar.

We may divide the headwater zone into two parts, the upper, cirque zone, and the lower trough headwall zone. The cirque zone comprises the ice-scoured and gouged depressions now occupied by lakes plus the steep cirque headwall at the back.

Cirques. Ice scoured and gouged depressions, cirques or corries, now occupied by lakes are a frequent and characteristic mark of glacial erosion at the head of glacial troughs. Each depression has the shape of a lawn chair with a high back, the cirque headwall, a backward sloping depression in the middle, the basin, and a rock ledge in front. The frontal rock ledge is preserved to a variable degree and is now generally covered by shattered and frost wedged debris or moraine. The ledge is now entrenched by the outlet channel.

When the cirque was occupied by a glacier lake in glacial times the cirque headwall at its back was most likely free of all frost wedged debris but now a variable amount of shattered debris accumulates under or on the cirque headwall.

In the Kaghan Valley occasionally two or more cirques appear one above the other on the same slope and form a cirque stairway. These are perhaps the result of a sequence of occupations by small glaciers during a series of advances and retreats. One such stairway occurs in the Thanda Nar near Chittawatta Baihk (Tato Butt) and can be seen from the roadside.

Adjacent as well as cirques on opposite sides of a watershed can lead to a number of conical peaks, horns, and a sharp ridge top. At places two cirques/corries are developed one above the other in a sort of step like sequence. However, cirques are not developed in all headwater zones.

The ledge downstream of the cirque basin is enterenched by the outlet channel which further below then flows in the form of rapids over a relatively steep segment of slope, the trough headwall, between the ledge and the flat part of the glacial trough.

The hummocky and irregular topography in the headwater zone is a consequence of the combined depositional and erosional processes and features.

Terminal Moraines. The terminal moraines are found in the headwater zones of the major tributaries of river Kunhar especially where some lake or cirques are found at the head of the glacial trough. They are prominent downstream of Dudipat Sar (lake) in the Purbi Nar and near Bans Gali in Putha Nar and Bans Katha. These deposits are characterized by uneven topography and accumulations of boulders.

Terminal moraines are also common at the downstream frontal ledges of all cirques at high levels.

A fairly big deposit, perhaps in part a terminal moraine is found between Besal and Duck villages downstream of Lulu Sar lake. A somewhat similar terminal moraine is found at the outlet of lake Saiful Muluk. The material of the moraines at the outlets of lakes Saiful Muluk and Lulu Sar is mostly local and has suffered minimal transport. It is like frost wedged material with a matrix. But the matrix has been largely removed at Besal where the material now resembles a Kaar (concentration of boulders). To a degree it resembles protalus ramparts (Daly 1912, Bryan 1941) coarse fragments sliding down the firm bank and accumulating at its toe as a ridge.

Boulder Pavement. In the trough headwall part of the headwater zone there are sections of valley floor comprising boulder pavements.

It is interesting to see a mosaic of boulders as if compressed with a road roller; flattened, and forming a smooth gentle pavement. Such pavements are found at a number of places including uppermost parts of the glacial troughs of Ratti Gali Nar and Ledi Nar. Deflation and water has removed the finer grain sizes leaving the coarse fraction unmoved as a lag concentrate which has taken the form of a flat stone pavement due to sheet erosion and compression by ice.

The headwater zone of major streams holds a commanding position over a network of navigational routes. A number of galis (saddles or passes are set fairly close to each other providing routes to an array of distant localities.

A variety and mixture of depositional features are characteristic of the Upper Kaghan landscape. Among these are glacial, glaciofluvial colluvial and fluvial types and mixtures of these. A part description of these features has been given while discussing the landforms of the glacial trough. This account relates mainly to the features appearing along the valley of River Kunhar.

Glaciofluvial fans

Morainic Platforms or Maidans at Battakundi and Burawai.

Lateral Moraines

Scree Aprons

Fluvial Terraces

Depositional Landforms

Glaciofluvial Fans

They accumulate at the mouths of the main tributaries to such major Nars as Purbi Nar, Jalkhad Nar, Putha Nar, etc. especially on the longer side of the asymmetric crossprofile. In the glacial trough the glaciofluvial fans coalesce together and with other deposits to give a raised undulating morainic platform which drains towards the stream. The fans have a concave long profile with an overall angle of nearly 24° but become rapidly gentle towards the stream. They have a convex transverse profile. They are traversed by shallow tributaries which flow radially outwards towards the main stream giving the fan surface a relief of upto 10 ft.

Major and prominent glaciofluvial fans also occur at places along the main valley of River Kunhar. One such place is the Seri area between Burawai and Jalkhad. Here a number of glaciofluvial fans are found in a complex of other scree and terrace deposits. Some fans occurring here show steps, the upper fan having been dissected to produce a second fan at lower level. The upper fan is steeper and its middle preserved part shows a riverward slope of about 15°.

The fans and deposits at Jalkhad further upstream are distinguished from those at Seri in having much more coarser fragments and boulders. It is because the Jalkhad deposits comprise mainly granitic material as against the soft calc-pelitic material of Seri deposits.

In the Wenjtar depression glacial and glaciofluvial deposits again abound. Scree aprons and high lateral moraines have been dissected to produce glaciofluvial fans and cones below. Similarly the high lateral and end moraines on the sides of major streams here have been breached to form glaciofluvial fans on the sides. The more than 200 ft. high closed hookshaped lateral and end moraines of the Wenjtar ka Katha have been punctured both upstream and downstream to produce two fans. Two big glaciofluvial fans adjacent to each other (bluffs 80 ft. and 2o ft. from river level) have been formed by the breaching and reworking of the lateral moraines besides Jabba ka Katha. The material of these fans is coarser towards apex and shows slight rounding indicating short distance transport. The fan has a strong convex curvature in a transverse sense.

Mainly fluvial fans are found at the mouths of major streams like Sapat, Lidi and Dhumdama further down the valley of River Kunhar.

Morainic Platforms at Battakundi and Burawai

Extensive morainic and glaciofluvial deposits occur at the mouths of major tributaries to River Kunhar in the Burawai-Battakundi Section. Those at the mouths of Jora Nala at Battakundi have been called Maidans. Similar flats also occur at the mouths of Lohya Lul Nar (Tato Butt) and Bans Katha (Bans Bandi). The maidan or Jora village is inside the Jora Nala and is smaller but is similar to those mentioned above. The Dumri Maidan at Battakundi is the most extensive followed by the Maidan at Burawai. Both these comprise of a complex of depositional landforms. One type of material is morainic. It is higher, more irregular on surface and occurs on the sides of Jora Nala and Dadar Nar. The other type of material is glaciofluvial. It occurs in the form of one or two levels of crescent shaped flat topped terraces besides the tributary Nars close to their confluence with River Kunhar.

The morainic material at Battakundi and Burawai comprises lateral moraines and ground moraines perhaps with a component of end moraine depending upon the place of their occurrence. These various types, however, merge into each other and into the glaciofluvial material and cannot be very sharply demarcated. The lateral moraines, however, occur to the sides and extend towards the River Kunhar from the bank spurs of Jora Nala and Dadar Nar.

The lateral moraines form the highest deposits (200 to 500 ft. from river level). They occur in the form of arms extending towards River Kunhar, their height increasing fast towards the mountain side. At Battakundi the uppermost level of the morainic arm which extends towards River Kunhar from the right bank spur of the Dadar Nar is 300 to 500 ft. higher than the river level and its top is irregular. On the left bank of Dadar Nar on the Lalazar side it is even higher.

The lateral moraines towards the riverside merge with ground moraines laterally towards Dadar Nar and Jora Nala. The ground moraines and end moraines are hummocky and irregular on surface and their part besides the River Kunhar might be considered an end moraine. At Battakundi Maidan this relief appears to take on the shape of inverted spoon shaped features which look like drumlins. A few such features are also found on the ground moraine at the confluence of the Jora Nars. The drumlins at Battakundi Dumri Maidan indicate sheet like glaciation in a limited area. A lake is found in the depression between low mounds at Jora while the relatively wider flat between drumlins type features at Battakundi are under potato-cultivation.

A glaciofluvial terrace with a gentle slope and flat top has been laid down on the inner side (towards Dadar Nar) of the moraines. This terrace level occurs about 100 ft. above Dadar Nar mainly on the right bank. The drumlin level occurs above it (150-300 ft. from Dadar Nar) but below the level of right bank lateral moraine This hummocky ground moraine level skirts around the glaciofluvial terrace and extends as a sort of end moraine of Dadar Nar making a high bluff on the left bank of River Kunhar.

The lateral moraine on the right bank of Jora Nala at Burawai likewise forms the highest (upto 300 ft. from river level) of the depositional landforms complex. Laterally towards the Jora Nar it merges with a ground moraine which is irregular on top and in turn gives away further towards Jora Nala to a crescentic glaciofluvial terrace (about 50 ft. from Jora Nala) on which the Burawai bazar and the rest house are located. There is still another lower smaller fluvial flat besides the Jora Nala.

The Rakhan village is located on a terrace about 100 ft. above river level on the right bank opposite Burawai. This terrace appears to be the same level as that of Burawai ground moraine. The Rakhan-Dharair area however at the back of the Rakhan terrace and further downstream also receives a number of scree aprons and one major glaciofluvial fan.

The flat ridge-like terrace at Bans Bandi on the left bank of Bans Katha looks like a lateral moraine but it has a nearly flat top and more likely correlates with the ground moraine level of Burawai and the Rakhan terrace.

The nearly flat terrace at Tato Butt (Chittawatta Baihk) is again a ground moraine/morainic platform though it's height above the stream is not as much, being in a much higher upper reach of the river compared to Burawai ground moraine.

The Shili wala Bela on the left bank downstream of Burawai is a terrace level about 30–40 ft. from river level. It may be correlated with the Burawai glaciofluvial terrace or with a lower level glaciofluvial terrace of River Kunhar.

Lateral Moraine

The lateral moraines are high ridge-shaped deposits found at the mouths of some major tributaries to River Kunhar. Those occurring at Burawai and Battakundi have already been discussed in the previous section. The lateral moraines, however, become particularly prominent at those places where they are not accompanied by major glacial/glaciofluvial platforms or maidans. Thus, those at Dunga Katha and Dabukan da Nar are particularly striking. They are linear ridge like and curved downstream towards Kunhar. The arcuate hook like nature of these ridges shows they are lateral moraines of tributary streams, which curved to join the trunk glacier. These high morainic arms (rising 200 to 500 ft. above river level) extend as a sort of continuation of the rocky spur towards the river. Towards the stream, Dunga Katha or Dabukan da Nar these lateral moraines, which have variable height and may have regular or irregular upper surface are replaced by the lower level ground moraine or by a glaciofluvial terrace/fan which has a relatively more even surface and gentler slope. Still lower levels of glaciofluvial terraces can exist closer to the stream each with an increasingly flatter surface.

Scree Aprons and Cones

The scree aprons and cones are ubiquitous and prominent depositional landform of Kunhar Valley especially between Jalkhad and Naran. What we here refer to as aprons means only a continuous cover of scree instead of separate cones.

In the section of River Kunhar mentioned above prominent and thick scree deposits are found on the right bank at Seri, around Rakhan and opposite old Battakundi. They are also found at Jabba, Wenjtar, and from old Battakundi to uptil opposite Sohch and Dhumduma on the left bank of River Kunhar. The scree deposits have also been discussed under landforms of glacial trough as morainic aprons and scree aprons.

We can differentiate three main types among the scree deposits, stable morainic aprons, loose scree aprons, glacial trough and the glaciocolluvial aprons. The first two types are more common in the glacial trough and have been discussed under landforms of glacial trough.

The third type, the concave glaciocolluvial occurs at many places along the slopes of main Kunhar Valley as mentioaed above e.g. around Rakhan, around Kandore and around Sohni. They generally comprise a cocave fluvial slope occurring below cliff faces. The material is mainly fine grained with admixture of boulders etc. They may show a very poor layering in cross-section. The deposit thickens downwards and close to the river where it may either make one or two bluffs by river side. In other cases it may be dissected by shallow streams which leads to the formation of a glaciofluvial cone at a lower level. The concave scree aprons occurring around Sohni and downstream uptil opposite Sohch village show one or two bluffs besides the river. At places, however, the bluff and the apron have been dissected by shallow streams to produce scree cones in the lower part.

At many places the scree aprons end on ground morainic or glaciofluvial terraces besides the river.

The glaciocolluvial aprons are stable and at many places support vegetation, conifers or herbs like Ghanula.

Some loose scree aprons also occur in the main Kunhar Valley apart from those in the glaciated troughs. One such place is the right bank section between Tato Butt and Gittidas Nala inlet to Lulu Sar. Here scree cones and aprons predominate below the cliffs in Gittidas Granite. Another place is the left bank depression between Jabba and Babun. Loose coarse scree cones coalesce to form aprons, again with cliffs of Babun granite above.

Fluvial Terraces

Apart from the fluvial flats of glacial troughs not many fluvial terraces are to be found in the Upper Kaghan region. Some flat topped fluvial terraces have developed between Utli Seri and Wenjtar. The lower level 10 to 30 ft above river level is more extensive. They are generally littered with boulders on top. The upper level 70 to 80 ft. above river is more restricted. It is developed near Tarli Seri and here its material is seen to comprise fine sand and some silt. Towards the mountain side these flats merge with fans and scree cones. Some low flats are also developed besides the river at places between Battakundi and Naran.

The Naran terrace is complex being partly of fluvial origin and partly a glaciofluvial fan contributed by left bank tributaries like the Saiful Muluk Katha, Gorian Katha, etc.

Lakes

Lakes of various sizes and origins are an important feature of the landscape upstream of Naran. Most of these lakes occur in valleys, especially in their upper reaches, many being in the headwater zones of glacial troughs. According to their origin we may list them as follows :

Damming lakes and slow stretches of Rivers

Cirque lakes or tarns

Kettle lakes

Ground moraine lakes

Meander zone lakes

Damming Lakes or Slow Stretches

These lakes or more appropriately slow stretches are a frequent feature along the major tributaries of River Kunhar and along River Kunhar itself. These are formed in the main river itself between Naran Lulu Sar or in the main streams in Upper Kunhar stretches which are subject to snow avalanching, glacial slides, dumping of glaciofluvial or landslides at present or have been in the past. A fan, a glacial avalanche or slide from a tributary dumps an enormous amount of material in the path of the stream which is temporarily blocked at least partially forming a lake at the back. As the stream continues to flow over this newly created barrier, the latter is gradually eroded and lowered. At the same time silt and fine sand settle at the back of the low dam. The lake thus is gradually shallowed, reduced to a braided stretch with channel bars and finally disappears altogether. A number of such partial blockades have formed along River Kunhar north of Naran. The one upstream of Naran and those at Wenjtar and upstream of Jalkhad at Kutawai are the most prominent. Such slow stretches have a constricted outlet over which the water flows with a rapid.

Even the big lakes Saiful Muluk and Lulu Sar also have a damming component. Although they both fill ice gouged depressions the streams continue at their back and their outlet is blocked, at least partially, by moraines at an altitude near 10500 ft.

Relatively smaller damming lakes other than on the river itself are built by many major tributaries as by Jora Nala near Reori, by Bans Katha north of Dila, by Purbi Nar at places and by Nili Nadi near Chhalayyan. The last is now nearly drained.

The upper flat segments of the valleys represent glaical troughs. Series of lakes in glacial troughs have been called paternoster lakes. They have been ascribed various origins some of them based on differential erosion. However, in Upper Kaghan, commonly shallow or slow stretches of the river in general, appear to result from damming.

Cirque Lakes or Tarns

At the highest reaches of the glacial troughs just near the watershed lakes are frequent. Most of these have an erosional origin and occupy cirque basins. The snow-gouged basins are now filled with water to form lakes with a few glacial patches, still preserved during summer, at the back on the lower part of the cirque headwall.

The beautiful and famous Dudipat lake at the head of the Purbi Nar is a cirque lake. It is about a kilometre across. However, it has been silted up to a fair degree and unless some artificial damming is provided this beautiful phenomenon is thereatened with extinction. Of course there are many other small tarns at the heads of the tributary valleys to Purbi Nar and at the heads of Ishgah Nar, Kamarbashi Nar, Gittidas Nala, Putha Nar (Aputha Nar), etc.

Not all the lakes in the headwater zone of major tributaries are erosional. At least some are formed in the depressions within end moraines or in the valley segments back of the end moraines.

The two largest and most famous lakes of Kaghan Valley are the Saiful Muluk Lake near Naran and the Lulu Sar Lake near Besal. The lakes, at least in part, owe their origin to ice gouging and will be discussed here along the cirque lakes.

Saiful Muluk Lake. This famous tourist resort near Naran is formed towards the head of the Saiful Muluk Nala but not quite at the head. One tends to get the wrong impression that the Saiful Muluk Nala ends at the lake. In fact it continues for many miles further back of the lake. The lake is formed just at the back of a knick point in the valley where the lower fluvial segment of the Saiful Muluk valley meets the upper glaciated segment of the valley. The lowermost part of the glaciated segment has been dammed by an end moraine and a rock ledge, back of which the depression has been partly scoured by snow accumulation. Now it is filled by lake which overflows and has trenched the end moraine. The upstream part of the glacial segment of the Saiful Muluk Nala drains into the lake building a delta fan at the back of the lake near village Dharian.

The Saiful Muluk lake thus has, in main, an erosional origin.

Lulu Sar Lake. The lower reaches of Gittidas Nala and Putha Nar flow towards each other along a SW-NE trend and drain into the Lulu Sar. The trend of River Kunhar which starts at the outlet of Lulu Sar and moves towards Besal on the other hand is nearly at right angles. The left bank spur of Gittidas Nala extends into Lulu Sar and given the lake its peculiar kidney shape. The main spur which dams the lake on its lower end, however, is the continuation of Saadullah Nar-Putha Nar watershed. This is now totally covered with frost shattered material and moraine giving it an irregular and hummocky shape. The cover of frost riven boulders, however does show solid rock outcrop underneath. Apparently the Saadullah Nar-Putha Nar spur once constituted a continuous barrier covered with end morain in front of the Lake. At that time Lulu Sar was a sort of midway cirque which received glaciers from Gittidas and Putha Nar. Later the outlet spur ledge was breached and the Lulu Sar started to drain through an outlet near village Duck. The term Duck in local language means a barrier.

Kettle Lakes

A group of few small lakes occur just along the roadside, one besides the main lake and the others upstream of Lulu Sar and are popularly known as Lulu Sar's offsprings. These lakes occur at the foot of steep segments of shallow valleys and have a crescent shaped lip of drift deposit in front towards the river. Another such lake occurs right on the old river bed downstream of Jalkhad.

These lakes are the result of glacial patches which detach themselves from the main glacier over steep slopes and then persist as partly buried stagnant/dead ice masses for long periods. A small push dam accumulates at the end of this patch giving it a morainic lip. Due partly to the action of gouging and mainly to collapse upon thawing out of the ice patch a depression is finally formed which is then filled with stream and melt water. In some of these lakes in Upper Kaghan still unmelt parts of the glacial patches can be seen even towards the end of summer. The shape of these lakes appears to approach remarkable circularity, the shape that any mass of ice will tend to assume as abalation progresses (Flint, 1957). Kettles, in general, occur in the terminal zone of the glacier on end moraines.

Ground Moraine Lakes

A small lake is found in the depression between the swells of the ground moraine at Jora village. On the other hand the depressions between the far more numerous mounds at Battakundi are mostly cultivated and do not make lakes.

Meander Zone Lakes

A number of marshy areas are found in the flat around the meandering stream in the glacial troughs. Among these, surface accumulations of water, in the form of lakes also result at few places. Some such lakes can be seen in Jalkhad Nar near Lalian.

Traverse along the Main Valley

The river Kunhar is considered to originate from Lulu Sar Lake. The Kaghan Valley, however, continues back of Lulu Sar as the valley of Gittidas Nala. The whole of Upper Kaghan Valley from Babusar to Naran shows signs of glaciation now mostly preserved in the form of glacial deposits,

The Babusar—Gittidas section can be subdivided into two parts the upper Gittidas Maidan section which occurs upstream of Alaso Baihk (12500 ft.) and the Tato Butt Section which occurs between Tato Butt and Lulu Sar. The Gittidas Maidan Section generalizes the cross-profile and landforms of a glacial trough including cliff, cirques, debris slope (covered with loose scree or moraine) morainic platform and floodplain. The lower elements of slope gradually disappear turn by turn as we move lower down the Gittidas Nala. In the Tato Butt section cliffs and scree cones predominate on right bank while the morainic aprons on the left bank are replaced by morainic arms (lateral moraines) on the sides of major tributaries. The morainic platform and floodplain of the trough are replaced by a riverside bluff The flat morainic platform at Tato Butt, although small is prominent.

The valley floor in the next Besal-Burawai section is generally wide as if straightened by a trunk glacier. Just downstream of Besal, however, the valley floor becomes hummocky and is full of boulders from the end moraine of Lulu Sar (ice-cake of glacial times) and from the frost shattering of left bank spur of Saadullah Nar. Moraines, glaciofluvial fans and scree aprons are extensive on the right bank in this section from Besal to Seri and on the left bank especially at and downstream of Jabba Wenjtar area. The contrast between the predominantly coarse and fine nature of material of deposits is very noticeable and correlates with its granitic or metasedimentary provinence. On the right bank this division is apparent upstream and downstream of Jalkhad respectively. Two slow and like stretches of the river are prominent. One occurs at Wenjtar and the other upstream of Jalkhad.

The main Kunhar valley in the Burawai Buttakundi section continues to be prominently wide at least down to Bans Bandi The morainic and glaciofluvial platforms of Burawai, Rakhan, Bans Bandi and Battakundi are very prominent as are the high lateral morains at Burawai, Dunga, Dabukan and Battakundi. The colony of drumlins/hummocks of Dumri Maidan at Battakundi is a very interesting feature.

Depositional landforms decrease in the Battakundi Naran section and most prominent of these are the scree aprons which mainly line the left bank slopes of the river. Here the slope may be subdivided into an upper rocky section made up of cliffs, cirques, broken cliffs, a long debris slope section covered by scree aprons which thicken downwards and a footslope section. The footslope may comprise one or two bluffs at the lower end of scree aprons or by riverside scree cones formed by dissection of scree aprons. The footslope at other places is represented by riverside cliff with or without a low fluvial terrace and by low fans at the mouths of major tributaries like Sapat, Lidi, and Dhumduma Kathas. The Naran terrace is complex being partly fluvial and partly glaciofluvial.

Discussion :

Geomorphology

The general altitude of the Upper Kaghan area ranges between 7500 ft. and 15000 ft. It enjoys a mountainous sub-humid temperate climate where average temperature decreases with altitude as the snowfall increases. Many of the cols, passes ahd ridges above 13000 ft. have a partial and patchy snowcover that persists through the year though the snow cover in winter is much more extensive.

Fluvial sculpturing is the main current geomorphic activity. There, are, however, unmistakable signs that the area especially in its higher parts have suffered glaciation in the not too distant past. Upwards of 11500 / 12000 ft. or so the valleys still exist in the form of modified glacial troughs. Cirques, truncated spurs, horns and aretes are some other common evidences of glacial erosion. Glacial depositional features, on the other hand, occur down to much lower altitudes. End moraines, lateral, ground moraines, glaciofluvial fans and scree aprons including the more recent results of frost wedging are commonly met with down to Naran. Boulder concentrations (Kaar) and boulder pavements, two glacial depositional cum-erosional features are confined to the higher regions and appear mostly in glacial troughs. Boulder pavements are especially restricted to the highest headward part of troughs.

Below the altitude of 10500 ft. the valleys show mainly a fluvial profile and signs of glaciation have been greatly reduced.

The Kunhar valley in upper Kaghan itself shows signs of glacial activity by large trunk valley glaciers at one time. This is evidenced by the ground and lateral moraines at Burawai, Bans and Battakundi and truncated spurs. The ground-and lateral moraines of Burawai and Battakundi occur at the confluence of principal tributaries with River Kunhar. The arcuate lateral moraines at the mouth of Dabukan and Dunga Katha are characteristic and signs of tributary glaciers joining the Kunhar trunk glacier.

Lakes are a rather common feature especially in the zone of cirques where they occur in the form of tarns. Dudipat Sar is a rock floor tarn or a cirque lake. The two other large lakes Saiful Muluk Sar and Lulu Sar are tarns too but formed somewhere down in the glacial trough.

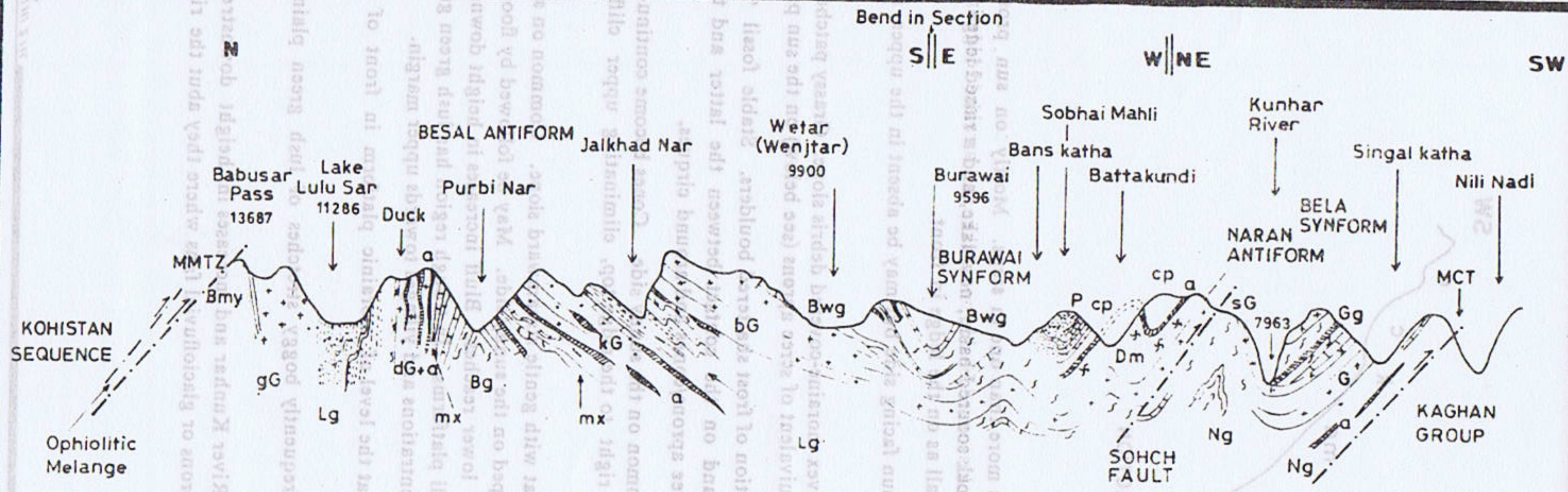
Snowline During Glaciation. What is the general height of the lowest cirques in Upper Kaghan ? Dudipat lake at the head of Purbi Nar is at 13000 ft. In Khotey Nar Gali the lower cirque lakes are at about 12500 ft. The lakes at Ishgah Gali are at the general altitude of 12500 to 13000 ft. Even in Butogah valley across the Kaghan watershed the cirque lake occur at 12500 ft. Tarns at the head of Putha Nar occur at 13000 ft. On the other hand the glaciated section of the major valleys by glacial trough may extend down to about 11500 ft. From the general altitude of the lowest cirque lakes at some 12500 ft. and the lower limit of glacial troughs at 11500 ft. We may place the climatic snowline at the time of glaciation at about 12000 ft.

Glacial deposits along Indus Valley, Kohistan and Karakoram occur frequently at much lower altitudes than in Kaghan These in fact may be older than those in Upper Kaghan but have been preserved due to paucity of rainfall in that area. These lower level glacial deposits may fill some hanging valleys. Obviously these areas have not been affected by the most recent glaciation of Upper Kaghan. Even so the riverside moraines of the Upper Kaghan have been dissected by upto 500 to 1000 ft. Traces of older glacial periods have mostly been erased.

Process. The sculpture along the Kaghan Valley above 11500 ft. is dominated by glacial cirques and troughs, aretes, cols, horns, and frost wedging and its depositional products. The deposits in this zone are mainly end moraines, boulder concentrations, morainic aprons scree aprons and subordinate glaciofluvial fans and cones. This is the zone of Alpine Sculpture (Davis, 1906). Alpine Sculputre is generally characteristic of mountain areas occupied now or formerly by a network of valley glaciers that never grew thick enough to bury or nearly bury the ridges and higher peaks.

The Lulu Sar and Saiful Muluk lakes mark the lowest cirque type ice-excavated features. The terrain below this limit of 10500 ft. is in main fluvially sculptured but does contain glacial deposits. The last major glacial deposits occur at Battakundi (8500 ft.). Thus, the next zone between 11500 and 8500 ft. is today dominated by fluvial sculpture and glaciofluvial and glacial deposits in the form of lateral moraines and moraines, ground moraines, glaciofluvial fans scree cones and aprons. Glacial erosional features on the other hand are few. We may term the zone between 11500 and 8500 ft. altitude as the zone of Glaciofluvial Sculpture.

Some glaciofluvial deposits and occasional moraines extend along the main Kaghan Valley down to Kaghan township at 6500 ft. These, however, are minor and we may term the zone below 8500 ft. i.e., Battakundi, in Kaghan Valley as the Zone of Fluvial Sculpture.



LEGEND

a Amphibolite, m Marble, cp Calcpilite, P Pelites, Dm Migmatite, Bmy Babusar Mylonite, mx Mixed zone

Granites; (Local Annotation) sG=Saiful Muluk Granite, bG=Babun Granite, kG=Besal di Khari Granite, dG=Duck Granite & gG=Gittidas Granite.

Gneisses, garnetiferous calcpelitic: Bg = Besal Gneiss, Bwg = Burawal Gneiss, Ng = Naran Gneiss & Gg = Gorian Katha Gneiss.

MMTZ = Main Mantle Thrust Zone, MCT = Main Central Thrust.

km. 10 5 0 10 km. approximate

Fig. 1. GENERALISED GEOLOGIC SECTION THROUGH UPPER KAGHAN, SOMEWHAT PARALLEL TO RIVER KUNHAR

Chaudhry and Ghazanfar, 1987.

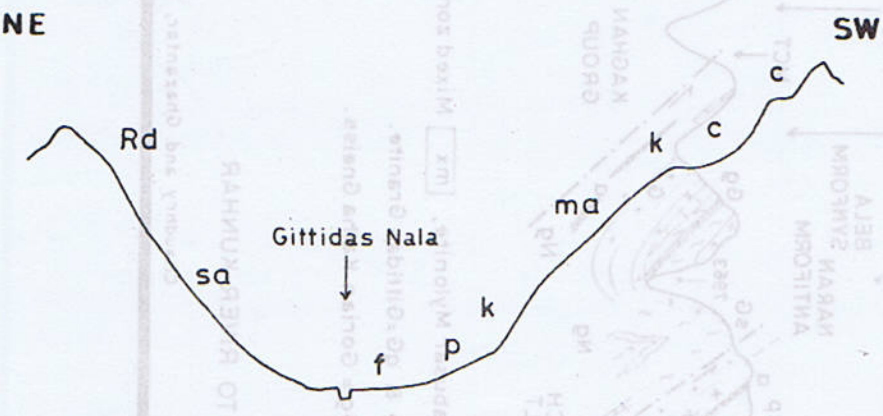


Fig. 2. c, cirque, generally one but may be more than one in steps. Mostly on sun protected side. Each has a cliffy headwall at back, a rock scoured basin, now lake, and a raised ledge in front. There is frost shattered 'kaar' below headwall as on the ledge in front.

uc, upper cliffs, prominent on the sun facing side but may be absent in the upper reaches of glacial trough. Also back of cirques.

ma, morainic aprons. Slightly convex moraine-covered debris slope. Grassy patches. 'Kaar' boulders fill local depressions, ma is the equivalent of scree aprons (see below) on the sun protected side.

k, kaar. Local term for concentration of frost shattered boulders. Stable fossil 'kaar' common in depressions of morainic aprons and on the contact between the latter and the lower morainic platform. Active 'kaar' below scree aprons/cones and around cirques.

sa, sc, scree aprons and cones, common on the sunny side. Cones become continuous aprons in the trough region, and may extend right to the ridge top, eliminating upper cliffs, uc. Fragments become coarse downwards.

p, morainic platform. Morainic flat with gentle streamward slope. Common on sun protected side. May be absent or poorly developed on the sunny side. May be followed by floodplain the trough or have bluff against stream in lower reaches. Bluff increases in height downstream. Examples Tato Butt, Burawai and Battakundi platforms. In trough region has lush green grass, may be boggy in lower part, and has 'kaar' concentrations and villages towards upper margin.

gf, glaciofluvial fans. May occur at the level of morainic platform in front of tributary streams. May coalesce with platform.

f, trough floodplain. Nearly flat frequently boggy stretches of lush green plain occurring below marainic platforms or fans.

r, riverside cliff. Common along River Kunhar and increases in height downstream. Develops in morainic platform or even scree aprons or glaciofluvial fans where they abut the river.

Chaudhry and Ghazanfar, 1987

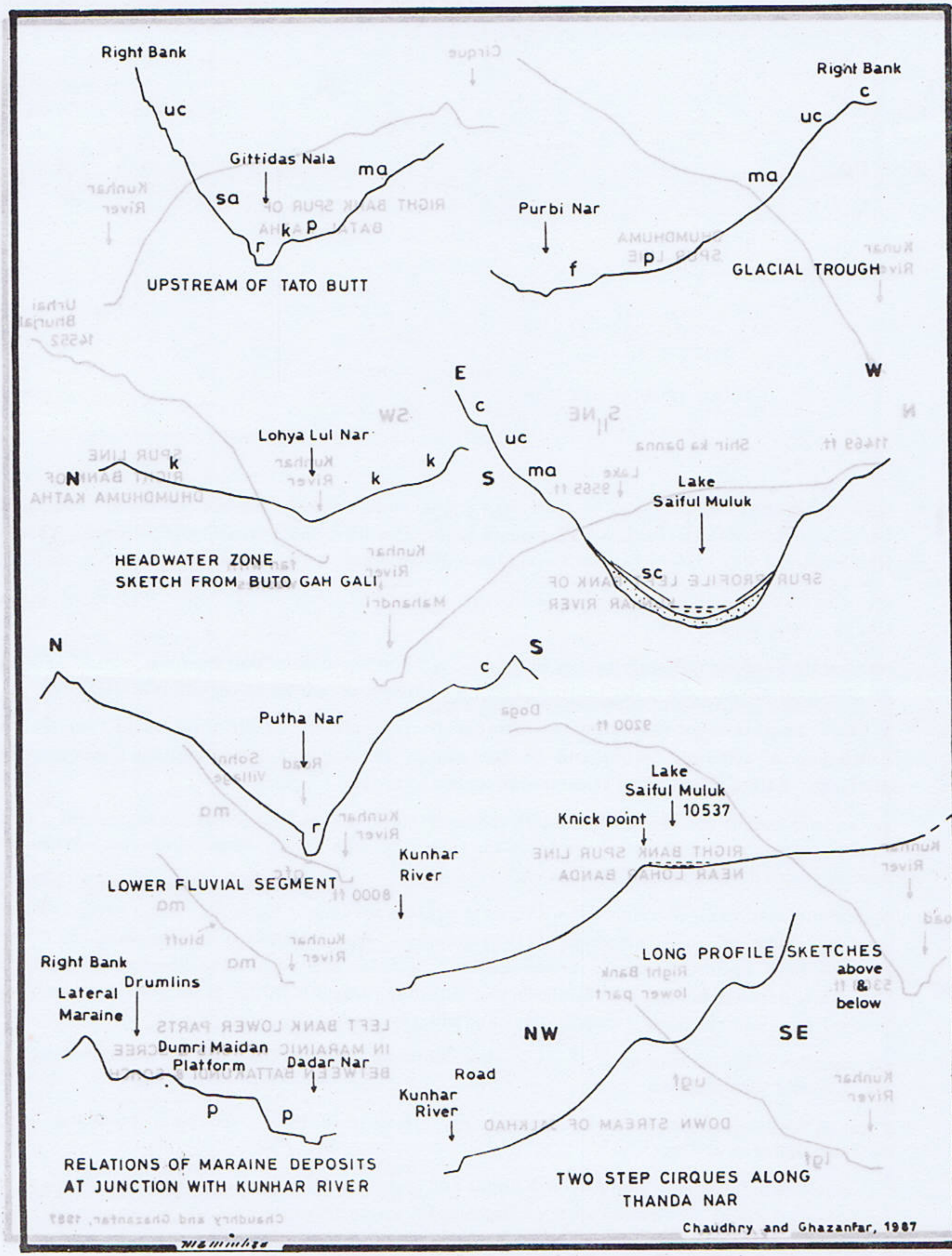


Fig. 3. Field sketch cross profiles of some major tributaries to River Kunhar in Upper Kaghan. c, cirque ; uc, upper cliff ; ma, morainic apron ; sa, scree aprons ; p, morainic platform ; f, trough floodplain ; r, riverside cliff ; k, kaar (boulder field).

Not to scale.

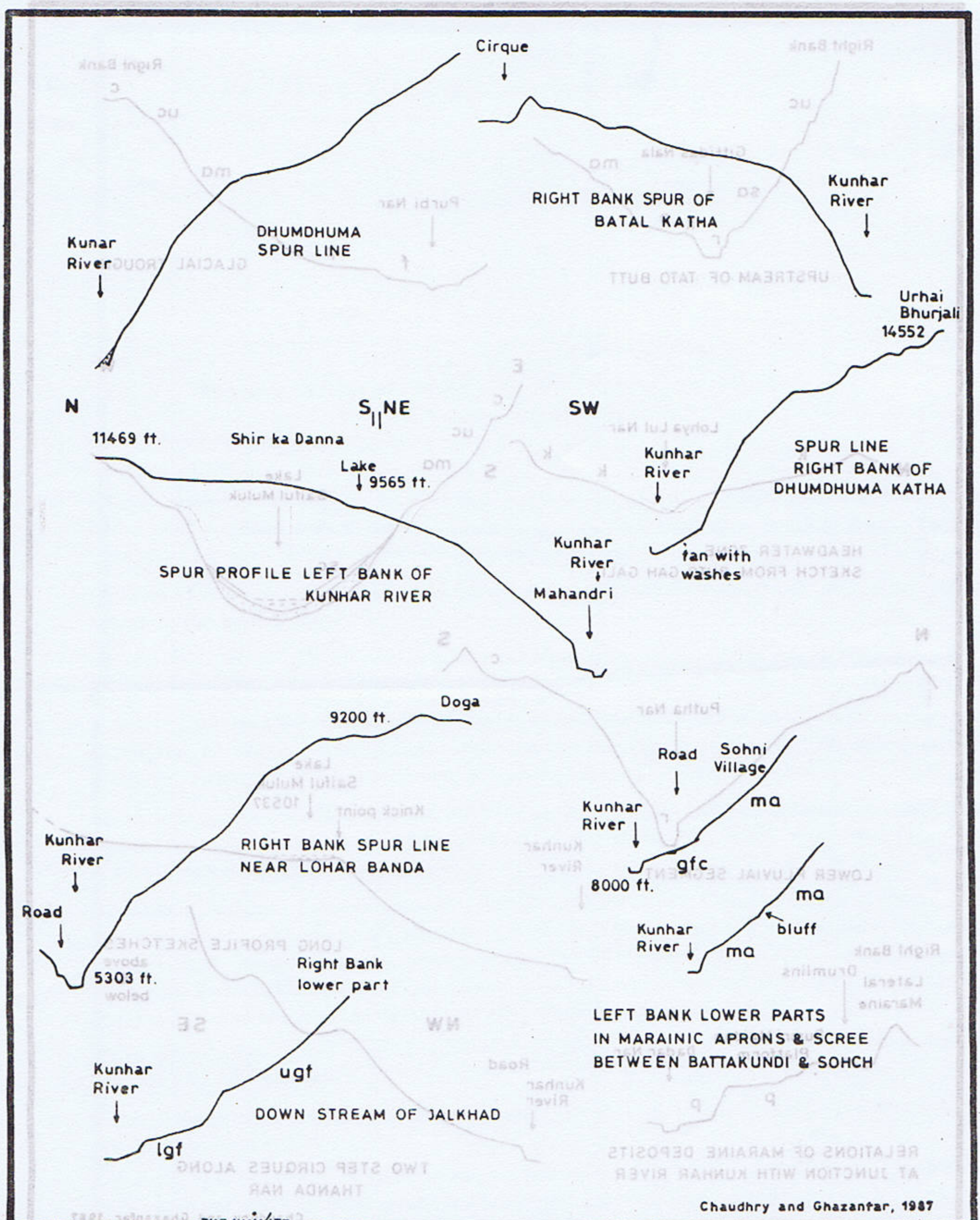


Fig. 4. Field sketch profiles of side slopes of River Kunhar in Middle and Upper Kaghan.
ma, morainic apron and scree slope ; ugf, lgf, upper and lower glaciofluvial fans ; gfc, glaciofluvial cone,

Not to scale.

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PETROGRAGHIC STUDIES OF SANDSTONES FROM THE EUREKA SOUND FORMATION ELLESMERE ISLAND, CANADIAN ARCTIC

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Abstract : *Two interesting phenomenon were studied in the sandstone from upper part of member I of the Eureka Sound Formatian. Pressure solution and replacement of the quartz with calcite are both related to the diagnetic and depositional processes. High pH conditions are thought to have existed in the depositional medium and in the post depositional environments when the waters with high pH percolated through the quartz grains to cause this pressure solution phenomenon. Similarly, the replacement of quartz by calcite is also a phenomenon that is thought to have taken place at elevated temperature and pH. This study is in conformity to the study of the clay minerals from Eureka Sound Formation (Masood,* 1987) *where the presence of clay mineral Berthierine indicates warm climates with high pH in the depositional medium at the Cretaccous Tertiary times in the Canadian Arctic.*

INTRODUCTION

Eureka Sound Formation is mainly composed of a monotonous sequence of rocks mainly fine grained in nature and consisting of very fine sands, silt and clays. It is exposed throughout the Canadian Arctic archipelago (Fig. 1 & 2). It has been subdivided into four members (West *et al.* 1981). The sandstone samples were collected from the upper part of the member I which is the only coarse and well lithified sandstone. These sandstones were studied by standard petrographic techniques and also by the scanning electron microscope. Purpose of this study is to investigate texture and mineralogy of sediment grains, study diagnetic changes these rocks have undergone and to relate textures, mineralogy, and diagenesis to depositional environments. Major constituents of these sandstones are quartz, with minor unaltered feldspar, micas, and matrix together with some reprecipitated calcite cement. Almost all feldspar has been altered. Sandstones are predominantly matrix-supported, except for 300 ft. sandstone in the upper part of Member 1 in which we have observed the pressure solution phenomenon and is grain supported. Pressure solution is evident in this almost pure quartz arenite.

MINEROLOGY

Light Minerals

Quartz is the most abundant detrital constituent of the sandstones. Framework quartz grains vary from 30 to 100 per cent. Framework quartz grains are subangular to angular according to the usual scale of Powers (1953).

Feldspars are the secondmost abundant detrital mineral in the Eureka Sound Formation. Percentage of framework feldspar grains varies from zero to 20 per cent. Since most of the feldspars show partial or total alteration, it is difficult to subdivide them meaningfully according to mineral. In some cases microcline twining is still seen, but it is not easy to distinguish altered orthoclase from microcline plagioclase.

All degrees of alterations are present often occurring preferentially along mineral cleavage. Fresh and altered grains are commonly found together in the same thin section, most likely because of post depositional weathering.

Rock Fragments occur as minor constituents and comprise less than 5 per cent of the grain fraction. Rock fragments are derived prinicipally from the siltstones, mudstones, granites or gneiss. Also present are fragments of chert and quartzite.

Mica constitutes up to 1 per cent of the grain fraction. Mica grains are typically elongate flakes of muscovite, with biotite occurring occasionally. Detrital mica grains are usually larger in size than other detrital minerals. Compaction has buckled micas around other detrital grains.

Detrital Matrix (material of less than 30 microns in diameter) occurs throughout sandstones of the Eureka Sound Formations. It is difficult to distinguish detrital matrix and that produced by the post-depositional alteration of labile grains. Matrix occurs either as fine-grained clayey materials or as an association of dominant finely granular quartz plus smaller amounts of feldspar, sericite, chlorite and other clay minerals, X-ray diffraction analysis reveals the precence of detrital and authigenic clay minerals present. There is no doubt that the matrix and cement complement each other in the production of indurated rock.

Quartz Calcite Relationship

Dissolution of quartz grains and their replacement by calcite is a common phenomenon observed in sandstones of the Eureka Sound Formation. In some cases nearly the entire grain is replaced and in others it is possible to see a ghost outline of a once-larger quartz grain. According to Dapples (1959), precipitation of calcite is directly associated with diagnetic instability of chert and quartz. In environments where calcite cement is actually precipitated, prominent embayments are present in the grains and calcite replacement textures are observed. In some rocks, solution of silica is characterized texturally by extreme irregularity of the grain boundary and 'ghost' remains of the chert or quartz in calcite. (Fig. 3 & 4). Correns (1950) anticipated that total solubilities of quartz and calcite are inversely related with respect to change in pH. As pH is elevated, calcite decreases, and silica increases in solubility. This general relationship has remained unchallenged by subsequent study. Additional work shows that the silica solubility curve remains relatively uniform for values of pH below 9 whereas a significant increase in solubility is observed above this value. Since pH values of 9 or higher are relatively rare in nature, changes in temperature are thought to have greater control on the precipitation of calcite and the solution of quartz (Siever 1962, p. 144). Replacement of quartz by calcite is observed in certain sandstones, particularly in the modern semi-arid climates, as suggested by Dapples (1959). However, the shift in pH is very important in locomorphic processes despite the very small difference in solubility. Local changes in the partial pressure of CO_2 resulting from temperature differences near the outcrop are considered to be an indirect cause of the changes in pH values. Similar mechanisms could produce similar replacement in the subsurface. The other evidence to be discussed later is the presence of the mineral Berthierine. Its presence suggests tropic like environments and conditions of high pH. Dissolution of quartz in the Eureka Sound Formation may in part be diagnetic and in part syngnetic because the sediment in general is unlithified and has exposed to water in the depositional basin for a long period of time.

Interlocked Texture in Coarse Sand

Interlocked texture, another interesting phenomenon was encountered in a unit of thick, massive, indistinctively stratified, course-gained sandstone in Member 1 Eureka Sound Formation. This is lacking in matrix and is the only sandstone in the formation that is compact and course grained. As pointed out by Dapples (1967) the granular interlock attained in flexible sandstone is a feature developed by the solution of quartz along intergranular surfaces. (Fig. 5 & 6). This texture is nearly identical to interlock that is developed in certain quartzites under metamorphism in which individual grains are strongly welded to one another by quartz precipitated along intergranular boundaries. This texture is an excellent illustration of the occurrence of an equilibrium shift that resulted in a change from solution to participation of quartz. By this process detrial grains are dissolved and authigenic quartz is precipitaed in the interstices and on the surfaces of grains.

Pressure Solution in Sandstones

Pressure solution refers to the influence of pressure and dissolution long portions of grain boundaries that are in contact with adjacent grains. It is not limited to seams as with stylolites. In contrast, solution along stylolitic seams is restricted to the seam itself, and adjacent grains not in actual contact with the seam may be unaffected. The anastamosing nature of many styolitic seams suggests that they owe their development to migration of solutions along laminae where detrital clay or organic material is concentrated. Pressure solution in the Eureka Sound Formation occurs where quartz grains are in contact, where calcite cement or clay matrix is scarce.

Description of Pressure Solution

The term pressured zones is used by Thomson (1959), refers to zones in which suturing of grains is well-developed. All stages exist between the zones with little or no solution activity, characterized by grains with point or long contacts, to zones in which grains have concavo-convex or sutured contacts. Two types of zones have been recognized in the Eureka Sound Formation.

Highly Dissolved Zones range in thickness from to five millimeters. Quartz grains have sutured contacts in which no preferred orientation is noted in relation to bedding. Clay or silica cement is between quartz grains.

Relatively undissolved zones in which the effect of the pressure solution on the boundaries is less apparent. Iron cement may surround some quartz grains, to infill intergranular pore space. Clay and calcite cement are scarce.

Factors Controlling Pressure Solution

Thomson (1959), has given a brief description of factors controlling pressure solution. The most important factors are clay content, grain orientation, metamorphism and depth of burial. These may combine to produce pressure solution and may also control the time of its occurrence. If clay is involved in the process either as a catalyst or an integral step in the series of physico-chemical it should be progressively altered as the process goes to completion.

Grain orientation also strongly influences pressure solution. Quartz is more easily dissolved among planes parallel to the base (0001) according to (Kennedy 1950). However, attitude of the original surface of contact between the two grains also has an effect because in a tightly packed sand the grain-contact surfaces are variously oriented (Lowry, 1956). This may be difficult to evaluate in grains where original contacts have been destroyed by pressure solution.

Grains with concavo-convex contacts usually demonstrate the effect of grain orientation on pressure solution (Kennedy 1950). This indicated that in general the process of pressure solution is significantly controlled by grain orientation. Perhaps sutured contacts develop when pressure solution develops to such an extent that the influence of grain orientation is overcome.

Relationship to metamorphism is another important factor controlling pressure solution. The effects of metamorphism are clearly exhibited on the relatively unaffected sides of even highly dissolved grains. These effects are manifest as "crush quartz" (Fellows 1943). These quartz grains developed due to shrotening of the rock parallel to the axis of greatest metamorphic stress. In contrast, sutures developed due to pressure solution under the influence of compaction only are oriented perpendicular to a vertical exis to the greatest stress prior to subsequent folding. Most stylolites apparently developed before metamorphism, but some seams seen to cut across quartz-filled joints that developed contemporaneously to folding. This late solution development may have developed as the folding opened fractures through which solutions could migrate.

Depth of Burial. Heald (1955, p. 105) noted well-developed staylolite seems in certain Pennsylyanian sandstones of West Virginia which had not been burried to depth greater than a few thousand feet hereby suggetsing that great thickness of overburden is not essential to the development of pressure solution. Taylor (1950) in a study of two Wyoming deep wells noticed that sutured grain contacts did not develop above a depth of 4535 feet and that the proportion of sutured contacts increased progressively with depth. This verifies that sutured contacts may develop under the influence of burial and compaction.

Carbonate Cement

Carbonate cementation, chiefly calcite ranges from development of a mere fringe of minute carbonate crystals on quartz grain surface to total replacement of matrix and extensive replacement of quartz grains to produce floating relict quartz. Several carbonate minerals in addition to calcite may cement the sandstone; ferran-calcite, dolomite and ferron-dolomite are also observed. Siderite, also be expected in these carbonaceous sandstones, in occasionally observed. Calcite cement may be micritic, microsparitic or may form a mosaic of anhedral subequant rhombs. Most of the calcite in the Eureka Sound Formation is micritic.

There are many possible sources for carbonate cement, including connate water, shell debris trapped within the sandstone and interstratal solution of limestone in the Eureka Sound sediments. Petrography of the cement indicates that it is relatively late and connate water therefore cannot be the source. Shell debris may be a minor source of calcite in the system; however, the major source of carbonate is from interstratal solution of older sediments.

Conclusions on Diagensis

Investigations show that the pH and Eh of pore space solution are the dominent controlling factors. The pH seems to be uniform in its control and is not restricted to certain horizons, such as a distributary channel or subserial levee sediments. Dominance of pH as a controlling factor is evident from several other factors discussed in this study for example, the silica overgrowths. presence of the mineral

Berthierine and quartz-calcite relations, since all these are possible under high pH and Eh conditions. Eh, unlike pH, varies dramatically from one stream to another and appears to be related primarily to permeability of sandstones, and to lesser extent, to the availability of organic material. More permeable rocks with less available organic matter produce stronger oxidizing condition.

Granular interlock texture is developed in some sandstones particularly in the upper part of Member 1. This texture illustrates that an equilibrium shifting between solution and precipitation and precipitation of quartz has occurred. By such a process, grains of the original detritus are gradually dissolved, whereas new syntexial quartz is precipitated in interatices and on the surfaces of other grains. In some cases, this is partly attributed to the pressure solution mechanisn. However, it seems that direct crystallization of the quartz from solution is doninent. This process appears to be associated with movement of water of very low salinity, but saturated silica at low temperatures.

Redoxomorphic changes are found to dominate modification of the sediments during and immediately after burial. Channel sandstones are transported and deposited in an aerated oxidizing environment. During this time the sediment passed through the essentially physical process of compaction, resulting in dewatering. The principal reactants involved are iron, oxygen, sulfur and carbon (in organic matter). Redoxomorphic changes are distributed unevenly throughout the succession. Some of the fine sandstones, siltstones and mudstones are interpreted to have been deposited in reducing environments, whereas others, like the distributory channel sandstones, remained oxygenated. The latter have high permeability and contain less organic debris. Some organic matter is easily oxidized and its sulfur compounds are removed as soluble sulfate ions after oxidation. Iron is preserved as ferric oxide and is present in some sandstones in the form of iron oxides and hydroxides. Within the locomorphic diagnetic stages may be interpreted to have occured, chemical reactions may be inferred, such as carbonate replacement of clay, calcite-dolomite replacement, feldspar-carbonate replacement and quartz-carbonate replacement. The quartz carbonate replacement is the most commonly observed phenomenon. The diagnetic history is further complicated by the carbonate-quartz relationship since this modifies the original proportion of the detritus deposited. Although it may seem that secondary quartz developed soon after deposition. Textural evidence suggests that carbonate cement in the form of siderite had first precipitated and was later removed by solution owing to fluctuating conditions. Evidence of such replacement is the presence of scattered inclusions of calcite in the secondary quartz. Siderite and pyrite are thought to have been formed in reducing, more or less euxinic conditions at earlier stages. They formed because anaerobic becteria were able to thrive on an abundance of plant and organic debris. This carbonate cement dissolved when the pH value declined and quartz began to be precipitated. Subsequently, the secondary quartz was partially replaced by a second generation of carbonate cement, which is directly associated with instability of quartz. In some sandstones the solution of silica is illustrated by extreme suturing of grain boundaries and "ghost" outlines of remnant quartz, frequently present as an island within the mass of calcite cement. This dissolution of quartz is attributed to a high pH value (between 8-9), in which carbonate precipitates. Finally the phyllomorphic stage, in which micaceous or clayey minerals form, is characterized by development of varities of muscovite, chlorite and the formation of authigenic clay minerals.

Small muscovite flakes seem to envelope some of the quartz grains. Other larger muscovite graings could readily become surrounded by quartz during the process of solution and reprecipitation, giving the appearance of precipitation through the grain. Such growth of authigenic muscovite is favored by an oxidizing or neutral chemical environment. During locomorphic change, biotite in the presence of calcite and in a slightly reducing environment alters to chlorite.

Provenance

The provenance of sandstone of the Eureka Sound Formation is complex not only because of multiple potential sediment sources, but because of the combined effects of weathering, differential sorting, and post depositional alteration. Bustin R.R. (1977), has divided the sediments of the Eureka Sound Formation into two petrographic provinces based on timing of the uplift of the Princess Margrett Arch during the Early (?) Palecene. Strata predating the uplift that crop out at Strand Fiord, Glacier Fiord and Foshiem Peninsula possess a mineralogy characteristic of metamorphic, volcanic-hypabyssal and sedimentary rock sources. Strata deposited during or shortly after the uplift that crop out at Mokka Fiord and Flat Sound possess a mineralogy indicative of volcanic-hypabyassal and sedimentary rock sequences.

Strata deposited prior to the uplift of the Princess Margaret Arch have a distinctive mineralogy characterized by coarse-grained platy muscovite, metamorphic, volcanic-hypabyssal and stable heavy mineral assemblages, chert, fresh and weathered feldspars, and quartz grains with reworked overgrowths. The minerals indicative of a sedimentary source, although they are most abundant, are not diagnostic of a specific source terrain. Similarly, plutonic heavy mineral assemblages are not unlike the mineralogy of northern Canadian shield areas described by various authors: The metamorphic minernls are, however, indicative of emphibolite. granulite (?) and greenschist facies metapelites (Williams et. el., 1954). The present distribution of metamorphic rocks of appropriate mineralogy which are possible source are restricted to northern Axel Heiberg and Ellesmere Islands (Trettin, 1969 ; Frisch, 1974) and northern Greenland (Dawes and Soper, 1973, and Dawes, 1976). In addition, the mineralogy of plutonic, volcanic and sedimentary rocks described from norther Axel Heiberg and Ellesmere Islands and northern Greenland is similar to the mineralogy of sediment of the Eureka Sound Formation from Ellesmere and Axel Heiberg Islands as described by Bustin (1977).

Not only do these are possess the appropriate mineralogy, but they also show active tectonism during the necessary time interval. Late Cretaceous tectonic activity has been reported from northern Greenland, the Wandel Sea Basin and Svalbard (Atkison, 1963; Herland, 1969 and Dawes, 1976). It has been proposed by several authors including (Herland, 1969 and Kerr, 1967) that Ellesmere Island, Svalbard and Northern Greenland were juxtoposed in the Cretaceous. Furthermore, Meneley et. al. (1975) have postulated Late Cretaceous uplift of the northern rim of the Sverdrup Basin, based on seismic and well data from Ellef Rignes Island, and Christie and Rouse (1976) have proposed Late Cretaceous or early Tertiary folding and possible thrust faulting on northern Ellesmere Island.

Other indications of north or northeasterly sources presented by Bustin (1977), are as follows :

(1) The distribution and relationship between sedimentary facies of the Eureka Sound

Formation, suggest that Eureka Sound sediments prograde in south and southwestward directions.

(2) The present erosional levels on northern Ellesmere and Axel Heiberg Islands are deep as compared to the areas in the north.

(3) Paleogeographic distributions interpreted from biotic provinces suggest that open marine seas existed to the south of the Ellesmere and Axel Heiberg Islands during the Maestrictian (Jeletzky, 1971 and Williams and Stelck, 1975), whereas non-marine environments have been also reported from the southeast Nugssveg and Svantenhuh Peninsulas, and on northwest Greenland (Rosenkrantz and Pulvertaft, 1969).

(4) Current directions determind by Bustin (1977) from sandstones with largescale sedimentary structures in the Eureka Sound Formation generally suggest a southward paleocurrent direction.

(5) A northern source for Tertiary sandstones of Spitzbergen Island has been demonstrated by Atkinson (1963) indicating the presence of a highland area north of Spitzbergen which, from plate tectonic reconstructions of Herland (1969) and others, also lay to the north of Ellesmere Island.

In addition to the postulated north and northeasterly source, the progressive easterly overstep on to older strata by sediments of the Eureka Sound Formation on Ellesmere Island indicates that this region was a topographic high during the initial deposition of the Eureka Sound Formation and thus possibly a source area as well. The mineralogy of eastern Ellesmere Island is however not well-known and further studies are necessary to evaluate the sediment contribution of this region.

Mid Paleocene to Eocene sandstones at Foshiem Peninsula possess a mineralogy which indicates sedimentary, metamorphic and plutonic source areas as well as abundant acid volcanic rock fragments. The minerlogy indicative of a metamorphic and plutonic source is similar to that of older strata which predate the uplift of the Princess Margaret Arch and indicates a continued sediment contribution from north or northeasterly sources. Acid volcanic rocks which may have contributed sediments have reported from northern Ellesmere and Axel Heiberg Islands (Trettin, 1969) and northern Greenland where acid volcanic rocks of Kap Washington Group outcrop over 600 square Km (Dawes, 1976). The Kap Washington Group has yielded minimum K-Ar dates of 35 million years (Dawes, 1976) and consequently may be too young to have contributed sediments during deposition of the Eureka Sound Formation. Volcanics on northern Ellesmere and Axel Heiberg Islands may have been a source during this interval, but the mineralogy is not diagnostic. Acid volcanic rock fragments are present in strata deposited at least in part contemporaeously with uplift of the Princess Margaret Arch, therefore, it is suggested they may have been derived from uplifted areas of Axel Heiberg Island.

Sediments of Late Paleocene to Mid Eocene age which are exposed at Flat Sound and Mokka are composed of sedimentary and volcanic-hypabyssal rock fragments, volcanic-hypabyssal and stable heavy mineral suities, chert and quartz grains with reworked overgrowths. In addition, diabase and sandstone pebbles are present at Mokka Fiord.

The mineralogy and rock fragments of Upper (?) Paleocene to Mid Eocene strata at Flat Sound and Makka Fiord are most similar to Mesozoic strata presently exposed to the west and northwest. Furthermore, the sediments at Flat Sound and Mokka Fiord were deposited after and possibly in part contemporaneous with uplift of the Princess Margret Arch, to the west, which is consistent with a westerly provence. Although the mineralogy is not diagnostic of any particular formation, the presence of diabase and poorly indurated sandstone pebbles at Mokka Fiord suggest a relatively short distance of transport. Large scale cross-bedding at Mokka Fiord as noticed Bustin (1977) indicate that atleast locally the paleoccurrent direction was to the south-southeast, which is in conjunction with the postulated northern source areas for strata at Foshiem Peninsula to the east supports the interpretation that the regional drainage was towards the south.

Uplift of the Princess Margaret Arch and the Stolz Fault undoubtedly provided a major source of sediment for areas both east and west of Axel Heiberg Island. The thick sequence of Early to Middle or Late Paleocene strata of the Eureka Sound Formation presently exposed at Strand Fiord and Expedition Fiord (Fricker, 1963, p. 183) are considered to have been derived primarily from the uplifted Princess Margaret Arch because of their proximity to the Arch and its magnitude of uplift.

CONCLUSIONS

1. The mineralogy of the sandstones of the Eureka Sound Formation indicate the source of sediments from north or north-easterly direction.
2. Replacement of quartz by calcite is attributed to the high pH conditions and warm climates in the depositional medium.
3. Post depositional environments also indicate presence of solutions with high pH that percolated through the grains and became the cause of sutured contacts as observed in the sandstone.

On the basis of these observations and the study of clay minerals as mentioned earlier, it is evident that the climatic conditions in the high arctic were considerably warm at the Cretaceous Tertiary time when the Eureka Sound Formation was deposited.

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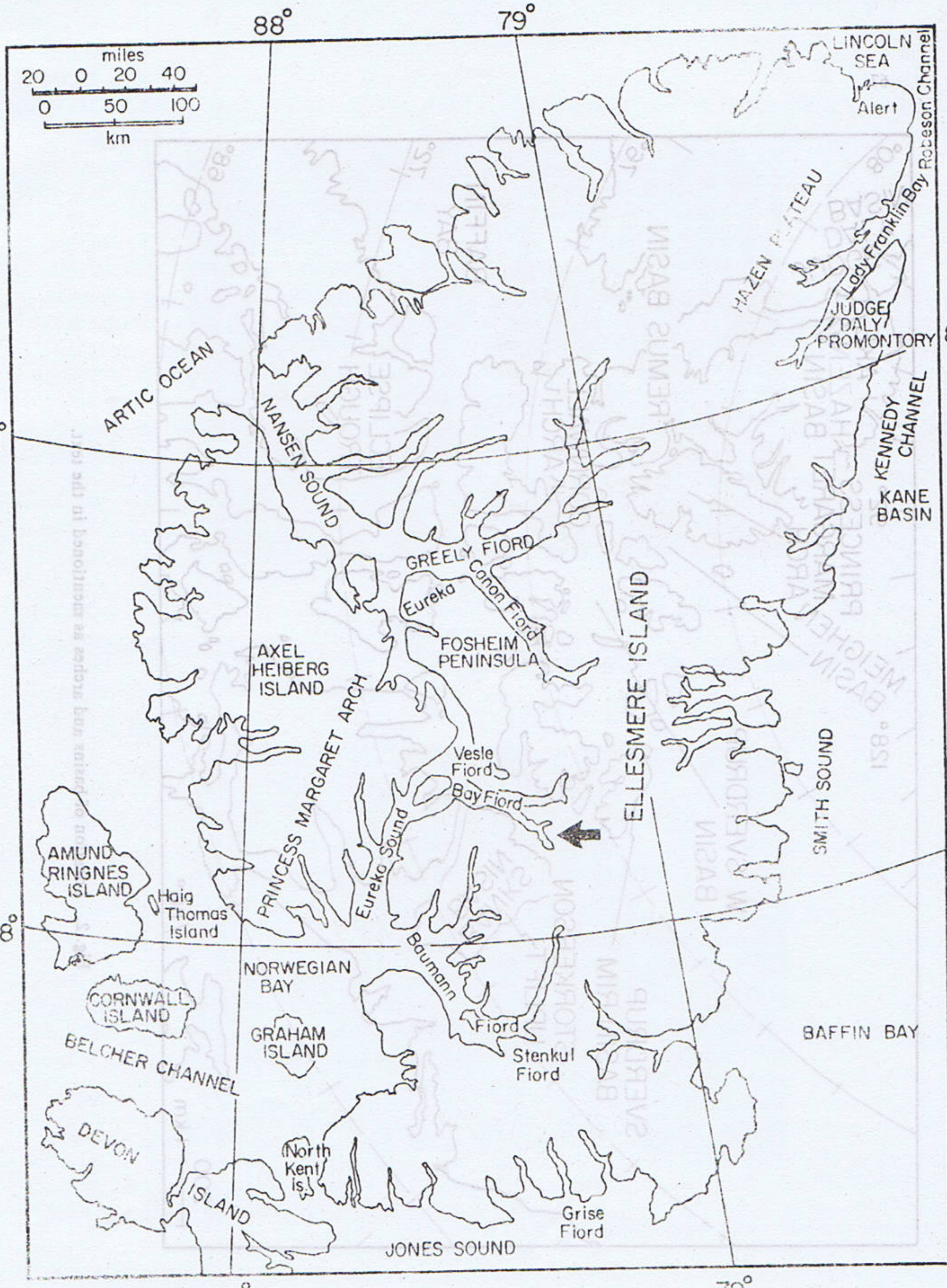

Fig. 1. Locality map : Arrow points towards the project area.

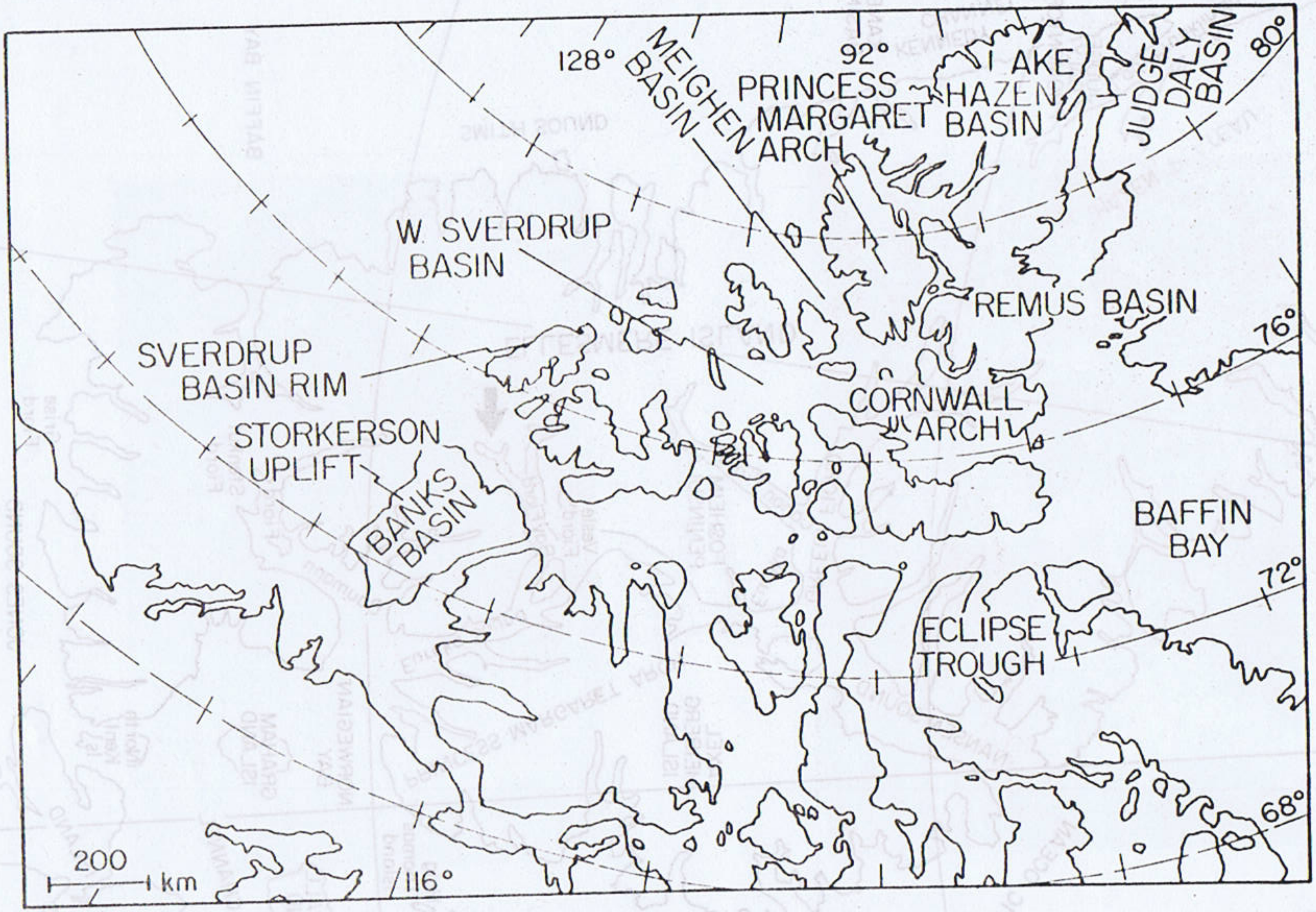

Fig. 2. Location of basins and arches as mentioned in the text.

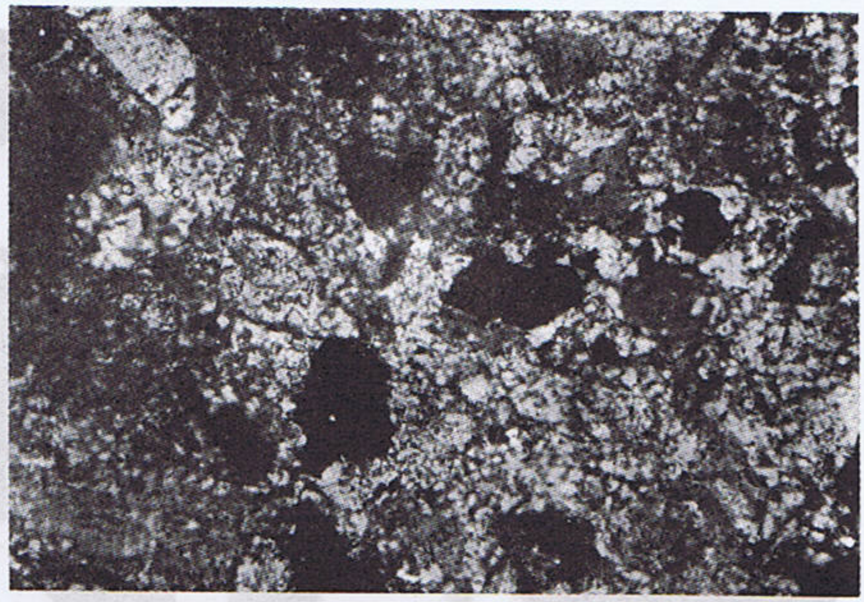

Fig. 3. Replacement of quartz by calcite.

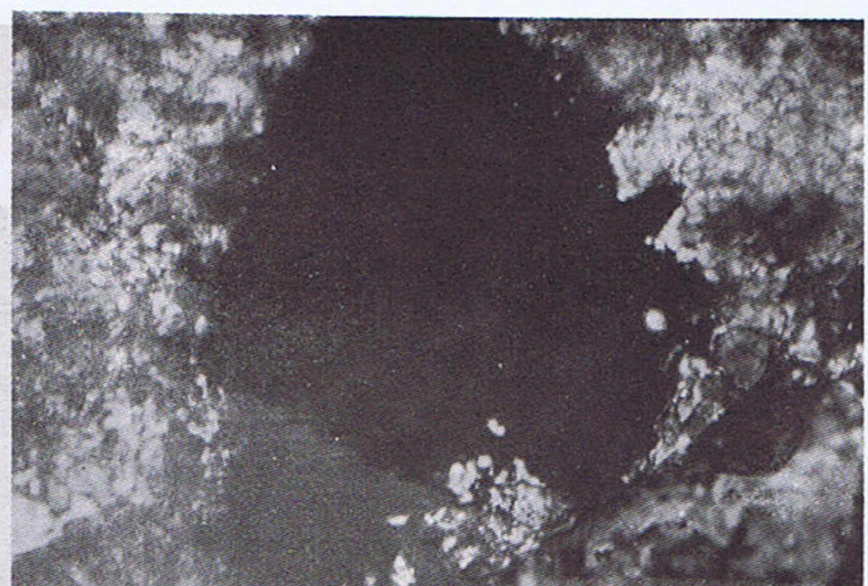

Fig. 4. Close up of the quartz grain from sample in figure 3.

Fig. 5. Photomicrographs of the sandstone showing sutured contacts.

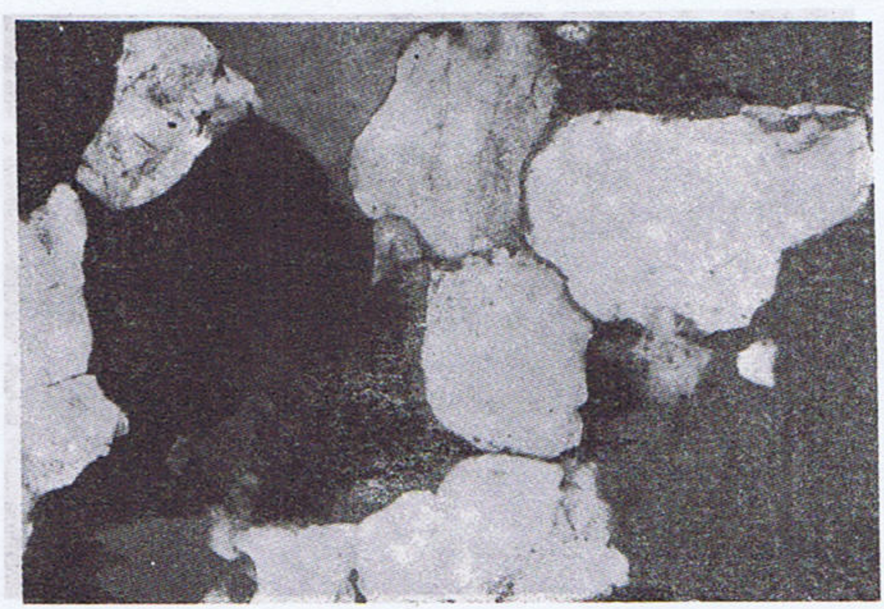

Fig. 6. Closeup of the sample from figure 5.

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THE PRESENCE OF A CHINESE STEGODONT PROBOSCIDEAN IN THE SIWALIKS OF AZAD KASHMIR, PAKISTAN

BY

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Abstract : *A stegodont fourth upper premolar is described from the Dhokpathanian of Bhimbar, district Mirpur, Azad Kashmir, Pakistan. The tooth being primitive in structure of its ridge-crests and the crown height has been compared with the primitive stegodonts. A detailed study has indicated that it is conspecific with the Chinese species,* Stegodon sinensis *Owen. This is the first stegodont species common to Chinese Tertiary and the Siwaliks. The discovery of a Chinese species from the Siwaliks means that the proboscidean migration was possible across Himalayas during Lower/Middle Pliocene.*

INTRODUCTION

A nicely preserved stegodont DP^4 (P.U.P.C*. 83/12) was unearthed from the Dhokpathanian outcrops about 2 miles north-west of Bhimbar during a field work in the year 1983. The tooth was found alongwith the isolated molars of *Hipparion theobaldi*, *Aceratherium*, *Dicoryphochoerus* and crocodillian teeth. The tooth exhibits primitive features i.e. absence of cement, low crown height and the dislocation of the pre- and posttrites. Being primitive, it has been compared with the species *Stegodon bombifrons* and was found to be different. A comparison with the non-Siwalik forms has proved it to be conspecific with the species, *Stegodon sinensis* which is known from China (Owen, 1870 ; Matsumoto, 1915 and Japan (Takai, 1936).

STEGODON SINENSIS Owen, 1870

TYPE

DP^3 (British Museum No. 41925) from "marly beds in the vicinity of Shanghai", China. According to Osborn (1942) probably from Upper Miocene (Lower Pliocene).

DISTRIBUTION

Stegodon sinensis is known from Pliocene of China (Owen, 1870 ; Matsumoto, 1915) and Pakistan (specimen under study) and from Pliocene of Japan (Takai, 1936).

SPECIMEN EXAMINED

P U.P.C. 83/12, a deciduous fourth upper premolar from Bhimbar, district Mirpur, Azad Kashmir, Pakistan.

DESCRIPTION (Fig. 1)

The tooth is excellently preserved. It is a brachyodont and broad crowned tooth (table 1). Cement is essentially lacking. There is no cingulum. Enamel is quite wrinkled all over the crown. Median longitudinal sulcus intersects almost all the ridge-plates. Besides, fore- and aft talon, there are 6 ridge-plates. Of these the first three were in use whereas the fourth ridge-plate was just touched by wear. Ridge-plates are obliquely placed. Fore talon

* Fossil Collection stored in Zoology Department, Punjab University.

is very small, quite low vertically and very thin anteroposteriorly. First and the last ridge-plates are smaller in transverse width than the others.

TABLE I

Measurements (in mm.) of left DP^4 (P.U.P C. 83/12) in *Stegodon sinensis*

Number of ridge-plates	1/2+6+1/2
Length (preserved)	112
Length (estimated)	114
Lamellar frequency	6
Transverse width	60
Width/Length index	53
Crown height	27
Height/width index	45
Enamel thickness	2.4

First ridge-plate was probably surmounted by ten conelets. Due to the wear, the valley posterior to it has become shallow. Second ridge-plate probably consisted of about fourteen conelets. The transverse valley, posterior to it, is comparatively much deeper than the anterior ones. Third ridge-plate is surmounted by seventeen conelets. It is in the early stage of wear. The conelets like those of the preceding ridge-plates are very small and very much superficial and would go just with a slight wear. The ridge-plate is wavy but the two halves are quite continuous. The fourth ridge-plate consists of 18 conelets. Its pretrite is just touched by wear, whereas, the posttrite is essentially unworn. Pretrite is posteriorly placed than the posttrite. The two halves of the fifth ridge-plate are still more displaced than those of the preceding ones. The median end of the posttrite is extended to the anterior side blocking the transverse valley. The last ridge-plate is quite smilar to that of the fifth ridge-plate but is low in vertical height. The hind talon is better developed than the fore talon *i.e.* its tubercles are more pronounced. It consists of 6 conelets.

DISCUSSION

The tooth under study has low ridge-plates with dislocated pre- and posttrites. Cement is lacking and the median longitudinal sulcus can be traced back to the last ridge-plate. Thus, among the Siwalik species, it can only be compared with the species, *Stegodon bombifrons*. However, the two can readily be differentiated in the morphological details. In the cotypes of *Stegodon bombifrons* figured by Falconer and Cautley (1846), the lectotype specimen figured by Lydekker (1886) and the referred teeth figured by Sarwar (1977), the ridge-plates are transversely linear and simple. The intervening valleys are filled with cement. The ridge-plates are dislocated and completely devoid of cement in the sample, P.U.P.C. 83/12.

A comparison with the non-Siwalik Stegodonts shows that it is comparable with the Chines stegodont, *Stegodon sinensis*. The type specimen of the species figured by Owen (1870) and the referred molar figured by Takai (1936) are low crowned and are devoid of cement in the intermediate valleys. These characters are also shared by the specimen under study.

The Chinese species, *Stegodon zhaotongensis* described by Chow and Zhai (1962) approaches the species, *Stegodon sinensis* in crown height. However, the former is somewhat advanced because of the presence of cement.

A

B

Fig. 1. A referred DP[4] (P.U.P.C. No. 83/12) of *Stegodon sinensis* Owen. A, crown view ; B, lateral view. X1.

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STRATIGRAPHY OF PART OF SULAIMAN RANGE

BY

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Abstract : *Detailed geological map of part of the Sulaiman Range on* 1 : 1,000,000 *scale has been produced covering D. G. Khan and Rajan Pur quadrangles. An attempt has been made to revise and correlate the stratigraphy of the region on the basis of comprehensive study of the lithostratigraphic units of the area. The nomenclature of the Neogene rocks (Shah,* 1977) *is not found to be in accordance with the normal practice of the stratigrahic nomenclature and thus has not been taken into account.*

INTRODUCTION

The first geological investigations in the mapped area (Fig. 1) were carried out by Vredenberg (1908), who reported Cretaceous Orbitoides from the Sulaiman Range and collected *Lepidorbitoides minor* from a loose sandstone boulder of the Pab Formation. Eames (1952) described the biostratigraphy of the Cretaceous and the Paleogene rocks from Rakhi Nala. Marks (1962) defined the variation and evolution in Orbitoides from the Cretaceous rocks of the Rakhi Nala. Latif (1962) subdivided the Paleocene and Eocene rocks of the area on the bases of pelagic foraminifera. Williams (1959) worked out the stratigraphy of the whole of lower Indus Basin. However, his descriptions are very generalized. Iqbal (1969) described the Tertiary pelecypods and gastropods from Drug, Zindapir and Vidor area. Hemphill et al (1973) mapped Bannu and D.I. Khan quadrangles and described the lithostratigraphic units in these areas.

The present work specifically describes the stratigraphy of D. G. Khan and Rajan Pur quadrangles. The lithological variations based on detailed section measurements have been carried out. A more precise nomenclature for the lithostratigraphic units has been proposed, taking into consideration, all different names used in the past and following the stratigraphic code of Pakistan.

The nomenclature used by the previous authors and the one presented in this paper is summerized in Table No. 1.

An attempt has also been made to correlate these rocks laterally within the Sulaiman Range and also with the rock formations of Upper Indus basin (Table 2 and Table 3 respectively).

STRATIGRAPHY

The sedimentary rocks ranging in age from Cretaceous to Recent are present in the area. The stratigraphic nomenclature used in this paper is mostly adopted after Hemphil (1973). However, some new names have also been introduced which are found to be more appropriate for mapping purposes.

The oldest exposed rock unit, the Mughal Kot Formation is mainly exposed in the core of usually asymmetrical anticlines and is extensively developed in the Sulaiman Province. The other rock units are repeated along the various folds.

The lithological description of individual rock formation is as follows.

Cretaceous

The Cretaceous System in the area comprises about 600 meters thick stratigraphic column and is divisible into :—Mughal Kot, Fort Munro, Pab and Moro Formations in ascending order.

Mughal Kot Formation. The formation is traceable throughout the Sulaiman Range and occupies the cores of major anticlinal folds. It comprises dark grey calcareous mudstone, shale and argillaceous limestone. The base of the formation is not exposed in the area studied, and the exposed thickness of the formation (in Rakhi Nala) exceeds 127 metres. Its upper contact with the Fort Munro Formation is transitional. Williams (1959, p. 386) reported *Omphalocyclus sp.* and Orbitoides sps. and according to him the formation appears to be Maastrichtian. Marks (1962, p. 16) designated the claystones (Mughal Kot Formation) below Orbitoides Limestone (Fort Munro Formation) as Hemipneustes beds and reported abundant Globotruncana and impression of Inoceramus sp. He assigned Companian age to overlying Orbitoides Limestone as such the Mughal Kot Formation can be Companian or even older and can never be Maastrichtian as tentatively described by Williams.

Fort Munro Formotion. The Fort Munro Member of Williams and the Orbitoides Limestone of Marks (1962) is referred here as the Fort Munro Formation, due to its well-persistant thickness and mappable nature. It comprises dark grey to black, hard, thick bedded limestone which is sandy in the upper part and argillaceous in the lower part. In Northern Sulaiman Range (Mughal Kot Section) the upper 50 meters of the formation comprises thick, very calcareous to argillaceous sandstone. The formation is widely exposed in Sulaiman Range. At the type section it is 100 meters thick and its upper canact with the Pab Formation (Plate I, Fig. 1 & 2) is transitional. Williams (1959) reported *Omphalocyclus macropora* and *Orbitoides sp.* and assigned Maastrichtian age to the formation.

Marks (1962) assigned companian age to the unit on the basis of *Orbitoides tissoti minima*, and *Orbitoides tissoti compressa*.

Pab Formation. The formation is extensively developed in the Sulaiman Range (See Fig. 1). It comprises quartzose sandstone with subordinate shale. The sandstone is pinkish white medium to coarse grained, subangular to rounded, cross-bedded, interclated with grey shales. At places, the carbonaceous shales are present. The thickness of the rock unit varies from 300—400 meters.

The upper contact with the Moro Formation is gradational.

Vredenburg (1908) reported *Lepid Orbitoids minor* from Rakhi Nala.

Williams (1959, p. 387) reported a mixed banthonic-pelagic assemblage of Maastrichtian foraminifera from type locality in Sind. This statement is not analogous to the overall paleogeographic conditions at the Pab Formation represents a more regressive phase in the area.

Moro Formation. The formation is well-developed in the area. It comprises limestone, shale, and sandstone. Limestone is grey, medium to thick bedded, shelly. Shales are dark grey to greenish grey. In Pisah area (39 J/1), the formation can be divided into 3 distinct units. The lower unit consists of thick bedded, shelly limestone, the middle unit is predominently sandstone whereas upper unit comprises limestone, marl and ferruginous shale.

The formation is 80—110 meters thick and is disconformably overlain by the Khadro Formation in the area. This disconformity is represented by lateritic encrunstation over the Moro Formation.

Hunting Survey Corporation (1961, p. 198) reported *Globotruncana Ginnei* and *Omphalocyclus macropora, Orbitoids sp., Siderolites sp.* and assigned Maastrichtian age.

TERTIARY

Paleocene

Khadro Formation. The formation is exposed throughout Sulaiman Range. It comprises sandstone, siltstone shale and minor limestones. Sandstone is olive green, yellowish brown, medium grained. Siltstone is grey, fine to medium grained, ferruginous. Limestone is light brownish grey and contains abundant *Cardita* valves.

The formation is 100 meters to 225 meters thick. The upper contact with Dunghan Formation is conformable and transitional. Eames (1952), reported *Corbula harpa, Leionucula rakhiensis, Venericardia Vredenburgi, Tibia rakhiensis* and other fossils from Rakhi nala and assigned an early Paleocene (Danian) age to this unit.

Dungan Formation. The formation is extensively developed in Sulaiman Range. The formation comprises limestone, shales with limestone conglomerate and sandy limestone. In the north (Mughal Kot section), the limestone is predominent, whereas in the southern Sulaiman Range (Rakhi Nala section) calcareous shale and mudstone constitute the bulk of the formation. Thickness of the formation in Burkohi Nala (39 J/1) is 170 meters, in Johand chur (39 J/3) it is 211 meters and 160 meters in Rakhi Nala section.

The formation has transitional contact with overlying Ghazij Formation. The Dungan formation is highly fossiliferous and includes various genera of foraminifera, gastropods, bivalves and algae. Species as *Miscellanea miscella, Ranikothalia nuttalli, Assilina dandotica* and *Lockhartia tipperi* indicate a Paleocene to Early Eocene age of the formation.

Eocene

Ghazij Formation. The name Ghazij Formation has been adopted after Williams (1959), Oldham (1890) considered it a group. The lithologies of the formation are not very persistant throughout Lower Indus Basin and Axial belt, instead a vast veriety of lagoonal, swampy to shallow marine deposits are observed. In Sulaiman Range the formation is predominently shallow marine and is easily divisible into three members.

Rakhi Gaj Shale Member : It comprises shales, marls, with occasional limestone bands. In the north (Mughal Kot area) the unit comprises shales with subordinate limestone. In the central part (Zinda Pir area) it consists of shales with marls and in the south, it comprises claystone with argillaceous limestone which is fibrous and barite bearing at places.

The shales are green to greenish grey, gypsiferous, calcareous and splintary. Limestone is grey, thin bedded and contains foraminifera, gastropods and lamellibranchs. Thickness of the member ranges from 350—1880 meters.

Drug Limestone member. It contains limestone and marls. The limestone is grey, offwhite to earthy grey on weathered surface, cherty and nodular. Marl is palish grey with abundant bivalves, gastropods and foraminifera. It is 65—225 meters thick.

Buska Shale Member. This member comprises shales, alabaster and gypsiferous limestone. Shales are green to greenish grey, calcareous, oxidizing. Limestone is pinkish grey with coquina beds. The Gypsum is white, massive and hard. Thickness of gypsum beds varies from 2.5 to 15 meters in different areas. The member is 55 meters thick in the area.

The thickness of the Ghazij Formation ranges from 600 meters to 2300 meters. The formation contains abundant foraminiferas, bivalves, and gastropods. The foraminiferas include *Coskinolina Lockhartia, Assilina sublaminosa*. Among the bivalves *Cardita mutabilis* are found. Eames (1952), and Latif (1964) assigned an Early Eocene age to the formation. The upper contact with the Kirthar Formation is transitional.

Kirthar Formation. The formation is widely distributed throughout Sulaiman Range (See Fig. 1). It has been divided into four members, with distinguished lithologies and a persistant lateral development from north to south.

Habib Rahi Limestone Member. It comprises limestone with some marls. The limestone is grey, greyish brown, buff, weathering colour is offwhite. It is platy, fine grained, thin bedded, argillaceous in lower part, cherty in upper part and exhibits typical conical weathering. Gives foetid smell on breaking. This member ranges in thickness from 20 meters to 60 meters.

Domanda Shale Member. It comprises earthy grey to greenish grey colours, and contains silty, calcareous shales with some limestone and siltstone beds. The limestone is light grey to cream, shelly and hard. Siltstone developed in the basal part is grey to brownish grey, weathers brown and gradually passes to claystone siltstone beds.

It is 85 meters to 460 meters thick.

Pirkoh Limestone Member. It comprises limestone with subordinate marls. The limestone is light grey to chalky white, buff to brown, thin bedded, fine grained, argillaceous and richly fossiliferous containing foraminiferas in abundance. Thickness of the member ranges from 8—13 meters.

Drazinda Shale Member. The member consists of shale with occasional beds of limestone in the lower part that passes dominantly into and siltstone and claystone in the upper part. The siltstone is yellowish brown, contains worm borrows filled by secondary lateritic mud. The thickness of the member is 85—520 meters.

The thickness of Kirthar Formation varies from 460—930 meters. The formation is highly fossiliferous and contains foraminifers, bivalves and gastropods. On the basis of studies of abundant species of foraminifera, both Eames (1952) and Keizer (1959) believed that the lower three members of the Kirthar Formation are of middle Eocene age and the upper-most part i.e. Drazinda shale member may be as Late Eocene. The foraminifera collected from Habib Rahi Limestone member and Domanda Shale Member contain *Operculina sp., Assilina sp. Nummulites sp.* etc.

The upper contact with Chittawatta Formation is disconformable, and is represented by presence of ferruginous clays and clay stone in the upper part of the formation. At places 0.5 – 1.5 meters thich laterite bed is present at the contact.

Oligocene-Miocene

Chittarwatta Formation. It is also well-developed in the area (See Fig. 1). In the north part of Sulaiman Range, it comprises sandstone, siltstone and claystone. The sandstone is reddish to brownish grey, fine to coarse grained, thick bedded to massive, cross-bedded, ferruginous, calcareous and carbonaceous at places. The claystone/sandstone ratio is 60 : 40.

At places hard ferruginous sandstone and conglomerate beds are developed at the top of the formation. In the southern Sulaiman

Range, the formation is composed of varigated sandstone, siltstone and claystone. The sandstone is raddish brown, purple and earthy grey, fine to medium grained, subangular to subrounded, thin to thick bedded, friable and at places, grades to silica sand category. The siltstone/claystone is reddish brown, purple brown, friable argillaceous ferruginous. A laterite bed 1.5 meter thick at its base marks the disconformity with the Kirthar Formation. The formation is almost 200 meters to 320 meters thick in the area.

The upper contact with the Vihowa Formation is disconformable reprensented by latritic encrustations. Eames (1950, p. 169) recognized an unconformity in Rakhi Munh section. The formation is Late Oligocene to Late Miocena on the basis of the occurrence of the flora *Croftiella rantzien* (Hemphil and Kidwai, 1973).

Pliocene

Vihowa Formation. The Pliocene is represented by fluvial sedimentation of about 3000 meters thick Siwalik group. The group includes Vihowa, Litra and Chaudwan Formations. The name Vihowa Formation is used here for the lower unit of the Siwalik Group.

The formation comprises claystone with subordinate sandstone. The claystone is red, maroon, sandy and silty. The sandstone is greenish grey, thick bedded, cross-bedded, micaceous and at places pebbly. Minerologically, it is feldspathic-greywacke. The formation varies in thickness from 313 meters to 770 meters.

Mammalian bone fragments have been observed by La Touche (1893, P-90). The upper contact with Litra Formation is transitional.

Litra Formation. Litra Formation is well-developed throughout the Sulaiman Range. The name Litra Formation is used for the middle unit of Siwalik Group. It comprises with subordinate claystone and conglomerate. The sandstone is light grey, thick bedded to massive medium to course grained, micaceous and at places conglomeratic (in upper part). The claystone is reddish brown to dull red in the lower part and light red to earthy brown in the upper part. It is mottled by pale, olive and dirty yellow colours and at places grades into siltstone. The average clay and sandstone ratio in the Litra Formation is 20 : 80.

The thickness of the formation varies from 1300 meters to 2000 meters. The upper contact with Chaudwan Formation is gradational.

The age of the Litra Formation as tentatively assigned is Late Pliocene on the basis of a horse tooth (*Hipparion cf. H. antelopinum*) collected from the middle part of the Litra Formation nearRakhi Munh village, (Whitemore in Hemphill and Kidwai, 1973).

Pliocene—Pleistocene

Chaudwan Formation. The Chaudwan Formation represents the upper unit of the Siwalik Group. The formation comprises conglomerate with subordinate sandstone and clay. The conglomerate is light brownish grey, comprises boulders, cobbles and pebbles of limestone, quartzite and sandstone embedded sandy and calcareous matrix.

The conglomerate is developed in the middle and upper part of the formation in the north, and lower and middle part in the south.

The sandstone is grey, whitish grey, fine to coarse grained, cross-bedded, micaceous and it is predominantly greywacke.

The clay/claystone is yellowish brown to dark brown, silty and sandy. In the north, it is developed in the lower part while in the south, it is developed in the lower and middie parts.

The formation is 130 meters to 1400 meters thick in the area.

The upper contact of the formation with the overlying surficial deposits of the Indus Plain and Dada Conglomerate is unconformable.

No fossil has been reported from Chaudwan Formation. It is believed that it is of Late Pliocene to Pleistocene age (Hemphill and Kidwai, 1973).

Dada Conglomerate. The Dada Conglomerate consists of conglomerate and subordinate sandstone. The conglomerate beds comprise boulders, cobbles and pebbles of limestone, quartzite sandstone and claystone. These vary in size from ½ cm. to 5 cm. A few are even upto 10 cm. in diameter and are cemented in sandy/calcareous matrix.

The formation has very low dips, generally 5° — 7° and rests with an angular confirmity on the older rocks such as Litra and Chaudwan Formations. Thickness of the unit is 6 meters in Dalana Nadi.

CONCLUSION

Some of the important conclusions are summerized below :—

1. A precise nomenclature based on stratigraphic code of Pakistan, reasonably more suited for mapping, purposes, have been presented.
2. The nomenclature of Siwalik Group of Upper Indus Basin as proposed by Shah (1977), is considered to be improper and non-applicable in the area as Chaudhwan Formation is indivisible and time equivalent to both Dhok Pathan and Soan Formations.
3. The Oligo-Miocene Chittarwatta Formation is also lithologically different from the Nari/Gaj Formation of Kirthar province, Lower Indus Basin. Thus, the Chittarwatta Formation represents a completly different unit and this name is maintained.
4. Paleogeographically the Sulaiman Basin represents a separate and complete entity. Thus this should be considered geologically independent from Kirthar and Baluchistan Basins.
5. As described in the text well established Stratigraphic breakes have been observed between (i) Cretaceous-Paleocene, (ii) Eocene-Oligocene and (iii) within Miocene times.
6. Detailed paleotonlogical studies are required to describe precise ages.

Period	Epoch		WILLIAMS (1959) For Sulaiman Range and Baluchistan	HEMPHILL et al (1973)	EAMES (1952)	MARKS (1962) (Rakhi Nala Section)	LATIF (1962) (Rakhi Nala)	SHAH (1977)	PRESENT PAPER (1988)
TERTIARY	PLEISTOCENE		Siwalik group	Siwalik Group: Chaudhwan form.				Soan formation	Dada Conglomerate Chaudhwan formation
TERTIARY	MIO-PLIOCENE		Siwalik group	Siwalik Group: Litra formation Vihowa formation				Dhok Pathan form. Nagri formation Chingi formation	Litra formation Vihowa formation
TERTIARY	OLIGOCENE		Gaj formation Nari formation	Chitter-Wata form.	Nari formation		Nari formation	Nari formation	Chitter-Watta form.
TERTIARY	EOCENE	L	Kirthar formation	Kirthar form.: Drozinda Sh. Mem. Pirkoh Lst. Mem. Domanda Sh. Mem. Habib Rahi Lst. Mem	Kirthar form.: Upp. Chocl. Clay White Marl band Lower Chocl. Clay Assilina beds		Chharat formation Kirthar formation	Kirthar form.: Drozinda Sh. Mem. Pirkoh Lst. Mem. Sirki Sh. Mem. Habib Rahi Lst. Mem.	Kirthar form.: Drazinda Sh. Mem. Pirkoh Lst. Mem. Domanda Sh. Mem. Habib Rahi Lst. Mem
TERTIARY	EOCENE	M	Ghazij formation	Baska Shale	Laki form.: Shale with Alabaster			Ghazij form.: Baska Shale and Alabaster Member	Ghazij form.: Baska Sh. Mem.
TERTIARY	EOCENE	E	Ghazij formation	Ghazij Shale	Laki form.: Rubbly Limestone Green Nod. Sh. Rokhi Gaj Shale		Ghazij formation	Ghazij form.: Sh. & Lst. Member	Ghazij form.: Drug Lst. Mem. Rokhi Gaj Sh. Mem
TERTIARY	PALEOCENE		Dunghan formation Rani kot formation Khadro formation	Dunghan formation	Rani kot formation: Zinda Pir Shale Zinda Pir Lst. Vinericardia Sh.		Rani kot formation	Dunghan formation Khadro formation	Dunghan formation Khadro formation
CRETACEOUS		L	Pab Sandstone	Pab Sandstone	Pab Sst. form.	Pab Sandstone		Moro formation Pab Sandstone	Moro formation Pab formation
CRETACEOUS		M	Fort Munro Member Mughal kot form.	Mughal kot form.	Orbitoides Limestone / Shale Bedded Clays & Inoceramus Clays	Orbitoides Limestone / Shale Hemipneustes beds		Fort Munro formation Mughal kot formation	Fort Munro formation Mughal kot formation
CRETACEOUS		E	Parh Limestone Goru formation Sembar formation	Parh Limestone Sembar formation					
JURASSIC			Sulaiman Lime-ston group						

TABLE NO I CHART SHOWING DIFFERENT NOMENCLATURE USED BY VARIOUS WORKERS IN SULAIMAN RANGE AND ADJOINING AREAS.

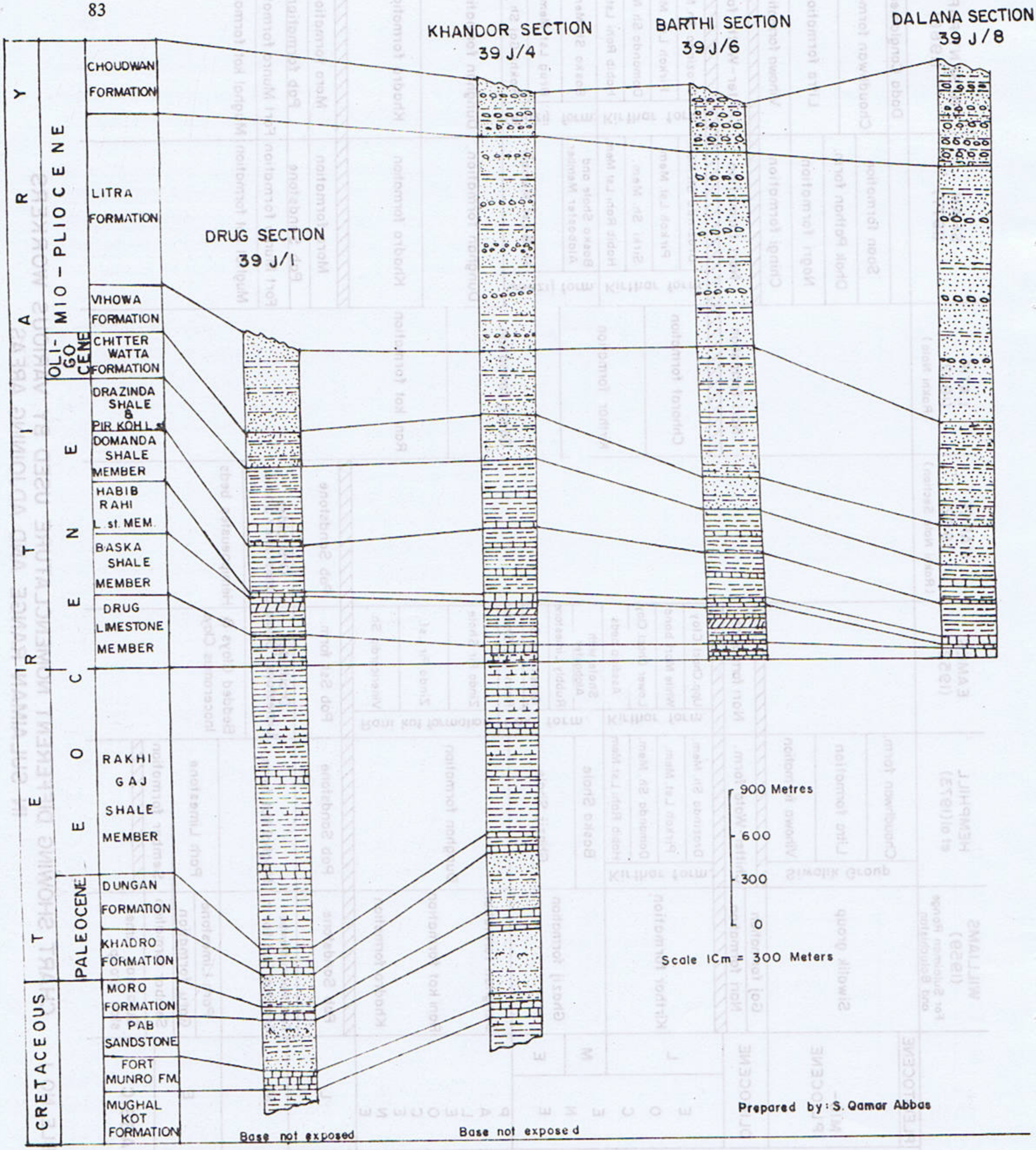

TABLE. 2 CORRELATION CHART OF E. SULAIMAN RANGE.

GEOCHRONOLOGIC UNITS			SULAIMAN RANGE			KOHAT-POTWAR PROVINCE		
ERA	PERIOD	EPOCH	GROUP	FORMATION	MEMBER	GROUP	FORMATION	MEMBER
CENOZOIC	QUATERNARY	SUB-RECENT & REC.						
		PLEISTOCENE	SIWALIK	Doda Conglomerate		SIWALIK	Lei Conglomerate	
	TERTIARY	PLIOCENE		Chaudhwan formation			Soan Formation	
				Litra formation			Dhok Pathan Formation	
		MIOCENE		Vihowa formation			Nagri Formation	
							Chinji Formation	
				Chitarwata formation		RAWALPINDI	Kamlial Formation	
							Murree Formation	
		OLIGOCENE						
		EOCENE		Kirthar formation	Drazinda shale mem. Pirkoh L.st. member Domanda shale mem. Habib Rahi L.st mem.	CHARRAT	Kohat Formation Kuldana Formation	
				Ghazij formation	Baska shale member Drug L.st. member Rakhi gaj shale mem.		Chorgali Formation Margala hill Limestone	
		PALEOCENE		Dunghan formation			Patala Formation	
				Khadro formation			Lockhart Limestone Hangu Formation	
MESOZOIC	CRETACEOUS	LATE		Moro formation				
				Pab sandstone			Kawagarh Formation	
				Fort Munro formation				
				Mughal kot formation			Lumshiwal Formation	
		EARLY		Base not exposed in map area			Continued (Fatmi – 1973)	

TABLE NO. 3
CORRELATION OF LITHOSTRATIGRAPHIC UNITS OF SULAIMAN RANGES WITH THOSE OF KOHAT – POTWAR PROVINCE.

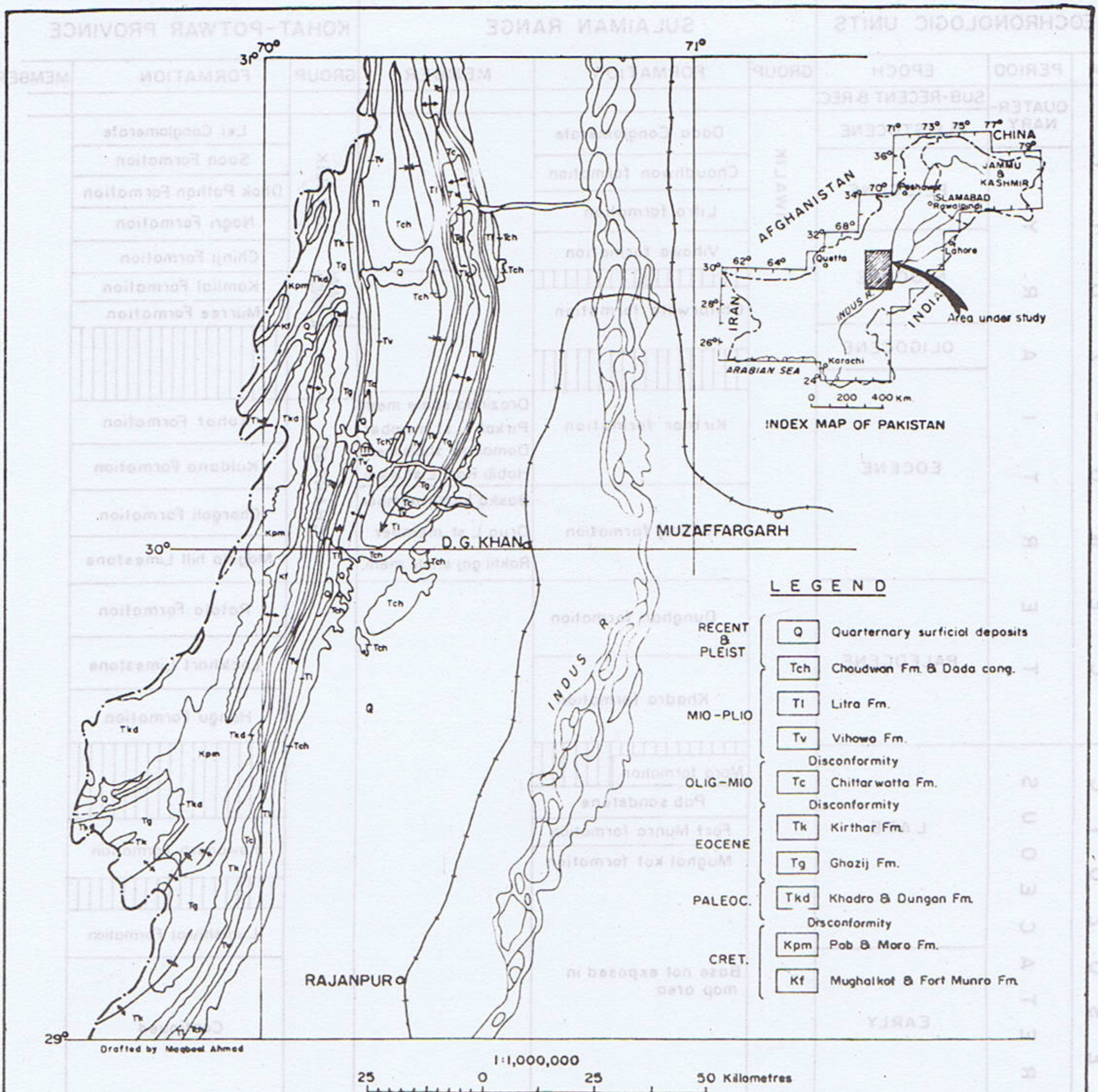

FIG. I. GEOLOGICAL MAP OF SULAIMAN RANGE

PLATE 1

Fig. 1. Cliff-marking Pab. formation at the top with Fort Munro formation at the base.

Fig. 2. Contact between Fort Munro formation and Pab. formation.

PLATE 2

Fig. 1. Flute cast in Pab. Fm. Showing current direction from SE.

Fig. 2. Contact between Pab. formation and Moro formation.

Fig. 3. Mudstone and Shale intercalation in Moro formation.

PLATE 3

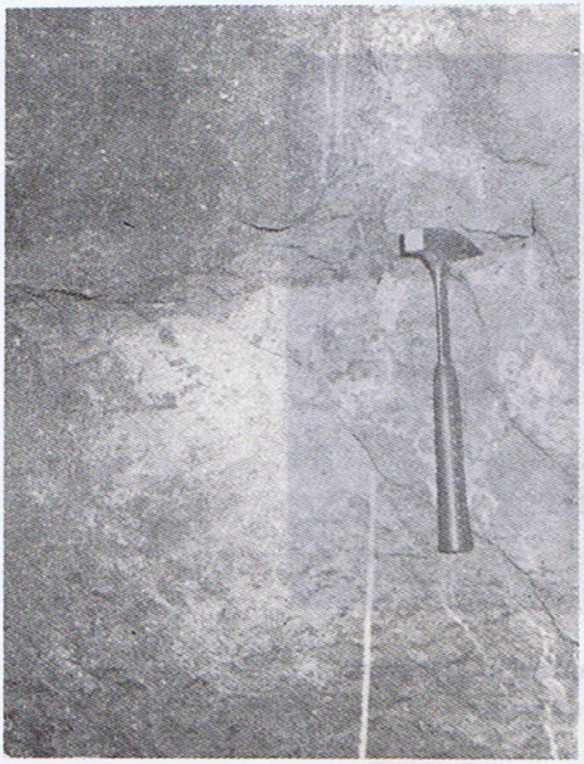

Fig. 1. A Shelly Limestone bed in the upper part of Moro formation.

Fig. 2. Contact of Moro formation with Khadro formation.

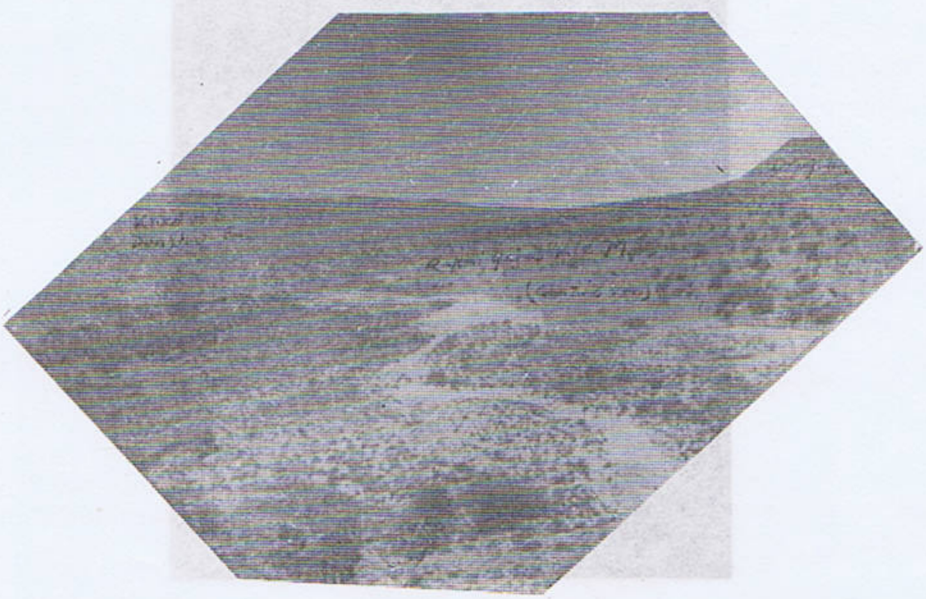

Fig. 3. Khadro and Dungan formation (left) Drug Limestone member (top) and Rakhi Gaj Shale member of Ghazij Fm. making slope.

PLATE 4

Fig. 1. Chert on bedding surface of Dunghan formation (Limestone bed).

Fig. 2. Intraformational (Limestone) boulders and pebbles in Dunghan formation.

PLATE 5

Fig. 1. Platy bedding of Habib Rahi limestone member with chert layers and lenses.

Fig. 2. Conical weathering of Habib Rahi limestone member of Kirthar formation.

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MILK MOLAR MORPHOLOGY IN *STEGODON DHOKAWANENSIS* SARWAR

BY

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Abstract : *A left maxillary portion bearing a deciduous fourth premolar (P.U.P.C.** 66/3) *of some stegodont skull is described from Pabbi Hills of district Gujrat, Punjab. On the basis of dental features, it has been referred to the species,* Stegodon dhokawanensis *described by Sarwar in* 1977. *Thus, P.U.P.C.* 66/3 *provides information about the morphology of the milk dentition in the species,* Stegodon dhokawanensis.

INTRODUCTION

In the year 1966, a maxillary portion of a stegodont skull was procured from the Pinjorian outcrops of the Pabbi Hills near the village Sardhok, district Gujrat, Punjab, Pakistan. It bears a fourth deciduous premolar of the left side. The tooth structure favours its inclusion in the species, *Stegodon dhokawanensis* known by an upper last molar (Sarwar, 1977). Seven species of the genus *Stegodon* are hitherto known from the Siwaliks. These are *Stegodon bombifrons*, *S. insignis* and *S. ganesa* described by Falconer and Cautley (1846) ; *S. pinjorensis* erected by Osborn (1929) ; *S. sardhokensis* and *S. dhokawanensis* founded by Sarwar (1977), and *S. rathiansis* reported by Sarwar (1985).

STEGODON DHOKAWANENSIS Sarwar, 1977

TYPE

P.U.P.C. 69/609, a left upper last molar from Tatrotian of the Upper Siwaliks. It was collected from Dhokawan, near Rohtas Fort, district Jhelum, Punjab, Pakistan.

DISTRIBUTION

The species is known from Tatrotian outcrops of Dhokawan, district Jhelum, Punjab (Sarwar, 1977) and from Pinjorian of Pabbi Hills, Gujrat, Punjab, Pakistan (Specimen under discussion).

SPECIMEN EXAMINED

P.U.P.C. 66/3, a portion of the left maxilla bearing DP^4, from near Sardhok, Pabbi Hills, Gujrat, Punjab, Pakistan.

DESCRIPTION (Fig. 1)

The tooth is much worn but its enamel contours indicate that the partially preserved anterior enamel loop belongs to the fore-talon and that the tooth was provided with five ridge-plates together with a fore- and an aft talon. Due to the deep wear, the anterior three ridge-plates and the fore-talon have formed a common dentinal plate. The wear was more confined towards the buccal side as a result of which the distinction between the anterior three ridge-plates can no more be made. However, the three rldge-plates can be marked at their lingual side. The overall enamel figure of the tooth shows that the ridge-plates were wavy and not transversely linear. The enamel loop is moderately thick and is produced into acute plications.

* Fossil collection stored in the Zoology Department, Punjab University, Lahore, Pakistan.

TABLE 1

Measurements (in mm.) of left DP^4 in *Stegodon dhokawanensis* (P.U.P.C. 66/3)

Number of ridge-plates	1/2+5+1/2
Anteroposterior length (preserved)	103
Anteroposterior length (estimated)	105
Lamellar frequency	6.3
Transverse width	60
Width/length index	57
Crown height (preserved)	17
Crown height (estimated)	28
Height/width index	47
Enamel thickness	3

The ridge-crests are thin and anteroposteriorly compressed. Due to the deep wear, the intervening valleys are almost disappearing. Although the transverse valleys are diminishing yet the presence of cement can be marked in the ultimate and penultimate valleys. The presence of cement is also indicated at the lingual side of the tooth. Overall contour of the tooth, shape of the ridge-plates and the relative preserved height of the ridge-plates suggest that the tooth crown was low.

DISCUSSION

The specimen under study, P.U.P.C. 66/3 is although much worn yet its number of ridge-plates can be counted which is very low i.e. five with fore-and aft talons. Such a low number of ridge-plates for DP^4 is either found in *Stegodon bombifrons* (Osborn, 1942) or in *S. dhokawanensis* (Sarwar, 1977). In teeth of the former, the enamel figure is quite simple and devoid of plications. Median longitudinal sulcus extends at least in the interior half of the tooth (Lydekker, 1886). In those of the later the enamel figure is not simple but rather plicated. Median longitudinal sulcus is essentially lacking and the enamel figure is not simple. It is highly plicated and the ridge-plates are wavy. Also. the crown height appears to be comparatively low than in the species, *Stegodon bombifrons* (Sarwar, 1977). It also differs from the non-Siwalik stegodonts with short or abbreviated type of teeth. In *Stegodon elephantoides*, the ridge-plates are essentially transversely linear (Clift, 1828; Falconer and Cautley, 1846). The similar contours are also exhibited by the ridge-plates of the species, *S. yushensis* described by Young (1935) from China. The wavy nature of the ridge-plates of P.U.P.C 66/3 also differentiate it from the transversely linear ridge-plates of South-East Asian species, *Stegodon sompoensis* erected by Hooijer (1964).

In view of the morphological similarities between the type tooth of the species, *Stedodon dhokawanensis* and the specimen under study, and its distinction from the non-Siwalik pigmy stegodonts, it is justified to include the later in the species, *Stegodon dhokawanensis*. The inclusion of P.U.P.C. 66/3 has thus added to the description of the species and its dental plate formula.

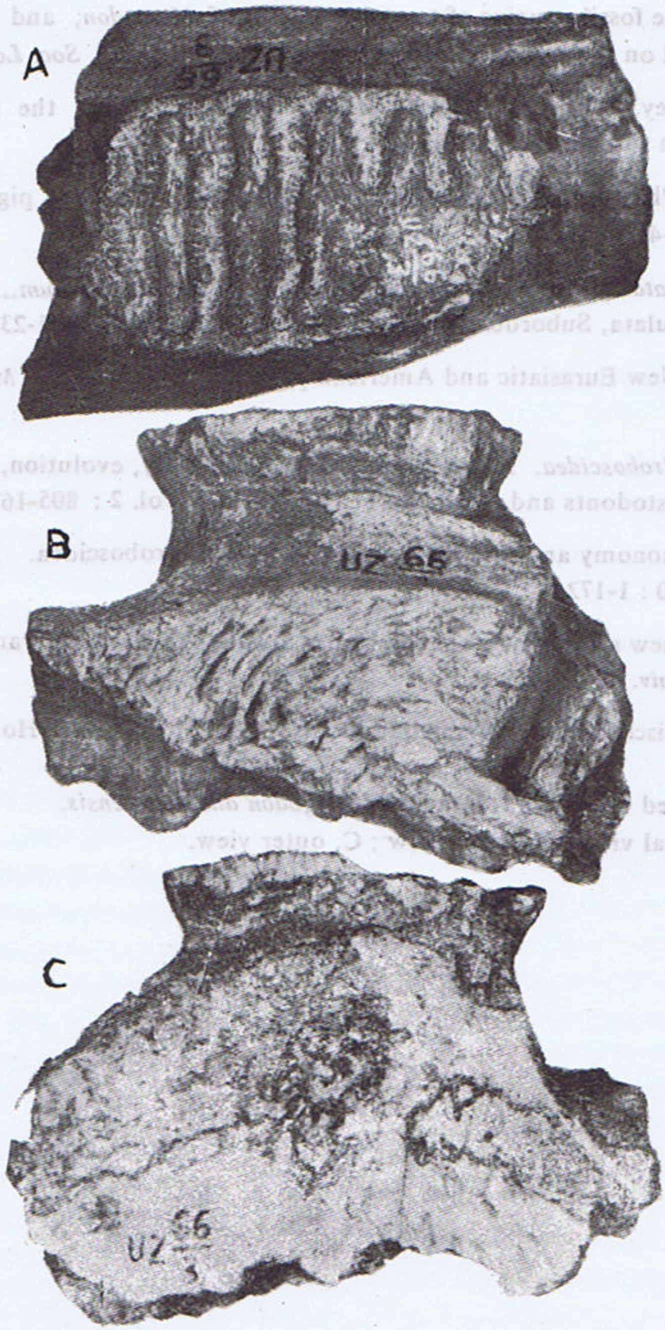

Fig. 1. A referred maxillary fragment of *Stegodon dhokawanensis*.
A. palatal view ; B, inner view ; C, outer view.

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Fig. 1. A referred maxillary fragment of *Stegodon dhokawanensis*.
A. palatal view ; B, inner view ; C, outer view.

CHEMICAL PETROLOGY OF A SODA-LITHIA RECONSTITUTED APLITE FROM MELDON, DEVONSHIRE, ENGLAND

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Abstract : *The aplitic part of a so-called layered aplite pegmatite body of soda-lithia type of rare occurrence is described and its petrography and chemistry discussed. Correlation and regression data are also discussed and chemical gains and losses (on the* 160 *oxygen unit cell basis) due to autometasomatism are related to its petrogenetic evolution.*

INTRODUCTION

The Meldon Aplite, Devonshire, is a soda-lithia rich aplite dyke about 20-25 metres in thickness occurring 1 km. northwest of the main Dartmoor granite. It is an irregular dyke extending almost two miles in length and is restricted to the "Calcareous Shale Group" of Carboniferous age containing the "dark igneous series". The "dark igneous series" are basic in nature. Early references include : De la Beche (1839), Rutley (1889), MacMahon (1893, 1894), Lowe (1901) and particularly Worth (1920) and McLintock (1923). The mineralogy of the aplite has been studied more recently by Chaudhry and Howie (1970, 1971, 1973-a, 1973-b, 1975), Chaudhry (1971), and Chaudhry & Chaudhry (1979).

Petrographically, the Meldon Aplite is a fairly heterogeneous intrusion. Albite, quartz, lithium-aluminium micas and orthoclase are the essential minerals and elbaite, topaz, fluorite, apatite and petalite occur as accessory minerals of the aplite. However, locally elbaite, topaz and petalite become essential minerals.

PETROGRAPHY

The body is essentially an aplite, large parts of which have been modified to variable degrees by recrystallization, autometasomatism, greisenisation and complex generation of coarse pegmatites and small pegmatitic veins. The Meldon aplite is cut by two types of thin (2 to 7 cm) veins ; in one type the pegmatitic veins are composed of orthoclase, quartz, lithium-aluminium micas, albite, and elbaite, and in the second type, the pegmatitic veins consist of orthoclase, lithium-aluminium micas, quartz, albite, topaz and petalite. The veins are richer in volatiles (F_2, B_2O_3 and H_2O), than the aplites types. The pegmatite and pegmatitic veins will be dealt with in a separate publication.

The aplite intrusion can be divided into the following major units :

1. Aplite (constituting about 92% of the body).
2. Pegmatite and pegmatitic veins (about 6%).
3. Greisens (about 1.5%).
4. Xenoliths (about 0.5%).

PETROGRAPHY OF THE APLITE

On the basis of colour, texture and comparative mineral constitution, the aplite is divided into the following types :

1. Blue aplite.
2. White aplite.
3. Brown aplite.
4. Mica-poor white aplite.
5. Porphyritic brown aplite.
6. Tourmalinized aplite.
7. Topazified aplite.
8. Petalitized aplite,
9. Reconstituted mixed aplite.

This classification is to some extent arbitrary as the various types show considerable intergradations. The blue aplite is the marginally chilled facies of the aplite dyke, and whereas the white aplite has not undergone much metasomatism, the brown aplite has undergone moderate metasomatism. All the other types are metasomatic derivatives of the first three types mentioned above, thus transitions exist between them and the other types. The transitional types embrace to varying degrees the petrographic characteristics of the classes between which or amongst which they fall.

The Blue Aplite

This aplite varies from light blue to pale azure in colour in hand specimen. Generally it is so fine-grained and appears so homogeneous that a majority of its constituents cannot be recognized in hand specimen. Microscopically, however, it is not homogeneous and consists of coarser crystals of apatite, albite, orthoclase and elbaite set in a very fine groundmass of albite, lepidolite, orthoclase and quartz. Albite is the chief mineral component of this rock variety. Albite, fluorite and elbaite all occur as poikilitic coarse-grained crystals of fairly variable dimensions. Its composition can be seen from table 1.

The White Aplite

The "blue aplite" grades into the "white aplite" over a short distance. The following major changes take place :

(1) Grain size increases substantially and flow-lined texture is replaced by compact saccharoidal texture.

(2) Quartz and lepidolite both increase rapidly in amount.

Most of the albite belongs to only one period of crystallization. Most of the orthoclase occurs either as individual megacrysts or aggregates of megacrysts. The development in large amounts of these megacrysts imparts a local porphyritic texture to otherwise typical saccharoidal aplite. Albite, quartz and even lepidolite may occur as inclusions. Megacrysts of pale or brown petalite also occur which include albite, quartz and mica, etc. It is often associated with megacrystic orthoclase. Lepidolite may often enclose or replace albite, quartz and sometimes even topaz. Elbaite and topaz are also replacement minerals (for modal composition of white aplite see Chaudhry & Mahmood, 1979).

The Brown Aplite

The "brown aplite" is of coarser texture and less compact than the previous two types of aplite. The comparison of this aplite with the "white aplite" and the "blue aplite" shows lower values of albite and higher values of lepidolite, quartz, orthoclase and fluorite. Within the "brown aplite" itself quartz and lepidolite increase progressively. Lepidolite generally replaces albite and quartz. The megacrystic-orthoclase has formed by replacement. "Brown aplite" often contains fluorite and some of its part is rather rich in it.

Strongly metasomatized Aplites. These aplites are the strongly metasomatized parts of the previous types of aplites and include the following :

Porphyritic brown aplite and Mica-poor white aplite. The former is a brown aplite while the latter is a white aplite in which due to strong K-metasomatism megacrystic orthoclase has developed. This orthoclase has generally ragged outline and is rich in albite, mica and quartz inclusions.

Topazified aplite, Tourmalinised aplite, Petalitized aplite and Reconstituted mixed aplite. They are distinguished by the concentration of otherwise accessory minerals like topaz, petalite and elbaite in such amounts that they become essential constituents of these rocks. Depending upon which of the three minerals, namely topaz, petalite and elbaite, or their combinations assume the status of essential minerals, they are accordingly called topazified aplite, petalitized aplite, tourmalinized aplite or reconstituted mixed aplite. In all these types, albite is extensively replaced. Mica and quartz may also show replacements by the minerals like topaz, elbaite and petalite. The variations in the mineral compositions of these rocks are considerable as can be seen from the last 34 modal analyses in Table 1 of Chaudhry and Mahmood (1979).

GEOCHEMISTRY

Twenty-four chemical analyses of aplites are given in table 1 ; correlation analysis are given in Table 2.

Correlation and regression analysis

SiO_2 shows significant correlation only with the major alkalis, namely Na_2O, K_2O and Li_2O. These relations, however, are of considerable importance in determining the mineralogical variations in the aplite intrusion. The content of SiO_2 shows a progressive increase with progressive crystallization and reconstitution. Na_2O shows a negative correlation and K_2O and Li_2O show positive correlations with SiO_2.

The total amount of alkalis in the aplite decreases with progressive crystalization. Na_2O shows a positive and K_2O a negative correlation with the total alkalis. It is thus concluded that with progressive crystalization, the amount of SiO_2, K_2O and Li_2O increases whereas the amounts of Na_2O and the total alkalis decrease. The contents of K_2O and Na_2O, and Li_2O and Na_2O show negative correlations. These relations lead to the accumulation of K_2O, Li_2O and SiO_2 which cause widespread metasomatic generation of lepidolite, quartz, orthoclase and petalite. This also gives rise to the formation of pegmatites and the pegmatitic veins in the early stages and greisens in the later stages.

Total iron and Li_2O, TiO_2 and Rb_2O, and Rb_2O and MnO show positive correlation, because they are concentrated in lepidolite and therefore their amounts increase or decrease together with the increase or decrease of the lepidolite content of the aplites. The contents of CaO and Li_2O are negatively correlated. The negative correlation between CaO and Li_2O is a result of negative correlation between albite, the chief mineral containing CaO, and lepidolite, the main lithium bearing mineral.

Simple linear equations for the various pairs of related oxides are as follows.

1. $SiO_2 = -0.96\ Na_2O + 73.53$
2. $SiO_2 = +1.61\ K_2O + 64.79$
3. $SiO_2 = +1.41\ Li_2O + 68.55$
4. $\text{Total Alkalis} = +0.54\ Na_2O + 6.41$
5. $\text{Total Alkalis} = -0.71\ K_2O + 10.69$
6. $Na_2O = -1.73\ K_2O + 9.28$
7. $Na_2O = -1.30\ Li_2O + 5.02$
8. $Li_2O = +1.06\ (\text{Total Iron}) + 0.48$
9. $Rb_2O = +0.18\ Ti_2O + 0.40$
10. $Rb_2O = +0.35\ MnO + 0.37$
11. $CaO = -0.45\ Li_2O + 1.69$

Comparative Chemical Characters of the Various Types of the Aplites

The overall geochemical relations amongst the various elements in the aplites have already been considered ; the comparative chemical characters of each of the petrographic units will now be presented. In the section on petrography, the aplite was arbitrarily divided into the "blue aplite", the "white aplite" and the "brown aplite". Here the "white aplite" is further divided into fine-grained white aplite" and "megacrystic "white aplite". The "brown aplite", depending upon the degree of reconstitution is further divided into "light brown aplite" and "brown aplite". The various groups have been arranged according to the increasing degree of reconstitution. This order is considered to be broadly time-sequential. For rendering ready comparison possible, the analyses have been arranged according to the increasing amount of SiO_2 in each of the groups. Before proceeding any further, it may be emphasised that these subdivisions are purely arbitrary, in an otherwise almost continuous sequential evolution from the "blue aplite" to the "brown aplite". The various units therefore, do not represent distinct and unique petrographic or chemical entities. They only represent changes within a single population. Strongly reconstituted minor types have not been considered.

Si_2O. The "blue aplite" has the lowest average SiO_2 content at 67.05% with a fairly restricted range. The other varieties have average contents representing a fairly continuous range from the "fine-grained white aplite" (69.35%) through to the "brown aplite" with 71.41%.

Al_2O_3. The "blue aplite" has the highest average alumina content at 19.10%, the other petrographic types having average values ranging from 18.64% (fine-grained white aplite) to 17.29% (brown aplite).

Na_2O, K_2O, Li_2O. The Na_2O contents show a fairly large variation between the petrographic types. The highest value is 6.49% (blue aplite) decreasing through the fine-grained white (4.6%) megacrystic white and light brown types to an average of 2.64% in the brown aplite. The average K_2O content increases from 2.71% (blue aplite) through the other types to 3.44% in the "brown aplite". The average Na_2O/K_2O ratios range from 2.39 (blue aplite) to 0.77 (brown aplite), the "blue aplite" having the highest average content of Na_2O+K_2O at 9 20% whereas the megacrystic "brown aplite" has an average value of 6.08%.

There is a general average increase in Li_2O from 0.41% (blue aplite) to 1.32% (brown aplite).

Total iron. The average $FeO+Fe_2O_3$ content varies from 0.35% (blue aplite) to 0.63% (brown aplite) but with a value of 0.64% for "megacrystic white aplite" associated with montmorillonitized petalite.

MnO There is a general increase from 0.06% (blue aplite) to 0.27% (brown aplite).

CaO The "blue aplite" has the highest average value at 1.75% decreasing to 1.22% in the "brown aplite".

P_2O_5 The apatite bearing "blue aplite" naturally contains the highest average P_2O_5 content of 0.50%. The fine-grained white, megacrystic white, light brown and brown aplite have average values of 0.19, 0.20, 0.29 and 0.29% P_2O_5, respectively.

Chemical Gains and Losses During Metasomatism

The fact that large parts of the aplite have been reconstituted by recrystallization and metasomatism has already been emphasized. Here a quantitative method of study has been used, following Barth (1948, 1952), to present these changes. This method consists of comparing the cations of the standard cell of the reconstituted to the original rock composition. The cations of the standard cell are the cations associated with 160 oxygens. This method assumes changes to be isovolumetric.

The sample MN 10 has been chosen for reference, since this sample can be regarded as pure and practically unmetasomatised aplite. All the cationic gains and losses have been evaluated with respect to this sample. The numbers of cations in the unit cells are listed in Table 3 and the cationic gains and losses are given in Table 4.

During crystallization and metasomatism a substantial overall decrease in Al^{3+} and Na^{+} occurs, The amounts of K^{+}, Li^{+}, and Mn^{2+} show a dominant overall increase. The contents of Mg^{+}, Fe^{+3} and P^{5+} generally increase, but in a few cases they may decrease. The contents of Rb^{+}, Fe^{2+} and Ca^{2+} probably remain constant. The samples showing gains are roughly balanced by the samples showing losses. This is most likely due to the irregular redistribution of these cations during metasomatism.

PETROGENESIS OF THE MELDON APLITE

The aplite melt at the time of its intrusion was partially crystalized. This is evident from the occurrence of small amounts of relatively bigger crystals of albite and orthoclase in the chilled, fine-grained and flow-lined groundmass of the "blue aplite". These crystals cannot be attributed to post-consolidation metasomatism, because they neither replace nor intersect the flow lineated aplite. However, associated with these crystals occur poikilitic crystals of apatite, tourmaline and fluorite. These belong to the postconsolidation replacement processes, for they clearly replace and interrupt the flow lining in the "blue aplite".

Away from the contact, the aplite shows considerable mineralogical but moderate chemical variation. A detailed analysis of mineral and chemical composition is presented in the geochemistry section. Therefore, here, only relevant generalisations will be given.

With progressive crystallization, and also subsequent metasomatism, the amount of albite decreases whereas the amounts of quartz and lepidolite increase rapidly. Orthoclase registers an overall slow and general, though irregular increase. It most commonly occurs as postconsolidation replacement megacrysts, diffused patches and pods. Primary crystals or megacrysts of orthoclase occur in relatively smaller amounts. Their mode of occurrence and important petrographical characters are discussed in a separate section of this chapter.

Lepidolite is more abundant and shows greater variation than orthoclase. Lepidolite develops in preference to orthoclase during the magmatic stage. This is because high amounts of volatiles (H_2O, F_2, Li_2O, P_2O_5) inhibit the formation of polysilicic orthoclase in favour of orthosilicic mica (Bowen, 1928). It also causes a widely spaced nucleation pattern for orthoclase, which in effect gives rise to megacrystic development of orthoclase.

Towards the last stages of consolidation of the aplite, a period of pegmatite vein formation started as a result of very mobile volatile rich residuum at relatively low temperatures. This residuum not only formed pegmatite and pegmatitic veins but also caused widespread metasomatism within the aplite itself. All those minerals which occur in the pegmatitic veins, also generally occur as rather thinly dispersed metasomatic minerals in various parts of the aplite. The following constituents took part in the metasomatic reconstitution of the aplite :

(1) Less mobile — K_2O, Li_2O, CaO, FeO and Fe_2O_3.

(2) Highly mobile — P_2O_5, B_2O_3, H_2O and F_2.

These constituents in various combinations give rise to the following minerals.

High-Temperature Pneumatolytic Stage

(1) K_2O, without appreciable amounts of F_2 and H_2O forms orthoclase megacrysts.

(2) H_2O and F, high values of fluorine compared with water form topaz and may inhibit, temporarily, the formation of notable amounts of mica.

(3) H_2O, F, Li_2O, K_2O, (FeO and Fe_2O_3). Depending upon the ratio of water to fluorine, topaz and lepidolite or lepidolite alone may form. If the amount of fluorine is small, lepidolite and petalite or lepidolite, petalite and orthoclase may all form.

(4) Li_2O, in the absence of fluorine forms petalite.

Low-Temperature Pneumatolytic Stage

(5) CaO and F, give rise to fluorite.

(6) P_2O_5, CaO and F, form apatite, fluorapatite and apatite and fluorite.

(7) H_2O, K_2O, and F, give rise to pale green muscovite (gilbertite).

The formation of these minerals overlaps. More than one generation of some of them may form. In view of these difficulties it is not possible to give their accurate sequence. However, an approximate sequence is presented in the Fig. 1.

Megacrysts of Orthoclase. The megacrysts of orthoclase can be divided into the following two types.

(1) The metasomatic orthoclase megacrysts.

(2) The magmatic orthoclase megacrysts.

The Metasomatic Orthoclase Megacrysts. These megacrysts show textural characteristics which suggest formation as a consequence of postconsolidation metasomatism rather than crystallization from a magma. Following are the arguments in favour of a metasomatic origin.

(1) They often contain the inclusions of all the primary minerals of aplite and therefore formed as a result of replacement following the consolidation of the aplite.

(2) These megacrysts have rugged outlines and imperfectly developed faces. Sometimes some crystal faces, even in the principal zones, may be suppressed. Such morphologic features are common place with minerals formed by replacement rather than by the primary magmatic crystallization.

(3) Orthoclase megacrysts may, sometimes, cut right across the contact between the aplite and the veins in the aplite. This indicates their time of formation as later than both the aplite and the veins.

Analogous textural features have been described by Stone and Austin (1961) from the granites of Southwest England. Their line of reasoning is accepted here except the argument that, "These megacrysts cannot be regarded as last minerals formed out of a magma for they are neither interstitial nor granular". For, the orthoclase crystals forming during the last stages of magmatic crystallization may continue to grow during and even following consolidation. These megacrysts, although dominantly late magmatic, will neither be interstitial nor indeed granular. Evidence of this kind of growth has been presented by Orville (1960).

(4) Megacrysts of orthoclase, at some places, cut right across the contact between aplite and the country rock. This feature was first recorded by Worth (1920) from the Meldon aplite. Such growths can be easily explained by metasomatic replacement rather than by uniform magmatic growth in two entirely different chemical and physical environments. From the preceding arguments, it is concluded that this particular class of megacrysts formed as a result of postconsolidation metasomatism.

THE MAGMATIC ORTHOCLASE MEGACRYSTS

These megacrysts grow at a high angle to the general direction of alignment of the crystals in the aplite. They have a simple crystal habit and are generally eumorphic. Such megacrysts have been described by Wheeler (1935), Jahns (1953), Orville (1960) and Volborth (1962). Staatz and Trites (1955), suggest that these megacrysts grow in a projected position above the surface of the already formed aplite. Jahns and Tuttle (1963), regard them as having formed contemporaneously with the aplite layers. The same view is shared by Windley and Bridgwater (1965) for the "layered aplite-pegmatite sheets of Kinalik, South Greenland". Orville (1960), regards similar megacrysts either postconsolidation, or that they formed as magmatic crystals and continued to grow after the consolidation of the aplitic rock. Those crystals which Orville (1960) believes formed after the consolidation of the aplite belong to the class discussed above. The crystals from the Meldon aplite being discussed here are euhedral and simple in habit. They deflect the parallel alignment of the aplite. Laths of aplite may butt against them. Sometimes, however, they may show some replacement towards their margins, as a result of small scale growth after consolidation. The above textural features suggest strongly that these crystals formed roughly at the same time as the enclosing aplite, but some of them continued to grow, as suggested by Orville (1960), to varying degrees after the consolidation of the aplite. So, it is suggested that the authors referred to in the foregoing are each stressing one of the many conditions of growth, each of which probably, is quantitatively the most important in each of their respective rocks.

These megacrysts assume very big sizes compared with the other minerals of the aplite, which formed with them. The reason for this is considered to be a very low density of nucleation of orthoclase compared with the other minerals. The cause of low nucleation of orthoclase is the chemical composition of the aplite melt, which, owing to its richness in lithium, water and fluorine, favoured the formation of lepidolite in preference to orthoclase. High volatile content also tends to keep potassium in the melt. This results in segregation of potassium which later forms orthoclase rich pegmatites and replacement megacrysts.

TYPES OF DISTRIBUTION OF THE MINERALS OF THE MELDON APLITE AND PETROGENETIC IMPLICATIONS

The distribution patterns have been studied by Chaudhry and Mahmood (1979). In the following section distribution patterns and paragenesis is discussed at some length. The eight minerals studied are albite, orthoclase, quartz, lepidolite, tourmaline, topaz, fluorite and petalite. Histograms of distribution are given in Fig. 2 and various statistics are given in Table 5. Elbaite, topaz fluorite and petalite show extreme positive skewness and positive kurtosis-Orthoclase also shows extreme positive skewness and albite is less positively skewed. Lepidolite and quartz are normal but quartz shows slight negative skewness.

Albite and orthoclase both display log-normal distributions. "Log-normality" in the case of albite is attributed to its being predominantly as a result of magmatic crystallization. Its amount decreased with progressive crystallisation. In the "brown aplite" and the other strongly metasomatized types its amount has undergone further significant decrease due to replacement by pneumatolytic processes resulting in the formation of orthoclase, lepidolite, tourmaline, topaz, petalite, etc. A mineral which owes its formation due mainly to magmatic crystalization should display distributions with distinct positive or negative skewness, the former type of skewed distribution being referred to as a log-normal distribution. Which one of the two skewed distributions will result would depend upon whether there has been a sudden (but very much restricted in space) increase or decrease in the amount of a certain mineral. The former condition corresponds with the positively skewed and the latter to the negatively skewed distribution. Albite in the present case has been subjected to metasomatic replacement by other minerals in all but "blue aplite" and some "white aplites" (especially the mica-poor "white aplite"). Therefore in the two unmetasomatized types of aplite the amount of albite remained undiminished and now these two types of aplite comprise the tail of the histogram (Fig. 2) representing some of the higher contents of albite than those of the other types. A predominantly magmatic evolution of albite is also evident from its considerably lower value of co-efficient of variation (V%) than of the other minerals, data for which are given in Table 5.

Orthoclase displays log-normal distribution whereas quartz and lepidolite show normal distributions, although all three of them owe their origin to the same kind of processes.

Orthoclase is distributed throughout the aplite. A magmatic generation has been succeeded by partial replacement by lepidolite, tourmaline, topaz, petalite, quartz, etc., and by superimposition of a metasomatic less general (in the sense of in space distribution) though quantitatively more important formation. The resultant distribution has been again affected by small replacements by lepidolite, quartz, tourmaline and topaz, etc.

In the case of lepidolite an earlier magmatic generation which showed progressive increase from "white aplite" to "brown aplite" has been superimposed by a more important and general formation due to metasomatism. The resultant distribution is due to the interaction of the two generations modified somewhat by a series of replacements by orthoclase, quartz topaz, petalite and tourmaline.

An earlier magmatic generation of quartz showed progressive quantitative increase from "blue aplite" to "brown aplite". This generation specially in the "brown aplite" and the other strongly reconstituted aplites has been superimposed by metasomatic quartz. This metasomatic generation is quantitatively as important, if not more, as the magmatic generation. The resultant distribution has been somewhat modified by replacing minerals like orthoclase, petalite, lepidolite, tourmaline and topaz etc.

From the above it is evident that all the three minerals, namely orthoclase, quartz and lepidolite are formed by superimposed magmatic and metasomatic processes. According to Rodionov (1961, 1965) a normal distribution of mineral content in igneous rocks is usually associated with the presence of the saperimposed processes which are manifest in the substantial replacement of given mineral by another or in the formation of an independent later generation of the same mineral. In the present case orthoclase defies Rodionov's principle, and it seems that this cannot be accepted as a strict rule. If two separate distributions represent two different processes such as a magmatic and a metasomatic resulting in the formation of a certain mineral, then the resultant distribution may be expected to be normal if one of the two populations is positively skewed and the other negatively skewed. Furthermore, the two oppositely skewed distributions should have the same mode. Such ideal combinations may or may not exist and consequently the resultant distribution of a mineral formed by more than a single process may or may not be normal.

Tourmaline and topaz are considered here as censored distributions. Since both these minerals are metasomatic, it is possible that the censored portion of the sample in the case of these two minerals corresponds with conditions of latent metasomatism below such degree as was critical for the formation of the minerals in amounts higher than 0.00 or values very close to it.

Fluorite and petalite are highly irregular in their distribution and they are believed to be bimodal as tested from their trend on probability graphs.

Conclusions

The skewed distribution curve and relatively low coefficient of variation conforms with the mainly magmatic origin postulated for albite in the aplite. For the metasomatic minerals it is found that the effects of the metasomatic processes involved in formation of elbaite and topaz differed from those involved in the production of petalite and fluorite. In the case of elbaite and topaz, the metasomatizing fluids appear to have permeated the intrusion as a whole whereas in petalite and fluorite they seem to have been operative only in restricted parts of the intrusion.

TABLE 1

Chemical Analyses of the Aplites

	Blue Aplites				White Aplites Fine-grained			White Aplites Megacrystic			
	MN75	MN92	MN149	MN11(N)	MN10	MN11S	MN202	MN80	MN33	MN14	MKCA
SiO_2	66.48	67.33	67.34	68.92	69.30	69.82	68.81	69.71	70.03	70.64	70.98
TiO_2	0.09	0.06	0.08	0.07	0.06	0.06	0.12	0.06	0.04	0.23	0.07
Al_2O_3	15.66	19.47	19.18	18.90	19.01	18.02	17.50	18.76	18.41	17.61	18.41
Fe_2O_3	0.11	0.08	0.07	0.14	0.17	0.16	0.54	0.13	0.14	0.22	0.14
FeO	0.30	0.34	0.16	0.14	0.36	0.14	0.65	0.44	0.38	0.21	0.35
MgO	0.16	0.06	0.20	0.03	0.08	0.14	0.22	0.08	0.08	0.04	0.04
CaO	1.62	1.36	2.27	1.00	1.12	1.20	1.39	1.00	0.84	0.84	0.78
MnO	0.03	0.06	0.09	0.06	0.08	0.09	0.20	0.02	0.14	0.57	0.15
Na_2O	6.83	6.50	6.13	4.40	4.80	4.60	4.20	3.90	3.40	2.56	2.50
K_2O	3.23	2.74	2.17	2.64	2.71	2.75	2.70	3.16	3.02	3.91	3.63
Li_2O	0.34	0.30	0.60	1.11	0.40	0.85	2.30	0.60	1.25	1.64	1.53
Rb_2O	0.35	0.35	0.43	0.45	0.41	0.40	0.56	0.44	0.35	0.65	0.70
Cs_2O	0.04	0.07	0.08	0.07	0.13	0.07	0.06	0.06	0.07	0.10	0.11
P_2O_5	0.73	0.62	0.14	0.13	0.18	0.16	0.16	0.18	0.28	0.22	0.18
H_2O+	0.72	0.55	0.67	1.41	0.80	1.31	0.70	1.16	1.11	0.58	0.61
H_2O-	0.11	0.17	0.25	0.17	0.30	0.19	0.13	0.21	0.24	0.08	0.06
Total	99.80	100.06	99.86	99.64	99.91	99.96	100.24	99.91	99.78	100.10	100.24

TABLE 1 contd.

Chemical Analyses of the Aplites

	MNA	MK27	MH2	MJ35	MKd	MN86	MN81	MN6	MN350	MN302	MNB2	MN353	MN85
SiO_2	69.40	69.98	70.60	70.69	70.95	71.01	71.23	71.38	71.44	71.45	71.63	71.76	71.85
TiO_2	0.07	0.05	0.06	0.07	0.07	0.07	0.06	0.09	0.11	0.07	0.05	0.06	0.06
Al_2O_3	18.04	17.42	18.45	18.39	18.40	16.44	16.16	17.42	16.61	18.14	17.50	18.09	16.55
Fe_2O_3	0.14	0.19	0.16	0.06	0.14	0.01	0.28	0.20	0.51	0.19	0.35	0.18	0.06
FeO	0.50	0.33	0.46	0.44	0.32	0.85	0.50	0.32	0.34	0.22	0.21	0.29	0.68
MgO	0.18	0.09	0.08	0.06	0.05	0.11	0.11	0.06	0.54	0.62	0.30	0.07	0.33
CaO	2.15	2.10	0.88	0.98	0.76	1.95	1.91	0.70	1.92	0.56	0.36	1.19	1.63
MnO	0.10	0.07	0.01	0.15	0.15	0.73	0.09	0.19	0.04	0.17	0.11	0.78	0.14
Na_2O	2.95	3.70	3.20	3.60	2.46	3.90	3.50	3.30	1.70	2.44	2.56	1.48	2.46
K_2O	3.45	3.80	3.33	2.90	3.61	3.22	3.32	3.20	3.60	2.97	3.78	3.85	3.67
Li_2O	0.62	0.60	0.70	1.51	1.52	0.85	1.82	1.10	1.23	1.80	1.68	0.90	0.99
Rb_2O	0.21	0.35	0.20	0.27	0.71	0.41	0.31	0.40	0.76	0.29	0.64	0.80	0.38
Cs_2O	0.10	0.12	0.20	0.06	0.09	0.06	0.08	0.08	0.06	0.05	0.09	0.16	0.05
P_2O_5	0.30	0.37	0.32	0.18	0.18	0.13	0.34	0.25	0.42	0.34	0.28	0.17	0.50
H_2O+	1.21	1.75	1.20	0.98	0.55	0.51	0.48	1.00	0.60	0.58	0.65	0.56	0.46
H_2O-	0.29	0.21	0.32	0.13	0.11	0.08	0.09	0.13	0.15	1.16	0.07	0.07	0.06
Total	99.71	100.13	100.17	100.27	100.07	100.33	100.28	99.82	100.03	100.05	100.26	100.41	100.17

TABLE 2

Data on Correlation amongst various Constituents of the Aplites

Correlation between	n	rxy	Degree of Freedom	t	t 0.05
$SiO_2:Na_2O$	24	-0.89	22	9.07	2.07
$SiO_2:K_2O$	24	+0.56	22	3.17	2.07
$SiO_2:Li_2O$	24	+0.50	22	2.70	2.07
$Rb_2O:TiO_2$	24	+0.41	22	2.11	2.07
Total iron					
$(FeO):Li_2O$	24	+0.44	22	2.29	2.07
$CaO:Li_2O$	24	-0.43	22	2.22	2.07
$Rb_2O:MnO$	24	+0.46	22	2.43	2.07
$Na_2O:Li_2O$	24	-0.50	22	2.70	2.07
$Na_2O:K_2O$	24	-0.65	22	4.01	2.07
Total Alkalis: Na_2O	24	+0.83	22	6.95	2.07
Total Alkalis: K_2O	24	-0.41	22	2.07	2.07

TABLE 3

Number of Cations on the Basis of 160 Oxygens

Sp. Nos.	MN75	MN92	MN149	MN11(N)	MN10	MN11(S)	MN202	MN80	MN33	MN14	MKC	MNA
Si	58.94	58.84	58.89	59.25	60.07	59.99	59.46	60.02	60.09	60.92	60.86	60.00
Ti	0.06	0.04	0.05	0.05	0.04	0.04	0.08	0.04	0.03	0.15	0.05	0.05
Al	18.93	20.06	19.77	19.16	19.42	18.25	17.82	19.04	18.63	17.90	18.61	18.38
Fe^{3+}	0.07	0.05	0.04	0.09	0.11	0.10	0.35	0.08	0.09	0.15	0.09	0.09
Fe^{2+}	0.22	0.25	0.12	0.10	0.26	0.10	0.47	0.32	0.27	0.15	0.25	0.36
Mg	0.21	0.08	0.26	0.04	0.10	0.18	0.29	0.10	0.10	0.05	0.05	0.23
Ca	1.49	1.28	2.13	0.92	1.04	1.11	1.29	0.92	0.77	0.78	0.72	1.99
Mn^{2+}	0.02	0.04	0.07	0.04	0.06	0.07	0.02	0.02	0.10	0.41	0.11	0 07
Na	11.40	11.02	10.40	7.34	8.06	7.66	7.04	6.51	5.66	4.28	4.15	4.95
K	3.55	3.06	2.42	2.99	3.00	3.02	2.98	3.47	3.31	4.30	3.97	3.80
Li	1.18	1.05	2.11	3.83	1.39	2.93	8.00	2.08	4.31	5.69	5.28	2.15
Rb	0.20	0.20	0.24	0.25	0.23	0.22	0.31	0.25	0.20	0.36	0.38	0.11
Cs	0.01	0.02	0.03	0.02	0.05	0.02	0.02	0.02	0.02	0.04	0.04	0.04
P	0.53	0.46	0.11	0.09	0.14	0.11	0.11	0.13	0.21	0.16	0.13	0.22
H	4.14	3.20	3.91	8.09	4.62	7.51	4.04	6.66	6.35	3.34	3.49	6.98
Total	100.95	99.65	100.55	102.26	98.59	101.31	10.228	99.66	100.14	98.68	98.18	99.42

TABLE 3 contd.

Number of Cations on the Basis of 160 Oxygens

Sp. Nos.	MK27	M.H.2	MN35	MK(d)	MN86	MN81	MN6	MN350	MN302	MNB2	MN353	MN85
Si	60.72	60.41	60.27	60.96	61.60	61.35	61.18	61.54	60.87	61.28	61.58	61.80
Ti	0.03	0.04	0.05	0.05	0.05	0.04	0.06	0.07	0.05	0.03	0.04	0.04
Al	17.82	18.62	18.49	18.64	16.81	16.41	17.60	16.86	18.22	17.64	18.30	17.09
Fe^{3+}	0.13	0.10	0.04	0.09	0.01	0.19	0.13	0.33	0.12	0.23	0.11	0.04
Fe^{2+}	0.24	0.33	0.31	0.23	0.62	0.36	0.23	0.24	0.16	0.15	0.21	0.49
Mg	0.11	0.01	0.08	0.06	0.14	0.14	0.08	0.69	0.79	0.38	0.21	0.42
Ca	1.95	0.81	0.90	0.07	1.81	1.76	0.64	1.77	0.51	0.33	1.09	1.50
Mn^{2+}	0.05	0.06	0.11	0.11	0.54	0.07	0.14	0.03	0.12	0.08	1.13	0.10
Na	6.23	5.35	5.63	4.10	6.56	5.85	5.48	2.84	4.03	4.25	2.47	4.10
K	4.20	3.64	3.16	3.96	3.57	3.64	3.50	3.95	3.23	4.12	4.22	4.03
Li	2.10	2.41	5.18	5.26	2.96	6.30	3.79	4.27	6.16	5.78	3.10	3.42
Rb	0.20	0.11	0.14	0.39	0.23	0.18	0.22	0.42	0.16	0.35	0.44	0.21
Cs	0.04	0.07	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.03	0.06	0.02
P	0.27	0.24	0.13	0.13	0.09	0.25	0.19	0.31	0.25	0.21	0.01	0.36
H	4.34	6.85	5.57	3.15	2.95	2.75	5.72	3.45	3.30	3.71	3.21	2.64
Total	99.43	99.05	100.08	97.23	97.96	99.32	98.99	96.79	97.99	98.57	96.18	96.26

TABLE 4

Gains and Losses during Reconstitution

Sp. No.	MN75	MN92	MN149	MN11(N)	Mn11(S)	MN202	MN80	MN33	MN14	MKC	MNA	MK27
Si	-1.13	-1.23	-1.18	-0.82	-0.08	-0.61	-0.05	+0.02	+0.85	+0.79	-0.07	+0.65
Ti	+0.02	±0.00	+0.01	+0.01	±0.00	+0.04	±0.00	-0.01	+0.11	+0.01	+0.01	-0.01
Al	-0.49	+0.64	+0.35	-0.26	-1.17	-1.60	-0.38	-0.79	-1.52	-0.81	-1.04	-1.60
Fe^{3+}	-0.04	-0.06	-0.07	-0.02	-0.01	+0.24	-0.03	-0.02	+0.04	-0.02	-0.02	+0.02
Fe^{2+}	-0.04	-0.01	-0.14	-0.16	-0.16	+0.21	+0.06	+0.01	-0.11	-0.01	+0.10	-0.02
Mg	+0.11	-0.02	+0.16	-0.06	+0.08	+0.19	±0.00	±0.00	-0.05	-0.05	+0.13	+0.01
Ca	+0.45	+0.24	+1.09	-0.12	+0.07	+0.25	-0.12	-0.27	-0.26	-0.32	+0.95	+0.91
Mn^{2+}	-0.04	-0.02	+0.01	-0.02	+0.01	-0.04	-0.04	+0.04	+0.35	+0.05	+0.01	-0.01
Na	+3.34	+2.96	+2.34	-0.72	-0.04	-1.02	-1.55	-2.40	-3.78	-3.91	-3.11	-1.83
K	+0.55	+0.06	-0.58	-0.01	+0.02	-0.02	+0.47	+0.31	+1.30	+0.97	+0.80	+1.20
Li	-0.21	-0.34	+0.72	+2.44	+1.54	+6.61	+0.69	+2.92	+4.30	+3.89	+0.76	+0.71
Rb	-0.03	-0.03	+0.01	+0.02	-0.01	+0.08	+0.02	-0.03	+0.13	+0.15	-0.12	-0.03
Cs	-0.04	-0.03	-0.02	-0.03	-0.03	-0.03	-0.03	-0.03	-0.01	-0.01	-0.01	-0.01
P	+0.39	+0.32	-0.03	-0.05	-0.03	-0.03	-0.01	+0.07	+0.02	-0.01	+0.08	+0.13
H	-0.48	-1.42	-0.71	+3.47	+2.89	-0.58	+2.04	+1.73	-1.28	-1.13	+2.36	-0.27

TABLE 4 contd.

Gains and Losses during Reconstitution

Sp. Nos.	MH2	MN35	MK(d)	MN86	MN81	MN6	MN350	MN302	MNB2	MN353	MN85
Si	+0.34	+0.20	+0.89	+1.53	+1.28	+1.11	+1.47	+0.80	+1.21	+1.51	+1.73
Ti	±0.00	+0.01	+0.01	+0.01	±0.00	+0.02	+0.03	+0.01	-0.01	±0.00	±0.00
Al	-0.80	-0.93	-0.78	-2.61	-3.01	-1.82	-2.56	-1.20	-1.78	-1.12	-2.33
Fe^{3+}	-0.01	-0.07	-0.02	-0.10	+0.08	+0.02	+0.22	+0.01	+0.12	±0.00	-0.07
Fe^{2+}	+0.07	+0.05	-0.03	+0.36	+0.10	-0.03	-0.02	-0.10	-0.11	-0.05	+0.23
Mg	-0.09	-0.02	-0.04	+0.04	+0.04	-0.02	+0.59	+0.69	+0.28	+0.11	+0.32
Ca	-0.23	-0.14	-0.97	+0.77	+0.72	-0.40	+0.73	-0.53	-0.71	+0.05	+0.46
Mn^{2+}	±0.00	+0.05	+0.05	+0.48	+0.01	+0.08	-0.03	+0.06	+0.02	+1.07	+0.04
Na	-2.71	-2.43	-3.96	-1.50	-2.21	-2.58	-5.22	-4.03	-3.81	-5.59	-3.96
K	+0.64	+0.16	+0.96	+0.57	+0.64	+0.50	+0.95	+0.23	+1.12	+1.22	+1.03
Li	+1.02	+3.79	+3.87	+1.57	+4.91	+2.40	+2.88	+4.77	+4.39	+1.71	+2.03
Rb	-0.12	-0.09	+0.16	±0.00	-0.05	-0.01	+0.19	-0.07	+0.12	+0.21	-0.02
Cs	+0.02	-0.03	-0.02	-0.03	-0.02	-0.02	-0.03	-0.03	-0.02	+0.01	-0.03
P	+0.10	-0.01	-0.01	-0.05	+0.11	+0.05	+0.17	+0.11	+0.07	-0.13	+0.22
H	+2.23	+0.95	-1.47	-1.67	-1.87	+1.10	-1.17	-1.32	-0.91	-1.41	-1.98

Table 5

Mineral			Censored Distributions			
N = 86	N	Y_o	in probits.	in percent	$\hat{\sigma}$	X^2
Elbaite	64	2.20	2.66	1.00	0.64	7.08 n = 5
Topaz	62	2.42	2.82	1.3	0.62	6.120 n = 5
			Normal Distributions			
N = 86	$\bar{X}$	s	V%	SK	K	
Lepidolite	15.04	8.25	54.87	0.28	-0.22	
Quartz	28.15	6.79	24.13	-0.55	-0.24	
			Lognormal Distributions			
N = 86	$\bar{X}$	slgX	V %	SK	K	
Albite	41.69	0.14	8.47	0.29	-0.64	
Orthoclase	3.23	0.50	98.18	-0.51	-0.52	
5 level				0.55	0.75	
1 level				0.65	1.06	

Distribution is considered normal if $SK \leqslant Sk_5$ and $K \lesssim K_5$ and not normal if $SK \geqslant SK$ and $K \gtrsim K_1$

$\bar{X}$ - arithmetic mean of mineral content (in volume percent)
S - standard deviation
slgX - standard deviation of logarithms of mineral content
X - geometric mean of mineral content
V - coefficient of variation
SK - skewness of the distribution curve
K - kurtosis of the distribution curve

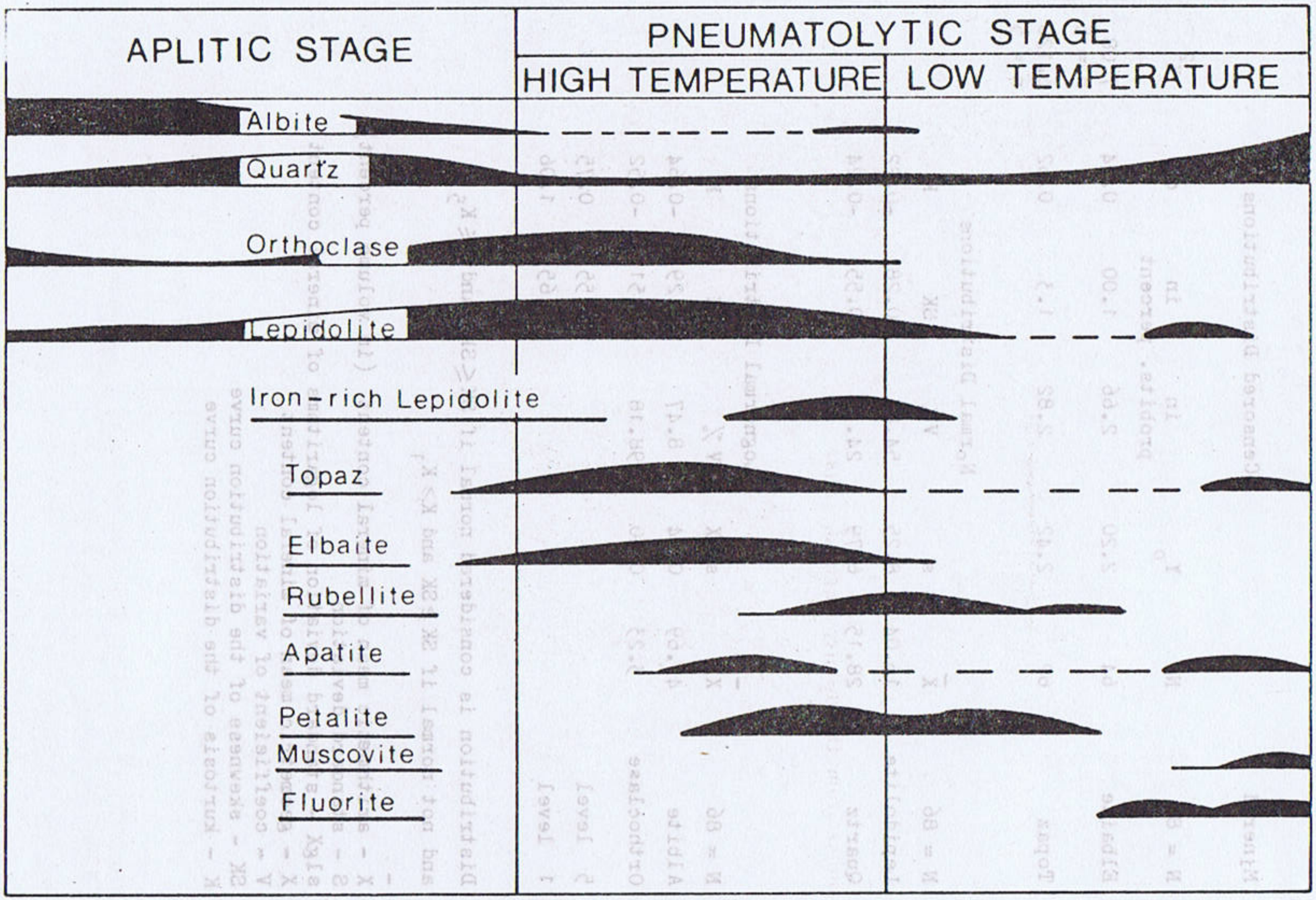

Fig. 1. **Relative periods of crystallization of the various minerals in the aplite.**

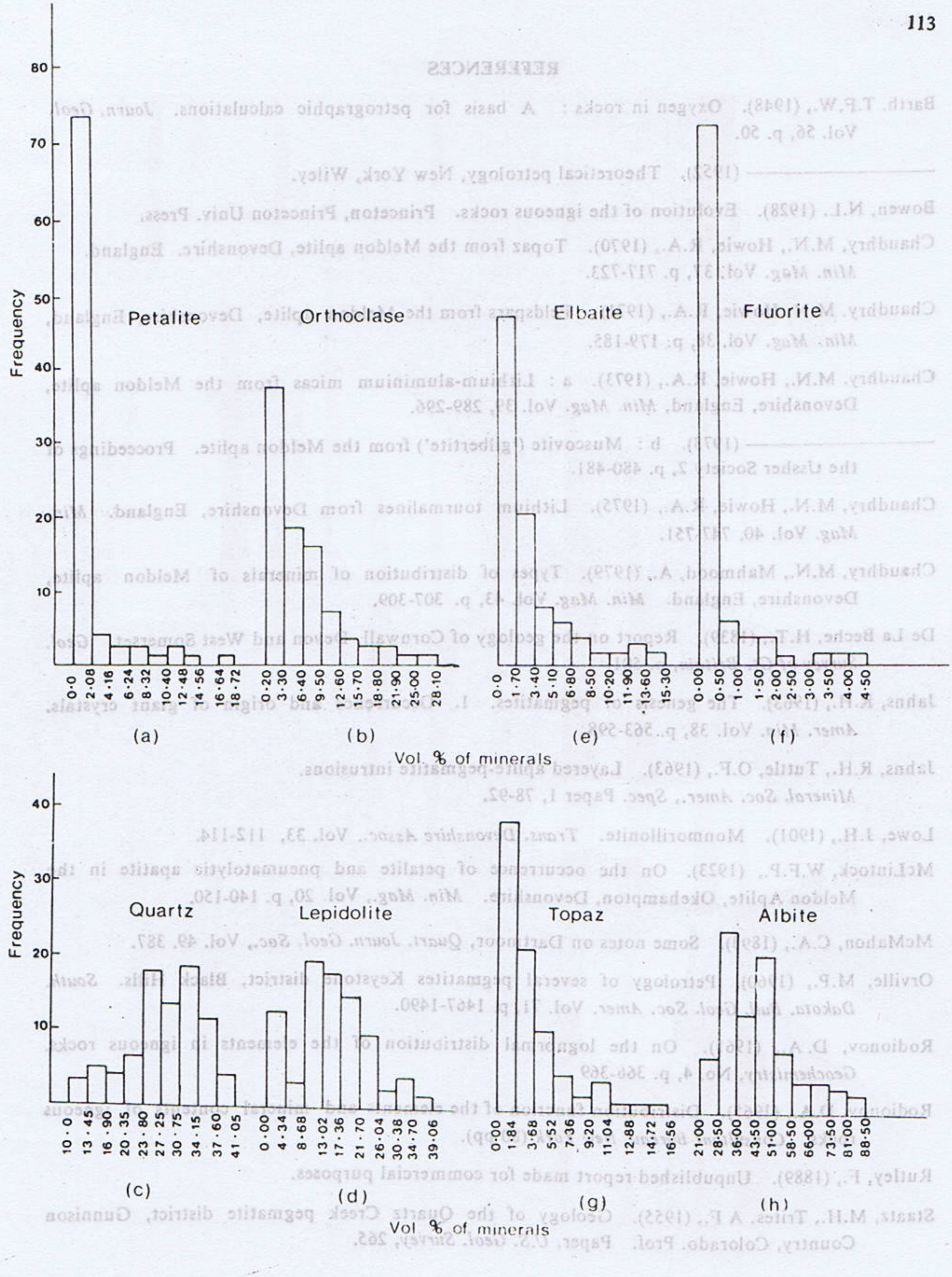

Fig. 2. Histograms of mineral contents.

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BENEFICIATION AND EVALUATION OF A PART OF THE NEPHELINE SYENITE DEPOSIT OF SWAT AS A RAW MATERIAL FOR GLASS MANUFACTURE

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Abstract : *Two samples "A" and "B" of Nepheline Syenite from Koga Swat were processed and evaluated as raw material for glass manufacture. They were initially reduced to minus 30 mesh. Representative portions of minus 30 plus 200 mesh fractions were then treated by magnetic separation to remove iron materials. Product recoveries were of the order of about 50 per cent in case of dry magnetic separation and iron contents as Fe_2O_3 were well within the glass grade specifications i.e. $\lesssim$ 0.01 per cent. Wet magnetic separation of the similarly sized portions resulted even lower recoveries i.e. 28 to 29 per cent. However, the product quality showed a definite improvement.*

INTRODUCTION

Nepheline syenite primarily is an alkaline rock and its alkalic composition alongwith alumina makes it useful for the replacement of feldspar in the manufacture of glass. (Miksch, 1976). It has advantages over feldspar when used in the glass batch because of its higher alkali ratio and lower fusion point. Its introduction in the glass batch significantly affects the batch formulation as it contains substantial amounts of Al_2O_3, Na_2O and K_2O. Its addition in the glass batch not only replaces feldspar but also requires adjustment of soda ash. To maintain soda levels, addition of soda ash is reduced. Although soda ash contributes only about 12-13 per cent of the batch weight, it can represent anything upto 70 per cent of the raw material costs. (Toon, 1986). Attempts to reduce costs of batch have focussed on using less soda ash and it can be brought about by partial replacement of soda ash with nepheline syenite.

The introduction of nepheline syenite also adds alumina content to the glass batch (Patric, 1980). The presence of Alumina (Steve Toon, 1986) in the glass batch improves strength and durability, inhibits devitrification and increases viscosity during glass forming process. Alumina can be made available from pure chemicals such as hydrated or calcined alumina but very frequently it is used in the form of feldspar or nepheline syenite.

The present work is the evaluation of the deposit of nepheline syenite exposed at Koga, a small village in lower Swat at a distance of

56 kilometers from Mardan for its utilization in the manufacture of colourless glass. For the purpose of this study, two bulk samples A and B representative of a fairly large area underlain by nepheline syenite were collected. Sample 'A' is described as bridge deposit (Sahbaga Bridge), which is medium grained, a medium grey colour with disseminated ferro-magnesian minerals randomly distributed. There are some coarse grains of sodalite to be found in this sample. A conservative estimate of the amount of nepheline syenite in this particular area runs about two million metric tons. The second sample 'B' is located about 1.5 kilometers to the west and is representative of a fairly large area underlain by the rock. It is medium grained, dark grey and very massive. The areas from where these samples were collected show no evidence of alteration.

GEOLOGICAL DESCRIPTION OF THE DEPOSIT

The nepheline syenite (Siddiqui, 1965) is horse shoe shaped with the north-west end open and the area enclosed by the ridge is occupied by an alluvial plain. From one side of the ridge to the other across the plain is about 1.5 kilometers.

The general area is underlain by intrusive rocks......syenites and granites (Siddiqui, 1967) which has intruded highly metamorphosed sedimentary rocks. Its main exposure stretches about eight kilometers in length and about six kilometers in width. The alkalic suite (Siddiqui, et al. 1968) of rocks merges into a carbonatite in the south-west. Different facies of rock are pegmatite dikes containing sodalite; sodalite bearing syenitic rocks etc. The colour and textures change from coarse and light grey to fine grained and dark with the ferromagnesian mineral content varying widely, some of it showing distinctly gneissic structure. The vivid blue sodalite is prominent in the pegmatite and some of the syenitic rocks.

The massive nepheline on the western side of the ridge exhibits a salt and pepper type appearance. Medium to coarse grains with abundant mafic minerals like magnetite, amphibole and biotite. The rock on the eastern side is dark to medium grey and fine grained. The mafic minerals on the eastern part of the ridge are prominent but lesser in quantity. The amphiboles show some lineation which gives it a gneissic appearance. The rock i.e. nepheline syenite on both eastern and western exposure of the ridge has been altered in places to a very friable granular material that can be excavated by pick. This is due to hydrothermal alteration.

For petrological details of these rocks and rocks of the wider alkaline province the reader is referred to Siddiqui (1965, 1967), Siddiqui et. al. (1968), Ashraf et. al. (1977), Chaudhry et. al. (1981), Ahmed et. al. (1969), Coulson (1936), Jan. et al. (1981-a, 1981-b), Kempe (1973, 1983), Kempe et. al. (1970, 1980) and Chaudhry et. al. (1983).

PROCESSING AND BENEFICATION

The sample was stage crushed initially to minus 77 mm. in a 180 × 250 mm. jaw crusher; then to minus 19 mm. in a 77 × 154 mm, jaw crusher. A representative portion of each was then reduced to minus 6.4 mm. in a 256 mm. cone crusher. Representative samples of the product from the cone crusher were detained for sieve, chemical and mineralogical analyses, and for further reduction to minus 30 mesh in a micropulverizer. The minus 30 mesh fraction was removed prior to reduction in a micropulverizer after each pass. Three passes were required to reduce the samples to minus 30 mesh. The minus 200 mesh was then removed and samples of minus 30 plus 200 mesh product were selected for sieve analysis and magnetic separation tests.

Mill iron and strongly magnetic minerals were removed from the minus 30 plus 200 mesh product by a permanent magnet following which the more weakly magnetic minerals were removed by the Carpco, high intensity dry magnetic separator. Samples of Carpco feed and non-magnetic products were selected for chemical analysis.

Following this preliminary work, additional representative samples of the cone crusher products were stage crushed to minus 65 mesh in the micropulverizer in eight passes. The minus 65 mesh fraction being removed after each pass to reduce over crushing. Samples of the minus 65 plus 200 mesh product were selected for heavy liquid separation tests and for wet magnetic separation tests. For comparison, a sample of minus 30 plus 200 mesh was prepared for wet magnetic separation tests by stage crushing a portion of the cone crusher product in a micropulverizer. Product recoveries, grading (B.S.I.S., 1952) and chemical analysis (B.S.I.S., 1958) and (Vogel 1959) are given in Tables 1-6.

MINERALOGICAL AND PETROLOGICAL EXAMINATION

Each sample was examined carefully and the fragments were selected by observing them microscopically. Slices were cut from the fragments and smoothed for the preparation of staining, a procedure that is diagnostic for potassium in silicate minerals. Parallel slices were made into petrographic thin sections. The results of thin section studies are for sample 'A'; Nepheline 30.20% Microcline 46.65% Albite 13.98%, Arfvedsonite 5.71%. Biotite, 1.57%, Sphene 1.28% and Garnet 0.57% and for sample 'B', it is; nepheline 11.0%, microcline 60.00%, Albite 3.00%, sodalite 12.00%, Biotite 10.00%, Ilminite 1.0% and Pyrite 3.00 per cent.

Magnetic Treatment

As the individual grains cannot readily be hand extracted, the alternative may be to crush the whole rock specimen and then effect a separation of minerals by means of a distinctive magnetic property. The rock should be crushed to a particle size between one quarter and one-tenth the average grain size of the rock. Crushing to a particle size that is too fine is not recommended. In the case of this rock, nepheline syenite, under study, the crushing was maintained to minus 30 plus 200. The crushed rock was sieved for ten minutes through a bank of British Standard Siever Nos. 8, 14, 30, 50, 100 and 200. The rock particles collected on sieves coarser than the 30 mesh were again pounded with a sted pestle in a steel mortar until on re-sieving, majority of them passed through 30 mesh.

A large variety of minerals may be separated from one another on the basis of their magnetic susceptibility. Initially the dry grains must have the magnetic components removed before being fed into the isodynamic separator. These strongly magnetic grains might be magnetite belonging to the rock and particles of the metallic iron that had been introduced during the crushing operation. These were separated by a weakly magnetised hand magnet to pull the strongly magnetic grains away from the powder. The powder was then ready for magnetic separation.

Although magnetite had already been removed from the powder, the sample was run through the isodynamic separator at 0.1 ampere. A first run at a higher amperage would otherwise cause clogging of the magnetic poles by attracted grains. The magnetic particles were collected in one pan. The central pan was for middlings and the last pan contained only the non-magnetic portion. The middlings collected in the second pan was again fed at the same amperage that is 0.1 ampere and the non-magnetic powder collected in the last pan was fed at 0.3 amperes to remove ilmenite and at 0.7 amperes to remove hornblende, biotite and pyroxene. The results of magnetic separation are given in Table 2.

Wet Magnetic Separation

Portions of the magnetic, middlings and non-magnetic fractions from wet magnetic separation of sample 'A' were indistinguishable and showed that the iron bearing minerals principally amphiboles were greatly reduced relative to the head sample.

Similarly, the middling and non-magnetic fractions of sample 'B' were indistinguishable and that the iron bearing minerals principally mica were greatly reduced relative to the head sample.

Density Separation

In tetrabromethane (Sp. Gr. 2.95), the minus 30 and plus 200 mesh fractions of both the samples gave sharp heavy liquid separations i.e. 8.5 per cent of sample 'A' and 6.8 per cent of sample 'B' being recovered in the sink portions. The basis of this method is that mineral grains of specific gravity lower than the liquid will float, whereas those of higher specific gravity will sink. The recoveries being low, and the heavy liquids being expensive, hence it becomes necessary not to practice density separation.

DISCUSSION

Nepheline syenite for use in glass manufacture is normally minus 30 plus 200 mesh in size. An alumina content in excess of 20 per cent is preferred alongwith a total alkali contents of at least 14 per cent. Iron as iron oxide should not exceed 0.1 per cent as it is a colour effecting impurity and gives rise to the problem of decolourisation (Toon, 1966, Tooley, 1961). The results show that upgraded samples are comparable to the glass grade specifications i.e. less than 0.1 per cent Fe_2O_3.

Both the samples were tough and were crushed with difficulty. Each tended to form slably particles on crushing and despite careful measures to avoid over crushing significant amount of minus 200 mesh waste fines were produced.

Liberation of principal impurity magnetite achieved at 30 mesh is less than at 65 mesh (Tables 3 and 4). This, not only, was below the desired size but reduction to minus 65 also resulted in additional quantities of unwanted 200 mesh fines (Table 3). The need for the fine grading in order to achieve acceptable beneficiation may not be as significant in the future as at present. Owing to the fuel crisis, current glass melting practice is tending towards electric melting. Grain size distribution of raw material is critical, affecting as it does meltability, mixing and segregation. As this material, nepheline syenite, is the most difficult to melt in the furnace, the coarser particles should be eliminated to aid melting. Fines on the other hand are also detrimental, as they lead to dust problems in handling and carrying over in the furnace. Most difficult to melt has shown a trend to less coarse material that does not de-gas rapidly to further reduce energy consumption. Under these conditions finer particles, but not the dust, of the batch component may not only be acceptable but may be desirable to speed melting.

Dry magnetic separation was not as successful in reducing the iron content of the minus 30 plus 200 mesh as that of wet magnetic separation. But at the same time the per cent recoveries of non-magnetics in case of dry magnetic separation is more encouraging than that in case of wet magnetic separation and density separation. But even then, both these samples, 'A' and 'B' continued to have iron contents at border line although sample B appears to be slightly superior in this regard (Table 6).

TABLE 1

Sieve Analysis – Wt.%
Head Sample and minus 30 mesh Products

Mesh Size	Sample A Cone Crusher	Sample A Mikro. −30 mesh	Sample A Pulv. −30+200 mesh	Sample B Cone Crusher	Sample B Mikro. −30 mesh	Sample B Pulv. −30+200
+8	14.3			12.8		
−8+14	38.2			42.5		
−14+30	16.9			18.3		
−30+50	9.8	25.8	37.2	9.5	31.3	39.6
−50+100	6.8	22.0	31.5	5.9	20.3	31.8
−100+200	6.2	22.4	31.3	4.8	18.6	28.6
−200	7.8	29.8		6.2	29.8	
Total	100.0	100.0	100.0	100.0	100.0	

TABLE 2

Dry Magnetic Separtaion – Wt. %
Minus 30 Plus 200 mesh

Fraction	Sample A Recovery	Sample A Net Product Recovery	Sample B Recovery	Sample B Net Product Recovery
Perm. Mag. Mag.	2.2	—	2.0	—
Non-Mag.	97.8		98.0	
	100.0		100.0	
Carpeo Mag.	22.5	49	20.5	51
Non-Mag.	77.5		79.5	
	100.0		100.0	

Perm-Mag—Stands for permanent magnet.

Mag—Stands for magnetic.

TABLE 3

Sieve Analysis – Wt. %
65 mesh from Mickro pulverizer

Mesh Size	Sample-A	Sample-B
+65	5	7
65+200	60	59
–200	35	34
Total	100	100

TABLE 4

Wet Magnetic Separation – Wt. %
minus 65, plus 200 mesh.

Fraction	Sample A		Sample B	
	Recovery	Net product recovery	Recovery	Net product recovery
Mag.	22.0		19	
Midd.	36.0	23	38	24
Non-Mag.	42.0		43	

Mag.—Stands for magnetic.
Midd.—Stands for middlings.

TABLE 5

Wet magnetic Separation – Wt.%
minus 30 plus 200 mesh.

Fraction	Sample A		Sample B	
	Recovery	Not Product Recovery	Recovery	Net product Recovery
Mag.	12.0		20.0	
Midd.	44.0		37.0	28
Non-Mag.	44.0	29	43.0	
Total ...	100.0		100.0	

TABLE 6

Chemical Analyses

Product	Compound – Wt. %							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	N_2aO	K_2O	LoI
Sample A								
Head (cone. Prod.)	59.52	21.21	2.72	1.44	0.28	7.61	6.41	0.55
Carpco Feed – –30+200 mesh	—	—	2.46	—	—	—	—	—
Carpco prod. (non. mag) (fraction)	60.28	23.05	0.10	0.90	0.10	7.89	6.52	0.63
65+200 mesh	——	19.22	10.34	—	—	5.51	6.30	—
Mag.								
Midd.	—	21.18	0.24	—	—	7.81	7.35	—
Non-Mag.	—	21.10	0.09	—	—	8.25	6.65	—
Sample B								
Head (Cone Product)	56.93	22.94	2.49	0.86	0.08	9.84	5.24	1.39
Corpco Feed (–30+200 mesh.)	—	—	1,72	—	—	—	—	—
Carpco prod. (non. mag. Fraction –65+200 mesh.)	58.94	23.57	0.89	0.84	0.03	9.92	5.30	1.37
Mag.	—	23.46	8.57	—	—	7.74	6.34	—
Midd.	—	21.31	0.25	—	—	10.00	5.41	—
Non-mag.	—	21.63 :	0.08	—	—	10.16	5.27	—

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THE CHANGING AGRO-ECONOMIC PATTERN OF KHABBAKI IN SUN SAKESAR VALLEY, DISTRICT KHUSHAB, PUNJAB, PAKISTAN

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Abstract : *Agriculture depends upon a number of factors, including social, economic and political but the most important is the physical environment.*

In the Sun Sakesar valley, an environmental phenomenon has emerged recently that has brought such changes as : expansion in the Khabbaki lake, change in the quality of its water, rise in the water table and water logging effects.

The cause of this phenomenon is not yet known. However, an important change in the agricultural pattern has warranted the present study. It is concluded that agricultural activity of the people of Khabbaki depends heavily on the environmental behaviour of the lake which should be kept in view for future planning.

INTRODUCTION

The Sun Sakesar Valley is located in the Eastern Salt Range, occupying an area between Long. 72° to 72° 15′E and Lat. 32° 32′ to 32° 39′N. In the North and South, the Valley is bounded by mountains with height of some of the hills rising upto 2750 feet.

There are two beautiful lakes located in the study area :

(i) Lake Khabbaki, towards eastern end, and (ii) Sun Sakesar Kahar towards western end.

Physically, the area is located in the Khushab Sub-Division of the Province of Punjab ; it can be further sub-divided into following three areas :

(i) *Thal area* : It is a part of the vast sandy tract, and is a wasteland.

(ii) *Mohar Area* : It comprises foot-hills of the Salt Range.

(iii) *Pahar Area* : It comprises the Sun Sakesar Valley, adjoining mountain range of the Salt Range, which runs across North of Khushab Tehsil and finally culminates at the Sakesar Hill. The southern face of the Pahar area rises very abruptly and, except for a few scattered patches of arable land, consists of almost bare-rocks.

Like the Salt Range, vegetation of the Sun Sakesar Valley is very different from that of the alluvial plains. The southern slope with its steep escarpment, is almsot devoid of vegetation Northern side of the hills has more gentle slopes, retain more soil and moisture, are covered, though scanty, with trees and bushes.

The characteristic trees of the area are such as Phulahi (ACACIA MIDESTA), wild olive Kau or Kavva (OLEA CUSPIDATA) a species of Oak (Vari-AUERCUS INCANA) wild fig Khabari (FICUS CARICA). However, the Lakura or Rahura (Tecom undulta), with its beautiful large bright orange coloured flowers and useful timber, Mulbury, Dhrek or Bakain are also common trees. Almond trees are also found in the Valley at some places.

Wolves are common in the Salt Range. Jackals are numerous every where and do considerable damage to the crops, especially to maize and sugar cane.

Among birds, Chikor and Sissi are very common while Ducks and Tatukas are found on ponds and lakes.

Near the Salt Range, the salt lakes, sometime also called Sammundars, are found. The surplus drainage from the hills finding no outlet, collects in the lakes The water of these lakes is saltish and not suitable for agriculture and human consumption. In addition, there are a number of rock-bound basins, with their lowest levels covered with water only after rain. Only two lakes are perennial, lake Khabbaki and Sun Sakesar Kahar. Basins that are occasionally flooded are Khutakka, Pail, Bhadrar, Mardwal ; Ugali and Shakar Kot : these basins dry up during the dry season.

The rainfall on the northern ridge drains northwards on to the Talagang Plateau while that of the southern ridge finds its way through numerous gorges southwards into the Sind Sagar doab.

In this study, attention has been focussed on the village Khabbaki as a representative case for the change in agricultural pattern caused over the last 10 years or so.

LAND USE PATTERN OF VILLAGE KHABBAKI

Village Khabbaki lies between Long. 72° 14′ to 72° 15′E and Lat. 32° 27′ to 32° 38′N and covers about 7682 acres. According to 1981 Census, total population of the village was 4126 persons, including 2189 females and 1937 males ; all population is Muslim. There are about 775 houses in the village.

The village is bounded by mountain ranges in the North and in the South. The access to the area is through a metalled road running in the East-West direction through the valley and joining Khushab.

It is an old settled village where land has been passed on from generation to generation. The division of land has resulted in very small holdings and consequently people are faced with poor economic conditions.

The methods of cultivation are still primitive and the tilling is mostly done with oxen. Only one farmer owns a tractor.

The area of the village has been classified into three categories for the purpose of landuse study :

(i) Forested Area.
(ii) Cultivated Area.
(iii) Un-cultivated Area.

(*i*) *Forested Area.* It includes all areas under natural as well as planted forests. Greater part of the area is under forests which are mostly natural forests. However, all forests are located on the hillsides and therefore are not recorded in the revenue documents of this village. Locally, these forests are known as RAKHS and, in District Census Reports of Sargodha for 1961, 1972 and 1981, they were recorded together as Rakh Khabbaki, covering an area of about 10976 acres and having a population of 188 persons living in 46 houses which are generally scattered.

(ii) *Cultivated Area.* This includes the land which has been cultivated or which has been left fallow for a year or so.

The total area of the village is 7680 acres, out of which an average of about 4143 acres are used for cultivation every year although the ratio of cultivable area varies every year. Table 1 shows that in 1959-60, the total cultivated area was 3576 acres which accounts for about 46.6% of the total area; it slightly increased in 1964-65 and the figure went up to 3580 acres. In 1969-70 and in 1974-75, the cultivated area decreased to 2722 acres which was only 35.4% of the total area. A major reason was that the lake started expanding sometime in 1970 and covered almost 313 acres (revenue survey, 1984). Thus, in 1969-70 and in 1974-75, many of the fields were engulfed and were not available for cultivation. In the succeeding years, 1980-81 and 1984-85, the total cultivated area increased to 3129 acres but was still less as compared to 1959-60 or 1964-65 figures.

The cultivated area is further sub-divided into two categories :

1. Current Fallow area.
2. Net Sown area.

There are many variations found in the current fallow area as is shown in Table II. In 1959-60, only 198 acres were felt follow while in 1964-65 it increased to 1502 acres but again decreased to 1317 acres in 1969-70; afterwards it continued to decrease so that in 1984-85 it was only 342 acres.

Table III shows that in 1959-60 only 5.5% of the cultivated area was left fallow, and it increased to 48.4% of the total cultivated area in 1969-70 and then from 1970 onward it started decreasing finally to 10.9% of the cultivated area in 1984-85.

The spread of the lake is maximum in this village and therefore the number of people affected is greater than in other villages. The area under lake Khabbaki in different villages is shown in Table IV which shows that there was about 40% increase in the total lake area. In village Khabbaki, the increase is about 36%, in Dhadhar it is aboot 38% while in Makrumi it is about 35%. Presently, the lake is expanding towards Makrumi village situated in the West.

The total number of affected people due to expansion of the lake is 1816, their distribution in different villages is given in Table IV.

It is notable that before 1970, water of the lake was saltish and only ducks werefound in this lake, but after 1970-72 successful fish farming was attempted and the lake is being used now for this purpose.

(iii) *Uncultivated Area.* This category includes the area which is not available for cultivation. It is used mostly for residential purposes, footpaths, cart tracks, sites for wells and graveyards. It also includes the area covered by ponds and lakes.

The uncultivated area has increased in 1969-70 and in 1974-75 and then slightly decreased in 1980-81 and 1984-85. In 1974-75, about 64% of the total area of the village was uncultivated which is a comparatively high figures. The classification of the uncultivated area is given in Table V.

Uncultivated area can also be further subdivided into two groups.

(a) Unculturable Area

The total unculturable area continued to increase from 1959-60 to 1974-75 so that about 863 acres were made unculturable, but it decreased again in 1984-85. Among minor causes may be the increase in population which increased house-building area, land used for wells, graveyards and ponds, but the overall proportion still remaining low.

(b) Culturable Waste

It includes the land which is going waste currently but where agriculture is possible if attempts are made for its improvement. The landuse record from about 1959 to 1985 shows only minor variations in this category. For instance, maximum of 196 acres was recorded culturable waste in 1969-70, which was 189 acres (only 7 acres less) than in 1959-60. In the next five years, it decreased to 180 acres which remained stable till 1984-85. The increase during 1969-70 may be due to low market prices of the agricultural products and it became unprofitable to cultivate the marginal lands. The peasants could not afford to use manures and chemical fertilizers because of their wretched economic conditions and therefore relatively less fertile fields, such as "Shamilats", were also included in the category.

Most of the culturable waste lands serve as rough pastures for the village cattle.

CROPPING PATTERN

Rabi

The agricultural year is divided into two seasons, Rabi or Hari (winter crop) and Kharif or Sawani (summer crop). There is always a predominance of Rabi crops, wheat being the more important grain. Rabi is a busy time of the year both for the peasants and their cattle, the latter have to plough and irrigate more lands. On average, Rabi crops occupy more than 60% of the cultivated area.

Table VI shows that there has been a decrease in Rabi average from 1959-60 to 1969-70. It was 67% of the total sown area in 1959-60, 55% in 1969-70 and it increased to 63% in 1980-81.

Table VII gives details of averages under various crops in both the seasons, expressed as percentages of total harvested areas.

Among food crops, wheat is the largest grown crop covering more than 90% of the harvested area in Rabi. It increased to 97.3% in 1969-70 and then decreased to 89.2% in 1980-81. Apart from wheat, other minor food crops are barley and gram, each occupying about 1% of the total sown area.

Pulses occupy only 0.2% of the harvested area while oilseeds have a higher percentage and account for about 8% of the harvested area, Taramira and mustard are common oil seeds. the former being more important. Among cash crops, tobacco is cultivated but to a very nominal acreages.

In 1980-81, about 4 acres of land which constitutes about 0.3% of the total harvested area was used for orange and almond growing (Table VI).

Not all the sown crops come to maturity. The amount of Kharaba or failed crops fluctuates from year to year according to unfavourable conditions.

Table VII further shows that crop failure in Rabi season had deceased ; it was maximum in 1959-60 (4% of the total cultivated area) and then decreased onward. In 1969-70, it was 0.1% and in 1980-81, it was Nil, so that 100% of the area cultivated was harvested. The reason may be that :

(i) Rainfall is less in Rabi than in Kharif.

(ii) Wheat is the major diet of people of the area, therefore, farmers try to save their wheat crop from unexpected climatic conditions and insects.

Kharif

Kharif crops are especially important in areas of higher rainfall. Due to density of population, there is a greater need of cereals in particular and other crops in general. Generally, 38% of the total sown area is cultivated during Kharif (summer).

In 1959-60, about 33% of the total sown area was under Kharif crop, in 1969-70 it was 45% and in 1980-81/37%.

Harvested area in Kharif is given in Table VIII which shows that the harvested area was minimum in 1969-70, and 98% of the cultivated area was harvested while in 1969-70, only 49.6% was harvested. It shows that the crop failure in Kharif was maximum in the year 1969-70. More than 50% of the cultivated crop failed in the year 1969-70, while in 1980-81, 100% of the cultivated area was harvested showing no crop failure.

The cultivation of cereals is more important as compared to other crops, important cereals being bajra, jawar and maize. Pulses are other prominent Kharif crops.

In 1959-60, about 81% of the land was under cereals while in the same year only 19% of the total harvested area was occupied by pulses.

In 1969-70, land occupied by cereals and pulses decreased to 76.9% and 11.4% respectively while fodder shows a remarkable increase in its acreage from the years 1959-60 to 1969-70, rising from 0.3% to 10.7%. While in 1980-81, total harvested area under cereals further decreased to 57.3% and the acreage of pulses increased to 41.5%. This shows that now the trend is towards cultivation of pulses, may be due to greater demand of pulses and increase in market price of pulses or both.

Some of the sown area in Kharif crop is also used for oil seeds, spices, cash crops, fruits and vegetables but the proportion of acreage as compared to cereals and pulses is very low.

The cash crops include sugarcane and cotton, sugarcane being more important than cotton. In 1959-60 and in 1969-50 and in 1969-70, 0.4% and 0.6% of the total harvested area was under cash crops respectively while 0.3% and 0.5% of the total sown area in 1959-60 and 1969-70 was under sugarcane. Cotton has a smaller acreage, that is 0.2% of the total sown area, in the years 1959-60 and 1969-70. The cash crops were completely absent in 1980-81 record.

IRRIGATION

Irrigated Land

Most of the land is barani. More than 95% of the cultivated land depends upon rainfall, while less than 5% of the total cultivated land is irrigated. However, proportion of the irrigated land is now increasing. It has been almost doubled after 1964-65 when only 2% of the total cultivated area was irrigated but now in 1984-85 about 4% of the total cultivated land is irrigated.

Though there are several means of irrigation like canals, wells, tubewells, springs, ponds, lakes but in the Khabbaki village, the irrigation is done only with the help of wells. There is not a single tubewell in the area, may be due to :

(i) The village was not electrified and the oil run tubewells are very expensive to maintain.

(ii) The water table was very deep so that it was expensive to dig too deep for tubewells.

Irrigation by wells is common in the village. Almost each and every family has its own well for irrigating the fields. Many farmers have more than one well. These wells are ox-driven.

Barani-Unirrigated

Barani land is much more in area than the irrigated land. About 97% of the land is Barani. The total acreage of the Barani area has slightly decreased from 98% in 1959-60 to 96% in 1984-85, as is shown in Table IX.

The Barani land has further sub-types ;

(i) Hail
(ii) Maira
(iii) Barani Awwal
(iv) Barani Doem
(v) Barani Soem

(*i*) *Hail.* It is the most inferior type of land. Table X shows that this category has decreased from about 35% in 1959-60 to 29.5% in 1974-75, while in 1984-85 no such land existed in the village.

(*ii*) *Maira.* It is also one of the inferior types of land but superior than Hail. In 1959-60 and 1964-65, about 50% of the unirrigated land was maira, which incseased to about 53% in 1969-70 and in 1974-75 ; again in 1980-81 and in 1984-85 it was totally absent.

(*iii*) *Barani Awwal.* It is the major type and the most useful land. The proportion of land in this category is less as compared to other categories, but this proportion is increasing at a rate of about 12 acres per year. Table X shows that in 1959-60 there was only 15% of the unirrigated land as Barani Awwal but now in 1984-85 it has increased to 27% of the unirrigated land.

(*iv*) *Barani Doem.* More than 50% of the unirrigated land falls in this category.

(*v*) *Barani Soem.* Only 20% of the unirregated land falls in this category.

CONCLUSION

The Khabbaki lake has expanded over years. This expansion is not related to the rainfall as it did not produce crop failure. It is believed that water is entering into the lake through springs in the floor. With the expansion in the lake, the culturable area and net sown areas have derceasd, the decrease in the net sown area is due to expansion of the lake.

The quality of the water has also changed. Some years earlier, the water of the lake was highly saline and only ducks could survive in the lake, but now the quality of water has changed so much that fish farming was found successful and is a regular activity eventhough on a small scale. Regular fish farming may help in meeting food requirements of the local population.

On expansion, lake water encroaches on agricultural land. It is desirable that water management is properly undertaken, including measures to contain the lake within suitable limits by draining excess water for agriculture or disposal.

TABLE I

Showing Percentages of Cultivated and Uncultivated Lands to the Total Area

Period	Total Area (acres)	Total cultivated (acres)	% of total area	Total Uu-cultivated (acres)	% of the total area
1959-60	7682	3576	46.6	4106	53.5
1964-65	7682	3580	46.6	4102	53.4
1969-70	7682	2722	35·4	4960	64.6
1974-75	7682	2722	35.4	4960	64.6
1980-81	7677	3129	40.8	4548	59.2
1984-85	7677	3129	40.8	4548	59.2
AV :	—	3143	—	4537	—

Source :—Revenue Record of Patwari (Lal Kitab of diffent years).

TABLE II

Showing Percentages of Net Sown and Fallow Lands to the Total cultivated Land

Period	Total Culti-vated (acres)	Net Sown (acres)	% of total Cultivated	Current Fallow (acres)	% of total Cultivated
1950-60	3576	3378	94.5	198	5.5
1964-65	3580	2078	58.0	1502	42.0
1969-70	2722	1405	51.6	1317	48.4
1974-75	2722	1754	64.4	968	35.6
1980-81	3129	2463	78.7	666	21.3
1984-85	3129	2787	89.0	342	10.9

Source :—As in Table I.

TABLE III

Percentage of Net Sown and Current Fallow Area to the Total Area

Period	Total Area (acres)	Net Sown (acres)	% of total area	Current Fallow (acres)	% of total area
1959-60	7682	3378	44.0	198	2.6
1964-65	7682	2078	27.0	1502	19.6
1969-70	7682	1405	18.3	1317	17.1
1974-75	7682	1754	22.8	968	12.6
1980-81	7677	2463	32.1	666	8.7
1984-85	7677	2787	36.3	342	4.5

Source :—As in Table I.

TABLE IV

Showing area under Lake Khabbaki in different village

Villages	Area in (Acres) 1974	Area in (Acres) 1984	Percentage Increas	No. of Affected persons
Khabbaki	313	426	36.0	1500
Dhadhar	246	340	38.0	284
Makrumi	4	18	350.0	32
Total ...	356	784	40.0	1816
Increase in Ten years	—	221	—	—

Source :—Revenue Survey in 1984.

TABLE V

Showing Classification of Uncultivated Land

Period	Total Uncultivated (acres)	Total Unculturable	% of total Uncultivated	Culturable Waste (acres)	% of total Uncultivated
1959-60	4106	3917	95.4	189	4.6
1964-65	4102	3917	95.8	185	4.5
1969-70	4960	4764	96.1	196	4.0
1974-75	4960	4780	96.4	180	3.8
1980-81	4548	4368	96.0	180	4.0
1984-85	4548	4368	96.0	180	4.0

Source :—As in Table I.

TABLE VI

Showing Proportion of Rabi and Kharif Crops to the Total Sown

Year	Kharif (acres)	% of the Total Sown	Rabi (acres)	% of the Total Sown	Total Sown (acres)
1959-60	1268	33.0	2568	66.9	3836
1969-70	1265	45.0	1537	55.8	2802
1980-81	947	37.0	1621	63.0	2568

Source :—As in Table I.

TABLE VII

Percentages of Rabi Crops to the total Harvested in Rabi

Year	Culti-vated (acres)	Harvested (acres)	CEREALS: Wheat	CEREALS: Barley	CEREALS: Gram	PULSES: Massar	PULSES: Others	OIL SEEDS: Taramira	OIL SEEDS: Mustarad	Spices	Cash Crop Tobacco	Fodder	Fruit	Crop Failure
1959-60	2568	2465	90.3	0.8	1.3	0.1	0.1	7.3	—	0.04	1.2	—	—	4.0
1969-70	1537	1536	97.3	0.1	—	—	—	1.6	0.2	0.26	0.3	0.2	—	0.1
1980-81	1621	1621	89.2	—	0.5	—	—	4.4	5.5	0.12	—	—	0.3	Nil

TABLE VIII

Showing Percentages of Kharif Crops to the total Harvested in Kharif

Year	Culti-vated (acres)	Harvested (acres)	CEREALS: Jowar	CEREALS: Bajra	CEREALS: Maize	PULSES: Mong	PULSES: Others	Oil Seeds	Spices	CASH CROPS: Sugar-cane	CASH CROPS: Cotton	Fodder	Fruits	Vege-table	Others	Crop Failure
1959-60	1268	1237	7.2	67.6	5.2	19.0	—	0.1	0.2	0.3	0.2	0.3	—	—	—	2%
1969-70	1265	629	13.2	48.6	15.1	11.4	—	—	0.3	0.5	0.2	10.7	—	—	—	50.4%
1980-81	947	947	30.0	22.4	4.4	4.9	41.0	0.5	—	0.2	—	—	0.1	0.4	0.4	Nil

TABLE IX

Showing Land Classification According to Irrigation

Period	Total Irrigated (acres)	% of the total cultivated	Unirrigated (acres)	% of the total cultivated	Total (acres)
1959-60	66	2.0	3510	98.0	3576
1964-65	68	2.0	3512	98.0	3580
1969-70	114	4.0	2608	96.0	2722
1974-75	114	4.0	2608	96.0	2722
1980-81	130	4.0	2999	96.0	3129
1984-85	130	4.0	2999	96.0	3129

Source :—As in Table I.

TABLE X

Showing Land Classification of Unirrigated Land and Proportion of Types of Unirrigated to Total Unirrigated

Period	Total Unirri-gated (acres)	Hail (acres)	% of the Total Un-irrigated	Maira (acres)	% of the Total Unirri-gated	Barani I (acres)	% of the Total Un-irri-gated	Barani II (acres)	% of the Total Un-irrigated	Barani III (acres)	% of Total Unirri-gated
1959-60	3510	1225	34.9	1751	49.9	534	15.2	—	—	—	—
1964-65	3512	1223	34.8	1749	49.8	540	15.4	—	—	—	—
1969-70	2608	769	29.5	1401	53.7	438	16.8	—	—	—	—
1974-75	2608	769	29.5	1400	53.7	439	16.8	—	—	—	—
1980-81	2999					819	27.3	1599	53.3	581	19.4
1984-85						819	27.3	1599	53.3	581	19.4

Soorce:—As in Table I.

ACKNOWLEDGEMENT

The authors are grateful to Mr. Abdul Waheed and Mr Muhammad Ghazanfar, U.G.C. Scholars who helped in the collection of data. Mr. Muhammad Amir Khan, Ganugo and Mr. Ghulam Muhammad, Patwari, permitted to consult unpublished data. The authors are indebted for this help.

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PETROLOGY OF BARITE DEPOSITS OF SOUTHERN HAZARA, N.W.F.P. PAKISTAN

BY

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Abstract : *The barite occurring in Southern Hazara district near Haripur is white to snow-white in colour. Barite is coarse grained massive and compact in nature. Barite occurs mostly as vein which contains impurities consisting of quartz, calcite and traces of pyrite, iron oxide and copper. Barites in Tanol area are mostly hosted in quartzitic sandstone and are cavity filling and epithermal vein type deposits.*

INTRODUCTION

Barite is an industrially important mineral. Its mining in Pakistan is concentrated in Baluchistan and North-West Frontier Province. It is mainly used for oil-well drilling with a minor amount of the output being used in paint and chemical industries. In 1984-85 Baluchistan produced 20,699 tonnes of barite and NWFP 437 tonnes (Griffiths, 1988).

In NWFP, barite occurs in many localities spread over in Peshawar, Hazara and Kohistan divisions. In Hazara Division, important deposits include Kohala near Nathiagali and Bir, Alul, Darwaza, Hil and Kacchi near Haripur. Observations herein described are largely based on field work, megascopic and microscopic studies of Tanol area barite deposits (Fig. 1). An attempt has also been made to discuss the genesis of these barites.

PREVIOUS WORK

The pioneer geological work was done by Wynne (1879) who gave an outline of geology of Hazara. The area is also included in the geological map published by Middlemiss (1896). Ali (1962) worked on the stratigraphy of south-western Tanol area. Ali, *et al.* (1964) studied mineral deposits of the southern part of Hazara Division. Besides discussing other mineral deposits, they described barite deposits of Kohala, Tipra, Faqir Muhammad and Kacchi. Killingar *et al.* (1967) discussed general geology of NWFP barites. Calkins *et al.* (1968) did a detailed geological survey of southern Himalayan region which includes description of southern Hazara barite deposits. Barite deposits of Peshawar and Hazara divisions have also been studied by Afridi (1986). Earlier work on NWFP barites includes their field relationship and grade of ore based on chemical composition but the data regarding petrography and genesis of these barites were still lacking.

FIELD RELATIONS

In southern Hazara barite district near Haripur three units are exposed : the Hazara slate Formation, the Tanawal Formation and Abbottabad Formation (Ali, 1962). The seven vein type and cavity filling barite deposits of the area are hosted in Tanawal Formation.

In Alul, Darwaza, Kacchi, Bir and Hil, the barite and associated minerals occur along faults. gashes and joints. The quality of barite ore varies by differential accumulation of $BaSO_4$ within deposits. A sharp contact of barite with host rock is noticed in the field. In each barite deposit, veins are scattered and irregularly distributed. In thickness, they range from few inches to a few feet and in length from several feet to tens of feet (Killinger, *et al.* 1967).

In Kacchi, discontinuous pods of barite occupy shear zones in medium grained, slightly metamorphosed quartzites of Tanawal Formation. Three other similar exposures were seen in which barite ranged from one to two feet in thickness. The veins range in strike between N5°E and N30°E (Ali, *et al.* 1964).

In Biar, the barite is hosted by quartzitic sandstone of Tanawal Formation, which is thinly bedded with intercalations of Phyllite and schist. The barite vein is about 10 feet long and 3 feet thick showing pinching and swelling behavior. Sometimes, quartzitic sandstone shows blue stains of copper. Similar types of veins also occur in Alul, Darwaza, Hil, Chinjiali and other deposits.

PETROGRAPHY

In thin sections, barite generally exhibits euhedral to subhedral crystals. Quartz and calcite are the main gangue minerals present. Coarse to medium size barite crystals surrounded by quartz and calcite crystals are noted commonly (Fig. 2). Barite occurs as massive aggregates alongwith coarse to medium size crystals of quartz and calcite (Fig. 3). Sometimes, alternate bands of barite, quartz, and calcite are also observed. Barite veins occurring in fractures of quartzite show sharp contact with the host rock. The crushed fine-grained silica is also noted at the margins of barite and gangue minerals. The aligned behaviour shown by minerals in some cases is due to filling of the cavity along fractures and joints which have definite orientations (Fig. 3).

Barite grains are coarse to medium in size. Two sets of perfect and an imperfect cleavages are commonly noted in the longitudinal sections of these barites (Fig. 3). Refractive index is high and birefringence is moderate. The subhedral grains of barite show straight extinction and blue and yellow colours of the first order of interference.

Petrographic studies reveal the presence of silica in two forms—one is the coarse to medium grained quartz of various shapes and the other is a set of veinlets of cherty quartz having cross-cutting relationship with the host rock.

Calcite occurs both as microspar and micrite. The calcite grains are of different shapes and sizes and show two sets of perfect cleavages (Fig. 4). The euhedral shaped grains of opaque minerals are irregularly distributed which are probably pyrite. Other minerals include the traces of iron oxide and copper (Fig. 5).

GENESIS

The geologic features of southern Hazara barite suggest that the barite was deposited in the faults, fractures and joints resulting from mechanical deformation. The coarse grain size of barite with well developed crystal faces and cleavages indicates the crystallization of barite at low temperature and pressure (Miller, 1984). The absence of primary bedding, erratic distribution of opaque ores like pyrite and galena in barite and cherty quartz with cross-cutting relationships also suggest epigenetic origin for these barites.

Barite mineralization in Tanol area is cavity filling and epithermal vein type. The coarse grain size and massive nature of barite is due to the deposition of the same mineral continuously on both walls until the cavity becomes filled. While presence of alternate bands of quartz and barite in the area suggests that successive crusts of different minerals have deposited upon the first one, perhaps with the repetition of earlier minerals, thus crustified vein results (Bateman, 1950).

Evidence of an igneous source for the ore solution is not available in the vicinity of these barite deposits. Solutions were probably derived from the sediments through which the solution travelled. Ground water solutions may have leached barium from the host rocks and redeposited in epigenetic veins (Brobst, 1960). More field and lab. data are required to collect evidence regarding the source of Barium solution which led to the deposition of southern Hazara barites.

Average physical and chemical properties of 20 barite samples from Tanol are as follows :

1,	Physical Analysis		
	Specific Gravity	...	4.10
2.	Chemical Analyses		
	Barite $BaSO_4$	...	92.50%
3.	Copper Cu	...	130.5 ppm.
4.	Lead Pb	...	78.5 ,,
5.	Zinc-Zn	...	51.18 ,,

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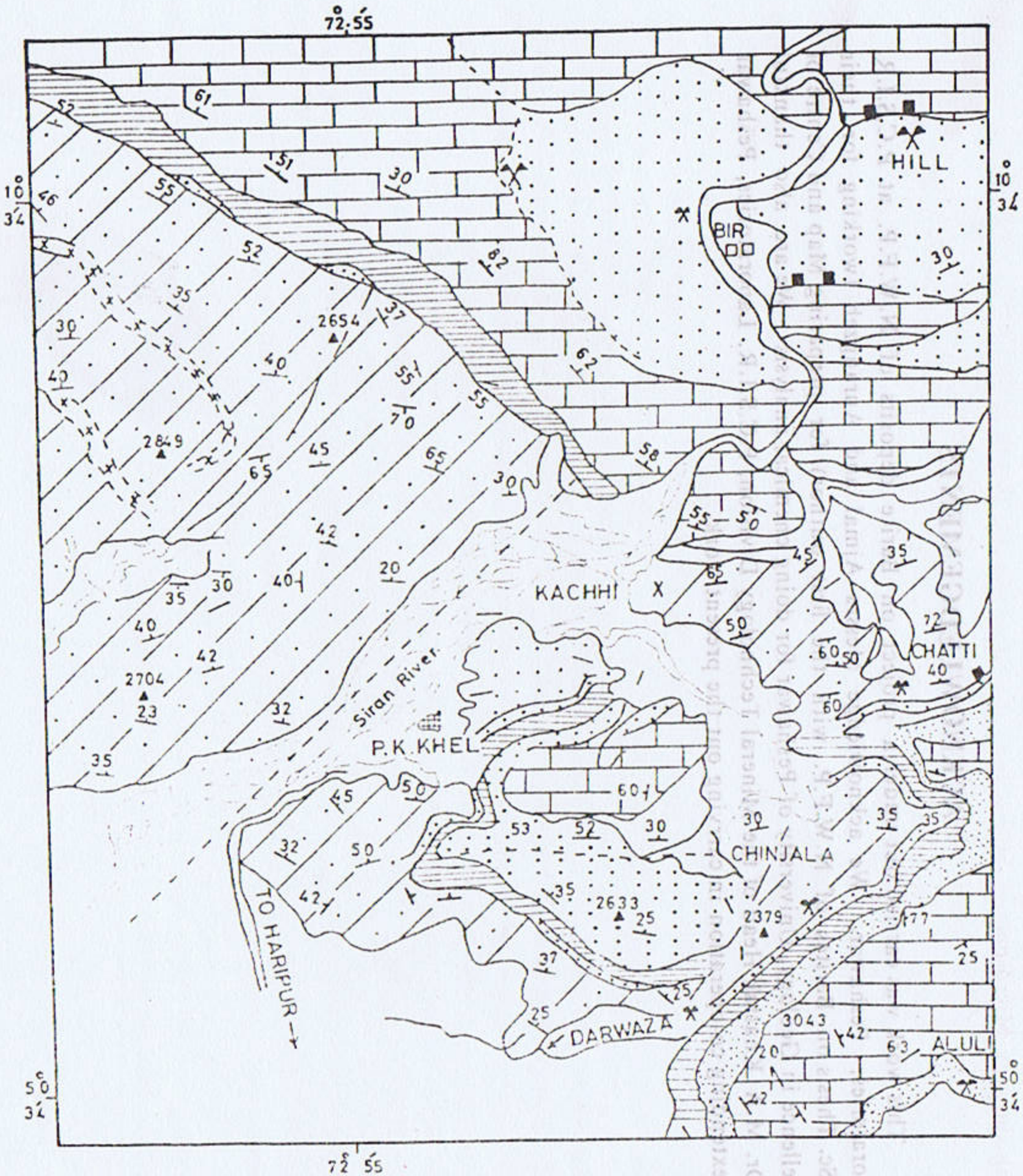
This work was carried out under a project on Barite deposits of N.W.F.P. at P.C.S.I.R. Laboratories, Peshawar. We acknowledge Messrs Ajmal and Aurangzeb (working for their M. Sc. Thesis on Barites of N.W.F.P. with the first author) for preparing Map and Centre of Excellence in Geology, University of Peshawar for doing chemical analysis We are also thankful to Dr. M.A Khattak Head of the Mineral Technology Division, P.C.S.I.R. Laboratories, Peshawar for extending co-operation in carrying out the present work.



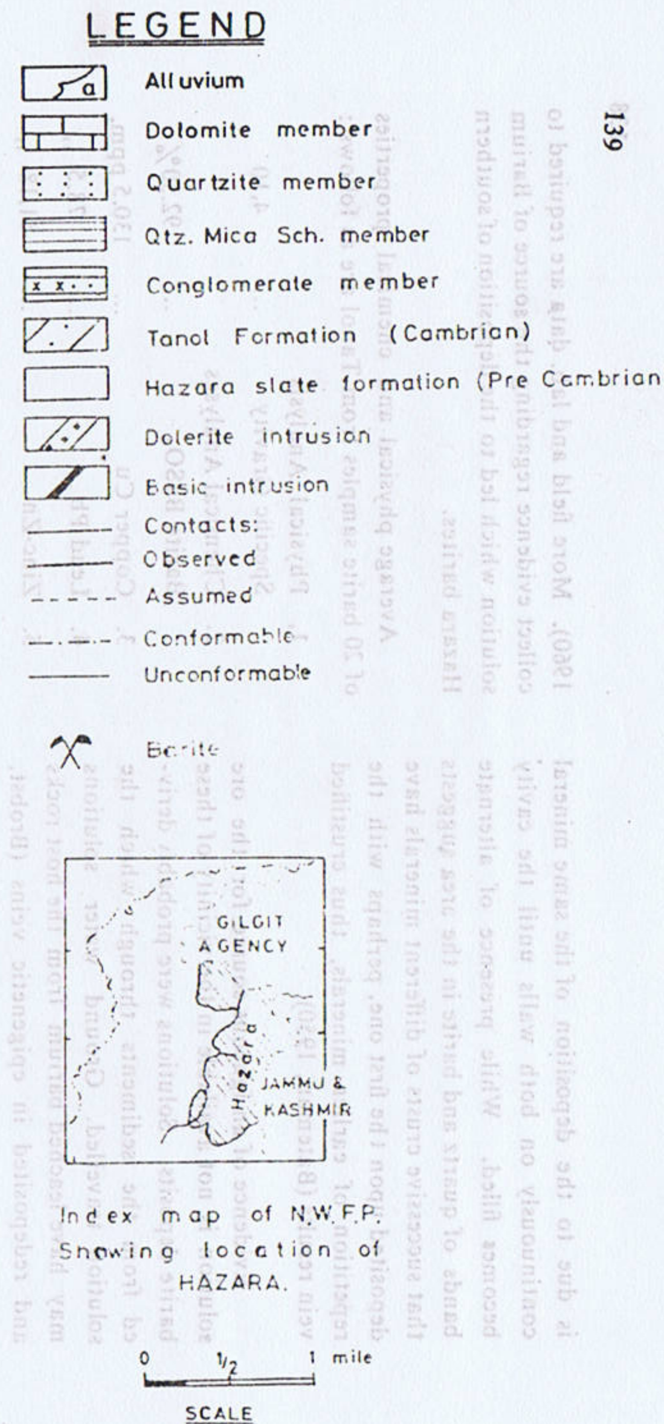


Fig. 1. Geological Map of South-Western Tanol Area, Hazara, N.W.F.P.

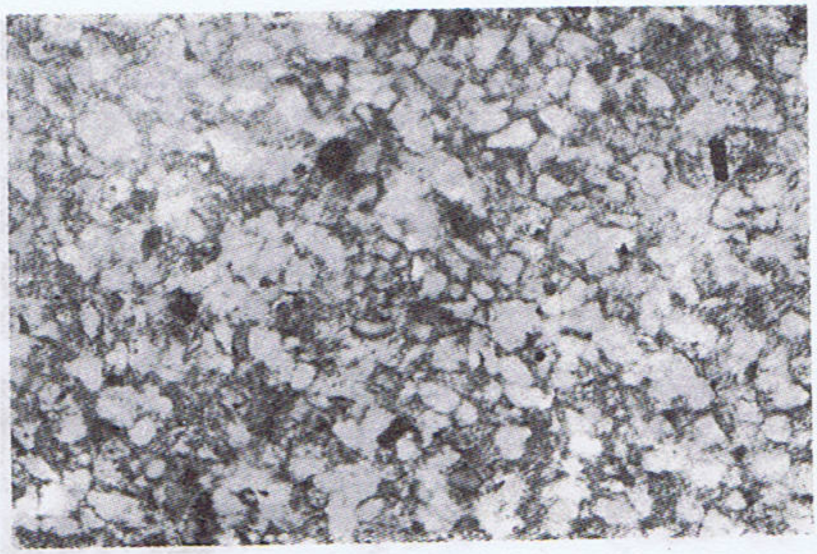


Fig. 2. Microphotograph showing euhedral to sub-hedral barite with Quartz and Calcite Grains. (Cross Nicols, 2.5X)

Fig. 3. Microphotograph showing Massive Crystals of Barite. (Cross Nicols, 2.5X).

Fig. 4. Microphotograph showing Microspar and Micrite (Cross Nicols, 2.5X)

Fig. 5. Microphotograph showing euhedral crystals of opaque minerals and traces of Iron (Cross Nicols, 2.5X).

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GEOLOGY AND PETROGRAPHY OF BARAWAL-DIR-BIBIOR AREA (TOPOSHEET No. 38 M/16), DIR DISTRICT N.W.F.P. PAKISTAN

BY

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Abstract : *A consolidated map of about 250 sq. miles of Dir-Barawal-Bibior area is presented on a scale of 1" = 1 mile. Out of this 100 sq. miles has been mapped by the authors for the first time. Geology, petrology and genesis of the igneous, metamorphic and sedimentary rocks of the area has been described. The amphibolits of the area represent an obducted sub-duction melange which is a metamorphosed sequence originally composed of a variable admixture of submarine lavas and an assortment of sediments of calcareous and siliceous marly nature and arc-derived detritus. Quartzites and calcareous schists have been derived mainly from the arc zone.*

The quartzites are overlain by slightly metamorphosed marls, calcareous shales and limestone beds and bands. The calcareous rocks contain Eocene foramanifera. Volcanic horizons containing flows as well as pyroclasts occur interbedded with metasediments. The arc-related acid to intermediate intrusives occur intruding the metamorphic sequence.

INTRODUCTION

Hyden (1914) for the first time mentioned the presence of schists, gneisses, quartzites and granites near Dir. Bakr and Jackson (1964) placed the rocks of the area in granite gneisses and schists with metasedimentary rocks possibly of Pre-Cambrian age into which granodiorite, syenite and diorites probably of early Tertiary age are intrusive.

Chaudhry et al. (1974a) and Chaudhry et al. (1974b) for the first time mapped small areas along roadside from Bibior to near Dir, classified the rocks, described them petrographically and assigned an Eocene age to the calcareous rocks on the basis of a discovery of Eocene foramanifera.

GEOLOGY

The following main rock units have been mapped and studied (Please see the attached map).

- Granite
- Granodiorite
- Tonalites
- Calcareous phyllites/schists with interbedded volcanics
- Quartzites with interbedded volcanics
- Amphibolites

The colour of amphibolites is from green to greenish black. The weathering colours are brown, reddish brown and rusty. Banded, layered and foliated structures are most common. Boudin structure is less common while augen structure is rare. At many places the amphibolites are massive. Various structures are intergradational and randomly associated.

Epidosite, acid to intermediate pegmatites and quartzo-feldspathic veins cut the amphibolite at places. At contact with the intrusive bodies narrow mixed zones are developed.

The quartzites are massive, tough and well jointed rocks. Their colour is from gray to grayish brown while weathering colours are from earthy to dark gray and rusty gray. Quartz, calcite and quartz-o-feldspathic veins cut them at places. These veins, at places, may show a pinch and swell structure. Small epidote-chlorite-calcite-(quartz) patches are present at places.

The calcareous phyllites and schists are well foliated and extensively jointed. They are generally from greenish gray to gray in colour. The calcareous horizons are off white, rusty gray and gray in colour. Some calcareous bands contain larger foramanifera. The weathering colours of these rocks are from earthy to rusty dark gray.

Quartzites as well as calcareous phyllites and schists have a large number of interbedded volcanics and some pyroclasts. The volcanic horizons vary widely in their dimensions (Fig. 1). They are dark red, chocolate, purplish red, green, bluish green and ash gray to off-white. They are from massive to foliated.

The proxene tonalite is speckled white and black, while weathering colours are gray to brownish gray. Quartz, quartz-o-feldspathic and pegmatite veins cut the pyroxene tonalite. Copper staining (blue and green) is present at places in them. Spheroidal weathering and exfoliation is commonly observed in these rocks.

The tonalite is grayish white and weathers to grayish brown. The rock is massive and well jointed. Quartz, quartz-o-feldspathic, pegmatite and aplite veins may cut the tonalite.

The granodiorite is a fairly coarse grained micacaceous and massive looking rock. It is white to off-white with dark brown biotite flakes. It shows extensive spheroidal weathering. Quartz-o-feldspathic, veins, epidosite, pegmatite, quartz and aplite veins cut the rock at places.

Granite occurs as small patches in amphibolites and granodiorite. It is compact and white looking rock. Its weathering colour is rusty brown. It is poorly foliated. It contains some pegmatite and quartz veins. The granite often weathers to friable spheroidal outcrops.

PETROGRAPHY

AMPHIBOEITES

Petrography of darker coloured amphibolites as well as lighter coloured amphibolites will be described together in order to avoid unnecessary repitition. The two types are closely associated, intermixed and even interbedded. However, in a general way the colour index decreases from South to North. Since the amphibolites display considerable modal, textural and structural hetrogeniety, therefore low colour-index areas, patches and zones may be encountered in darker coloured amphibolites, while high colour index parts may be encountered in the lighter coloured variety (Please see the modal composition).

The amphilbolites show a very wide range of structure and texture. Banded, foliated, layered and massive types are all present. They are from fine to coarse grained. However, medium to coarse grained varieties are most common. Pegmatitic varieties, though rare, are also present. Small sacchroidal patches are also sometimes met with. Xenoblastic, hypidioblastic and porphyroblastic varieties are common. Porphyroblastic varieties are often poikiloblastic. Idioblastic types are indeed very rare. The modal compositions of amphibolites are given in Table 1.

Hornblende and aluminous hornblende are commonly present as subhedral to eumorphic crystals. Anhedral crystals are subordinate. The porphyroblasts are often poikiloblastic and contain inclusions of quartz. Hornblende is from green to bluish green and strongly pleochroic. It is from prismatic to bladed. Hornblende may alter to epidote, chlorite and biotite. The variety tremolite though present is rare.

Three varieties of epidote namely zoisite, clinozoisite and pistacite are met with. They occur as prismatic, columnar and granular masses. Epidote often forms myrmekite-like intergrowths with quartz.

Quartz occurs mostly as small anhedral grains and as aggregates. It often shows strong strain extinction. It also occurs as inclusions in amphibole.

Plagioclase is mainly subhedral and subprismatic. Its composition generally lies within andesine range. It is mostly cloudy due to alteration. It alters to epidote, calcite, illite, kaolinite and sericite.

Biotite occurs in some samples. It is brown and pleochroic from light to medium dark brown. Chlorite is clearly a secondary mineral and occurs as flakes, scales and their aggregates. It is from neutral green to medium green. It often occupies crystal boundaries, cracks and cleavage. Sphene, orthoclase, clay, carbonate and iron oxides occur as accessories.

QUARTZITES

Quartzites are from massive to banded but the impure bands are subschistose. They are from medium to fine grained. Xenoblastic and granoblastic textures are common while porphyroblastic and granoblastic textures are rare. Their modal composition is given in Table 2.

Strained anhedral quartz is the main mineral of quartzites. Plagioclase is the next most common mineral. It mostly ranges in composition from oligoclase to andesine. Magnetite is the most common accessory mineral. Hornblende, micas, chlorite, garnet, sphene and orthoclase show a fairly erratic distribution.

CALCAREOUS PHYLLITES

These rocks are fine grained and foliated. At places moderate schistosity is developed. Their modal compositions are given in Table 3.

Quartz and calcite are the main minerals. Chlorite, sphene, hornblende, micas and iron oxides show erratic and irregular distribution. Some bands contain Nummulites and Assilina.

VOLCANICS

The volcanic rocks are from hollocrystalline to merrocrystalline. They are slightly metamorphosed. They are often flow-lined. Chalcedony occurs in some samples and shows both a salt and pepper as well as subradial structure. These rocks are often porphyritic (-blastic) and hyidiomorphic (-blastic). They range in composition mostly from rhyolites to dacite. Some andesites are also present. Presently these rocks are slightly metamorphosed and altered.

Albite (An_6-An_8) occurs in rhyolites while rhyodacites and dacites contain oligoclase ($An_{14}-An_{20}$) and andesites contain andesine ($An_{32}-An_{42}$). They generally occur in two generations. The bigger generation occurs as subhedral, prismatic and well twinned crystals, while the smaller generation occurs as slender flowing and poorly twinned laths. It generally shows alteration to clay, epidote and calcite. Quartz occurs mainly as small anhedral grains and as granular aggregates. It also forms thin veins cutting the rock.

Calcite is a secondary mineral and occurs as randomly distributed grains, small patches and veins.

Epidote is pale green and non-pleochroic. It occurs as discrete grains as well as aggregates. It is from granular to columnar and prismatic. It may also occur as thin veins.

Amphibole is medium green and moderately pleochroic. It often shows alteration to biotite and chlorite. Biotite often encloses small grains of iron ore.

Volcanic glass occurs as relict and irregularly distributed diffused patches. It is undergoing devitrification. Small patches and streaks of chalcedonic matter showing either salt and pepper or subradial to sheaf-like structure show a random distribution. Haematite is widespread and in some samples assumes the status of an essential mineral.

PYROXENE TONALITES

The pyroxene tonalite is often foliated and hypidiomorphic rock. It is subporphyritic to porphyritic at places. Myrmekitic textures are also present. Their modal composition is given in Table 4.

Plagioclase is from subhedral to anhedral. It is an andesine ($An_{32}-An_{39}$). Some phenocrysts of plagioclase contain inclusions of hornblende, magnetite, biotite and quartz. In some thin sections, zonal structure of plagioclase is obvious.

Both orthopyroxene and clinopyroxene may occur in tonalite. The orthopyroxene is mainly subhedral and is pleochroic from light green to pale-red. It appears to be iron rich hyperthene. The clinopyroxene is a colourless augite. Inclusions of biotite, haematite and magnetite are often present in pyroxenes. Pyroxenes show marginal alteration to amphibole.

Amphibole shows a wide variety of form. It is often from anhedral to subhedral but occasionally it is eumorphic. It is strongly pleochroic from light pale green to dark green.

Reaction rims of hornblende around pyroxene and of biotite around amphibole are some times seen. Biotite occurs as strongly pleochroic flakes. It is brown and pleochroic from light brown to dark brown.

Epidote, orthoclase and iron oxides occur as accessories.

The tonalite complex occurs as a small body cutting the amphibolites. It is in the main a tonalite but near the contact with amphibolite, quartz decreases and diorite develops.

TONALITE

These rocks often exhibit a porphyritic to subporphyritic hypidiomorphic texture. Simple hypidiomorphic and allotriomorphic textures are also seen. These rocks are from medium to coarse grained. Their modal compositions are given in Table 5.

Plagioclase is an andesine ($An_{32}-An_{40}$). It is subhedral and often prismatic to subprismatic. It may enclose inclusions of quartz, specially near the contact with amphibolite. Sometimes epidote may also occur as inclusions.

Hornblende occurs as prismatic to subprismatic crystals. It may contain inclusions of quartz and epidote. Near the contact with amphibolites it may become poikilitic.

Clinozoisite as well as zoisite commonly occur as small crystals and granular aggregates. Biotite is greenish brown to medium brown and moderately pleochroic. Inclusions of magnetite in biotite may often occur. Sphene, orthoclase and iron oxides are the accessories.

GRANODIORITE

It is a coarse-grained, hypidiomorphic porphyritic to subporphyritic rock. Some samples show a myrmekitic texture. The main core of the intrusion is mainly of biotite granodiorite, while near contacts with the country rocks a zone of 3 to 30m thick also contains amphibole porphyroblasts. These porphyroblasts are often subpoikiliblastic. Quartz, feldspar and micas are the main minerals while sphene, apatite, chlorite, epidote and iron oxides are the accessories. The modal compositions are given in Table 6.

GRANITE

It is from medium to coarse grained hypidiomorphic granular rock. At places it may show a subporphyritic texture. Some samples show a myrmekitic texture. Quartz and feldspars are the main minerals while micas, iron oxides epidote and chlorite are minor/accessory minerals.

PETROGENESIS

The area under study represents a subduction melange in the south-east and a sedimentary-volcanic sequence to the north-west. The sedimentary volcanic sequence is in turn intruded by tonalites and pyroxene tonalites, marginal zones of amphibolite are also cut by granodiorites and tonalite.

The amphibolites represent an obducted subduction melange which is a metamorphosed sequence originally composed of a variable admixture of submarine lavas and an assortment of impure sediments of calcareous and siliceous marly nature (Chaudhry et al. 1974 a, 1974 b, 1984) and Butt (et al 1980).

The meta-sedimentary sequence is fairly impure, hetrogeneous and composed of feldspathic quartzites and chlorite-rich calcareous phyllites. They also contain epidote, albite, plagioclase, chlorite etc. Presence of volcanic fragments and highly heterogeneous nature of these rocks clearly shows that they have been derived from an arc zone. Interbedded with these rocks are acid to intermediate volcanic flows and pyroclasts. The upper foramaniferal beds represent submarine shelf facies.

This volcanism (sedimentary - volcanic sequence) is associated with northwards directed subduction of the Tethys along a NE-SW zone. The older subduction and arc formation took place in Yasin-Chitral region. The partial melting of the Tethys floor has given rise to rhyolites, rhyodacites, dacites and andesites (Chaudhry et al. 1983, 1984 and Butt et al. 1980). This is, therefore, another Andean type margin. An earlier margin developed along MKT (Chaudhry et al. 1984).

The tonalite/diorite / granodiorite / granite are the plutonic equivalents of the volcanics. They have formed under hydrous conditions due to the melting of the subducting Tethys plate. The pyroxene tonalite has formed due to the partial melting of the Tethys plate under anhydrous conditions and at relatively greater depths.

The origin of amphibolites has already been discussed by Chaudhry et. al (1974).

Xenoliths, screens and bands of marble, quartzite and schist in various stages of transformation are present in Northern Dir amphibolites. Banding and layering is also common. It is, therefore, concluded that the northern Dir amphibolites are not purely para-amphibolite as believed earlier by Chaudhry et. al (1974). They are transformed volcanics and sedimentary admixture.

TABLE 1
Modal Analysis of Amphibolites

T.S.N.	16585	16315	16380	16388	16305-A	16330	16267	16326	16333
G.R.	764144	798173	772171	760147	782165	834176	794196	824176	840177
Hornblende	83.2	81.8	68.2	63.8	62.2	61.1	57.0	55.7	45.4
Epidote	14.2	3.2	3.0	4.6	4.7	5.2	2.3	29.7	16.7
Quartz	—	6.0	23.3	14.5	3.0	5.8	37.7	3.9	9.1
Plagioclase	—	1.2	—	9.7	21.6	23.0	—	—	0.3
Biotite	—	4.8	2.2	0.8	5.7	1.9	3.0	8.7	7.6
Muscovite	1.5	—	0.9	1.0	—	—	—	—	0.3
Sphene	—	2.6	0.5	2.5	—	0.7	—	—	—
Magnetite	0.3	0.4	1.9	—	0.5	1.4	—	1.8	5.5
Limonite	—	—	—	—	2.0	0.5	—	—	15.1
Haematite	0.8	—	—	3.1	0.3	0.4	—	0.2	—
Chlorite	—	—	—	—	—	—	—	—	—
Orthoclase	—	—	—	—	—	—	—	—	—
Calcite	—	—	—	—	—	—	—	—	—

TABLE 2
Modal Analysis of Quartzites

T.S.No.	16275	16264	16316	16399	16401	16402	16404	16406
G.R.	788224	832255		813308	821316	823317	838357	830352
Quartz	50.48	95.28	61.40	82.29	82.99	75.72	53.39	51.56
Plagioclase	0.43	0.00	31.34	7.74	15.25	16.38	11.20	8.48
Hornblende	0.00	0.00	0.00	5.92	1.14	3.49	0.00	13.22
Biotite	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00
Muscovite	0.00	0.00	4.59	0.00	0.00	0.00	0.00	0.00
Epidote	44.48	0.00	0.00	0.81	0.00	0.00	33.82	0.00
Calcite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.26
Garnet	0.00	9.00	0.00	0.00	0.00	0.00	0.00	22.96
Chlorite	3.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sphene	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnetite	0.15	0.29	0.00	3.24	0.00	3.67	1.59	0.52
Hematite	0.13	4.43	0.00	0.00	0.00	0.00	0.00	0.00
Orthoclase	0.00	0.00	2.67	0.00	0.62	0.00	0.00	0.00

TABLE 3
Modal Analysis of Calcareous Phyilites

T.S. No.	16342	16393	16364	16309	16352	16341	16313	16261	16308	16279	16272
G.R.	777244	833321	742215	756230	737230	779243	767242		755228		782216
Quartz	51.78	39.00	47.07	45.09	35.81	28.04	18.24	22.50	40.47	26.92	23.10
Calcite	34.01	43.12	31.89	35.01	38.09	40.96	39.10	49.32	30.26	44.13	46.10
Chlorite	8.87	6.95	10.92	15.10	12.11	11.98	6.20	12.21	13.53	9.85	14.61
Muscovite/Sericite	2.51	8.62	4.94	2.05	9.26	12.88	27.89	13.85	5.29	6.24	9.48
Biotite	0.00	0.00	0.00	0.00	0.90	0.80	1.90	0.00	0.00	0.82	2.01
Hornblende	0.00	1.00	3.93	1.68	0.00	0.00	0.46	0.00	9.00	9.25	1.77
Plagioclase	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron Oxide	0.94	1.31	1.25	1.07	3.83	5.34	6.21	2.12	1.45	2.79	2.93

TABLE 4
Modal Analysis of Pyroxene Tonalite

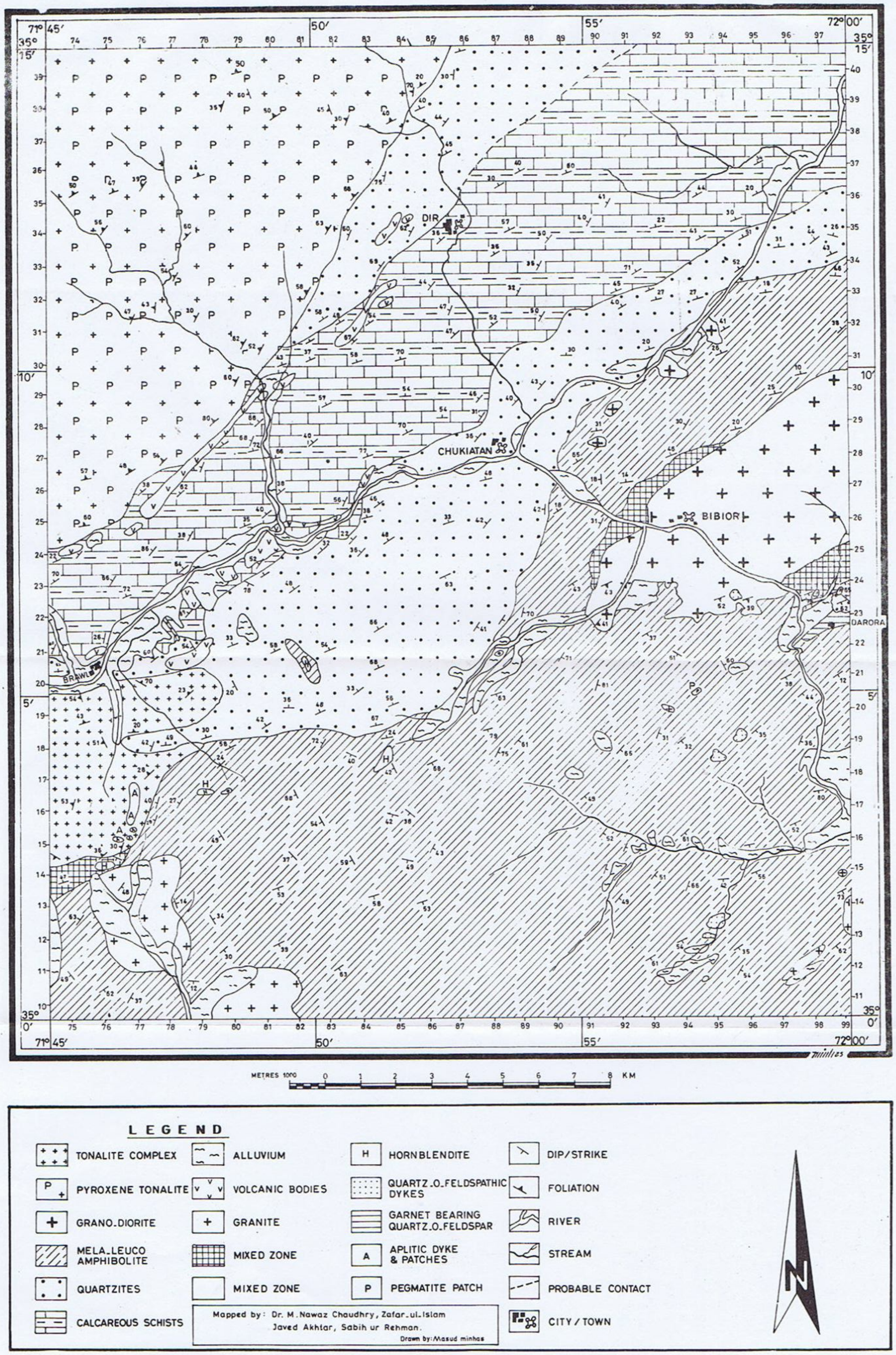
T.S. No.	16375	16373	16357	16356	16408	16410	16398	16400	16359	16360
G.R.	783278	788283	747247	745247	822356	810353	810315	830356	750251	749255
Quartz	17.99	26.02	25.22	28.46	37.36	24.95	53.03	26.73	20.67	22.79
Hornblende	10.53	2.03	11.35	7.50	0.58	0.00	24.58	0.08	3.96	7.91
Plagioclase	35.05	50.42	46.31	51.42	39.64	58.38	16.97	42.26	45.89	44.45
Biotite	9.07	18.31	12.12	10.19	10.13	10.76	0.30	8.78	15.50	13.55
Magnetite	6.48	2.17	1.64	0.48	1.85	1.20	2.63	2.48	0.87	1.22
Pyroxene	19.02	1.05	3.36	1.95	10.13	4.71	2.04	19.27	1.81	3.29
Hematite	1.86	0.00	0.00	0.00	0.31	0.00	0.45	0.40	0.00	0.00
Orthoclase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.30	6.79

TABLE 5
Modal Analysis of Tonalite Complex

T.S. No. G.R.	16389 774167	16259 763195	16389-A 774167	16257-A 765153	16377 749197	16296 791195	16283 775202	16385 764152
Plagioclase	28.59	7.09	26.94	20.21	6.23	5.27	13.49	16.09
Quartz	51.27	25.83	50.21	28.92	33.07	42.06	52.65	35.63
Orthoclase	9.15	13.56	10.85	1.67	1.21	0.00	0.00	0.00
Hornblende	4.71	40.92	1.23	33.34	40.79	31.19	1.68	38.21
Pyroxene	0.03	0.33	1.02	0.00	0.00	0.00	0.00	0.00
Biotite	6.25	8.50	4.01	1.52	2.77	2.30	0.00	1.35
Sphene	0.00	0.00	0.00	1.13	0.43	0.00	0.00	0.00
Muscovite	0.00	0.00	5.38	0.60	1.36	1.70	2.20	0.16
Magnetite	0.00	2.65	0.45	2.05	6.31	0.99	0.00	0.49
Epidote	0.00	1.12	0.00	10.56	6.98	15.10	29.98	6.20
Chlorite	0.00	0.00	0.00	0.00	0.85	1.39	0.00	1.87

TABLE 6
Modal Analysis of Granodiorite Intrusion

T.S. No.	MNGD-1	MNGD-2	MNGD-3	MNGD-4	MNGD-5	MNGD-6	MNGD-7	MNGD-8
Plagioclase	55.24	43.14	45.86	34.65	35.68	37.10	21.90	28.93
Quartz	28.77	38.71	25.28	36.98	32.76	35.74	35.07	39.90
Orthoclase	3.05	6.61	8.93	13.77	13.34	15.77	33.77	17.84
Biotite	7.18	7.37	3.42	10.83	0.44	4.19	5.26	10.38
Hornblende	2.55	2.42	15.00	0.00	11.92	0.00	0.00	0.87
Chlorite	0.19	0.06	0.12	2.18	5.40	0.48	0.00	0.00
Epidote	0.44	0.59	0.64	0.38	0.06	0.00	0.00	0.00
Sphene	0.00	0.35	0.22	0.13	0.40	0.00	0.00	0.00
Magnetite	2.49	0.75	0.53	0.45	0.00	4.58	0.19	0.23
Apatite	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tourmaline	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00
Muscovite	0.00	0.00	0.00	0.00	0.00	2.14	3.81	1.85


DIR
CHUKIATAN
BIBIOR
DARORA
BRAWL
71° 45′
50′
55′
72° 00′
35° 15′
10′
5′
35° 0′
METRES 1000
KM
LEGEND
TONALITE COMPLEX
PYROXENE TONALITE
GRANO.DIORITE
MELA.LEUCO AMPHIBOLITE
QUARTZITES
CALCAREOUS SCHISTS
ALLUVIUM
VOLCANIC BODIES
GRANITE
MIXED ZONE
MIXED ZONE
HORNBLENDITE
QUARTZ.O.FELDSPATHIC DYKES
GARNET BEARING QUARTZ.O.FELDSPAR
APLITIC DYKE & PATCHES
PEGMATITE PATCH
DIP/STRIKE
FOLIATION
RIVER
STREAM
PROBABLE CONTACT
CITY / TOWN
Mapped by: Dr. M. Nawaz Chaudhry, Zafar-ul-Islam
Javed Akhtar, Sabih ur Rehman.
Drawn by: Masud minhas

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DISCOVERY OF LEPIDOLITE FROM SHINGUS AREA GILGIT PAKISTAN

Several pegmatite localities in Gilgit and Chitral were sampled in a bid to investigate their Lithium content.

There are a few unpublished previous reports about pink micas from northern area *i.e.* Ruby mines of Hunza area etc. Some of these samples were analysed and were found to be rose muscovite (Nawaz, Personal Comm.). Kazmi et-al. (1985) reported an occurrence of lepidolite from Bulechi area in Gilgit. However they did not produce supporting mineralogical or chemical data.

Mica samples of various colours were collected from Chitral areas and analysed for Lithium. It has been observed that pink, greenish, smoky and colourless micas from these pegmatites contain anomalously high Lithium but do no approach the Li_2O concentration to be classified as Lepidolite.

Garam Chashma area in Chitral contains micas with highly anomalous Li_2O content of the order of 0.45% Li_2O. Associated white micas within a single body of pegmatite clearly fall in two catagories in terms of their Lithium content.

(i) Lithium rich micas	...	0.45% Li_2O
(ii) Lithium poor micas	...	0.008% Li_2O

None of the muscovite analysed from this area approached lepidolite.

Similar sampling was carried out in Shingus (Gilgit) area. Once again associated micas gave two populations :

1. Lithium rich micas	...	4.24% Li_2O
2. Lithium poor micas	...	0.05% Li_2O

Lithium rich micas of shingus area can be classified as Lepidolote. Considering the similarity of Lithium distribution patterns in the two areas, it is concluded that the complex pegmatites in Chitral also hold a good potential for the discovery of Lithium minerals. It may be added that this is the first report in Pakistan wherein the occurrence of Lepidolite has been confirmed on the basis of chemical data.

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REFERENCE

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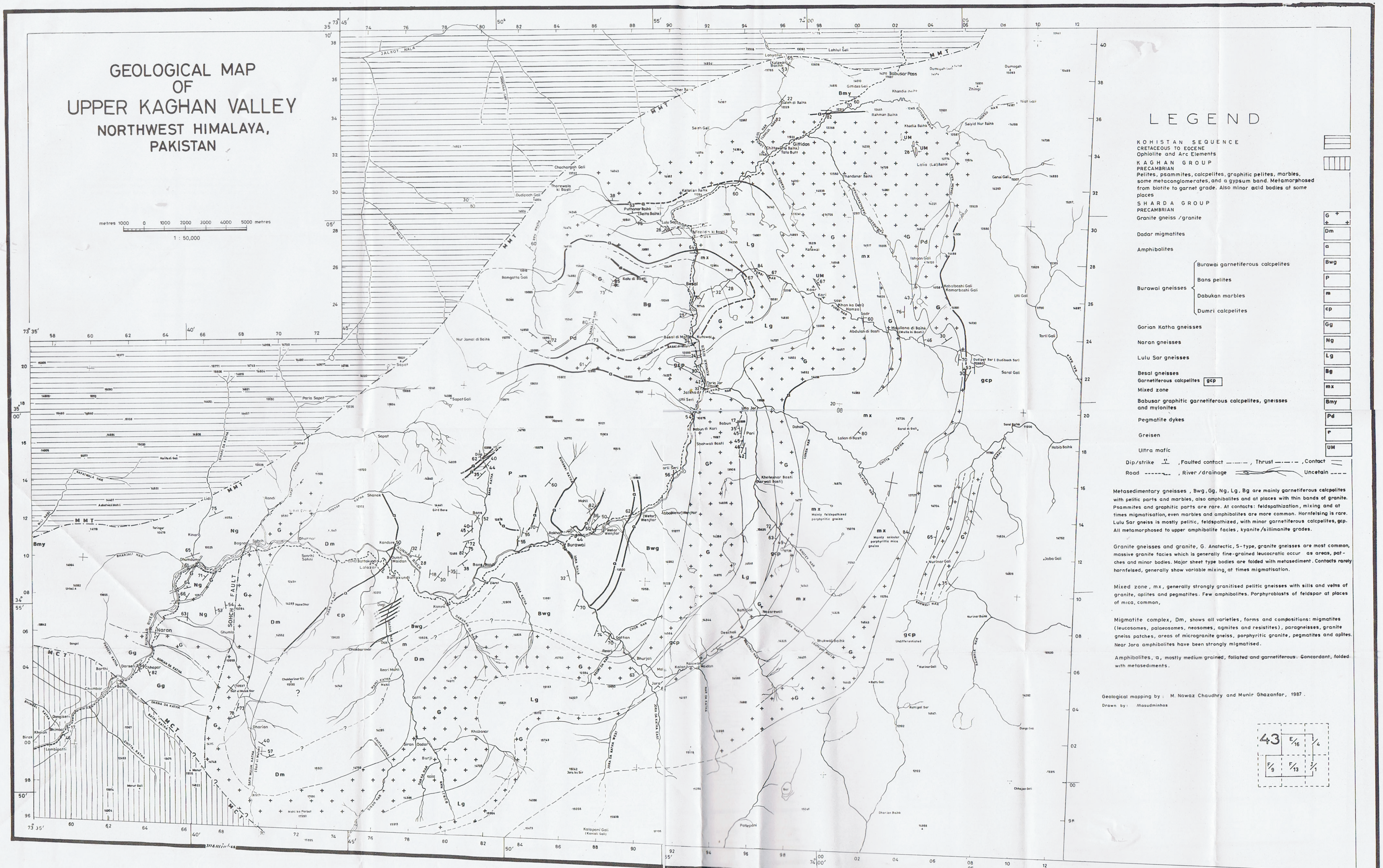
OBITUARY

Prof. Dr. H. MENSINK was born on 14-2-1927 in Hilten, West-Germany. As a schoolboy he collected fossils and rocks. After his Abitur he studied geology and paleontology at the Universities of Bonn, Tubingen and Graz, Austria. In 1958 he took his degree of doctor at Bonn with a thesis on the Jurassic rocks of the NW-Iberian Ranges of Spain, their sedimentology, biostratigraphy and paleogeography. Then he started his inaugural dissertation on the evolution of the gastropods within the isolated meteorite crater-lake of Steinheim/Albuch formed during the Miocene. He finalized that in 1968 at Bochum. In between he established the Institute of Paleontology at Bonn, stayed about 2 years at the University of Kabul, Afghanistan, teaching paleontology and investigating the Jurassic sequences and he helped to establish the Institute of Geology at Ruhr-University Bochum. Since 1968 he did a lot of research in different fields: In Iberia he focussed upon the development of Jurassic sedimentation, in Asturias he discovered the world's biggest footprints of dinosaurs. In Germany he worked on Mesozoic and Paleozoic outcrops in the Weser-and Wiehengebirge, within the Sauerland and in its southern parts. In 1985 a joint research with Pakistanis was initiated. During the whole period he never ceased to supervise the studies of a lot of students and graduates from Germany and from abroad. Scientific guests came to work with him from Romania, Netherlands, China and Pakistan. He died suddenly on 4-9-1988 at Bochum.


GEOLOGICAL MAP
OF
UPPER KAGHAN VALLEY
NORTHWEST HIMALAYA,
PAKISTAN
metres 1000 0 1000 2000 3000 4000 5000 metres
1 : 50,000
LEGEND
KOHISTAN SEQUENCE
CRETACEOUS TO EOCENE
Ophiolite and Arc Elements
KAGHAN GROUP
PRECAMBRIAN
Pelites, psammites, calcpelites, graphitic pelites, marbles, some metaconglomerates, and a gypsum band. Metamorphosed from biotite to garnet grade. Also minor acid bodies at some places
SHARDA GROUP
PRECAMBRIAN
Granite gneiss /granite G
Dadar migmatites Dm
Amphibolites a
Burawai gneisses
Burawai garnetiferous calcpelites Bwg
Bans pelites P
Dabukan marbles m
Dumri calcpelites cp
Gorian Katha gneisses Gg
Naran gneisses Ng
Lulu Sar gneisses Lg
Besal gneisses Bg
Garnetiferous calcpelites gcp
Mixed zone mx
Babusar graphitic garnetiferous calcpelites, gneisses and mylonites Bmy
Pegmatite dykes Pd
Greisen r
Ultra mafic UM
Dip/strike, Faulted contact, Thrust, Contact
Road, River/drainage, Uncetain
Metasedimentary gneisses, Bwg, Gg, Ng, Lg, Bg are mainly garnetiferous calcpelites with pelitic parts and marbles, also amphibolites and at places with thin bands of granite. Psammites and graphitic parts are rare. At contacts: feldspathization, mixing and at times migmatisation, even marbles and amphibolites are more common. Hornfelsing is rare. Lulu Sar gneiss is mostly pelitic, feldspathized, with minor garnetiferous calcpelites, gcp. All metamorphosed to upper amphibolite facies, kyanite/sillimanite grades.
Granite gneisses and granite, G. Anatectic, S-type, granite gneisses are most common, massive granite facies which is generally fine-grained leucocratic occur as areas, patches and minor bodies. Major sheet type bodies are folded with metasediment. Contacts rarely hornfelsed, generally show variable mixing, at times migmatisation.
Mixed zone, mx, generally strongly granitised pelitic gneisses with sills and veins of granite, aplites and pegmatites. Few amphibolites. Porphyroblasts of feldspar at places of mica, common,
Migmatite complex, Dm, shows all varieties, forms and compositions: migmatites (leucosomes, palaeosomes, neosomes, agmites and resistites), paragneisses, granite gneiss patches, areas of microgranite gneiss, porphyritic granite, pegmatites and aplites. Near Jora amphibolites have been strongly migmatised.
Amphibolites, a, mostly medium grained, foliated and garnetiferous. Concordant, folded with metasediments.
Geological mapping by : M. Nawaz Chaudhry and Munir Ghazanfar, 1987.
Drawn by: Masudminhas
43 E/16 I/4 F/9 F/13 J/1
MMT
MCT
SOHCH FAULT
Babusar Pass
Naran
Burawai
Besal
Lulu Sar
Gittidas
Jalkhad