The

GEOLOGICAL BULLETIN

of the

PUNJAB UNIVERSITY

Number Twelve

October, 1976

CONTENTS

GEOLOGY AND CLASSIFICATION OF ACID MINOR BODIES OF MANSEHRA AND BATGRAM AREA, HAZARA DIVISION, PAKISTAN

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Abstract: *Seven types of acid minor bodies have been identified in the Mansehra and Batgram region of Hazara division on the basis of their mineralogical composition and structures. The acid minor bodies classified are* (1) *albitites,* (2) *aplites,* (3) *simple pegmatites,* (4) *complex pegmatites,* (5) *albitized or replacement bodies,* (6) *composite bodies and* (7) *quartz veins. Subclasses of these minor bodies are made possible by detailed field and microscopic studies. They are distributed in the area in such a way that each type has a direct bearing on the site where it has crystallized. Three zones have been recognized* (*i*) *Interior-lateral zone* (1750-5500 *feet above sea level, containing albitites, albite-aplites/pegmatites, albite-(microcline)-aplites/pegmatites),* (*ii*) *interior-marginal zone* 5000 to 9000 *feet above sea level containing albite-microcline-aplites/pegmatites, microcline-albite-aplites/pegmatites and some complex pegmatites) and* (*iii*) *marginal exterior zone (over* 9000 *feet above sea level; containing mainly complex pegmatites). The acid minor bodies vary in thickness from less than a centimetre to over* 20 *metres and in length from one to* 100 *metres and occur as lensoid, lenticular branching, pinch and swell, patch, pod, ptygmatic, tabular bodies with regular and sharp boundaries and irregular to diffused contacts in a few cases. Internal structure of the bodies varies from one type to another. Zonation is perfect in some pegmatites. In other types the textural variation is marked from wall inwards.*

INTRODUCTION

Earlier workers described in detail the geology, structure and petrogenesis of the igneous and metamorphic complexes of the Mansehra and Batgram area. The present work gives a detailed account of the acid minor bodies. This is a part of the work carried out as a suppliment to studies on geochemistry and petrogenesis of the acid minor bodies. For the problem under consideration every nook and corner of the said area was covered to identify different acid minor rock types keeping in view their distribution, localization,size, shape, form, external structure, relationship with the host rocks and internal structure.

The area studied for the acid minor bodies lies between longitude 72° 56' to 73° 23' E and between latitude 34° 15' to 34° 45' N. The area is characterized by its contrasting topography (1750 to 10349 feet above sea level). Steep ridges form an arcuate structure and enclose large alluvium filled intermontane basins (Pakhli and Chhatar Plains).

Geologically, the area (Fig. 1) is a small portion of the northwest Himalayan mountain chain, and is composed of semi-pelitic to psammitic schists and quartzites which are associated with a plutonic complex of granitic rocks of varying types and of different ages. The granitic rocks have been grouped into the Hazara Granitic Complex (Shams, 1967). The various facies of the granites recognized by Shams (1967, 1969) and Ashraf (unpublished work) are (i) the Susalgali granite gneiss, a thoroughly gneissic variety covering about 85% of the granitic complex, (ii) the Mansehra granite—a porphyritic granitoid facies of the complex, (iii) the Hakle tourmaline granite—a later non-porphyritic granitoid with tourmaline as an essential mineral and (iv) the Chailsar microgranite which is perhaps later facies than the Hakle tourmaline granite and is more sodic. The metamorphics of the area have suffered Barrovian type regional metamorphism upto the kyanite grade (Shams, 1967).

Structurally, the area constitutes hard crystalline core of a m jor syntaxial loop of the north west Himalayas (Wadia, 1931). The general strike of this structure swings in an arcuate fashion (Shams, 1969). The Jhelum-Balakot syntaxial loop is close by to the east of this area. Further west, is located the Indus re-entrent. The strata show inwards dip at different inclinations in the area.

Previously no detailed account on the occurrence of acid minor boides has been given from the Mansehra and Batgram area. Anyhow, a litt e-information about a few occurrences, their mineralogy and chemistry have been given by Ali et al. (1964), Khan (1964), Offield et al. (1966), Rehman (1966), Sabri et al. (1967), Shams (1967, 1969), Faruqi et al. (1968) and Calkins et al. (1968). Recently Ashraf and Chaudhry (1974a, 1974b) have given a detailed account of the occurrence of pegmatites near Dadar, and quartz, quartz-ilmenite and quartz-kyanite veins from the Mansehra and Batgram area.

GEOLOGY OF THE ACID MINOR BODIES

The term minor bodies includes those rocks which were formed from the alkalic and volatile rich melts and hydrothermal solutions derived after the formation of the granitic complex. The acid minor bodies have been classified and differentiated on the basis of mineral composition, form, size, relationship with the enclosing rocks, internal and external structures. In the light of the above facts the acid minor bodies will be discussed under the following headings :

1. Types of the acid minor bodies
2. Distribution and localization
3. Size, shape, form, external structure and relationship with the enclosing rocks
4. Internal structure

1. Types of Acid Minor Bodies.

In the area under investigation, the major rock types were determined on the basis of their mineral composition. This classification is based on megascopic studies in the field, supplemented by the microscopic identification for the finer-grained minerals. All those rocks which are less than 1 to 2 mm in size are classified as fine-grained rocks (aplites and some albitites), 2 to 3 mm in size medium-grained bodies (albitites and aplites) and more than 3 to 4 mm in size as coarse grained bodies (pegmatitic-albitites or pegmatites). Classification of the seven major types of acid minor bodies is as follows :

1. Albitites
2. Aplites
3. Simple pegmatites
4. Complex pegmatites
5. Albitised or Replacement bodies
6. Composite bodies
7. Quartz bodies

These rock types are, in turn, further subdivided as follows :

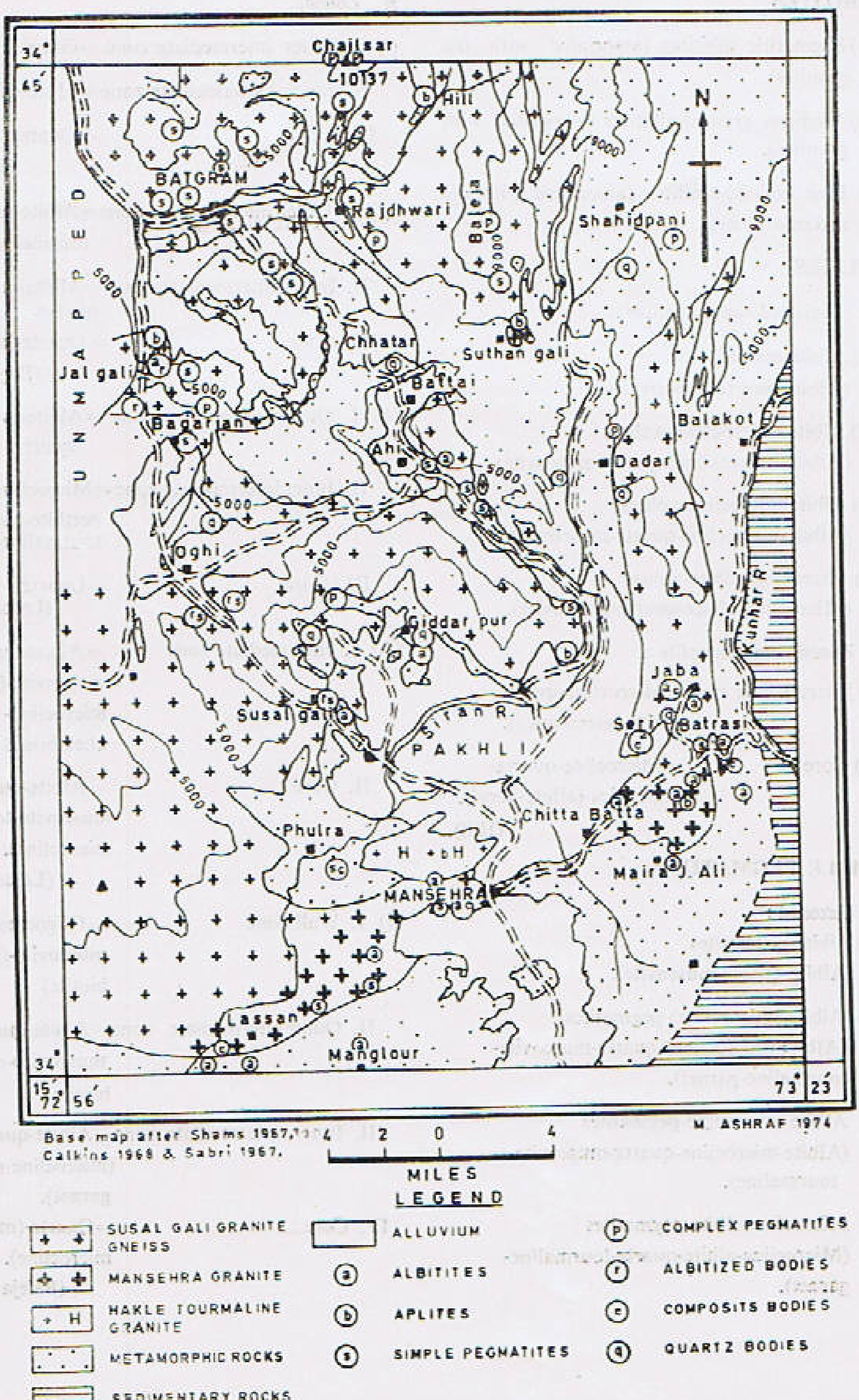


Fig. 1. Geological Map of Mansehra and Batgram Area showing Location and Distribution of Acid Minor Bodies.

1. ALBITITES

(*i*) Pegmatitic albitites (associated with the granites).

(*ii*) Medium grained-albitites (associated with granites).

(*iii*) Fine grained-albitites (associated with the metamorphics).

2. APLITES

A. **Unzoned simple aplites :**

(*i*) Albite-aplites
(Albite-quartz-muscovite)

(*ii*) Albite-(microcline)-aplites
(Albite-(microcline)-quartz-muscovite).

(*iii*) Albite-microcline-aplites
(Albite-microcline-quartz-muscovite)

(*iv*) Microcline-albite-aplites
(Microcline-albite-quartz-muscovite).

(B) Zoned complex aplite :

(*i*) Intermediate zone = Microcline-quartz albite-(green mica).

(*ii*) Core = Microcline-quartz-green mica-(albite-beryl).

(Hill).

3. SIMPLE PEGMATITES

A **Unzoned :**

(*i*) Albite-pegmatites
(Albite-quartz-muscovite).

(*ii*) Albite-(microcline)-pegmatites
(Albite-(microcline)-quartz-muscovite-tourmaline-garnet).

(*iii*) Albite-microcline-pegmatites
(Albite-microcline-quartz-muscovite-tourmaline).

(*iv*) Microcline-albite-pegmatites
(Microcline-albite-quartz-tourmaline-garnet).

B Zoned.

(*i*) I. Outer intermediate zone = Graphic granite
II. Inner intermediate zone = Muscovite-quartz.
III. Core = Quartz
(Batgram).

(*ii*) I. Outer intermediate zone = Albite-muscovite-tourmaline-quartz.
II. Inner intermediate zone = Albite-muscovite-quartz.
III. Core = Quartz-(albite).
(Bagarian)

(*iii*) I. Outer intermediate zone = Albite-muscovite-quartz.
II. Inner intermediate zone = Microcline perthite-muscovite-tourmaline-quartz.
III. Core = Quartz
(Lassan East).

(*iv*) I. Intermediate zone = Albite-quartz muscovite-(biotite-microcline-chessboard albite).
II. Core = Albite-quartz-muscovite-tourmaline-microcline).
(Lassan East).

(*v*) I. Wall zone = Oligoclase-quartz-muscovite-(garnet-biotite)
II. Outer intermediate zone = Albite-quartz-muscovite-microcline-biotite).
III. Inner intermediate zone = Albite-quartz-(microcline-muscovite-garnet).
IV. Core = Quartz-(muscovite-microcline).
(Baleja South).

(*iv*) I. Intermediate zone = Microcline-albite-quartz-tourmaline.

II. Core = Tourmaline-quartz. (Batgram Northeast).

4. COMPLEX PEGMATITES

A. Unzoned :

(*i*) Microcline perthite-albite-quartz-muscovite (tourmaline-beryl).

(Baleja, Chailsar)

B. Zoned Symmetrical :

(*i*) **Pegmatitic stage :**

I. Border+wall zone = Albite-microcline-quartz-muscovite-(tourmaline).

II. Outer intermediate zone = Microcline perthite-muscovite-quartz.

III. Inner intermediate zone = Microcline perthite-quartz-(muscovite-garnet).

IV. Core = Quartz-(garnet-muscovite).

Replacement stage = Muscovite-beryl-tourmaline.

Hydrothermal stage = Kaolinite.

(Baleja).

(*ii*) **Pegmatitic stage :**

I. Border+wall zone = Albite-quartz-muscovite-(tourmaline).

II. Intermediate zone = Microcline perthite-muscovite-tourmaline-granet.

III. Core = Quartz.

Pneumatolytic stage = Cleavelandite-muscovite-beryl-tourmaline.

Hydrothermal stage = Kaolinite-sericite.

(Dadar).

(*iii*) **Pegmatitic stage :**

I. Border+wall zone = Albite-quartz-(tourmaline-muscovite).

II. Intermediate zone = Microcline perthite-(muscovite).

III. Core = Quartz.

Pneumatolytic stage = Beryl

Hydrothermal stage = Kaolinite-sericite.

(Rajdhawari).

C. Partially Zoned Symmetrical :

(*i*) **Pegmatitic stage :**

I. Border+wall zone = Albite-quartz-(muscovite-tourmaline).

Intermediate zone = Microcline perthite-quartz-(muscovite).

III. Core = Microcline perthite-quartz.

Pneumatolytic stage = Beryl-cleavelandite tourmaline.

Hydrothermal stage = Kaolinite-sericite.

(Chailsar).

(*ii*) **Pegmatitic stage** :

I.	Border+wall zone (western)	=Albite-microcline perthite-muscovite-(biotite).
II.	Intermediate zone	=Microcline perthite-albite-quartz-(muscovite-biotite).
III.	Core	=Microcline perthite-smoky quartz-(albite).

Pneum tolytic stage =Beryl-cleavelandite-tourmaline.

Hydrothermal stage =Kaolinite-sericite.

(Chailsar).

D. Zoned Asymmetrical :

(*i*) **Pegmatitic stage** :

I.	Border+wall zone (western)	=Albite-quartz-tourmaline muscovite.
II.	Outer intermediate zone	=Microcline perthite-(muscovite).
III.	Inner intermediate zone	=Microcline perthite-(muscovite-quartz).
IV.	Core	=Quartz.
V.	Inner Intermediate zone	=Albite-quartz-(muscovite).
VI.	Outer intermediate zone	=Graphic granite.
VII.	Border+wall zone (eastern)	=Oligoclase-muscovite.

Pneumatolytic stage =Beryl-columbite-samarskite-muscovite-garnet-tourmaline-microcline perthite.

Hydrothermal stage =Kaolinite-sericite

(Bagarian).

(*ii*) **Pegmatitic stage** :

I.	Border+wall zone	=Albite-quartz-(muscovite).
II.	Outer intermediate zone	=Microcline perthite.
III.	Inner intermediate zone	=Microcline perthite-quartz-(muscovite).
IV.	Core	=Quartz.

Pneumatolytic stage =Beryl-blibinite-tourmaline-garnet-muscovite.

Hydrothermal stage =Kaolinite-sericite

(Rajdhawari).

5. ALBITIZED OR REPLACEMENT BODIES

(*i*) Oligoclase- quartz-muscovite-biotite).

(Oghi South).

(*ii*) Albite-quartz-(muscovite).

(Jalgali).

(*iii*) Albite-quartz-(muscovite-tourmaline)

(Jalgali).

(*iv*) Albite-quartz-(biotite-sphene-apatite).

(Susalgali).

(*v*) Albite-(quartz-muscovite-chlorite--apatite)

(Susalgali).

6. COMPOSITE BODIES

(*i*) Pegmatitic-albite, albite-aplite, albite-microcline-aplite/pegmatite.

(Lassan).

(*ii*) Fine to medium grained-albitite, layered-albitite, layered-aplite, albite-pegmatite.

(Batrasi R.H.).

(*iii*) Pegmatitic-albitite, medium-grained-albitite.

(Batrasi, Mansehra).

(*iv*) Pegmatitic-albitite, medium grained-albitite, albite-aplite.

(Mansehra).

(*v*) Pegmatitic-albitite, medium grained-albitite, albite-aplite, albite-(microcline)-aplite. (Seri).

(*vi*) Pegmatitic-albitite, medium grained-albitite, albite-(microcline)-aplite.

(Jaba).

(*vii*) Albite-(microcline)-pegmatite/aplite, fine grained and pegmatitic-albitite (xenoliths).

(Phulra).

7. QUARTZ BODIES

(*i*) Quartz

(Chitta Batta).

(*ii*) Quartz-ilmenite

(Giddarpur).

(*iii*) Quartz-kyanite-(muscovite-chlorite-biotite).

(Shahidpani).

2. DISTRIBUTION AND LOCALIZATION

Late magmatic acid minor bodies have intruded the Hazara granitic complex and the metamorphics. They are distributed in the area (Fig. 1) in such a way that they have direct bearing on the place where they have got crystallized. Heinrich (1963) recognized three distinct zones for the formation of pegmatites ; they are interior, marginal and exterior. In the area under investigation three zones have been recognized by the present workers according to the height above sea level as (I) interior-lateral zone between 1750 to 5500 feet above sea level (ii) interior-marginal zone between 5000 to 9000 feet above sea level and (iii) marginal-exterior zone over 9000 feet above sea level. Albitites, albite-aplites/pegmatites, albite-(microcline)-aplites/pegmatites are characteristic bodies of interior-lateral zone. Albite-microcline, microcline-albite-aplites and pegmatites are dominantly present in the interior-marginal zone where simple and complex pegmatites both unzoned and zoned are also present. But in the marginal exterior zone dominantly complex pegmatites have been observed. Therefore, the distribution and localization of these acid minor bodies are discussed here under accordingly.

(*i*) *Albitite*: : All medium to coarse-grained albitites are present in the granites while the fine-grained varieties of albitites are met within the metamorphics in the interior-lateral zone mostly along the foliation plane and rarely along the joints. The albitites are mainly present within the Mansehra granite and the associated metamorphics while there are scanty bodies associated with the Susalgali granite geneiss around Ahl,Giddarpur (South), Jalgali and Susalgali. Some of the albitites occur as comopsite bodies, they are pegmatitic-albitite, medium-grained-albitite and albite-aplite (Seri, Mansehra), and also as composite bodies with albite aplite, albite-microcline-aplite and pegmatites (Lassan). The albitite bodies associated with Mansehra granite and the metamorphics are concentrated near the following localities : Seri, Batrasi, Jaba, Chitta Batta (NE), Maira, J. Ali, Mansehra, Lassan and Manglour.

(*ii*) *Aplite*. : They occur as independent and composite bodies which may be massive, sheared, layered and ptygmatic, mostly associated with the granites. Their occurrence in the metamorphics is rare, thin and poorly developed bodies are generally present near the contact. The albite-aplites are present only in the southern most portion of the area in the lower interior-lateral zone where microcline bearing aplites are rare. The albite-aplites occur near Seri, Batrasi, Jaba, Mansehra and Shaikhabad. The minor microcline bearing aplites occur in interior-lateral zone near Seri, Jaba and Suthangali. The microcline rich aplites occur in the same zone near Jalgali, Bagarian, Phulra and Lassan. Only one complex zoned aplite was found in the interior-marginal zone near Hill in the metamorphics.

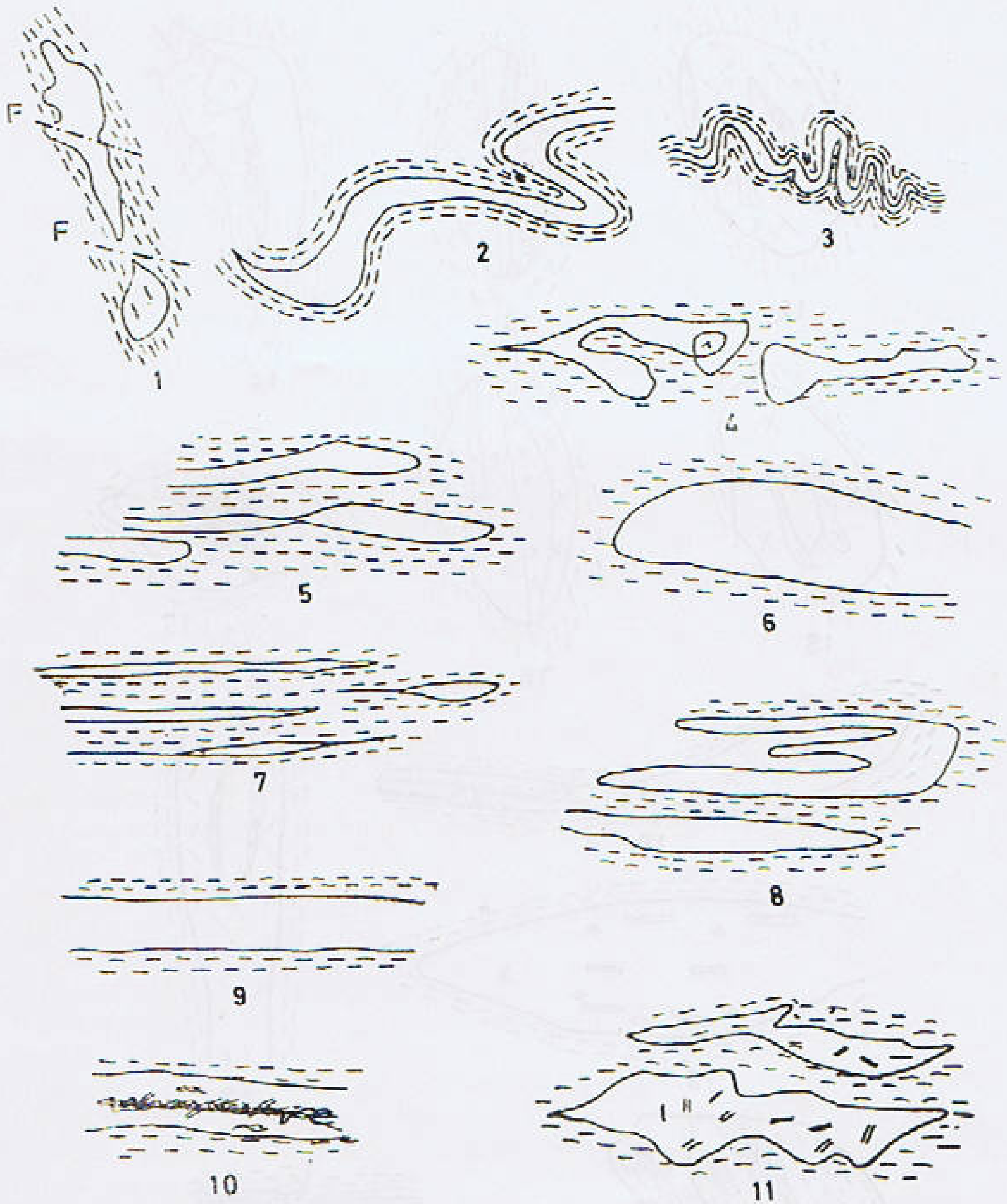
(*iii*) *Simple pegmatites*: They are most extensively developed all over the area from a stringer to over 50 feet thick bodies. Unzoned simple pegmatites are abundantly present but zoned simple pegmatites are also not uncommon in the granites as well as in the metamorphics. The albite, albite (microcline)-and albite-microcline-pegmatites are very common in the Susalgali granite gneiss in the interior-lateral to marginal-exterior zone. In Mansehra granite (interior-lateral zone) the pegmatites are less common it rather has dominant albite-pegmatite and sometimes albite-(microcline)- pegmatite types. The pegmatites associated with Susalgali granite gneiss occur near Baleja, Batgram, Rajdhawari, Bagarian, Jalgali, Ahl, Oghi(NE), Oghi (South), Dadar, Battal-Batgram Road, Phulra and Susalgali etc. The pegmatites associated with Mansehra granite occur near Seri, Batrasi, Mansehra, Lassan, etc.

Simple small pod like bodies (Fig. 17) are widely developed in Susalgali granite gneiss in the area northwest of Batgram. The same type of bodies are met near Oghi in the Susalgali granite gneiss and a few occur in metamorphics near Rajdhwari.

(*iv*) *Complex pegmatites* : They are not so extensively developed as the simple pegmatites. They are emplaced in both Susalgali granite gneiss and the associated metamorphics as interior-marginal and marginal-exterior bodies. The pegmatites of Bagarian (Fig. 13), Rajdhawari (Fig. 4), Hawagali and Dadar (Fig. 12) are interior-marginal while those occurring near Baleja. Chailsar and Shahidpani are marginal exterior. Most of these pegmatites are completely zoned both symmetrically and asymmetrically. The unzoned varieties are also found in the same localities.

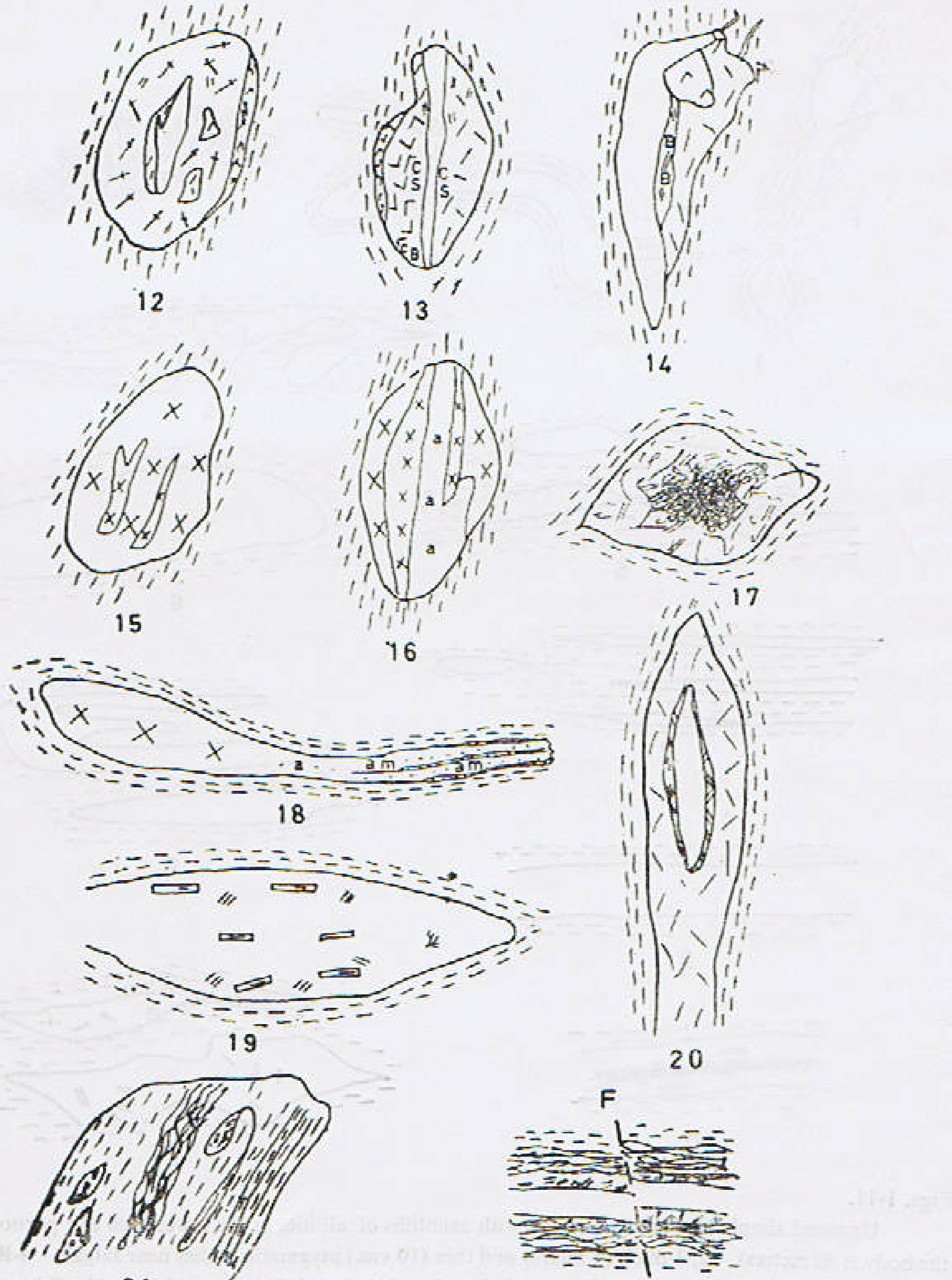
(*v*) *Replacement bodies* : They occur usually in the Susalgali granite gneiss as irregular to pseudo-ptygmatic bodies (Fig. 4.). It is seen that the replacement is volume by volume and the original structure of the granite still persists. Apart from relict structure of the rock and dominant change in mineralogy biotite persists as golden to dark coloured flakes. Mostly there is sodium metasomatism of the granite gneiss but at places boron metasomatism also occurred as another phase to give rise to tourmaline. The replacement bodies are dominantly present in the area around Oghi (South) Jalgali, Bagarian and Susalgali at a height around 4000 to 6000 feet in the upper interior-lateral zone to lower interior marginal zone.

(*vi*) *Composite bodies* : They occur mostly in the Mansehra granite and the associated metamorphics in the interior-lateral zone. The pegmatitic-albitite, medium grained-albitite and aplite type composite bodies (Fig. 15, 16) occur near Seri, Jaba, Mansehra and Batrasi. The pegmatitic-albitite, albite-aplite, and albite-microcline-aplite pegmatite type bodies occur south of Lassan on a new road cut. The layered-albitite, layered-aplite, and albite-pegmatite type bodies (Fig. 21) occur just south of Batrasi rest house (R.H.).



Figs. 1-11.

Unzoned simple lenticular pegmatite with xenoliths of albitite in the lower bleb like portion (length of the body is 40 metres). 2, 3-thick (1 metre) and thin (10 cm.) ptygmatic bodies near Jalgali. 4-Replacement body 15 to 20 cm in width and 3 to 5 metres in length. 5, 6, 7, 8, 9-Tabular and lensoid albitite and aplite bodies, their sizes vary from stringer to quite sizeable bodies (upto 20 metres thick) having sharp and concordant behaviour. 10-Zoned tabular pegmatite with distinct core of tourmaline and quartz (size 10 cm × 100 metres). 11-Simple unzoned lenticular pegmatite (50 cm to 1 metres wide and 2 to 3 metres long).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(*vii*) *Quartz veins* : They are very widespread in the area both in the granites and the metamorphics. They occur as stringer like veins, in tension gashes, in joints and along the foliation plane mostly in the interior-lateral zone. One of the most important quartz veins occur, near Chitta Batta. This vein is quite extensive and is present in the Mansehra granite, upto 10.5 metres thick body on the road cut, which after about half a kilometre enters into the metamorphics where it thins out and branches off into two veins almost parallel to each other. Other quartz veins occur near Giddarpur, Jaba, Battal, Dadar and Mansehra.

The ilmenite bearing quartz veins are present in the metamorphics near Giddarpur and Oghi (NE).

The quartz-kyanite pegmatitic veins (Fig. 19) occur in the metamorphics generally along the foliation planes near Shahidpani, Giddarpur (West) etc.

3. SIZE, SHAPE, FORM, EXTERNAL STRUCTURE AND RELATIONSHIP WITH THE ENCLOSING ROCKS

The acid minor bodies vary in thickness from less than a centimetre to over 20 metres as lensoid, lenticular branching, pinch and swell, patches, pods, ptygmatic, tabular etc., bodies usually with regular and sharp boundaries but in a few cases irregular to diffused contacts. The acid minor bodies and the related rocks, could be reviewed in the light of classification suggested by Ginsburg (1928), Jahns (1955) and Edelman (1968). In the light of their classification the acid minor bodies are discussed separately as under :

(*i*) Almost all types of *albitite and aplite* bodies present in the area are tabular and lensoid (Figs. 5, 6, 7, 9) as they are formed along the foliaton plane of the granites and the metamorphics. The foliation plane of the major bodies is less than 25° to 80° and even exactly 90° in some cases. Some of the bodies are dyke like. The stringer types are quite common in the granitic rocks while streak types occur in the metamorphics particularly in the quartzites. The stringers are seen to occur along as well as across the joints. The streaks are also seen oriented almost parallel to the foliation of quartzite. The usual sizes of albitite and aplite bodies are generally between 1.5 to 10 metres wide and at places, are exposed for some five to seventy meters in length but full length of the bodies is not exposed in many cases due to cover of alluvium. Most of the bodies emplaced in the granites are

Figs. 12-22.

12-Dadar complex zoned pegmatite, about 6 metres long (wall + border zone on the left, outer intermediate zone with relicts of microcline, inner intermediate zone of microcline and core of quartz). 13-Bagarian asymmetric complex zoned pegmatite about 75 metres long with thin wall + border zone, outer intermediate zones, inner intermediate zones, quartz core and C = columbite, S = samarskite B = beryl, ‖ = muscovite. 14-Rajdhawari complex asymmetric zoned pegmatite about 80 metres long with outer intermediate, inner intermediate zone and quartz core. 15,16-Composite pegmatitic-albitite, medium-grained-albitite, or albite-aplite (sizes of the bodies vary from 12 to 20 metres by 8 to 10 metres). 17-Simple pod pegmatite near Batgram (size 10 mm. to 15cm). 18-Composite pegmatitic-albitite, albite-aplite, albite-microcline-aplite pegmatite. 19-Lensoid quartz-kyanite body about 1 × 3 metres in size. 20-Lensoid to lenticular simple zoned pegmatite near Batgram, with outer, inner intermediate zones and quartz core about 5 × 25 metres in size. 21-Composite layered albitized-layered-aplite and albite-pegmatite body near Batrasi R.H., its size is 60 × 100 metres. 22-Tabular zoned simple pegmatite near Batgram showing different zones, its outer intermediate zone is sheared and the body is faulted.

concordant and their contact is very sharp as shown by fairly large number of albititic and aplitic bodies. Slight chilling is also observed at places in the albitites. The fine-grained albitites which are emplaced in the metamorphics show gradational contact as seen in the bodies near Manglour, Lassan, Batrasi and Giddarpur. At some places like Jaba and Seri due to much shearing and crushing around the contacts of albitite and granite a sort of gradation into each other is seen. On the whole albitites occur as massive, compact, layered, banded, sheared (Fig. 21), and well-jointed bodies. Both albitites and aplites are sometimes closely associated, showing either a gradation or a sharp contact as seen near Seri, Jaba and Mansehra. Those albitite bodies which have sharp contact with the host rocks show fairly uniform composition right from the contact towards centre because there is hardly any exchange of material across the contact. The irregular shape of albitites in the metamorphics is due to sodium metasomatism of the host rock just around them and diminishes away. The sheared contacts of some albitites and aplites particularly in granites show that the intrusion was forceful and the exchange of material was negligible. The contacts in composite pegmatitic-albitite, medium-grained-albitite and albite-aplite are usually very sharp (Fig. 16) as the grain size suddenly changes from coarse to medium e.g., Seri, Jaba, Batrasi and Mansehra.

(*ii*) *The simple and complex pegmatites* occur along the foliation planes of the host rocks and the joints. These pegmatites show a spectacular variety of forms such as tabular Figs. 10,22), lensoid, lenticular (Fig. 20), branching, pod (Fig. 17), pinch and swell and ptygmatic (Fig. 3) etc. They occur as individual stringers and swarms, particularly the simple pegmatites occur as swarms ranging in size from stringer to sizable bodies. They commonly occur as concordant and discordant bodies. Some bodies may be concordant at one end and discordant at the other.

The simple pegmatites are both unzoned (Figs. 1, 11) and zoned (Figs. 12, 22). The latter type is quite abundant in the northern area. The tabular, lensoid and lenticular bodies occur mostly in the larger sizes, but the pod, pinch and swell and ptygmatic types are usually of small sizes. The pod pegmatites particularly occur as round to oval shaped bodies from less than 10 mm to around 10 to 15 cm. The ptygmatic bodies occur as small as 5 mm thick and very occasionally thicken upto 2 metres. The pinch and swell bodies have lengths of 10 to 20 metres. The tabular, lensoid, lenticular and branching type bodies are 0.4 to 1.5 metres thick but 1.5 to 3 metres thick bodies are usually common, even the thicker bodies 16 to 20 metres are not uncommon. Their length as recorded varies from tens to more than 100 to 150 metres. Most of these pegmatites show internal foliation. The simple pegmatites on Baffa-Battal road and Ahl are mostly massive or slightly foliated bodies which are sometimes crushed. The simple pegmatites around Mansehra are mostly bimineralic as seen in the handspecimens. These are usually associated with aplite or albitite. The zoned simple pegmatites occur from 4 cm to 3 metres thick bodies usually developing two to three zones with a length ranging from 8 to more than 50 metres.

(*iii*) *The complex pegmatites* occur mostly as zoned (Figs. 12, 13, 14) bodies with a few unzoned and partially zoned bodies. At most places the complex bodies occur in groups of one to three and swarms are only met in the Chailsar area where more than fifteen bodies have been recorded in about one square kilometre. Generally the complex pegmatites are 1.5 to 30 metres wide, but those occurring in Chailsar are from a stringer to mostly 1 to 5 metres wide and about 17 to 80 metres long. The Chailsar pegmatites are usually tabular and lensoid bodies. Their contact with the host rocks is usually sharp. The two asymmetric complex zoned pegmatites near Bagarian and Rajdhawari are the largest so far recorded in the area as their dimensions are 30 × 75 metres and 20 × 80 metres respectively. The Bagarian pegmatite (Fig. 13) is doubly convex lens shaped body. The Rajdhawari pegmatite is a lenticular body and branches into stringers (Fig. 14). The Dadar pegmatites are zoned, as shown in Fig. 12, and have sharp contact with the surrounding metamorphics. Some of them are tabular and pipe-shaped. The unzoned pegmatites are generally 7 to 11 × 90 metres in size with the same type of shape and form as found in the other pegmatites.

(*iv*) *The replacement bodies* are pseudoptygmatic, irregular (Fig. 4) and tabular with sharp to diffused outlines. The replacement of the granite is usually irregular and the contacts are therefore, diffused. The pseudoptygmatic appearance of some bodies is due to contemporaneous ptygmatic folding of the surrounding rocks and the the ptygmatic bodies. These ptygmatic bodies are 2 to 5 mm to over 2 metres thick and may be upto 20 metres long in some cases. Particularly interesting replacement bodies have tabular shape which are usually 1.5 to 6 metres into 10 to 20 metres in size.

(*v*) *The composite bodies* are the combinations of tabular to lensoid bodies. The Lassan composite body is 15 to 20 cm thick as pegmatites and aplites, tabular and sheet like and 1.15 metres thick as lensoid albitite (Fig. 18). The Batrasi composite body Fig. 21) is tabular layered and branching type. It is 60 × 100 metres in size near the top and is not fully exposed all along its length due to being covered by alluvium and debris.

(*vi*) *The quartz veins* occur either as simple quartz bodies or as quartz-ilmenite and quartz-kyanite-muscovite-chlorite bodies. They are present as veins and lenses in the granites and in the metamorphics. They have always very sharp contact with the host rocks. Usually the quartz veins and lenses are from stringer to 2 metres thick. But the Chitta Batta body is quite sizeable 10.5 metres wide near this village and about one kilometre long and branches into two bodies while entering the metamorphics. The quartz-kyanite-muscovite-chlorite bodies are discontinuous to 1.5 metres wide and some 2.5 to 7 metres in length lensoid bodies (Fig. 19). The quartz-ilmenite bodies occur as lensoid to tabular veins and lenses, about 1.5 to 2 metres wide and about 3 to 7 metres in length.

4. INTERNAL STRUCTURE

The internal structure of the acid minor bodies varies from one type to another. Zonation is perfectly developed in the pegmatites where mineralogical changes from one zone to another are pronounced. In some other type of bodies the textural variation is marked while zonation is well developed to poor. Most of the apparently unzoned bodies are texturally different from the walls inward.

(*i*) *Albitites* : Most of the albitite bodies are unzoned where the mineral composition and texture from wall inward remains unchanged except minor secondary variations. In the albitite bodies which are emplaced in the metamorphics, an irregular border + wall zone is formed due to sodium metasomatism and a uniform zone is present inside. These albitite bodies are present near Maira J. Ali, Giddarpur, Jaba, Manglour, etc. The border + wall zone (about 10 to 35 cm thick) in these bodies is very fine-grained with some coarser grains of the metamorphics while the main body is usually 1.75 to 7 metres thick and is fine to extremely fine-grained. The albitites do show zonation (Figs. 15, 16) in those bodies which are emplaced in the granites. In the bodies of Seri, Mansehra and Batrasi a zone of coarse-grained (pegmatitic) albitite is developed from the wall inward and becomes medium-grained having sharp contact with the former (Fig 15). This sort of zonation is tabular to lensoid in some cases and concentric to irregular in others. These bodies are symmetrical as well as asymmetrical and sometimes composite with aplite (Fig. 16) or with aplite and pegmatite. The thickness of the different zones is from 1.5 to 3 metres. There is no evidence of internal replacement of minerals except the development of chlorite along the sheared portions.

(*ii*) *Aplites* in the area are completely unzoned and have uniform composition everywhere in the body. They have minor albititic lenses or pods at places. Sometimes the aplites also enclose the pegmatitic pods having mineral compostion albite, quartz and muscovite.

(*iii*) *Simple pegmatites* are both unzoned and zoned (Fig. 9). The simple unzoned pegmatites occurring in the interior-lateral zone are mostly compact, massive and are non-sheared. But many larger unzoned pegmatites are sheared and foliated (Fig. 22) and occur in the upper interior-lateral zone to interior-marginal zone. They do show a fine-grained border and wall zone texturally quite different from the main pegmatites. The main pegmatite bodies are usually sheared and foliated in the form of bands forming a sort of uniform texture possibly due to the readjustment which took place amongst the minerals during the shearing thus feldspar, quartz and tourmaline are evenly distributed in most bodies. The fabric of these rocks is coarse to very coarse-grained, where the coarsest minerals have been rounded off and in most cases fine to medium-grained materials have been filled in between. The shape of these bands is usually lenticular or tabular and their thickness varies from 3 to 20 cm or more. This type of pegmatite occur dominantly near Oghi, Jalgali, Batgram and Phulra.

The simple zoned pegmatites have two to four well developed zones. The grain size in different zones of these pegmatites varies widely. In these pegmatites if the wall and border zones are present they are fine to medium-grained and foliated as the mica flakes align themselves parallel to the contact. The border + wall zones are usually less than 1 to 5 mm in thickness and are discontinuous. In the border and wall zones the minerals are usually quartz, feldspars and muscovite. In the succeeding zones the grain size becomes coarse to very coarse. In thin zoned pegmatites like those of Lassan (NE) and Baleja (South) the grain size varies between 2 to 15mm and may increase locally. The Batgram and Bagarian pegmatites have very coarse-grained intermediate zones. In one of the Batgram pegmatites (Fig. 20) the individual crystal size may reach 10 to 36 cm or more in the intermediate zone. The zones in relation to one another have sometimes sharp to slightly irregular and sometimes quite undulatory contacts. The shape of the zones is tabular, lensoid and branching type. In the pod pegmatites of Batgram (Fig. 17) the tourmaline and quartz concentrate in the centre like some thin pegmatites of Lassan (NE). Replacement is not very common in these pegmatites, only tourmalinization of certain zones takes place.

(*iv*) *Mineralogically complex pegmatites* are the most well developed and thick zoned bodies (Figs. 12, 13, 14). In all the pegmatites the zones are quite distinct and measureable in metres. These zoned pegmatites occur as asymmetric and symmetric, partially to fully zoned bodies. Almost all of them show pneumatolytic to hydrothermal modification of the zones. Nearly three to six zones have been recognized in these bodies, e.g. Bagarian pegmatite has six zones (Fig. 13) ; Rajdhawari (Fig. 14), Hawagali and Chailsar have three and Baleja and Dadar (Fig. 12) have four zones. Their complete details are given in the preceding pages.

(*v*) *The replacement bodies* as mentioned-previously are present in the Susalgali granite gneiss only. There is relict gneissic internal textural arrangement in them. They are mostly of uniform composition within the bodies as compared to their crenulated boundaries which have definitely the mineral composition approaching the gneiss.

(*vi*) *Composite bodies* The internal structure of the albititic composite bodies has been mentioned under albitites, whereas the internal structure of the composite albitite-aplite and pegmatites near Lassan is worth mentioning here. The albitite of this body on its border is albite-aplitic and becomes pegmatitic inward which laterally changes into tourmaline bearing albite-aplite (Fig, 18, a) and then in a further lateral extension it becomes a zoned pegmatite in the centre of aplite (Fig. 18, am) and unzoned pegmatite on the upper and lower margins. The texture of these bodies is very contrasting as observed in the field.

(*vii*) *Quartz veins* occur as uniform bodies throughout their width and breadth. The quartz-ilmenite veins are similar to quartz veins with non-uniform distribution of ilmenite in the quartz bodies. In the quartz-kyanite-muscovite-chlorite bodies-there is partial development of the zones. In the outer zone there are quartz-kyanite-muscovite and chlorite relatively more than the inner zone where quartz is much more abundant (Fig. 19).

ACKNOWLEDGEMENT

The authors are thankful to Mr. Waheed ud Din Ahmad, Director Geological Survey of Pakistan for critical review of the manuscript. Thanks are also due to Dr. F.A. Faruqi, Head of Research Division PCSIR Laboratories, Lahore for arranging the field expenses. They cannot forget the cooperation sought from M/s Rafiq Shah, Aurang Zeb Khan, Sultan Ahmad, Col. Yar Mohammad, Sardar Shah, Mir Zaman and M. Ibrahim of Mansehra and Batgarm areas in locating some of the deposits. Their thanks also go to D.L. Rossman of the U.S.G.S. with whom some discussion in the early stages of this work were held.

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(Manuscript received January, 1975)

GEOLOGY AND PETROLOGY OF MALAKAND AND A PART OF DIR (TOPOSHEET 38 N/14)

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Abstract : *A geological map of a part of the Malakand Agency and of Southern Dir District covered by the toposheet No. 38 N/14 is presented. Succession of rocks of the area has been worked out. Detailed petrography of all the major units of the area is described. Six modal analyses of the pelitic rocks, fifteen modal analyses of the calcareous rocks including marbles, six modal analyses of the amphibolites, thirteen modal analyses of the Malakand granite gneiss and twenty seven modal analyses of the Malakand granite are presented. Twelve chemical analyses of the granites were done. Petrogenesis of the rocks of the area is presented.*

INTRODUCTION

The area studied is covered by toposheet No. 38N/14. The area lies in the Malakand Agency and the Southern Dir District. Malakand is the headquarter of the agency. The area is traversed by a metalled road and a number of unmetalled roads. A small part of the area was mapped earlier by Chaudhry et al. (1974). The present work involved a total field work of over four months followed by laboratory studies and subsequent field checking of about three weeks.

Previous Work : Tipper (1906) described the rocks penetrated by the Malakand tunnel, as mica schists on either side of the tunnel and a uniform granite in the middle. Hyden (1915) described the rocks between Dargai and Malakand as chiefly the hornblendic schists, much foliated, crushed and full of quartz veins. According to him, these rocks are replaced by granite on road to Chakdara. According to Gulzar (1964) the Malakand granite is surrounded by schistose rocks which include garnet mica schist with bands of pure coarse-grained-limestone and hornblendite to the east and mica gneiss in the southwest and north. The intrusive body contains xenoliths and inclusions of mica calcareous schists.

Saleemullah and Rizvi (1964) of Punjab University after geophysical survey found a sharp anomaly near Laliband which lead them to conclude the emplacement of granite as being laccolithic.

A part of the Malakand Agency was mapped and studied by Chaudhry et al. (1974).

REGIONAL GEOLOGY

Following regional geological set up of the area can be formed from the available informations.

The area falls in the southern part of Attock-Hazara Area of Pakistan folded arc. The area is most probably a part of the external flank of the Himalayan meganticlinorium. It is composed of Attock Slates of Pre-cambrian age, with a few limestone and sandstone intercalations at places. The area is cut by a number of intrusions (Wadia, 1935 ; Sokolov and Shah 1966). Bakr and Jackson (1964) in their geological map of Pakistan have marked the area occupied by the Attock Slates as extending from far beyond east of Malakand upto Landi Kotal towards west. Ahmed (1969) believes that the slates extend far into Afghanistan. If the above authors are correct then the Malakand metamorphics are high grade metamorphic facies of the Attock Slates.

Towards the north is the amphibolite and basic complex (Chaudhry et al. 1974b) and towards south extend metamorphics (chlorite-biotite-muscovite schists, quartzites and garnet-mica schists) and ultramafic complex of Harichand (Uppal 1972). The complex is composed of large bodies of harzburgite with small outcrops of dunite rock. These bodies are partially surrounded by peridotite rocks.

To the north lie ortho amphibolites and para amphibolites (Chaudhry et al., 1974) and to north east is the hornblendic group (Martin et al., 1962). They are intruded by intermediate and basic complex (Chaudhry et al., 1974 b). Further north occur Cretaceous and Eocene metasedimentary rocks (pelitic, calcareous, marly and quartzitic) which are intruded by later granites, granodiorites and diorites. Near the Lowari pass occur granite gneiss and quartzitic and pelitic rocks. In the follwoing is presented a generalised sequence of rocks according to their relative ages.

(6) *Amphibolites* (Metas)

Main ortho amphibolites and some dikes of ortho amphibolites..

(5) *Granites* (*Igneous*)

(*a*) Malakand granite, with pegmatites and aplites.

(*b*) Malakand granite gneiss

(4) *Amphibolites* (Metas).

Para-amphibolites and some ortho-amphibolite dikes.

(3) *Calcareous Rocks* (Metas).

Calcareous schists and marbles.

(2) *Arenaceous Rocks* (Metas).

(1) *Pelitic Rocks* (Metas).

Garnet-mica schists, with minor calcareous beds and bands.

Biotite-chlorite schists

REGIONALLY METAMORPHOSED ROCKS

Pelitic Rocks

The regional metamorphism of pelitic rocks ranges from biotite to garnet grade. Pelitic rocks include biotite chlorite-muscovite schist and garnet-mica schists.

Biotite chlorite muscovite schists. These are extensively developed in southern part of the area. The southern side is in contact with alluvium but in the north these rocks are in contact with the garnet-mica schists.

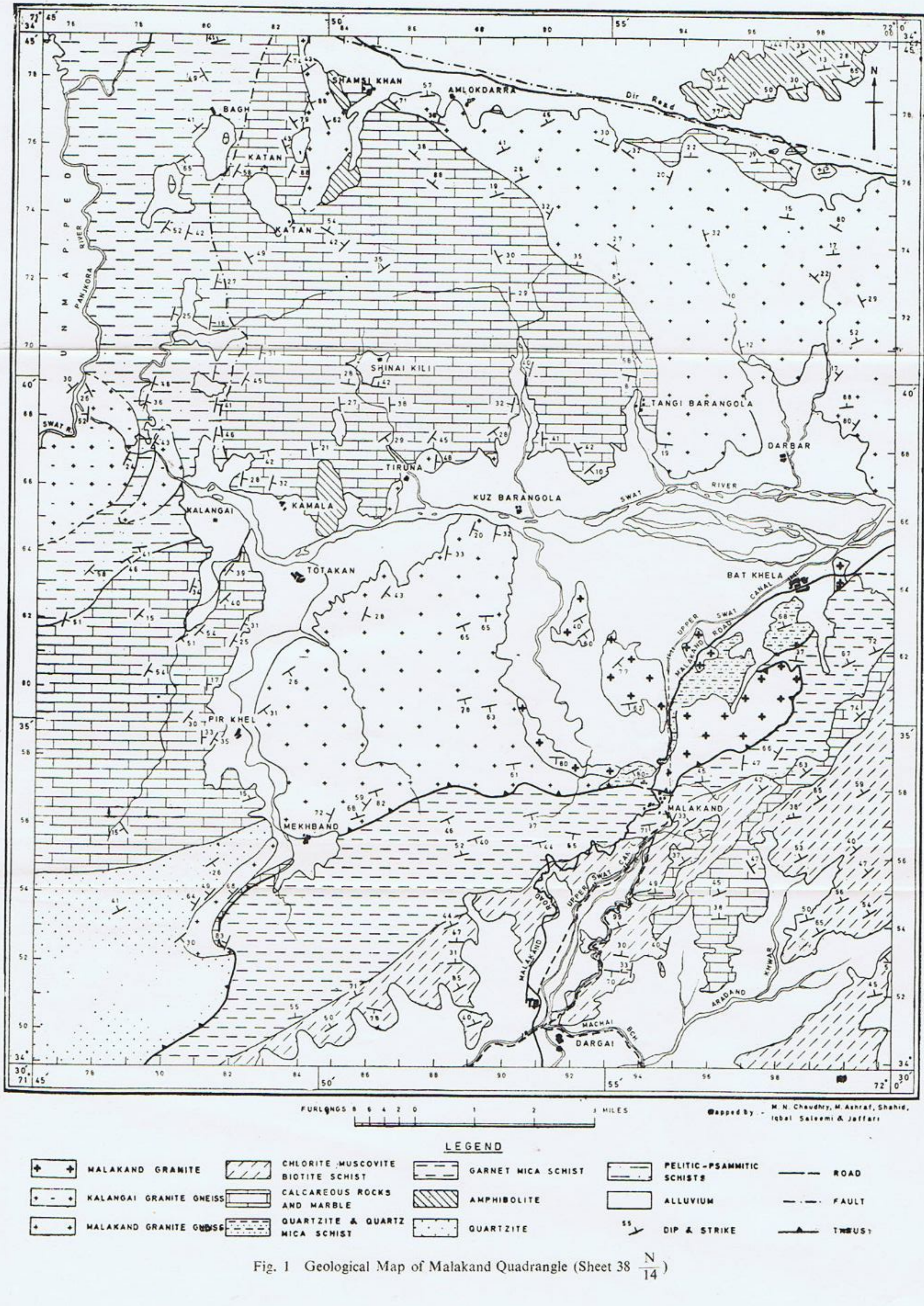


Fig. 1 Geological Map of Malakand Quadrangle (Sheet 38 $\frac{N}{14}$)

The schists are of various colours, but the grass green colour is most common. Localized changes in colour are also observed. The grey and black colours are due to the presence of graphite while the brown and reddish brown colours are due to iron staining. Milky coloured quartz veins, folded in an intricate manner are quite common in the schist. The quartz veins also show pinch and swell structures. The rocks are well-bedded and well-jointed. Quartz and micas are the only recognizable minerals in the field. At places these schists grade into black colured graphitic schists.

Under the microscope, biotite, muscovite, quartz, graphite, chlorite and chloritoid (in a few beds) with accessories like magnetite, sphene and limonite are recognized.

Biotite occurs as numerous minute scales forming small continuous bands and marks the schistosity. It is normally yellowish brown in colour. It ranges from 8—15%**. Chloritoid occurs only at a few places. It occurs as prismatic crystals. Limonite, haematite, graphite, sphene and spessartine garnet occur as accessories. Spessartine garnet is not an ubiquitous accessory.

Graphite Schists: These are greyish black to black coloured schists which occur as bands and beds within the chlorite biotite schists of the area.

Mineralogy of the graphitic schist is the same as that of the ordinary chlorite biotite schists except the higher percentage of graphite and mica. Graphite forms layers, streaks and films along the schistosity planes. It also occurs as disseminated grains. Quartz ranges from 20—45%, muscovite from 25—45%, biotite from 6—17% and graphite from 3—17%. At many places economically valuable graphite bands and beds occur.

Garnet-Mica Schists: The garnet mica-schist varies in colour from green to greyish brown to brown. Reddish brown almandine garnet crystals of almost uniform size can be easily identified. The schistosity is well developed. It is not a uniform unit. It contains intercalated calcareous schists, marble bands and minor amphibolite bodies.

Under the microscope, quartz, muscovite, biotite, and K-feldspar are identified as the essential minerals while tourmaline, limonite, magnetite and graphite are the accessories. The garnet is reddish brown almandine, which forms subhedral to anhedral crystals which thrust apart schistosity planes. Garnet crystals contain quartz inclusions. Garnet is 3—8%. It tends to form sharply bounded porphyroblasts and encloses spiral grains of quartz and mica which indicate rotation of the garnet during growth. Muscovite as slender scales forming continuous bands marks the schistosity along with biotite. Muscovite makes from 20—40% of the rock.

Biotite is yellowish brown and strongly pleochroic. It constitutes from about 6—12% of the rock. Small anhedra of orthoclase constitute from about 0.5—2.5% of the rock.

Quartz occurs as small lenses, streaks and bands. It forms from about 25—40% of the rock.

Graphite occurs as small patches, veinlets and varies from 0.3% to a maximum of 5%.

Tourmaline occurs as small anhedra. Limonite and magnetite are the other accessories.

Calcareous schist bands also occur in this unit. They are composed chiefly of calcite with some quartz, mica, graphite and magnetite. At places actinolite also develops.

Calcareous Rocks

Calcareous rocks are extensively developed in northern and western part of the area. The main body in northern area is compact, massive and non-foliated. In the east these rocks are in contact with the granite gneiss.

**These percentages and those in the proceeding pages are based on the estimates of a large number of samples. But in the tables only selected modal analysis are given.

TABLE I

Modal Analyses of Pelitic Rocks

	*158	238	220	245	202	239
Quartz	53.70	46.19	41.69	27.78	23.58	16.81
Muscovite	34.91	27.54	27.46	53.52	..	28.90
Biotite	0.71	5.77	7.61	..	..	5.51
Chlorite	..	..	12.11	4.99	57.75	..
Garnet	..	5.02	7.02	..	..	22.31
Orthoclase	2.04	0.87	..	..	5.50	..
Plagioclase	..	5.42	..	8.03	..	..
Andalusite	..	..	..	..	..	16.49
Zoisite	..	2.58	..	..	1.69	..
Sphene	..	1.35	..	..	..	2.04
Graphite	3.21	..	3.15	2.38	..	5.76
Ore	5.43	5.26	0.92	3.30	11.49	2.13

***This and othe similar numbers refer to the catalouge of specimens in the collection of Department of Geology, University of the Punjab, Lahore.**

TABLE 2

Modal analyses of Calcareous Rocks

	241	2	214	94	232	181	74	155	151	183	144	111	83	123	112
Calcite	94.92	94.73	93.84	79.59	70.00	65.37	63.55	62.61	61.91	56.24	46.81	38.21	30.04	26.70	7.88
Quartz	1.14	2.63	..	5.51	11.84	23.02	27.49	31.02	20.28	17.14	25.36	9.05	25.38	12.41	30.70
Muscovite	1.88	1.49	..	8.62	1.55	5.89	2.26	.14	.92	19.30	5.58	25.67	26.84	12.92	7.56
Garnet	..	..	..	..	..	1.93	..	..	..	..	6.06	9.59	5.40	16.96	9.44
Biotite	..	..	..	..	0.82	..	..	..	..	..	2.83	..	1.78	0.63	26.78
Epidote	..	..	..	..	..	1.18	..	..		0.42	1.29	1.36	..	..	5.51
Zoisite	..	..	..	..	..	..	..	2.21	..	1.17	2.83	0.6	..	0.1	9.24
Sphene	..	..	..	..	0.60	1.32	..	1.39	.18	..	1.05	..	0.62	..	..
Apatite	..	..	..	..	..	..	..	..	..	0.78	..	1.21	..	..	..
Axinite	..	..	..	..	13.81	..	..	..	..	..	..	11.02	..	..	..
Orthoclase	1.08	..	.	1.31	..	..	2.72	2.61	2.95	0.71	4.06	..	6.57	19.07	..
Plagioclase	..	..	..	..	0.73	..	..	..	9.83	0.88	2.87	2.31	1.88	6.69	0.50
Ore	0.97	1.13	6.15	4.93	0.65	1.07	3.95	..	3.53	3.36	1.26	1.00	1.49	4.60	2.40
Rutile	..	..	..	..	..	0.22	0.04	..	0.39	..	..	..	..	..	..

Calcareous rocks are mostly grey brown and brick coloured. At places these rocks give rusty appearance due to weathering. In hand-specimen calcite, quartz and garnet crystals can be identified. At places within the calcareous unit, pure marbles are also developed. These marbles are black to almost white in colour and well crystallised. At places in the northwestern part of the area 3-20 feet thick beds of graphitic schists occur. These beds are economically important. Microfolding is commonly encountered within this unit. Amphibolite rocks are present within the unit. Calcareous rocks can be classified into the following types.

1. *Banded and Foliated :* Due to the segregation of quartzitic and calcite material, bands of calcite and quartz are formed. These bands alternate with each other.

2. *Massive :* The rock is mostly massive and compact (especially at its contacts with the granite gneiss).

Contact in the eastern side of the calcareous rocks with granite gneiss is not sharp. These two rocks alternate with each other over a distance of about 1500 feet. Garnet is extensively developed in the calcareous rocks. There is no chilling effect at the contact. Development of axinite skarns has taken place at some places. At some places amphibolites have developed at the contact. Contact of the calcareous rocks with the granite gneiss on the northern side along Dir road in very sharp.

Microscopic study of calcareous rocks shows calcite, quartz and mica as the essential minerals whereas garnet, sphene, magnetite, limonite, epidote, apatite and tourmaline are present as accessories. At some places garnet assumes the status of an essential mineral. Calcite anhedra are dominant in these rocks. It makes up 90—95% in the pure marbles and 55—77% in the other calcareous rocks. In black varieties graphite is enclosed by calcite grains.

Quartz grains are subhedral to anhedral. It makes up 8 25% of the rocks.

Small flakes of muscovite are distributed randomly in the rock. It constitutes upto 25% of the rock. Magnetite may make upto 4% of the rock. Garnet, orthoclase, plagioclase and biotite are the other accessories. These rocks contain white, black and banded black and white marbles, which can be used for building stones, tiles and chips making of which the reserves are very large.

Psammitic Rocks

Quartzites and quartz mica schists have been mapped as a single unit in the field, but due to great deal of structural and textural differences they need separate consideration.

Quartzites: Quartzites are mostly confined near the Malakand police station and in the east of Malakand at bifurcation point of Dherai Jolagram road. They are also present to the west of village Mekhband.

These are massive compact, thickly bedded and almost unfoliated rocks, which display a great deal of variation in colour. Colour ranges from brown, reddish brown, rusty grey to dirty white. The weathered surfaces are brown to reddish brown due to iron staining. Quartz and micas are the only minerals which can be recognized in the field.

Texturally the rocks are granoblastic to poorly schistose. Quartz, potash feldspar, muscovite and plagioclase are the essential minerals and biotite, chlorite and epidote are the accessories.

Quartz ranges from 60—80%. It occurs from subhedral to elongate grains which may often show sutured boundries. Potash feldspars form 6—3% of the rock. It occurs as anhedral crystals. Muscovite ranges from 6—20% of the rock. In some cases well crystallized muscovite flakes are irregularly distributed whereas in others they are arranged in preferred orientations marking schistosity. Biotite ranges from 0.2—2%, epidote from 0.3—2% and limonite from 0.5—1.5%.

Quartaz Mica Schist. Quartz-mica schist is found in the south-eastern part of the area alongwith the granite contact. The contact is sharp, conformable and concordant. The general trend is east west and the beds dip south at angles of 45°—65°. With increase in the amount of muscovite the quartizites grade into quartz mica schist. It differs from quartzites, in having well developed schistosity and microfolding.

Petrographic study shows the rock to be composed chiefly of quartz, muscovite and feldspar. Biotite, garnet, epidote, sphene, graphite, magnetite and limonite occur as accessories. Some fluorite grains occur in the schist near the granite contact.

Quartz occurs as rounded and elongated grains. Muscovite marks the schistosity of the rock and its aggregates often show microfolding. Quartzites and quartz mica schists are often interbedded.

AMPHIBOLITIES

The main amphibolite body is developed about two miles north of the Dir road near the village Kuz Chikhu (G.R. 982791). It extends towards north while the other three sides are bounded by alluvium. The general trend of the rock is north east and dip is towards north west. Local variations in dip and strike are common. The amphibolites weather to brown and reddish brown colour due to oxidation. They are well foliated and jointed. They show ptygmatic and layered structures. Ptygmatic folding is the result of shortening within the competent layers. Layering is developed due to the segregation of dark and light minerals in layers in alternate positions with each other. The rock is cut by quartz, quartz-o-feldspathic and aplitic veins and dykes. Intermediate pegmatites are present in the amphibolites. A quartz porphyry band 50 feet thick is present in the amphibolite and runs almost east west over a fairly long distance. Quartz and feldspar are the main constituents of the porphyry bodies. Its colour index is very low. It is also kaolinised. It can be useful as a pottery stone. Amphibolites are medium to coarse grained. They are mostly porphyroblastic and poikiloblastic.

Hornblende is anhedral to subhedral. The crystals are bladed and prismatic in outline. It makes 40-60% of the rock. Its colour is yellowish green to dark green. Hornblende usually alters to epidote and chlorite.

Quartz is subhedral to anhedral and fine to coarse-grained. It ranges from 5—18% of the rock. It also occurs as inclusions in hornblende and epidote.

Epidote occurs as eumorphic to anhedral grains. It makes upto 20% of the rock. Its crystals are medium to coarse-grained. The interference colours are usually anomalous (zoisite).

Chlorite is a secondary mineral and forms mainly at the expense of hornblende. It is colourless to green in thin section. It ranges from 2—10%.

Orthoclase, plagioclase, muscovite, sphene, magnetite, limonite and garnet are the main accessories.

Amphibolities within the Calcareous Rocks. These amphibolites are developed within the calcareous rocks at different places especially near the contact with the granite gneiss. These are of dark green colour and weather to blackish green colour.

Microscopically these rocks are medium to coarse-grained and are composed mainly of epidote, chlorite and muscovite. Magnetite and garnet occur in subordinate amounts.

TABLE 3

Modal Analyses of Amphibolites

	126	225	120	47	24	22
Hornblende	61.14	60.07	54.19	51.84	47.97	42.35
Orthoclase	2.24	4.13	10.00	..	..	2.60
Quartz	17.50	13.58	3.80	..	..	13.95
Zoisite	..	..	..	16.20	16.68	8.67
Epidote (clinozoisite)	0.94	8.01	..	16.99	22.38	7.54
Muscovite	..	..	..	2.52		
Chlorite	..	..	11.33	10.77	9.22	..
Plagioclase	..	..	1.48			2.31
Kaolin	0.14	..	..	..	..	18.73
Ore	4.22	10.90	1.35	1.65	3.73	3.83
Sphene	0.60	..	3.93	..	..	..
Garnet	13.23	3.28	13.94	..	..	..

Amphibole is green coloured mineral which shows pleochroism from dark green to light green. It ranges from 5—60%.

Epidote is subhedral to anhedral. It makes upto 22% of the rock. It is a zoisite which is easily distinguished from other minerals by its anomalous blue and yellowish green colours.

IGNEOUS ROCKS

The Malakand Granite Gneiss

It crops out at two places. One of the outcrops lies in the south of the River Swat where it comes in contact with the Malakand granite and the associated metamorphics. The second exposure of the granite gneiss is in the northern part of the area. Here it comes in contact mainly with the metamorphic calcareous rocks.

The general trend of the gneiss (Fig. 1) is along northeast-southwest and the dip is towards north-west in the northern part and towards south-east in the southern area.

The Malakand granite gneiss is medium to coarse grained foliated rock. Gneissic structure is well developed due to parallel alignment of the minerals. The colour is white to greyish white and the weathering colour is grey to dirty brownish.

Quartz, quartzo-feldspathic veins and metamorphic screens are commonly present in the granite gneiss. Metamorphic screens are baked and granitized. The amount of mica is higher in the screens than in the gneiss.

Contact Relations : The contact between granite gneiss and the calcareous rocks is described in the following.

1. Contact of granite gneiss and calcareous rocks in the western side of the gneiss is not sharp. Bands of gneiss and calcareous rocks alternate with each other over a distance of about 1500 feet.

2. Intrusion of granitic magma has caused hornfelsing of the country rock showing baking at the contact of the calcareous rocks.

3. Recrystallization of different rocks has taken place at the contact. Extensive development of garnet has also taken place near the contact.

4. The contact of the granite gneiss with the calcareous rocks in the northern part of the gneiss is sharp.

5. A sheared zone is developed at some places in this area.

6. Apophyses of granite gneiss are present in the calcareous rocks.

7. The contact of granite gneiss in the eastern side with the metamorphics is very sharp.

Contact of granite gneiss with the Malakand granite is described below :

1. The contact is irregular and apophyses of Malakand granite are often seen cutting the granite gneiss.

2. Garnet is developed in abundant quantity than usual.

3. Screens of granite gneiss are present in the Malakand granite.

4. The contacts are sharp and discordant.

The granite gneiss is hypidiomorphic granular, with gneissic structure. Shearing and segregation of individual minerals is seen.

Plagioclase forms subhedral to anhedral grains of medium to coarse size. The smaller grains are free of inclusions. The composition of plagioclase varies from albite to oligoclase. At places specially where the granite has assimilated calcareous material the composition goes upto andesine. The porphyroblasts contain inclusions of sericite and epidote. Slight to moderate alteration of plagioclase to clay minerals is common.

TABLE 4

Modal Analyses of Granite Gneiss

	76	11741	11743	7	53	93	114	13	11480	42	58	11576	11711
Microcline	19.32	39.45	38.42	37.90	36.09	35.04	31.90	27.84	27.14	26.45	23.68	17.32	10.32
Plagioclase	20.99	27.06	25.45	14.62	23.79	22.25	18.88	9.19	31.26	27.69	29.61	31.69	33.38
Quartz	35.52	25.76	28.20	32.98	26.47	33.64	32.97	31.67	35.02	31.13	26.05	41.43	38.99
Muscovite	13.71	4.20	4.52	11.70	11.84	6.11	12.30	27.42	1.65	11.37	20.16	9.33	16.95
Biotite	0.00	2.33	0.35	0.00	0.00	0.00	0.00	3.32	1.55	0.96	0.00	0.00	0.00
Epidote	0.00	0.00	1.99	0.73	0.00	0.33	0.77	0.23	0.23	0.40	0.47	0.00	0.36
Sphene	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00
Ore	1.53	0.00	0.00	2.09	0.91	0.00	1.51	0.29	0.00	0.36	0.00	0.00	0.00
Garnet	3.82	0.00	0.00	0.00	0.87	0.00	0.00	0.00	3.17	0.00	0.00	0.00	0.00
Kaolinite	0.00	0.45	0.25	0.00	0.00	2.60	1.72	0.00	0.00	1.60	0.00	0.00	0.00
Calcite	2.77	0.74	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Microcline grains are subhedral to anhedral and commonly constitute 10—43% (Table 4) of the rock. Microcline occurs both as megacrysts as well as smaller grains. Megacrysts are sometimes found with inclusions of quartz and sericite. Myrmekite is developed at places.

Quartz occurs as subhedral to anhedral grains. It shows wavy extinction. Drop quartz is also found.

Muscovite occurs in the form of small flakes dispersed throughout the rock.

Biotite occurs as brown coloured, pleochroic flakes.

Epidote, garnet, sphene and magnetite are the minor and accessory minerals.

The Malakand Granite

This granite is well exposed near Malakand. It is about 8 by 5 km in size and is roughly oval shaped. It trends northeast-southwest.

Malakand granite shows perfect spheroidal weathering. The weathered surfaces are brown to brownish black in colour. The Malakand granite is compact unfoliated to poorly foliated and leucocratic. It is predominantly fine-grained and non-porphyritic. Sheared zones are developed at places mostly due to local faulting where the granite (in these zones) is foliated.

A mixed zone is developed in the northwestern area with the metamorphics. The rocks are hornfelsed and potash feldspar porphyroblasts are developed due to potash metasomatism in the mixed zone. Xenoliths of country rocks are commonly present and are usually confined to the marginal zones. The xenoliths are strongly baked, granitized or hornfelsed. Abundance of pegmatitic and aplitic veins is the dominant feature of the Malakand granite. Pegmatite veins vary greatly in size. Aplite and quartz veins in metamorphic screens are folded and show boudinage structure. The granite is often moderately to strongly reconstituted in stronger aplitized and pegmatized zones.

Contact Phenomena : The contact between the Malakand granite and the metamorphics is sharp. At some places a narrow contact zone is developed where numerous granitic injections are cutting across the bedding of the metamorphics.

A sheer zone is developed at granite-metamorphics contact in the north eastern part of the area. Near Malakand proper, a big apophysis of granite cuts across the bedding of the metamorphics. Here the granite has caused hornfelsing of the country rocks and contact schists are strongly baked.

The contact of the Malakand granite with the Malakand granite gneiss is irregular. Apophyses of granite are often seen in the granite gneiss. Garnet is extensively developed at the contact. The contact is sharp and irregular.

The granite shows mostly hypidiomorphic texture. It is fine to medium-grained rock, which is porphyritic at some places.

Mineralogically the rock consists of albite, microcline, quartz and muscovite.

Plagioclase occurs as euhedral to anhedral grains. In most cases its composition is in the range of An_4 to An_9 but at a few places the plagioclase compostion is from An_{11} to An_{14}. Plagioclase is being replaced by microcline and it does replace quartz grains partly to fully. Sometimes sieve like texture is presented by megacrysts of plagioclase enclosing quartz droplets, whereas small laths of plagioclase having irregular outlines are enclosed in microcline. Muscovite also replaces plagioclase grains along margins and along the cleavage. The megacrystic plagioclase are usually subhedral and full of

TABLE 5

Modal Analyses of Malakand Granite

	○ 11693	○ 11463	○ 11471	○ 11488	○ 11458	○ 11560	○ 11363	★ 11683	● 11693	● 11550	* 11711	* 11465	● 11687	* 11466
Plagioclase	47.84	47.06	45.86	41.09	40.09	38.87	36.42	35.50	34.77	34.57	33.38	32.63	32.33	32.11
Microcline	8.92	13.52	12.07	10.95	18.34	17.25	16.11	15.91	28.37	21.86	10.32	17.32	27.88	13.64
Quartz	35.98	33.61	30.57	39.23	33.38	31.52	39.35	30.24	30.18	36.68	38.99	27.21	32.63	29.77
Muscovite	2.95	2.10	3.91	8.15	4.45	10.61	7.63	16.21	4.98	4.84	16.95	22.67	5.03	24.31
Epidote	0.96	0.10	0.33	0.35	1.74	1.30	0.49	0.36	1.70	1.74	0.36	0.00	2.13	0.00
Sphene	0.00	0.24	1.23	0.00	0.35	0.00	0.00	0.72	0.00	0.08	0.00	0.00	0.00	0.00
Calcite	2.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00
Biotite	0.48	3.37	6.01	0.23	1.75	0.10	0.00	1.06	0.00	0.00	0.00	0.17	0.00	0.17
Garnet	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnetite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 5

Modal Analyses of Malakand Granite *(Continued)*

	o 11641	** 11490	** 11540	** 11650	** 1157?	*** 11565	● 11672	*** 11645	** 11549	● 11491	***● 11561	** 11576	● 11725
Plagioclase	30.60	29.33	28.65	27.22	25.55	25.32	25.16	25.00	23.88	22.43	8.88	31.64	31.25
Microcline	30.31	13.58	15.87	24.10	18.39	10.24	30.90	10.30	10.77	36.71	33.38	17.32	27.71
Quartz	31.70	45.80	42.00	40.67	45.55	47.35	35.51	42.37	50.78	37.28	42.37	41.43	34.09
Muscovite	5.42	10.33	11.27	7.45	9.51	14.63	6.37	20.64	12.61	1.86	14.39	9.43	5.44
Epidote	1.97	0.96	0.32	0.56	0.97	0.00	0.00	1.09	1.76	0.38	0.98	0.00	1.14
Sphene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.19	0.00	0.00	0.18	0.00
Calcite	0.00	0.00	1.83	0.00	0.00	2.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biotite	0.00	0.00	0.00	0.00	0.00	0.00	1.90	0.23	0.00	1.28	0.00	0.00	0.17
Garnet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnetite	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.06	0.00	0.00	0.00

o Relatively pure Malakand granite.

• Muscovitised granite.

** Silicified granite.

*** Muscovitised and silicified granite.

● Microclinised granite.

***● Muscovitised, silicified and microclinised granite.

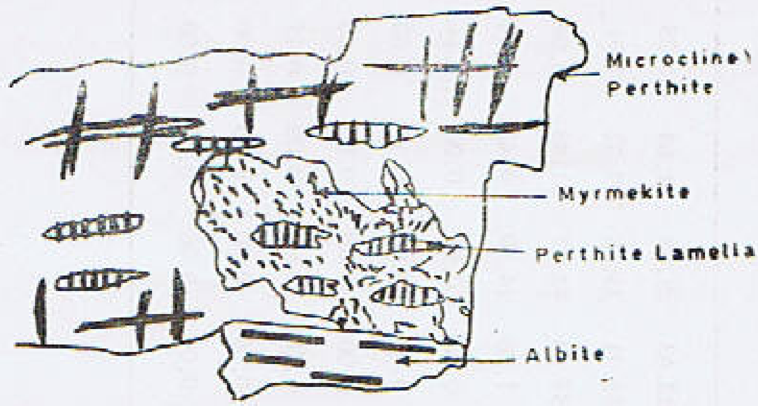


Fig. 2 Myrmekitic Replacement of Microcline Perthite of Granite Gneiss.

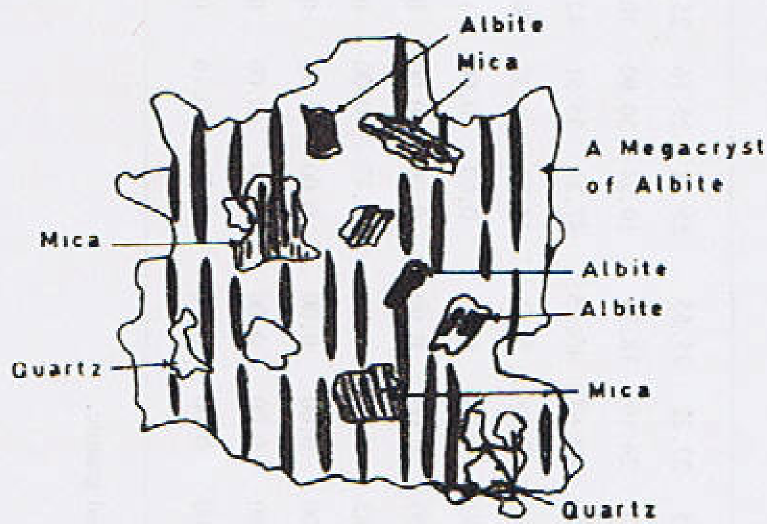
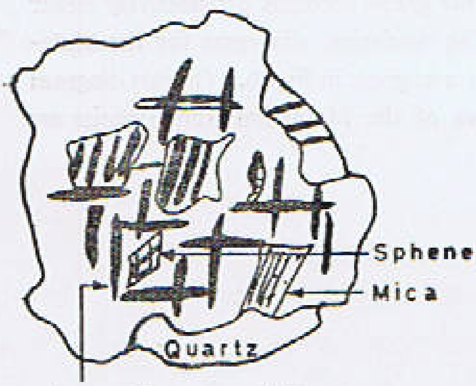


Fig. 3 Development of Plagioclase Megacrysts showing inclusions of Quartz, Mica and Primary Albite.

inclusions. The inclusions are of quartz, muscovite and also primary albite (Fig. 3). It shows that the megacrysts have developed in solid medium. Quartz, muscovite and epidote are also enclosed in these megacrysts of plagioclase. Plagioclase shows alteration to sericite and kaolinite on a small scale. It makes about 20 to 47% of the rock (Table—5).

Microcline is usually present as two generations. The smaller grains are of the first generation while the second generation forms big anhedra (Fig. 4). The latter enclose small crystals of albite and quartz. In some rocks the grain size is highly variable. Microcline is usually perthitic. The megacrysts of microcline have irregular and ragged outline. Sometimes these megacrysts contain substantial amounts of inclusions of quartz, plagioclase, epidote, sphene, and muscovite, which show that megacrysts have formed as a result of replacement of an earlier aplitic groundmass. The microcline megacrysts are much more abundant than the albite megacrysts.



Microcline Perthite Megacrysts Enclosing Albite Sphene & Muscovite.

Fig. 4. Anhedra of microcline containing inclusions.

Myrmekitic growth generally occurs in coarse-grained granite. It has two modes of occurrences i.e. at the contact between plagioclase and microcline when the microcline is strongly perthitic. The perthitic lamellae continue across the myrmekitic growths undisturbed. In the second case, myrmekite occurs at the margin of microcline and may grow inward but albite at the contact is not present.

Quartz occurs as anhedral to subhedral and small to medium sized grains. Coarser grains show strong strain extinction. Small sized grains occur as inclusions in albite, microcline and garnet.

Very little calcite occurs as interstitial plates along grains boundaries and replacing albite and K-feldspar.

Muscovite occurs as distinct laths and as greisenization or replacement product of plagioclase and microcline.

Biotite, epidote, sphene and apatite are the common accessories.

Pegmatites and Aplites

Malakand granite, granite gneiss and metamorphic rocks are cut by light coloured pegmatites and aplites. These show extensive cross-cutting. These pegmatites are filling the joints in the rocks. Patchy, irregular & replacement pegmatites are also seen. The pegmatites range in size from a few cm to about 5 metres in thickness and about 0.5 to 15 metres in length.

Pegmatites/Aplites are divided into the following types.

1. Albite-microcline-quartz pegmatites/aplites.
2. Microcline-albite-muscovite-quartz pegmatites/aplites.
3. Tourmaline-fluorite-microcline-albite pegmatites/aplites.
4. Zoned pegmatites.
5. Composite aplites and pegmatites.

The first type of pegmatites occur in the form of patches. These pegmatites are indefinite in their outline and show evidence of replacement. Small amount of muscovite and epidote is also present alongwith quartz, microcline and albite.

The second type of pegmatites/aplites are mostly tabular bodies filling joints and fractures of Malakand granite, granite gneiss and metamorphic rocks. Composition is microcline, albite muscovite, and quartz.

Tourmaline-fluorite bearing pegmatites were found only in one locality i.e. near the Malakand Rest House. In addition to quartz, microcline and plagioclase these contain tourmaline, fluorite and sphene. The zoned pegmatites have essentially two zones, the intermediate zone and the core. Their mineralogy is same as in types (*i*), (*ii*) and (*iii*) but the core does contain more quartz. The composite aplites and pegmatites are commonly present in the Malakand granite and the associated schistose rocks having composition of type (*i*) and (*ii*).

CHEMISTRY OF THE GRANITIC ROCKS

Twelve rocks of the granitic complex were analysed taking representatives of all varieties of rocks identified in the field and studied microscopically. Four samples of the gneissic granite have been analysed taking three normal gneissic samples and one aplitic gneiss. Three samples of the Malakand granite gneiss were analysed. They represent relatively pure and earlier formed phases. The variation within the gneiss can not be shown without further data. Petrographic study however indicates that starting from K_2O rich phases the gneiss becomes progressively richer in Na_2O. The variation diagrams for the Malakand granite are given in Fig. 6. On this diagram four analyses of the Malakand granite gneiss are also ploted.

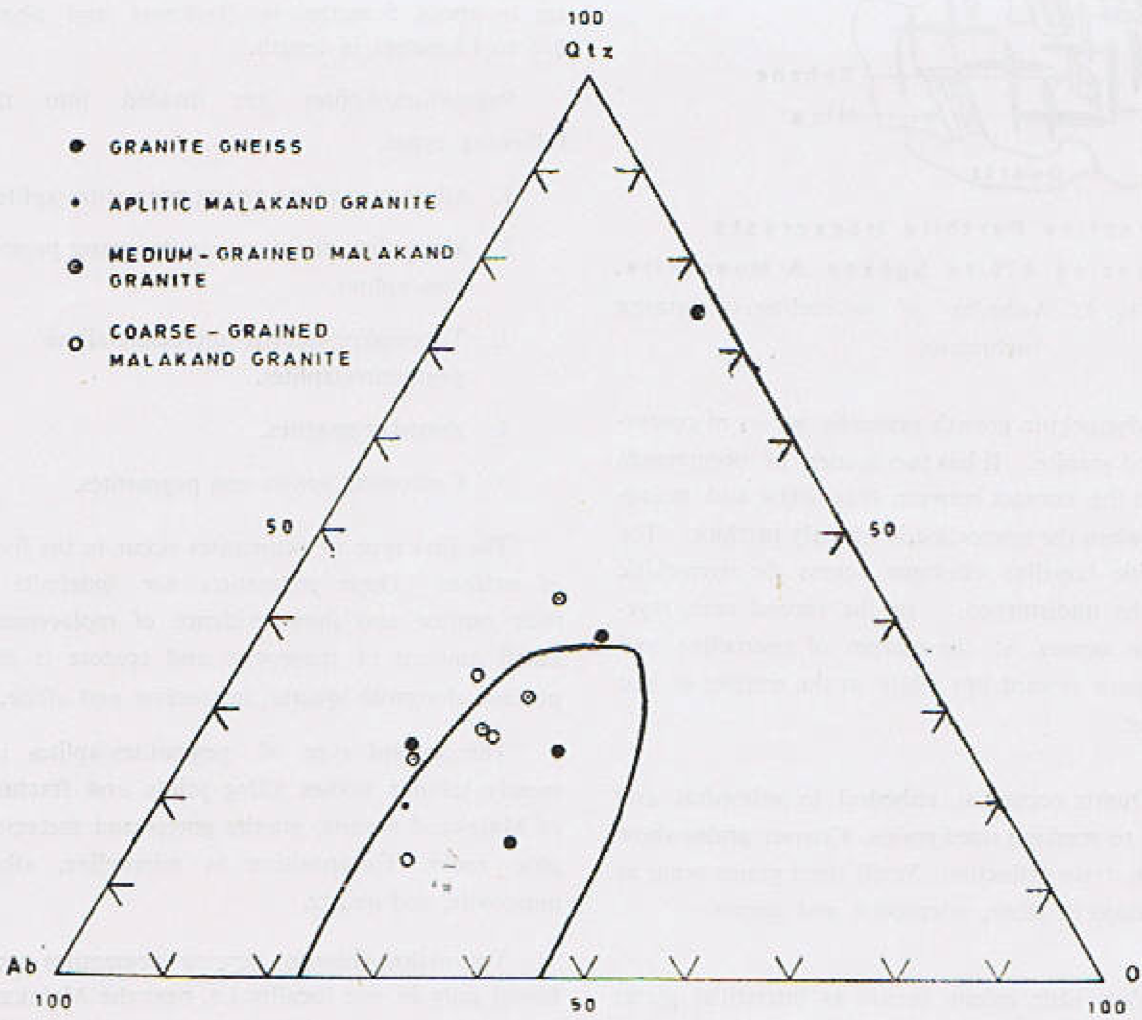


Fig. 5. Normative Albite, Orthoclase and Quartz Diag-am of the Analysed Granitic Rocks Recalculated to 100%. The Plots lie Within and close to Petrogeny Residua.

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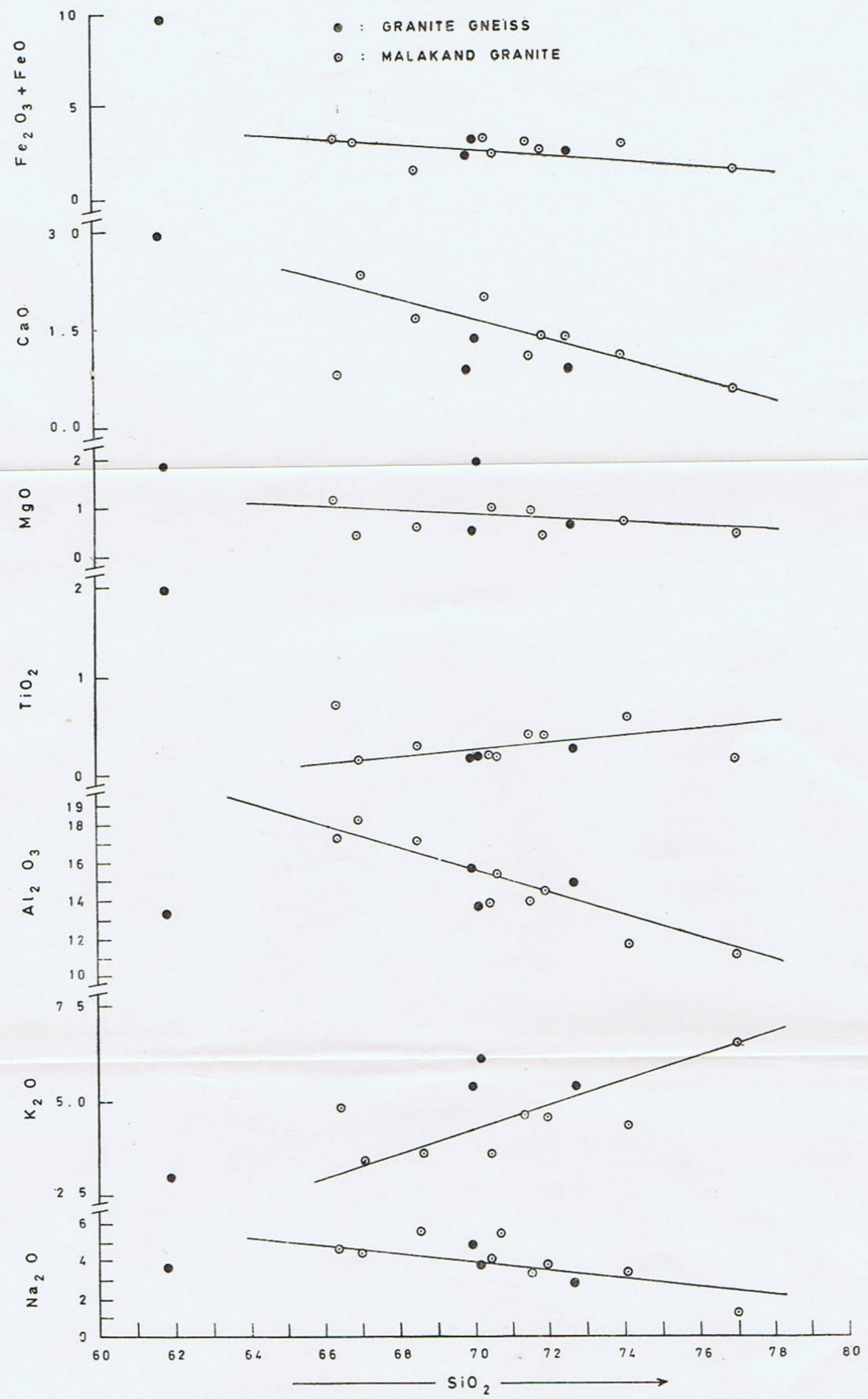

Fig. 6. Linear Correlation Diagram between SiO_2 and Principal Oxides of Granitic Rocks.

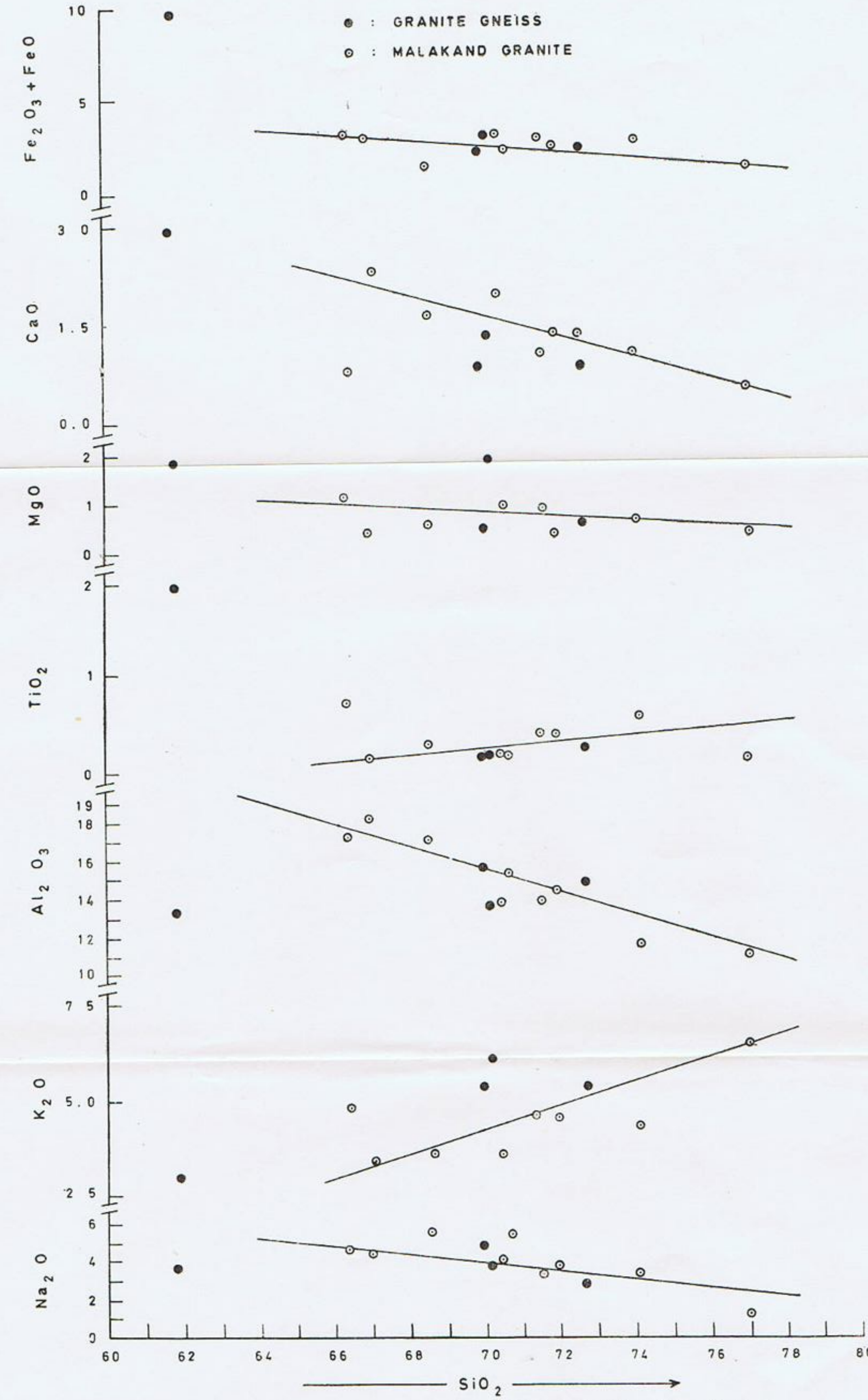

Fig. 6. Linear Correlation Diagram between SiO_2 and Principal Oxides of Granitic Rocks.

TABLE 6

Chemical Analyses of Granites

	Malakand Granite								Granite Gneiss			
	11645 (a)	11645	11409(b)	11710	11687	11725	11561	N/10	11480	11572	11741	11712
SiO_2	66.28	68.48	70.46	71.56	71.86	74.04	77.01	70.68	69.95	72.66	70.12	66.09
TiO_2	0.71	0.28	0.18	0.35	0.35	0.53	0.10	0.13	0.13	0.18	0.22	0.13
Al_2O_3	17.39	17.03	13.84	13.88	14.35	11.54	11.02	15.18	15.63	13.51	14.18	18.19
Fe_2O_3	3.53	1.40	2.51	3.40	2.06	2.31	1.57	1.77	1.17	2.73	1.67	2.59
FeO	0.14	0.44	0.16	0.12	0.11	0.21	0.26	0.29	0.83	0.16	0.74	0.35
MnO	0.57	..	0.02	..	..	..	0.18	..	0.06	0.04	..	0.05
MgO	1.17	0.50	0.99	0.97	0.35	0·61	0.33	0.81	0.40	1.16	1.50	0.41
CaO	0.86	1.54	2.10	0.94	1.30	1.20	0.62	1.84	0.82	0.68	1.45	2.25
Na_2O	4.55	5.55	4.C0	3.25	3.70	3.30	1.09	5.44	4.89	2.68	3.68	4.48
K_2O	4.35	3.70	3.55	4.70	4.65	4.15	6.16	4.25	5.90	5.15	5.48	3.25
P_2O_5	0.21	0.03	1.18	0.17	0.12	1.08	0.08	0.02	0.01	0.66	0.01	0.15
H_2O+	0.53	0.71	1.20	0.73	0.82	0.98	1.38	0.15	0.25	0.40	0.70	1.18
H_2O-	0.13	0.22	0.08	0.09	0.21	0.07	0.11	0.05	0.08	0.13	0.11	0.20
	99.90	99.88	100.27	100.16	99.88	100.02	99.91	100.61	100.12	100.14	99.75	99.32

Following observations were made by plotting these analyses :

(*i*) The normative plots (Fig. 5) of plagioclase, orthoclase and quartz (recalculated to 100%) fall very close to the petrogeny residua, showing that both granites are products of crystallization from a melt.

(*ii*) Fig. 6 shows variation diagram plotted between SiO_2 and various other oxides present in the rocks, namely Al_2O_3, TiO_2, total iron, MgO, CaO, Na_2O and K_2O. The variations observed in this diagram show that with increase in SiO_2.

(*a*) Al_2O_3 decreases.

(*b*) Total iron remains almost unchanged.

(*c*) TiO_2 increases possibly due to crystallization of sphene.

(*d*) MgO and CaO decrease.

(*e*) Na_2O decreases but not sharply which might be due to the growth of megacrystic plagioclase.

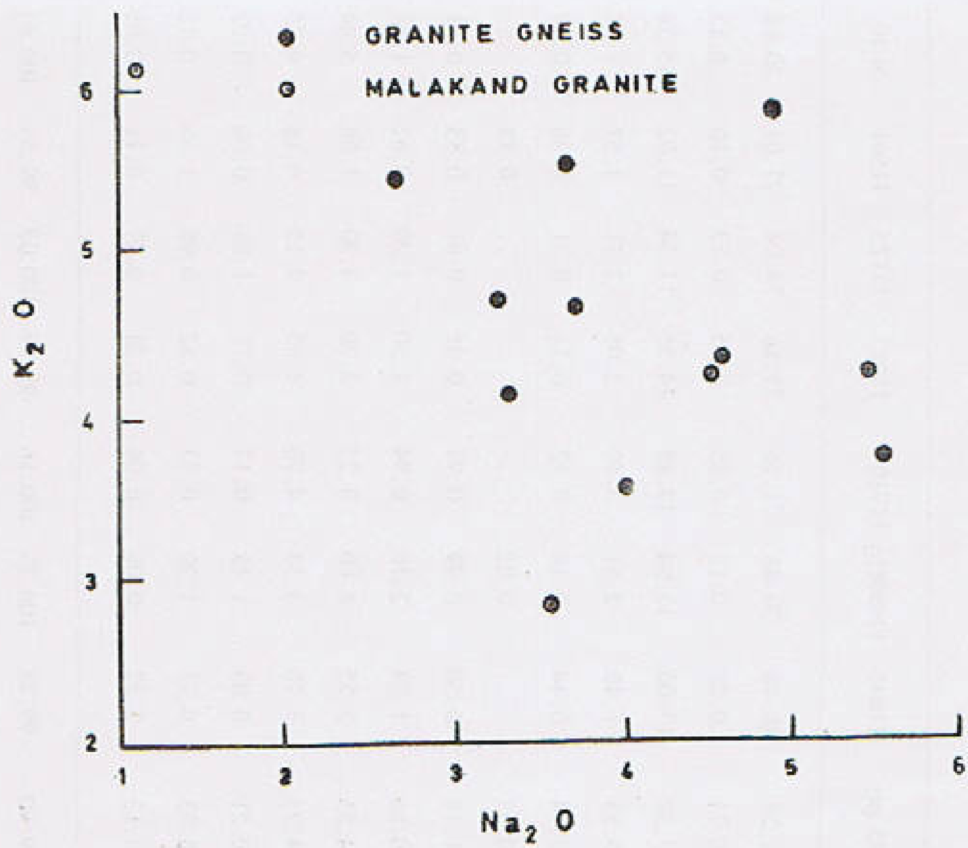

Fig. 7. Variation Diagram between Na_2O and K_2O.

(*f*) K_2O increases and shows scattering due to reconstitution of the Malakand granite.

(*g*) The migmatized granite gneiss shows abnormal plotting in the Fig. 5.

Fig. 7. shows the plotting of Na_2O vs K_2O. This diagram shows the following facts :

(*a*) The older granitic gneiss does not show appreciable change in the amount of K_2O with the increase in Na_2O. The only exception is due to samples of biotitic migmatized gneiss.

(*b*) Inverse correlationship occurs between Na_2O and K_2O in the case of Malakand granite i.e., with increase in K_2O, the amount of Na_2O decreases and vise versa.

PETROGENESIS

1. Pelitic Rocks

The pelitic rocks fall in the biotite and garnet grades of regional metamorphism. They have been formed by low to medium grade regional metamorphism of the argillaceous sediments rich in the carbonaceous material which gave rise to the graphitic schists. At places the graphitic matter is present in sufficient amounts to give rise to graphite deposits of economic importance.

Chloritoid has been formed at places in the pelitic rocks. It has formed due to the reaction between mica and iron bearing solutions in the presence of carbonaceous matter according to the following reaction :

$$2H_2KAl_3\ Si_3\ O_{12} + 3Fe\ (OH)_2 = 3H_2FeAl_2\ SiO_7 + 2KOH + 3SiO_2 + H_2O$$

(Tilley, 1925-26)

Biotite formed due to the reaction between muscovite, chlorite, iron ore and possibly rutile. Garnet formed first directly from chlorite and subsequently according to the following reaction :

$$KFe_3Si_3AlO_{10}(OH)_2 + KAl_3Si_3O_{10}\ (OH)_2 + 3SiO_2 = 2KAlSi_3O_8 + Fe_3Al_2Si_3O_{10} + 2H_2O.$$

At least in part the garnet zone in the south appears to be piezothermal. In the northern area garnet is extensively developed. In calcareous beds it must contain appreciable grossularite molecule.

2. Psammitic Rocks

They have formed as a result of regional metamorphism of sandstones and argillaceous sandstones.

3. Calcareous Rocks and Marbles

They have formed as a result of low to medium grade metamorphism of limestones, clayey limestones and marls. Pure limestone beds recrystallized to form medium to good quality marbles. The argillaceous limestones and marls developed muscovite, biotite and garnet. At places amphibole also develops. Some bands of appropriate composition have been locally converted to amphibolites and amphibole gneisses. Biotite in these rocks develops as a result of reaction between muscovite and chlorite. Garnet develops from reaction amongst chlorite, clay and carbonate. At places the effects of superimposed contact metamorphism can also be seen. Here axinite bearing skarns, amphibole bearing contact rocks and rocks enriched in garnet develop. This unit contains interbedded carbonaceous argillite bands which have been converted to graphite schists. Many of these are economic graphite deposits. One such occurrence is in the western part of the area near Hardial Kandao.

Amphibolites

There are two types of amphibolites in the area. The first type occurs as discordant to concordant intrusions. Their contacts with the metasedimentary country rocks are sharp. They intruded as basic dykes which underwent regional metamorphism to give rise to the amphibolite bodies. The second type which occurs in the northern part of the area mapped is a part of the southern Dir amphibolite complex. It is an ortho amphibolite. Its origin has been discussed in detail by Chaudhry et al. (1974 b).

Origin of the Granitic Rocks

Before discussing the origin of the Malakand granite gneiss and the Malakand granite important field petrographic and chemical evidences will be briefly summed up. The Malakand granite gneiss is a body of batholithic dimensions whereas the Malakand granite is a minor pluton (Rastall, 1945). Field and geophysical evidences suggest the Malakand granite to be a shallow laccolithic body (Saleemullah and Rizvi, 1964). The granite gneiss is basically potash granite whereas the Malakand granite is basically a soda granite.

The contact of the granite gneiss with the metamorphic rocks is sharp. Baking and contact hornfelsing is often observed. Minor discordance and apophyses of the granite gneiss in the metasediments are often seen. The contacts of the Malakand granite with the country rocks are often very sharp. Chilling at the contact is observed at many places. At the contact baking and the hornfelsing of the metasediments are also seen. The contact between the Malakand granite gneiss and the Malakand granite is not so sharp. Dykes, streaks and apophyses of the Malakand granite in the Malakand granite gneiss are common. At the contact there is considerable intermixing.

Both the granites show reactions at the contact with the metasediments. These reactions are in keeping with contact metamorphism, metasomatism and assimilation. Biotite hornfelses develop at contacts with the pelitic rocks. At these contacts both the granites are enriched in biotite. Here the granites may also contain garnet.

Malakand granite and specially the Malakand granite gneiss has assimilated considerable argillaceous material at a few places. This has resulted in the formation of the mixed zones. At some places the contact between the granite gneiss and the calcareous metasediments is marked by the development of axinite—garnet and amphibole-garnet skarns. This is due to the introduction of silica, iron, boron, water and fluorine, into the calcareous metasediments from the granite gneiss.

Both the Malakand granite gneiss and the Malakand granite show hypidiomorphic, graphic, myrmekitic and saccharoidal textures. The normative $Ab+Or+qz=100$ when plotted on the petrogeny residua fall in or very close to the low temperature trough (Fig. 5).

All the above evidences clearly show that these granites are products of crystallization from a hot at least partially molten and mobile mass. On this assumption in what follows the petrogenetic evolution of these granites will be discussed.

The experimental work in the granite system has been done by Tuttle and Bowen (1958). Luth et al. (1964), continued their work in greater detail. They studied the system ($NaAlSi_3O_8$—$KAlSi_3O_8$—SiO_2—H_2O) at 3 to 4 Kbs and 5 to 10 Kbs respectively. Bowen (1937) emphasized that the progressive crystallization in the magmas will yield liquids falling in the petrogeny residua. According to Luth et al. progressive increase in $P(H_2O)$ will shift the position of the isobaric quaternary minimum downwards in terms of temperature and towards $NaAlSi_3O_8$ and H_2O. Orville (1960), Burnham and Jahns (1962), Norton et al. (1962), Jahns and Tuttle (1963) and Booth (1967) have studied the composition trend from normal granitic rocks to the later differentiates. This has been done in relation to variation in $P(H_2O)$. Shams and Rehman (1966) and Ashraf (1974 a, 1974b) have also studied the Mansehra granites and considered the effect of increase of $P(H_2O)$. With increase in $P(H_2O)$ soda rich members start coming. Hall (1972a, 1972b, 1973) has also studied in detail the soda enrichment with increase in $P(H_2O)$.

Keevil's (1952) studies also showed $P(H_2O)$

increases with falling temperature. Within water—albite system, with cooling, (Goranson, 1928 and Burnham and Jahns, 1962) the water content increases to 16.8%. For albite melt this is maximum H_2O that can be held. According to Tuttle and Bowen (1958) further rise in vapour pressure can bring about crystallisation. With this a second boiling point (Turner and Verhoogen 1960) comes about with precipitation of albite and enrichment of the liquid with other components. The vapour pressure after reaching a maximum starts decreasing. After a certain point SiO_2, K_2O and volatiles can be enriched. In the case of pressure quenching soda rich fraction can be quickly deposited and the residues may be enriched in K_2O and SiO_2. Malakand granite gneiss and the Malakand granite will be discussed in the following in the light of the above.

The Malakand granite gneiss was intruded as a mobile mass. The crystallisation started with predominant microcline and subordinate albite/plagioclase. With progressive crystallisation the amount of microcline started decreasing and that of albite started increasing. On the whole Table—6 shows that the gneiss is rich in K_2O. During crystallisation there was a progressive increase in $P(H_2O)$. At a certain stage a soda rich fraction started developing. This fraction was later emplaced as an oval shaped body called the Malakand granite. Field and petrographic evidence suggests that this intrusion was accompanied or closely followed by pressure release. This resulted in the formation of aplitic to semi- aplitic Malakand granite. First few modal analysis of Table—5 represent such phases while the others have been subsequently metasomatised moderately to heavily. This granite is soda rich. It probably represents pressure quenching. This gave rise to a rest phase [due to a rapid fall in $P(H_2O)$] rich in K_2O, SiO_2, H_2O and F. It attacked the solidified or semi solidified Malakand granite. During this phase microcline porphyroblasts, mica flakes, books and pools, and quartz grains and its pools erratically replaced the Malakand granite.

It caused great mineralogical and textural variations in the Malakand granite. These reactions are irregular and erratic as can be seen from (Table—5) modal analyses of the Malakand granite. Such phenomena have also been reported from Meldon, Devenshire, England by Chaudhry (1967).

Myrmekites

Various theories of myrmekite formation have been put forth. Becke (1908) considered the formation of myrmekite due to the internal chemical activity of solutions causing replacement of potash in feldspar by soda and lime and releasing free quartz. According to Sarma and Raja (1959) portions of plagioclase break down under stress and release quartz which form the myrmekite growths. Shams (1967) has suggested the following reaction.

$$KAlSi_3O_8 + Na-O-Si(OH)_3 = NaAlSi_3O_8 + SiO_2 + H_2O + KOH$$

His applications of this reaction to the Mansehra area rocks and the time and conditions of reaction are outside the scope of present work. But the mechanism (reactions) suggested is convincing. In the Malakand granite myrmekites are extensively developed. They are developed at the interfaces between potash feldspar and soda feldspar. So the myrmekites developed due to the replacement of potash feldspar by sodic matter at interfaces between the two feldspars. Or simply due to the replacement of potash feldspars by the sodic solutions.

THE AGE OF THE ROCKS

The metasediments of the area consist of two main groups namely a pelitic group and a calcareous group. The former group consists predominantly of pelitic rocks with subordinate arenaceous and calcareous bands and beds. This unit compares well with the Attock Slates and represents higher grade metamorphic facies of the same. Its age is therefore the same as that of the Attock Slates. The age of the Attock Slates is also not known definitely but has been regarded as Pre-cambrian. The Malakand pelitic metamorphics are regarded as Precambrian. The overlying sequence consists of thick marbles, calcareous schists and quartizites and some minor beds of graphitic schists. In many respects this sequence compares with the lower Paleozoics elsewhere such as the Abbottabad Group. This is regarded as lower Paleozoic. The metasediments of the area are therefore regarded as from Precambrian to lower Paleozoic. No radioactive dating has been done on the granites. It is therefore not possible to assign any definite age to them. But they are regarded as early to middle Mesozoic.

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(Manuscript received March 1975)

JURASSIC BAUXITE AND KAOLINITE DEPOSITS OF CHHOI AREA, KALA CHITTA RANGE, PUNJAB, PAKISTAN.

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Abstract : *Sedimentary reworked bauxite and kaolinite deposits have been found in the Kala Chitta area for the first time. These deposits are of Jurassic age and they occur on an erosional unconformity at the top of Triassic Rocks. Due to reworking of bauxite and kaolinite from the same source area the physical appearance of these deposits is almost identical. The bauxitic zones are occasionally more compact than the kaolinite zones. The basal bed always consists of kaolinite. The alternations of bauxite and kaolinite continue upward. This cyclic deposition is conceived due to alternate deposition of kaolinite and bauxite. Moreover, the occurrence of bauxitic nodules in the kaolinite zone at places show that the whole deposit is of reworked nature and cyclic. These bauxite and kaolinite zones have been evaluated in detail by chemical, X-ray and D.T.A. methods.*

INTRODUCTION

In Pakistan about 500 million tons low iron bearing bauxite, clay and laterite deposits have been reported in the recent years by Ali et al. (1964), Stauffer (1968), Nizamuddin (1970), Khan (1971), Faruqi (1964, 1966, 1972), Malik and Valiullah (1971, 1972), Ashraf et al. (1972a. 1972b) and Hussain and Naqvi (1972), particularly in the Punjab, North Western Frontier Province and Azad Kashmir. Out of these the most important deposits occur in the Central Salt Range and Kala Chitta Range of the Punjab. The Central Salt Range deposits occur along an erosional unconformity of post Permian age and are overlain by beds of Paleocene/Eocene age (Ashraf, 1972b). The Kala Chitta Range deposits (Fig. 1) occur within the Datta Formation of Jurassic age (Hussain et al., 1967). Since Hussain et al. mapped this area, the deposits due to their non-pisolitic and shale like appearance were known as clay deposits. Similar deposits occur in the Datta Formation in the vicinity of Musakhel, Salt Range Area which according to Faruqi (1966) consists of boehmite and kaolinite. Whereas the deposits in the Chhoi area are mainly formed of diaspore and kaolinite.

Mining for bauxite and clay is in operation in the Salt Range and Kala Chitta area. At present this material is being used for making refractories in Pakistan. Experiments are also being carried out for the extraction of alumina from bauxites having high Al_2O_3 and low SiO_2 contents by the PCSIR Laboratories.

In the past, samples from the same outcrops were studied geologically and chemically by Hussain et al. (1967) and Hussain and Khan (1967) who on the basis of surface samples classified these deposits as fireclays with chemical composition averaging 30 to 48% Al_2O_3, 40 to 44% SiO_2 etc. In 1972 Hussain and Naqvi determined some physical properties of different clays and bauxites from the Punjab including the project area.

The objective of the present studies was to determine the chemical and mineralogical variations in some of the deposits. For this purpose channeled samples were collected from lithologically and physically different zones of a profile and were studied by chemical, differential thermal (DTA) and X-ray diffraction methods.

GEOLOGY

General : The Kala Chitta Range consists of sedimentary rocks. These rocks range in age from Triassic to Pliestocene (Siwaliks). The oldest rocks in the area are represented by the Mianwali Formation (Triassic) which is exposed at two places of the faulted anticline (Hussain et al., 1967) of small dimension. Overlying is the Kingriali Formation of the Triassic age, formed of limestone and dolomitic limestone. The Jurassic (Datta Formation) is represented by Chadkdalla iron and clay beds of light, grey cream to purple coloured (bauxite and kaolinite deposits), overlying are red clays and argillaceous limestone of grey to dark grey colours. Basal part is made up of marl of greyish white colour with abundant ammonites, pectondes and corals (Fatmi, 1972). Overlying Datta Formation is Samana Suk Formation (Jurassic) consisting of grey to brownish grey limestone, the lower part of which is fragmentary. After a small unconformity there occurs Chichali Formation of the Upper Jurassic consisting of shales and belemnites. Above this lower Cretaceous grey sandy limestone; clayey limestone, marl and glauconitic sandstone occur. The Paleocene and Eocene rocks consists of limestone, shale and marl. The youngest rocks are those of Oligocene and Siwaliks (Pliestocene) consisting of sandstone and shale.

STRATIGRAPHIC COLUMN

Oligocene-Pliestocene (Siwaliks)	Argillaceous and ferruginous sandstone and shale.
Paleocene-Eocene	Argillaceous limestone, calcareous shales ; massive nodular limestone with marl.
Late Jurassic to Cretaceous	*Chichali Formation* : Glauconitic shale & sandstone with belemnites and ammonites.
Early & Middle Jurassic	*Samana Suk Formation* : Grey to brownish grey limestone.
Early Jurassic	*Datta Formation* : Cream to light grey coloured bauxites and clays with occasional patches of pink, brown, red to dull red lateritic material.
.. .. Unconformity	.. ..
Triassic	*Kingriali Formation* : Dolomitic-limestone.

Bauxite and Kaolinite Deposits : The bauxite and kaolinite deposits crop out in an east-west trending zone along the Kala Chitta Range. The area is highly folded and faulted, therefore, the outcrops were observed at more than one place in the Datta Formation. The strata dip 70° to 79° and occasionally with a dip angle of about 45° either to the south or north with strike about east-west to N72°W. The aluminous rocks were studied in detail from four profiles in the area near Chhoi rest house. The kaolinite occupies a zone above bauxite. In the area wide range of variations have been observed in the sense that in one profile (Fig 2, SR-2) there is dominantly kaolinite with a lens of bauxite 30 to 50 cm thick and irregular patches of aluminous laterite (ferruginous bauxite).

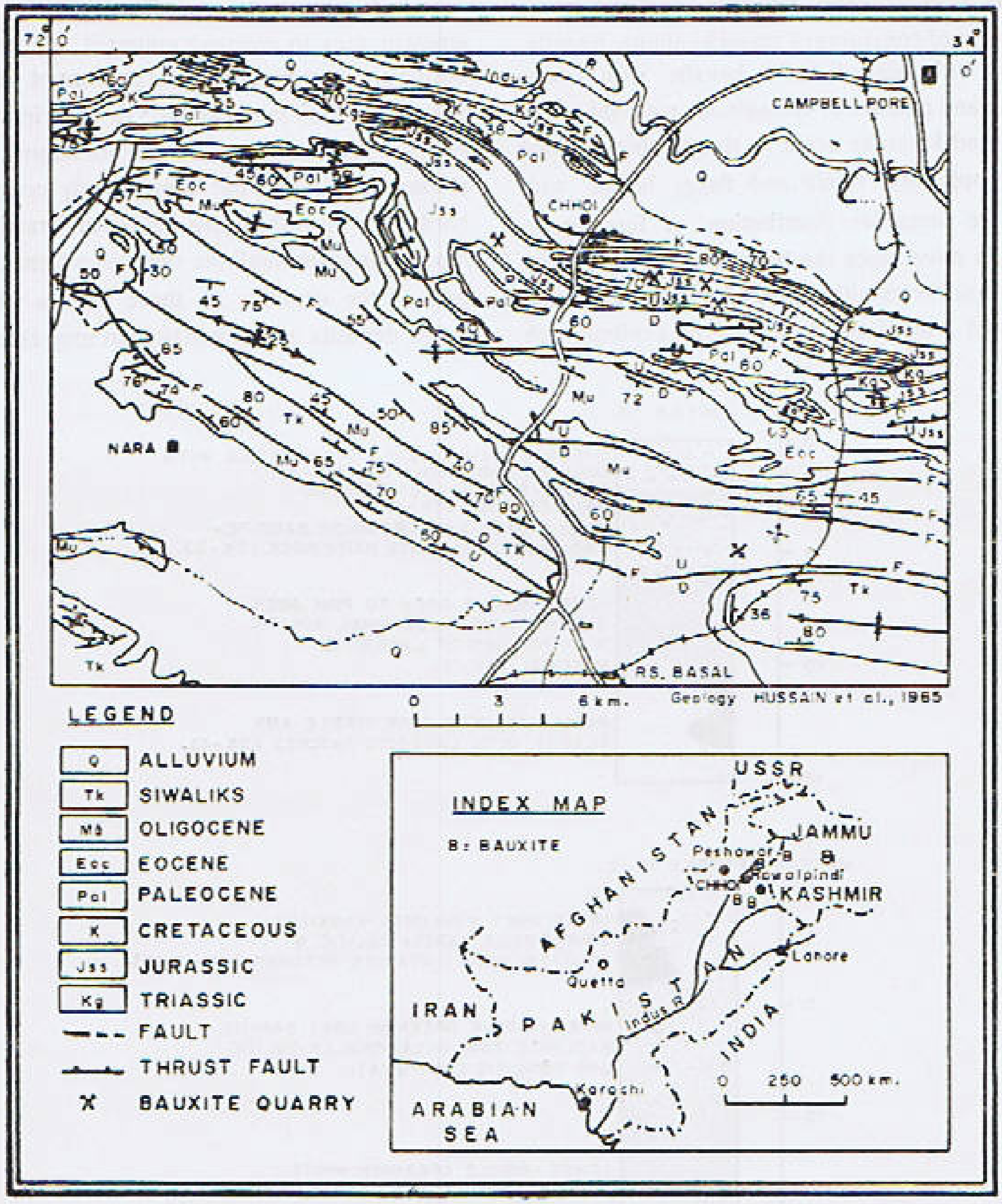

Fig. 1 Geological Map of Chhoi Area, Kala Chitta Range, Punjab Pakistan, Showing Different Profiles, and other Places of Bauxite in Pakistan (Index map).

Whereas at other places different lithologic layers were observed consisting of major kaolinite, bauxite, kaolinite with minor bauxite, bauxite with minor kaolinite and patches of ferruginous material. The bauxite and kaolinite occur as thin to thick bedded massive splintary, fissile and flaggy layers with patchy to irregular distribution of ferruginous mass. In most cases the bauxite rich zones occur as lenses and layers with rare development of bauxitic nodules of 2 to 25 cm in size in the kaolinite rich zones of some outcrops. The kaolinite is light greenish grey to creamish coloured splintary non-oolitic and non-pisolitic. The amount of pisolites is not usually very large, about 5 to 10% in kaolinitic rocks. The bauxite rich zones are almost of same colours as kaolinite but compartively compact and hard and with little micro-oolites and rarely pisolites. Most of the kaolinite rich zones form the basal part of the deposits in those profiles where the major deposits are of bauxite but may alternate as

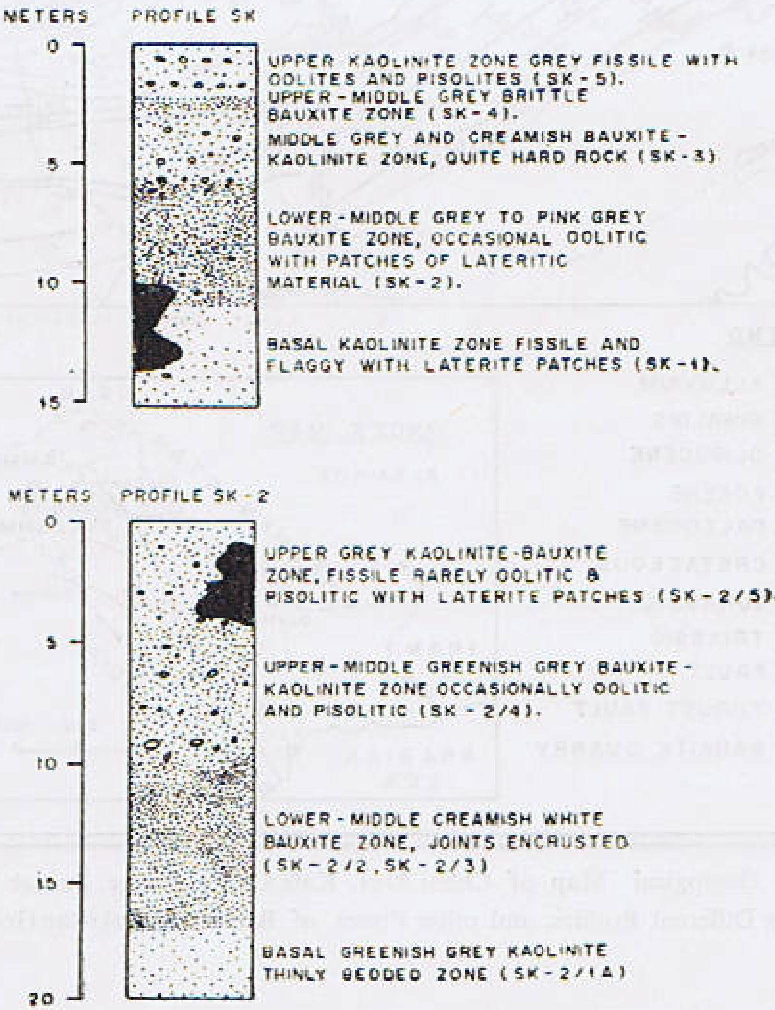

Fig. 2. Lithologic Variations through Profiles SK and SK—2.

a few cm to 2 meters thick zones. On the weathered surfaces the rocks become yellowish white, reddish and light in weight. The fresh outcrops are of light grey and grey to cream coloured. In the quarries irregular distribution of cherty red to dull, red laterite has been observed in bauxite and kaolinite deposits. In places the joints of both bauxite and kaolinite layers are encrusted with reddish and pinkish material.

At various quarried places different type of lithologic variations of the vertical sequence were observed. They are illustrated separately in Fig. 2 giving brief details.

Profile SK : This occurs in the eastern part of the Chhoi Area. There is a deep quarry which exposed five distinct zones from base upward : namely basal kaolinite zone, bauxite zone, kaolinite-bauxite zone, bauxite zone and upper clay zone (Fig. 2, Profile SK).

Profile SK-2 : This is exposed about half a kilometer west of profile SK in the same out-

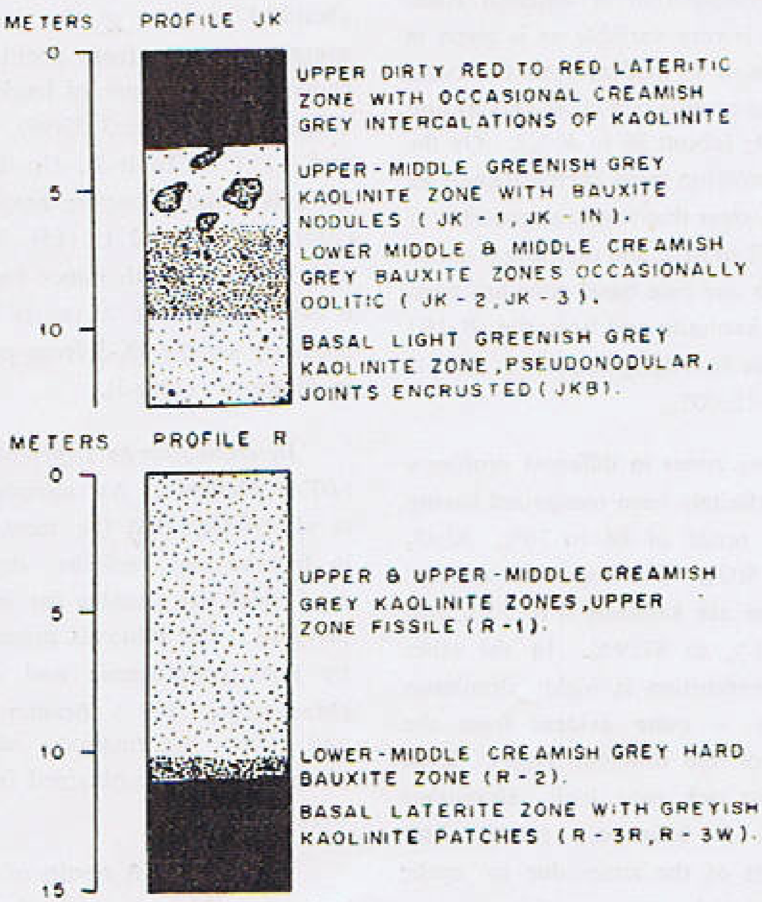

Fig. 2 Lithologic Variations through Profiles JK and R.

crop. There are again repeated zones of kaolinite, bauxite-kaolinite, kaolinite-bauxite, kaolinite and patches of laterites quite thick and irregular at places.

Profile JK : It occurs in the southern limb of the folded Datta Formation about 400 meters south of quarry SK. The bed consists of four distinct zones and is fully exposed for its entire width of about 12 meters.

Profile R : This profile occurs on the west of Chhoi-Basal road. The different zones are well exposed over there. There are three quarry places. In this profile older zone is lateritic. The bauxitic zone is thinly deposited in this locality.

CHEMICAL COMPOSITION

The chemical composition of different zones of the four profiles is very variable as is given in Table I. From this, it is evident that the basal zones in almost all the cases is rich in Al_2O_3 (around 41 to 44%), and SiO_2 (about 36 to 40%). On the basis of mineral calculation from chemical analyses (Table 2) it becomes clear that kaolinite contents in the basal zones are 77 to 81% and diaspore is about 10 to 15%. Only in one case basal zone has been found to consist of kaolinite and hematite (R-3R) as chemically this zone has Al_2O_3=32.00%, SiO_2= 37.6% and Fe_2O_3=12.00%.

In the succeeding zones in different profiles a bauxitic zone has definitely been recognized having composition in the range of 68 to 76% Al_2O_3 and 2.5 to 11.6% SiO_2. The important mineral contents of this zone are kaolinite 4 to 23% and diaspore from 68.8% to 87.9%. In the other zones either the composition is highly aluminous or kaolinitic. This is quite evident from the chemical analyses of the different zones. Even at places in kaolinite rich zone high aluminous nodules (sample JK-1N) have been found. This shows the formation of the zones due to cyclic deposition of the material.

Other oxides like Fe_2O_3, TiO_2, CaO, MgO, SiO_2 Na_2O, K_2O and P_2O_5 are more or less uniformly distributed in almost all the zones. The only contrasting variation found is due to high concentration of lateritic lenses at places in the profiles studied.

MINERALOGY

Due to extreme fine grained nature of the rock grains their identification is not possible with ordinary microscope. Therefore, X-ray, differential thermal (D.T.A.) techniques were employed to identify the bauxite and kaolinite minerals.

Determination by X-ray Method : X-ray analyses were carried out on three selected samples. Two of the three samples are rich in alumina and the third one is rich in silica (as found out by chemical analyses of the rocks). Out of three samples two are from profile-SK. Sample SK-5 shows major amount of kaolinite as shown by 'd' values 7.16 (100), 3.57(90), 4.47(50), 4.35 (50), and 4.15 (50) (Table-3). On the other hand sample SK-2 is mainly diaspore having 'd' spacings 4.04 (100), 2.34 (75), 2.15 (65), 2.10 (85), 1.65 (65), and 1.62 (20), with minor amount of kaolinite as is evident from the 'd' values 7.02, 3.56 and 1.47. Similarly sample JK-3 from profile JK is also rich in diaspore (Table-3).

Determination by Differential Thermal Analysis (DTA) Method : As already noted by Ashraf et al. (1972), that the most common minerals in bauxite and kaolinite deposits are of the type which are suitable for investigation by DTA methods. The minerals present can be indentified by thier endothermic and exothermic reactions (Mackenzie, 1957 ; Bradley and Grim, 1951) and some information about their relative abundance can be obtained from the intensities of the reactions.

In Fig. 3 DTA results of profile-SK have been presented although most of the sample were run

TABLE I

Chemical Analysis

	SK—1	SK—2	SK—3	SK—4	SK—5	SK—6*	SK—2/1A	SK—2/2	SK—2/3	SK—2/4
SiO_2	36.00	11.60	27.90	9.70	37.80	43.20	39.80	7.60	6.01	22.00
Al_2O_3	44.00	68.00	51.78	68.95	43.10	36.60	41.60	71.43	74.00	58.10
Fe_2O_3	0.50	0.25	0.62	1.25	0.75	0.37	0.37	0.50	0.50	0.75
TiO_2	3.68	4.20	4.10	3.71	2.40	4.00	2.30	3.87	4.00	3.70
CaO	1.35	0.70	1.40	0.62	1.40	1.52	1.40	0.67	0.70	0.70
MgO	0.57	0.35	0.50	0.27	0.57	0.53	0.55	0.45	0.50	0.51
Na_2O	0.08	0.09	0.10	0.13	0.30	0.15	0.48	0.16	0.22	0.13
K_2O	0.002	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01
P_2O_5	0.40	0.50	0.55	0.25	0.36	0.60	0.38	0.35	0.40	0.39
Ignition Loss	13.70	14.70	13.60	14.40	13.60	13.60	13.40	14.40	14.00	13.80
TOTAL:	99.28	99.95	100.56	99.27	100.30	100.58	100.29	99.41	100.35	100.09

*Composite sample of weathered surface of the outcrop.

Contd.—TABLE 1

	R—1	R—2	R—3W	R—3R	R—2/2H	JKb	JK—3	JK—2	JK—1	JK—1N
SiO_2	41.74	37.61	40.40	37.60	14.40	39.80	2.55	2.80	24.00	4.70
Al_2O_3	38.80	43.00	40.75	32.00	69.10	41.15	76.05	76.22	55.53	74.58
Fe_2O_3	0,50	0.50	0.25	12.00	0.50	0.75	1.25	0.78	1.37	0.62
TiO_2	2.20	2.50	3.40	3,20	3.62	2.25	4.20	2.88	3.20	4.00
CaO	1,42	1,45	1.25	1,40	0.65	1.25	0.35	1.82	0.70	0.70
MgO	0,53	0.47	0.39	0,50	0,35	0.75	0.25	0.50	0.50	0.50
Na_2O	0,06	0.22	0.21	0.18	0.14	0,19	0.11	0.10	0.16	0.15
K_2O	0.002	0.02	0.01	0.01	0,03	0,01	0.002	0.02	0.02	0.01
P_2O_5	0.42	0.41	0.36	0.33	0.30	0,35	0.33	0.25	0.37	0.40
Ignition Loss	14,30	13.70	13.50	12.80	14.40	13.80	14.20	14.62	14.00	14.20
Total :	99.97	99.88	100.61	100.02	100.49	100.29	99.29	99.99	99.85	99.86

TABLE 2

Normative Composition

	SK—1	SK—2	SK—3	SK—4	SK—5	SK—6*	SK—2/1A	SK—2/2	SK—2/3	SK—2/4
Diaspore	15.85	68.78	34.08	71.80	14.08	0.00	11.11	77.02	81.64	46.79
Kaolinite	77.00	23.45	56.76	19.22	77.24	91.95	79.28	13.31	10.42	45.66
Quartz	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Albite	0.83	0.30	1.05	1.05	2.62	1.30	4.19	1.26	1.57	1.05
Orthoclase	0.02	0.03	0.05	0.06	0.11	0.06	0.05	0.06	0.11	0.05
Calcite	1.50	0.90	1.30	0.65	1.75	1.50	1.60	0.45	0.40	0.40
Magnesite	1.19	0.73	1.05	0.56	1.19	1.10	1.15	1.00	1.05	1.05
Apatite	1.01	1.34	1.35	0.50	0.84	1.36	1.01	0.84	1.01	1.01
Rutile	2.64	4.20	4.10	3.71	1.64	4.00	2.30	3.87	4.00	3.70
Hematite	0.50	0.25	0.62	1.25	1.00	0.37	0.37	0.50	0.50	0.75

*Composite samples of weathered surface of the outcrop.

Contd.— TABLE 2

	R—1	R—2	R—3W	R—3R	R—2/2H	JKB	JK—3	JK—2	JK—1	JK—IN
Diaspore	4.29	13.68	8.32	0.00	68.35	10.34	87.93	87.30	41.90	82.54
Kaolinite	89.65	78.38	84.39	79.72	27.50	81.08	3.92	4.61	49.58	8.05
Quartz	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Albite	0.63	1.57	1.57	1.57	1.31	1.57	1.05	1.05	1.31	1.31
Orthoclase	0.02	0.11	0.03	0.06	0.17	0.04	0.01	0.11	0.05	0.06
Calcite	1.60	1.70	1.45	1.90	0.60	1.45	0.00	2.71	0.40	0.40
Magnesite	1.10	1.47	0.81	1.05	0.73	1.54	0.52	0.15	0.15	0.15
Apatite	1.01	1.01	0.84	0.67	0.67	0.84	0.67	0.60	1.01	1.01
Rutile	2.20	2.50	3.40	3.20	3.62	2.50	4.20	2.88	3.20	4.00
Hematite	0.50	0.50	0.25	12.00	0.50	0.75	1.25	0.78	1.37	0.62

on DTA apparatus for their identification. Sample SK-1 shows major endothermic reaction at about 590°C with a small trough at 510°C and an exothermic reaction at about 950°C which shows major amount of kaolinite and some diaspore, the presence of diaspore in other samples has been confirmed in these rocks by X-ray. Similarly in a sample from zone SK-2 the major endothermic reaction at 535°C is due to diaspore mineral and minor exothermic kink at about 920°C possibly shows the presence of minor amounts of kaloinite. Sample SK-3 from middle zone shows a well marked endothermic peaks at 540°C and 590°C which are due to presence of diaspore and kaolinite in appreciable amounts in the rock. The exothermic reaction at 950°C is also well elaborated. Sample SK-4 is diaspore rich from an upper middle zone. This is evident as the early endothermic reaction is a 640° C and no other endothermic or exothermic peak has been observed. In the top most zone (SK-5) the kaolinite is the major constituent with minor amounts of diaspore as endothermic reactions have been obtained at 520°C for diaspore

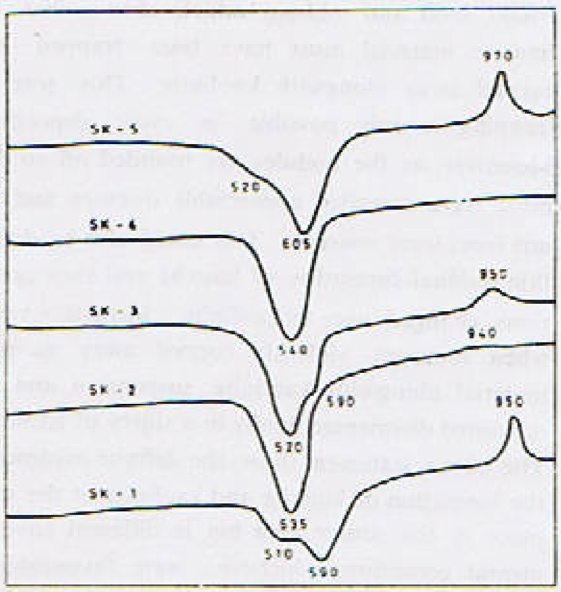

Fig. 3 Differential Thermal Analysis Curves of Bauxite from Profiles SK.

TABLE 3

X-ray Diffraction Data

SK—2		SK—5		JK—2	
'd'	I	'd'	I	'd'	K
7.02	10	7.16	100	4.7	5
4.80	20	4.74	10	3.9	100
4.04	100	4.47	50	3.18	10
3.56	20	4.35	50	2.32	30
3.24	10	4.15	50	2.12	70
2.58	50	3.98	30	2.05	70
2.34	75	3.83	30	1.62	60
2.15	65	3.74	10	1.59	50
2.10	85	3.57	90	1.56	5
1.91	10	3.51	30	1.47	50
1.83	10	3.37	10	1.39	30
1.73	20	2.56	50	1.37	50
1.65	65	2.53	10	1.33	30
1.62	20	2.49	50	1.32	30
1.47	10	2.34	30	1.29	30
		2.33	50	1.28	20
		2.29	30	1.25	20
		2.13	20	1.24	20
		2.07	10	1.21	5
		1.99	20	1.195	20
		1.98	20	1.17	40
		1.89	10		
		1.79	10		
		1.67	20		
		1.66	20		
		1.63	20		
		1.62	10		
		1.49	50		

and sharp endothermic and exothermic peaks for kaolinite at 605 and 970°C respectively. The results obtained above are comparable with chemical analyses and the X-ray analyses of the kaolinite and diaspore rich samples.

GENESIS

It has been emphasized by Gee (1944) and many present day workers that in the Salt Range and adjoining areas in Jurassic times there was definite evidence or subareal conditions due to the occurrence of ferruginous and light coloured bauxite. But it was found in the field and has been investigated in the laboratory that there are distinct zones of bauxite, kaolinite and patches of ferruginous material of contrasting composition which possibly cannot happen in areal conditions and is a product of repeated deposition. The bauxite and kaolinite deposits of the Chhoi area are the result of cyclic sedimentation in the epicontinental environments stable shelf regimes characterized by comparatively slow deposition, and with sandstones generally subordinate to argillaceous material (in the similar way Duff et al., 1967, found out).

The deposition of bauxite and kaolinite occurred in definite and distinct zones. In this area under study the basal (brown limestone) was uneven at the time of deposition and on this kaolinite material was deposited in variable thickness (even the succeeding bauxitic or kaolinite zones have variable thickness, which shows that with each deposition either there was a minor unconformity of short duration or the supply of the material was not uniform). It is conceivable from the kaolinite deposition that in the source area as soon as kaolinization was complete the material was transported to the present place. But as the next zone is of bauxite it is thought that in the source area bauxitization process must has been favourable, i.e., the remaining alumino-silicates were dissolved by weathering to form aluminium hydroxide and iron hydroxide in the tropical to subtropical humid environments. After the formation of bauxite in the source area and its removal and deposition in the present place, the weathering condition must have been subordinately persisting. This means there occurred a quick change from dry to tropical and humid conditions, which muddled up and formed a sort of mixture of kaolinite and bauxite. This is evident from the deposition of the above material in the area of profile SK as SK- bed. The deposition of 45 cm material (SK-4) in the same profile shows that the bauxitization conditions were again favourable for the formation of high purity bauxite. The deposition of mostly kaolinite rich top zone throughout the profiles studied show that the final environments in the source area were not favourable to proceed further to form bauxite. The conditions were only favourable to form kaolinite. In the profile JK in the top kaolinite zone nodules of bauxite have baeen observed. These nodules are round, oval and oblong which shows that the bauxite material must have been trapped and carried away alongwith kaolinite. This sort of trapping is only possible in cyclic deposition. Moreover, as the nodules are rounded off so they must have travelled appreciable distance and are not from local sources. This could also be due to thin residual formation of bauxite and then conditions changed over to kaolinite formation which when removed violently carried away as solid material alongwith kaolinite suspension and got deposited disoriented finally in a slurry of kaolinite. The above statement shows the definite evidence of the formation of bauxite and kaolinite at the same place in the source area but in different environmental conditions whichever were favourable in their formation.

The occurrence of irregular and patches of ferruginous material shows that the formation of laterite was not regular in all the zones, because the source rocks must have been rich in aluminium than iron and might be locally rich in iron. This lateritic material is not always rich in iron (Profile, R, about 12% Fe_2O_3), whereas the rest of the chemical constituents appear to be nearly fixing in kaolinite structure (in normative composition). The occurrence of lateritic thin films in the grey or grey creamish material along their joints and around the grains of bauxite and kaolinite is due to percolation of iron solutions.

The weathered surfaces have altogather different chemico-mineralogical composition (Table-1) as compared to the fresh outcrops—a phenomina already observed by Ashraf et al. (1972 a). It is also observed in the preceding pages that the composition of bauxite zone is not soley diaspore rather it is a mixture of diaspore and kaolinite. Therefore the weathered surfaces of outcrops of bauxite are conceived to be enriched in kaolinite (in dry environments) possibly due to leaching out major amount of aluminium hydroxide and minor amount of clay from the mixture by a reaction with acid solutions formed from percolating rain water and pyrite (a process contrary to the process of bauxitization) :

$$2Al(OH)_3 + 3H_2SO_4 = Al_2(SO_4)_3 + 6H_2O.$$

The paragenesis of diaspore in contrast to boehmite found at the same stratigraphic horizon in the Salt Range by Faruqi (1966) could be explained. The Salt Range boehmite occurs in structurally mildly folded and faulted area whereas in the present area the bauxite zone occurs in strongly faulted and folded environments. This sort of structural disturbance has caused a minor dynamic metamorphism which has changed boehmite to diaspore, the most stable form of aluminous hydroxide mineral (Deer, Howie and Zussman, 1962).

ACKNOWLEDGEMENT

The authors are grateful to Mr. Mahmood ul Hassan of Pakistan Geological Survey for useful field discussions. They are obliged for the X-ray studies of samples to Dr. Rizvi, PCSIR Laboratories, Karachi. Dr. Okuda of Japan and Professor Dr. H.J. Oel, Glass and Ceramics, University of Erlangen, West Germany. Mr. Riaz Ahmad of PCSIR Laboratories, Lahore, kindly carried out DTA of the samples. They are thankful to Farzand Ali Gill for his help during chemical analysis. The critical review of the manuscript by Mr. Waheedud Din Ahmad Director, Geological Survey of Pakistan and Dr. P.L.C. Grub of Institute of Mining Research, University of Rhodesia, is highly acknowledged.

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(Manuscript Received March, 1975)

TABLE 1

Chemical Analyses of Chromites from Serpentinite Belt, North of Muslimbagh.

	54*	56	58	59	60	61	67
Cr_2O_3	58.89	58.25	49.95	54.63	55.34	50.66	53.95
Al_2O_3	9.60	10.32	20.31	13.89	12.86	18.86	13.29
Fe_2O_3	5.51	4.01	1.14	2.50	1.88	2.34	3.68
V_2O_5	traces	traces	0.07	Nil	traces	Nil	Nil
FeO	9.41	11.33	15.04	17.34	18.95	12.26	16.80
MgO	15.98	15.03	12.96	11.31	10.50	15.26	11.60
MnO	0.11	0.35	0.36	0.20	0.26	0.22	0.22
CaO	0.04	0.04	0.06	0.05	0.04	0.01	0.04
NiO	Nil	traces	0.04	traces	Nil	Nil	traces
TiO_2	0.28	0.26	0.09	0.13	0.09	0.16	0.17
SiO_2	0.16	0.32	Nil	Nil	0.24	0.27	0.25
Total	99.98	99.91	100.02	100.05	100.16	100.04	100.00
Cr/Fe	3.61	3.43	2.70	2.45	2.35	3.10	2.36
RO/R_2O_3	1.01	1.02	1.00	1.02	1.03	1.01	1.01
MgO/RO	0.75	0.69	0.60	0.53	0.49	0.68	0.54
Fe_2O_3/R_2O_3	0.07	0.05	0.01	0.03	0.02	0.03	0.05
MgO/MgO+FeO	0.63	0.57	0.46	0.39	0.36	0.55	0.41
$Cr_2O_3/Cr_2O_3+Al_2O_3$	0.86	0.85	0.71	0.80	0.81	0.73	0.80

Sample No.	Description
54	Dark brown massive chromite
56	Reddish brown chromites with serpentine in the interstices replaced by carbonate minerals.
58	Light brown massive chromite with carbonate mineral occupying the interstices.
59	Brown massive chromite with interstices filled by carbonate mineral.
60	Light brown massive chromite with interstices filled by carbonate mineral.
61.	Dark brown massive chromite with interstices filled by carbonate minerals.
67.	Light brown massive chromite.

*Numbers of samples correspond to numbers given in Ph.D. thesis.

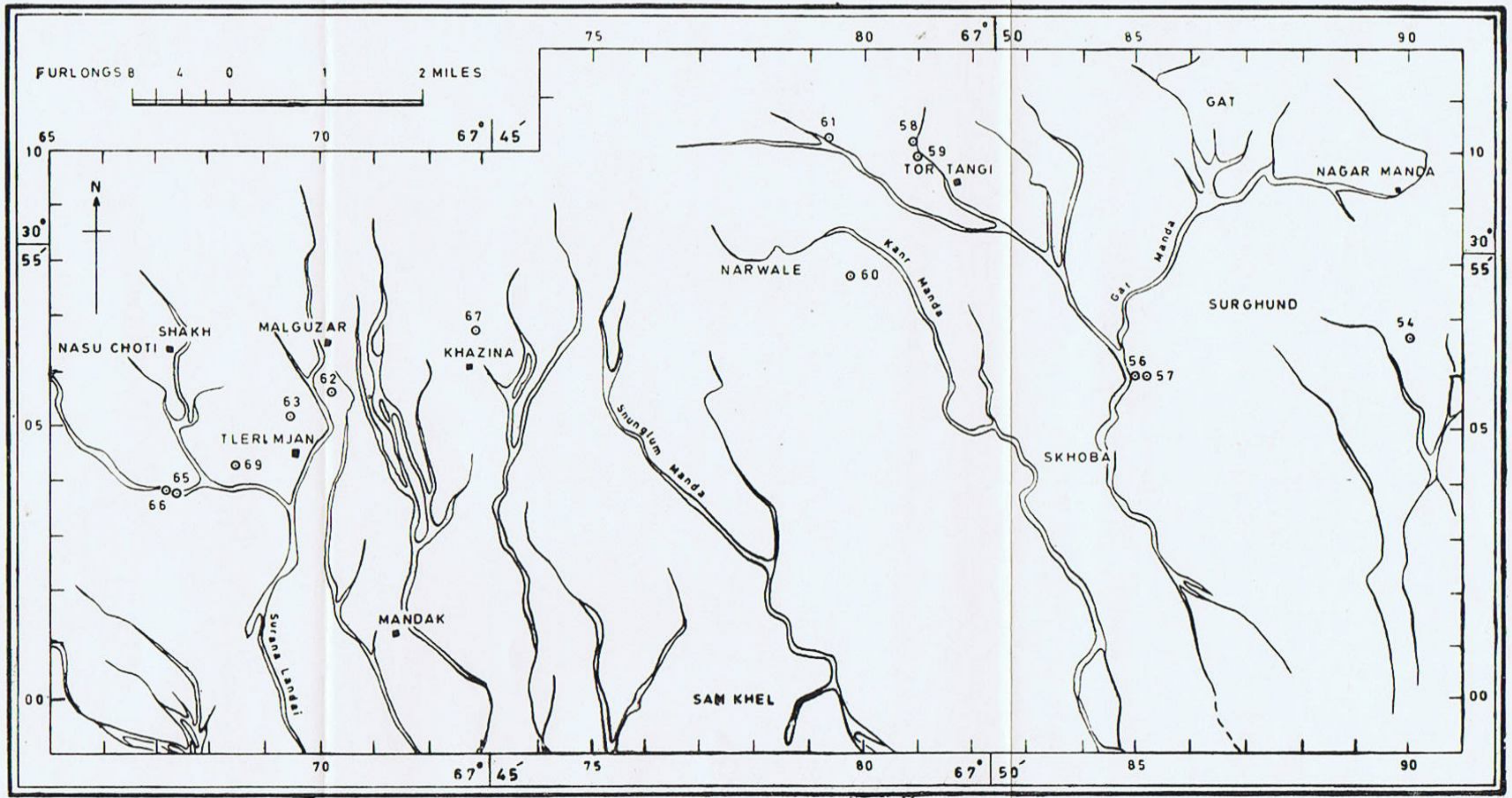

Fig. 1. Map showing location of Chromite sample studied.

56-57

TABLE 2

Unit Cell Contents on basis of 32 (O)

	Cr	Al	Fe^{3+}	Fe^{2+}	Mg	Composition
54	12.01	2.92	1.07	1.97	6.03	$Cr_{75}Al_{18}Mg_{76}$
56	12.03	3.18	0.79	2.39	5.61	$Cr_{75}Al_{20}Mg_{70}$
58	9.83	5.96	0.21	3.15	4.85	$Cr_{62}Al_{27}Mg_{61}$
59	11.25	4.26	0.49	3.69	4.31	$Cr_{70}Al_{25}Mg_{49}$
60	11.59	4.02	0.39	4.08	3.92	$Cr_{72}Al_{25}Mg_{49}$
61	10.01	5.55	0.44	2.51	5.49	$Cr_{62}Al_{38}Mg_{69}$
67	11.17	4.10	0.73	3.63	4.37	$Cr_{70}Al_{26}Mg_{55}$

End Member Percentages

Formula percentage

	54	56	58	59	60	61	67
Spinel	18.24	19.87	37.25	26.66	25.10	34.72	25.64
Magnesiochromite	57.19	50.24	23.55	27.26	23.93	33.95	29.02
Ferrochromite	17.88	24.96	37.88	43.03	48.52	28.59	40.81
Magnetite	6.69	4.93	1.33	3.05	2.45	2.74	4.53

Wright Percentages

	54	56	58	59	60	61	67
Spinel	13.52	14.71	28.46	19.54	18.24	26.71	18.80
Magnesiochromite	57.48	50.29	24.23	27.08	23.47	35.29	28.72
Ferrochromite	20.90	29.08	45.64	49.71	55.42	34.62	47.07
Magnetite	8.10	5.92	1.67	3.67	2.87	3.38	5.41

TABLE 3

Physical Properties of Chromites

	54	56	58	59	60	61	67
Specific gravity	4.455	4.485	4.418	4.547	4.590	4.383	4.549
Microhardness	1249	1225	1283	1211	1204	1299	1211
Cell edge dimension.	8.302	8.258				8.268	

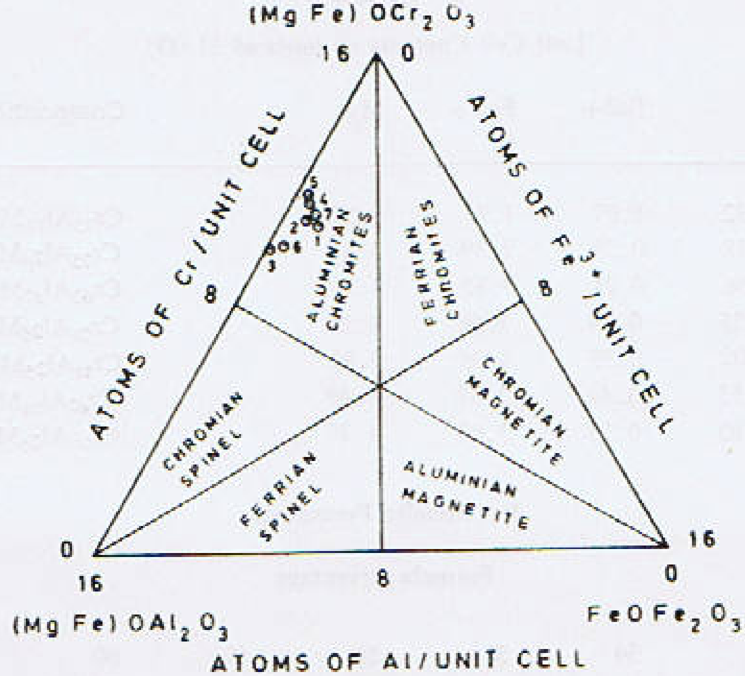

Fig. 2. Triangular Diagram showing Composition of Analysed Chromites North of Muslimbagh. (Sample Nos. 1-7 correspond to 54-67 given in table-1).

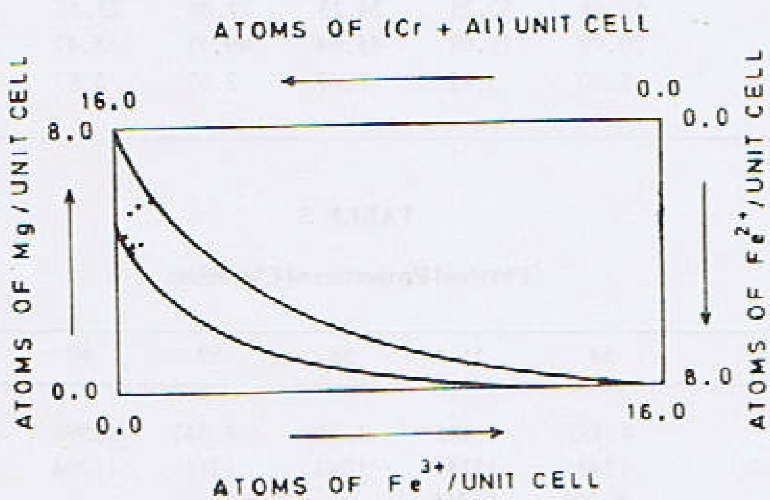

Fig. 3. Rectangular Diagram with Zone of Isomorphism, Composition of Analysed Chromites shown by Dots.

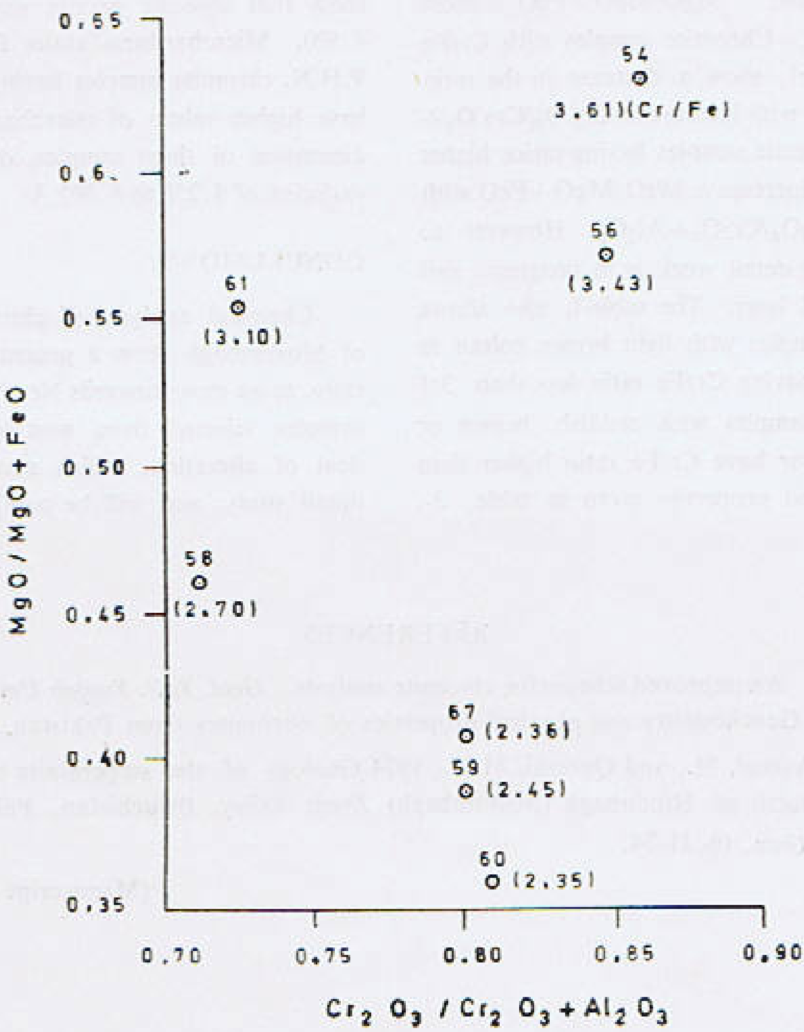

Fig. 4. Relation between $Cr_2O_3/Cr_2O_3+Al_2O_3$ and MgO/Mg+FeO in Chromites from north of Muslimbagh, (Cr/Fe Ratio given in brackets)

ratio varies from 2.35 to 3.61. Plot of Cr/Fe ratio in the map showing location of studied samples, show that Cr/Fe ratio decreases towards north. The contents of Cr_2O_3, decreases from 58.89% (S. No 54) to 49.95% (S. No. 58) whereas Al_2O_3 increases from 9.60% (S. No. 54) to 20.31% (S. No. 58).

The chemical analyses of purified chromite samples given in table-1, show that chromites from North Muslimbagh have a compositional variation of Cr_{62-73} Al_{18-37} Mg_{49-75}.

The formula percentages of spinel varies from 18.24% to 37.25%. Magnesio chromite varies from 23.55% to 57.19%. Ferrochromite varies from 17.88% to 48.52%. Magnetite varies from 1.33% to 6.69%.

The chemical composition of chromites plotted in spinel triangle (Fig. 2) show that all these chromites are aluminian chromite. A plot of the analysed chromites in rectangular diagram (Fig. 3) show, all the chromites lie in the zone of isomorphism. Fig. (4), a plot of the ratios Cr_2O_3/

$Cr_2O_3+Al_2O_3$ and $MgO/MgO+FeO$ show two set of curves. Chromite samples with Cr/Fe ratio less than 3:1, show a decrease in the ratio $MgO/MgO+FeO$ with increase in $Cr_2O_3/Cr_2O_3+Al_2O_3$. The chromite samples having ratios higher than 3:1 show an increase in $MgO/MgO+FeO$ with increase in $Cr_2O_3/Cr_2O_3+Al_2O_3$. However to establish this fact detail work is in progress and will be published later. The table-1, also shows that chromite samples with light brown colour in thin section are having Cr/Fe ratio less than 3:1 while chromite samples with reddish brown or dark brown colour have Cr/Fe ratio higher than 3:1. The physical properties given in table 3-, show that sepecific gravity varies from 4.383 to 4.590. Microhardness varies from 1204 to 1299 V.H.N. chromite samples having higher Al_2O_3% have higher values of microhardness. Cell edge dimension of three samples, determined show a variation of 8.258 to 8.302 A°.

CONCLUSIONS

Chemical analyses of chromites from North of Muslimbagh show a general fall in the Cr/Fe ratio, as we move towards North. All the chromite samples selected from west have suffered a good deal of alteration, which marks the subject of a detail sutdy, and will be published later on.

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(Manuscript received July, 1976).

INVESTIGATION OF NONOPAQUE HEAVY MINERALS FROM SANDSTONES OF PAB AND LOWER RANIKOT FORMATIONS IN SIND PROVINCE

BY

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Abstract : *Investigation of heavy fractions greater than 2.8 specific gravity of selected surface samples of sandstone from Pab Range and selected core sandstone samples of Lower Ranikot Formation from wells drilled in Thano Bulla Khan area of Sind Province indicate the presence of nonopaque heavy minerals such as tourmaline, amphibole (mainly hornblende), zircon, pyroxene (mainly augite), biotite, garnet, epidote and staurolite. Opaque heavy minerals are pyrite, magnetite and ilmenite. The percentage of heavy minerals vary from one sandstone bed to another in the same formation though variety and type of heavy minerals remain the same.*

Sandstones of Pab Formation of Upper Cretaceous age and Lower Ranikot Formation of Lower Paleocene age may be differentiated on the basis of nonopaque heavy minerals such as tourmaline and epidote. Tourmaline and epidote are negligible to absent in Pab Sandstone where as they are commonly present in Lower Ranikot Sandstone. Tourmaline is more in abundance than epidote in Lower Ranikot sanstone and is easier to recognize. So tourmaline may be considered as the diagnostic nonopaque heavy mineral to differentiate the two sandstones namely Pab and Lower Ranikot. Comparative study of the two sandstones is given in table-1 and their nonopaque heavy mineral proportions and frequencies in tables-2 & 3.

INTRODUCTION

Heavy minerals were investigated from surface sandstone samples from Pab Formation of Upper Cretaceous age, which were collected by special party from Pab Range. Selected core sandstone samples from Lower Ranikot Formation of Lower Paleocene age were collected for heavy minerals investigation from core—2 of Hundi—1 well at depths between 1156 to 1159 metres, cores 28 to 37 of Hundi—2 well at depths between 1327 to 1445 metres, cores 28 to 31 of Gadularo-1 well at depths between 1634 to 1859 metres and cores 9 to 19 Khothar—1 well at depths between 1332 to 1810 metres. These wells are located near Thano Bulla Khan area in Dadu district of Sind Province.

Pab Sandstones are generally dirty light yellow to light grey, compact, hard, pyritic and slightly to highly calcareous. Terrigenous grains are angular to rounded, mostly poorly sorted, of very fine to coarse sandy sizes and mainly quartz. Larger quartz grains are often cracked. Other constituents are feldspars, and rock fragments in argillaceous-calcareous matrix which forms up to 40%. Lower Ranikot Sandstones are variegated dirty white and black, moderately soft to soft, generally friable, micaceous (mostly muscovite), highly pyritic, mostly nondolomitic and noncalcareous to slightly calcareous with residue of lignitic materials in different proportions and frequently lenses of arenaceous shale of different sizes. Clastic grains are fairly sorted, angular to subrounded but mainly subangular, very fine to medium sandy sizes and mainly quartz. A few coarse sandy grains are also present, which are often cracked. Other clastic constituents are mainly feldspars (mostly basic plagioclase), mica (muscovite) and rock fragments in carbonaceous-argillaceous matrix which constitutes between 10 to 30 %.

The above two sandstones namely Pab and Lower Ranikot are thickly bedded sandstones intercalated with shales and are generally fossiliferous. Preliminary investigations of heavy minerals are made at the suggestion of Chief of Laboratories Dr. M.H. Khan in order to determine the diagnostic characters and differentiate Pab Sandstone from Lower Ranikot Sandstone. An attempt is made in this direction and further detailed heavy mineral investigations are to be made in order to divide each formation into zones and sub zones.

METHOD

Each sample of about 50 grams is crushed with morter to liberate the heavy mineral grains. It is then passed through 45 sieve (0.35 mm) and is retained on 200 sieve (0.075 mm). This procedure removes coarse sand as well as silt and clay. Thus sample having grains between 0.35 mm and greater than 0.75 mm is obtained, which is boiled in diluted hydrochloric acid of about 20% strength in a porcelain dish for about fifteen minutes to dissolve carbonates and iron oxides. Diluted acid is then decanted and washed out with ordinary water till acid traces are removed. Complete removal of acid is confirmed by litmus paper, which remains unchanged in case no acid trace is present. The sample is then dried at temperature between 100°—150°C in an oven and is ready for separation of heavy fraction.

Twenty to twenty five grams from the dried sample is taken out and put into a separating glass funnel, the stem of which is attached with a piece of rubber tube closed by a pinch clamp and having about 100 cc boromoform of specific gravity of about 2.8. It is stirred at intervals so that heavy minerals do not stick to the walls of the glass and are settled into the stem of the funnel. The pinch clamp is then opened in order to let the heavy fraction come out, which is retained on a filter paper placed on a second glass funnel. The second glass funnel is kept below the stem of the separating funnel for this purpose. The filter paper containing the heavy fraction is then washed with acetone till boromoform traces are removed. Heavy fraction is dried in an oven at about 50°C. It is weighed and the percentage of heavy fraction is calculated. Now heavy fraction is ready for microscopic examination. Minerals are examined both in heavy liquids and in slides mounted with Canada balsam. Relative percentages of heavy minerals are determined by counting the number of grains of different minerals present in the slide. Two or more slides are examined from each fraction in order to get the relative percentages of heavy minerals which are represented by proportions and frequency numbers as shown below :—

Approximate %	Proportion	Frequency
Greater than 60	Very abundant	8
30—60	Abundant	7
15—30	Fairly abundant	6
7—15	Very common	5
4—7	Common	4
2—4	Fairly common	3
1—2	Scarce	2
Less than 1	Rare	1

DISCUSSION

Comparative petrographic investigations of sandstones from Pab and Lower Ranikot formations

TABLE 1

Comparative Petrographic Study of Pab and Lower Ranikot Sandstones

LOWER RANIKOT SANDSTONE	PAB SANDSTONE
(1) Lower Ranikot Sandstone is of lower Paleocene age.	(1) Pab Sandstone is of Upper Cretaceous age.
(2) Lower Ranikot Sandstone is mostly variegated dirty white and black, moderately soft, generally friable, micaceous, highly pyritic, mostly non-calcareous to slightly calcareous, unfossiliferous with residue of lignitic materials in different proportions & frequency of lenses of arenaceous shale of different sizes.	(2) Pab Sandstone is light yellowish to grey, compact, hard, pyritic, slightly to highly calcareous and mostly unfossiliferous.
(3) Terrigenous grains of sandstone are fairly sorted, angular to subrounded but mainly subangular, generally very fine to medium sandy sizes and mostly quartz. Other detrital constituents are feldspars, mica (mainly muscovite) fragments.	(3) Terrigenous grains of sandstone are angular to rounded, mostly poorly sorted, very fine to coarse sandy sizes and mainly quartz. Other constituents are feldspars, and rock fragments.
(4) Matrix of sandstone is mainly carbonaceous and argillaceous and varies from 10 to 30 %.	(4) Matrix of sandstone is mainly argillaceous and calcareous and forms up to 40%.
(5) Molasse like sandstone i.e., mainly subgrawacke to protoquartzite.	(5) Flysch like sandstone i.e., mainly grawacke type.
(6) Heavy minerals are mainly tourmaline, hornblende, zircon, pyroxene, biotite, garnet, epidote, pyrite, ilmenite and magnetite.	(6) Heavy minerals are mainly hornblende, zircon, pyroxene, biotite, garnet, pyrite, ilmenite and magnetite.
(7) Heavy minerals are mainly angular to subrounded and so seem to have been derived mainly from igneous and metamorphic rocks.	(7) Heavy minerals are angular to rounded and so seem to have been derived from all the three main groups of rocks mainly igneous, metamorphic and sedimentary.
(8) Among nonoqaque heavy minerals, pleochroic minerals such as tourmaline hornblende, biotite and epidote are nearly equal to nonpleochroic minerals such as zircon, pyroxene and garnet.	(8) Among nonopaque heavy minerals, pleochroic minerals are always less than nonpleochroic minerals and generally less than 35%.
(9) Tourmaline and epidote are commonly present in heavy fraction. Tourmaline is always more in abundance than epidote and is easy to recognize and so may be considered as the diagnostic heavy mineral for Lower Ranikot sandstone to differentiate from Pab Sandstone.	(9) Tourmaline and epidote are rare or absent.

TABLE 2

Nonopaque Heavy Minerals, their Important Properties, Proportions and Frequency Number in Pab and Lower Ranikot Sandstones.

Minerals	Colour & Pleochroism	Diagnostic characters	Lower Ranikot Sandstone		Pab Sandstone	
			P	F	P	F
Tourmaline	(*i*) Pinkish to dark. (*ii*) Yellowish green to dark.	Absorption w>e Uniaxial (—)	C	4	R	1
Hornblende	(*i*) Bluish green to dark. (*ii*) Yellowish to dark. (*iii*) Dark brown to red.	Absorption Z>Y>X Biaxial (—) ; 2 sets of cleavages at 56° & 124° but are occassionally observed.	FA	6	A	7
Zircon	Colourless to dirty.	Uniaxial (+) ; dirty because of minute inclusions.	VC	5	VC	5
Augite	Colourless to neutral	Two sets of cleavage at about 90° ; Biaxial (—).	A	7	A	7
Biotite	Dark brown with occasional greenish at edges.	Isotropic or nearly isotropic because of basal plane ; Symmetrical uniaxial interference figure (—).	VC	5	C	4
Garnet	Colourless to Pinkish.	Isotropic with conchoidal fracture.	FC	3	VC	5
Epidote	Colourless to yellowish green (not uniformly distributed).	Biaxial (—).	FC	3	R	I
Staurolite	Golden yellow (Inclusions common).	Absorption Z>Y>X : Hackly to subconchoidal fracture ; Biaxial (—).	R	1	R	1

Approximate %	60	30—60	15—30	7—15	4—7	2—4	1—2	1
Proportion (P)	Very abundant (VA)	Abundant (A)	Fairly abundant (FA)	Very common (VC)	Common (C)	Fairly Common (FC)	Scarce (C)	Rare (R)
Frequency numbers (F)	8	7	6	5	4	3	2	1

are given in table—1. Nonopaque heavy minerals mainly hornblende, zircon, pyroxene, biotite and garnet are recognized in Pab Sandstone where as in Lower Ranikot Sandstone the identified nonopaque heavy minerals are mainly tourmaline, hornblende, zircon, pyroxene, biotite, garnet and epidote. These nonopaque heavy minerals vary in percentage from one bed to another in the same formation, though variety and type remain the same. So representations are made by proportions and frequency numbers as shown in tables 2 and 3. It is evident from tables that the two sandstones belonging to Pab and Lower Ranikot formations may be differentiated on the basis of the presence of tourmaline and epidote. Tourmaline and epidote are rare or absent in Pab Sandstone whereas they are commonly present in Lower Ranikot Sandstone. Tourmaline is comparatively more in abundance than epidote in Lower Ranikot Sandstone and is also easier to recognize and so tourmaline may be considered as the diagnostic heavy mineal to differentiate the two sandstones namely Pab and Lower Ranikot.

TABLE 3

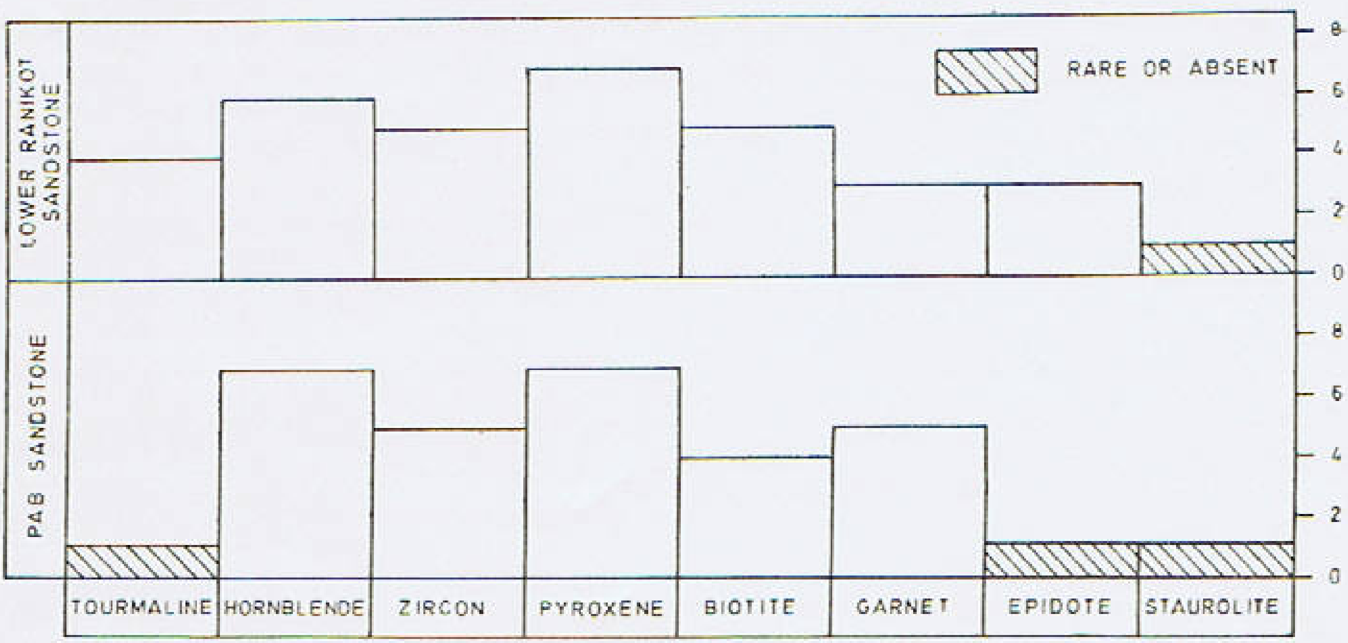

Table. 3 Histograms showing Nonopaque heavy Mineral's Frequencies in Pab and Lower Ranikot Sandstones.

(Manuscript received December, 1975).

GEOLOGY OF BABUSAR AREA, DIAMIR DISTRICT, GILGIT, PAKISTAN

BY

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Abstract : *A geological map of 67.4 sq. km. area near Babusar, Gilgit Agency, Pakistan, has been prepared on a scale of* 1 : 63, 360. *Detailed petrography of various rock units with* 20 *selected modal analyses is given. Ten chemical analyses are reported. Regional metamorphites of both ortho-and para-type occur in the Babusar area in addition to a small peridotite body.*

Pelitic, carbonaceous and calcareous schists of upto almandine grade belonging to the Precambrian Salkhala Series lie in the south. Between these and the Thak Valley Igneous Complex to the north are concordantly present metaigneous rocks of chlorite to almandine grade and a higher grade banded amphibolite. Minor dykes and sills intruding these metasedimentary and metaigneous rocks, were subjected to amphibalite facies regional metamorphism. A Tertiary **alpine** *peridotite was intruded into the banded amphibolite as a curved L—shaped lensoid body.*

INTRODUCTION

The Babusar area is situated in the northern Pakistan, West of the Nanga Parbat mountains in Gilgit Agency. The present geological investigations are related to 67.4 square kilometers area lying between the longitudes 74°0′ and 74°5′ east and latitudes 35°8′30″ and 35°13′30″ north. It includes the 4115 metres high Babusar Pass, an important road route connecting the Kaghan Valley to its south with the Indus Valley to its north. The area possesses very high relief, and altitude ranges from 3048 metres to 4725 metres.

The only literature available prior to the present study describing in significant detail the geology of the area is a paper by Wadia (1933) on the Nanga Parbat region. However, our results are very much different from his paper. A comparison of our geological map (Fig. 2) and that by Wadia (Fig. 1) shows a clear difference even in the names and outcrop pattern of the rock units mapped.

GENERAL GEOLOGY

The rock types exposed in the Babusar area may be considered as belonging to three broad groups :

(*a*) *Metasedimentary Rocks* : These are the oldest rocks of the area belonging to the Salkhala Series of Precambrian age (Wadia, 1933). They are exposed in the southern part of the area, including the Babusar top, and also occur beyond the southern boundary of the area. They are perfectly schistose and intensely folded and crenulated. However, the contacts between various lithotypes are more or less parallel to one another in an east-west direction, which is their general strike direction. Petrographically, they

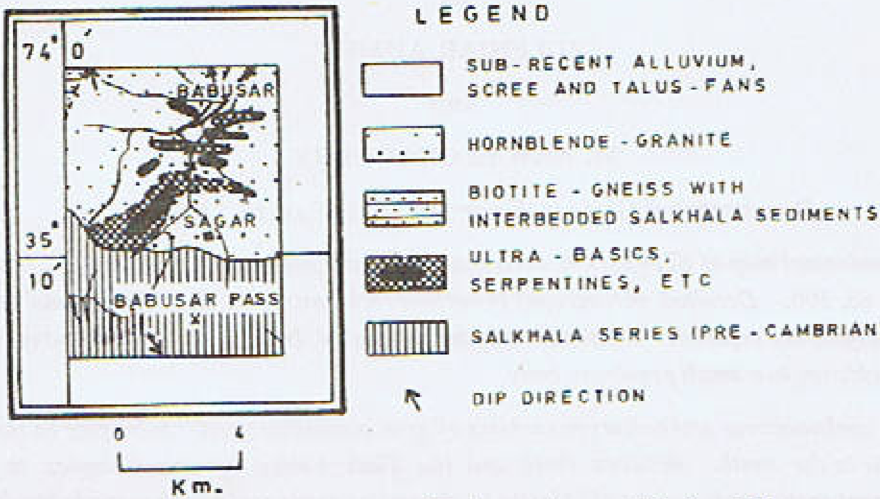

Fig. 1. Geological Map of Babusar Area. (Wadia, 1933).

may be divided into chlorite schist, graphitic mica schist, calcareous schist, garnet mica schist and quartzitic schist. The last two are not shown on the map, as they occur as interbeds in the graphitic mica schists and calcareous schists.

(*b*) *Metaigneous Rocks* : This group includes rocks of gneissic nature and is only gently folded except the chlorite schists. Their foliation shows an approximate constant east-west strike with gentle to moderate northerly dips. The contacts between different rock units run almost parallel to one another in east-west direction. This group includes the following six units encountered from south towards north : banded amphibolite, garnetiferous banded amphibolite, biotite-chlorite, gneiss, chlorite gneiss, chlorite schist. The banded amphibolite also shows small outcrops inside chlorite gneiss and chlorite schist.

In addition, there are dykes, sills and veins of dark coloured amphibolite that occur in both the metaigneous (chlorite schist and gneiss) and metasedimentary rock outcrops.

(*c*) *Peridotite* : It is a small curved "L" shaped lens of peridotite intrusive into the banded amphibolite and the garnetiferous banded amphibolite as shown in the geological map (Fig. 2). It pinches out gradually at both ends. Apparently, it lacks a contact metamorphic aureole. Its contacts are conspicuous.

PETROGRAPHY

(*a*) *Metasedimentary Rocks* : The outcrops of the Salkhala Series cover the southern one fourth part of the mapped area. These are perfectly schistose rocks with a general east-west strike of their foliation. Very often they are complexly folded and crenulated. In the geological map they are shown as three rock units, i.e., the chlorite schists, the graphitic mica schists and interbedded calc-pelitic schists. The last two outcrops contain abundant interbeds of the garnet mica schists and quartzitic schists. Thus the calc-pelitic schists are composed of calcareous schists, pelitic mica-and garnet mica-schists.

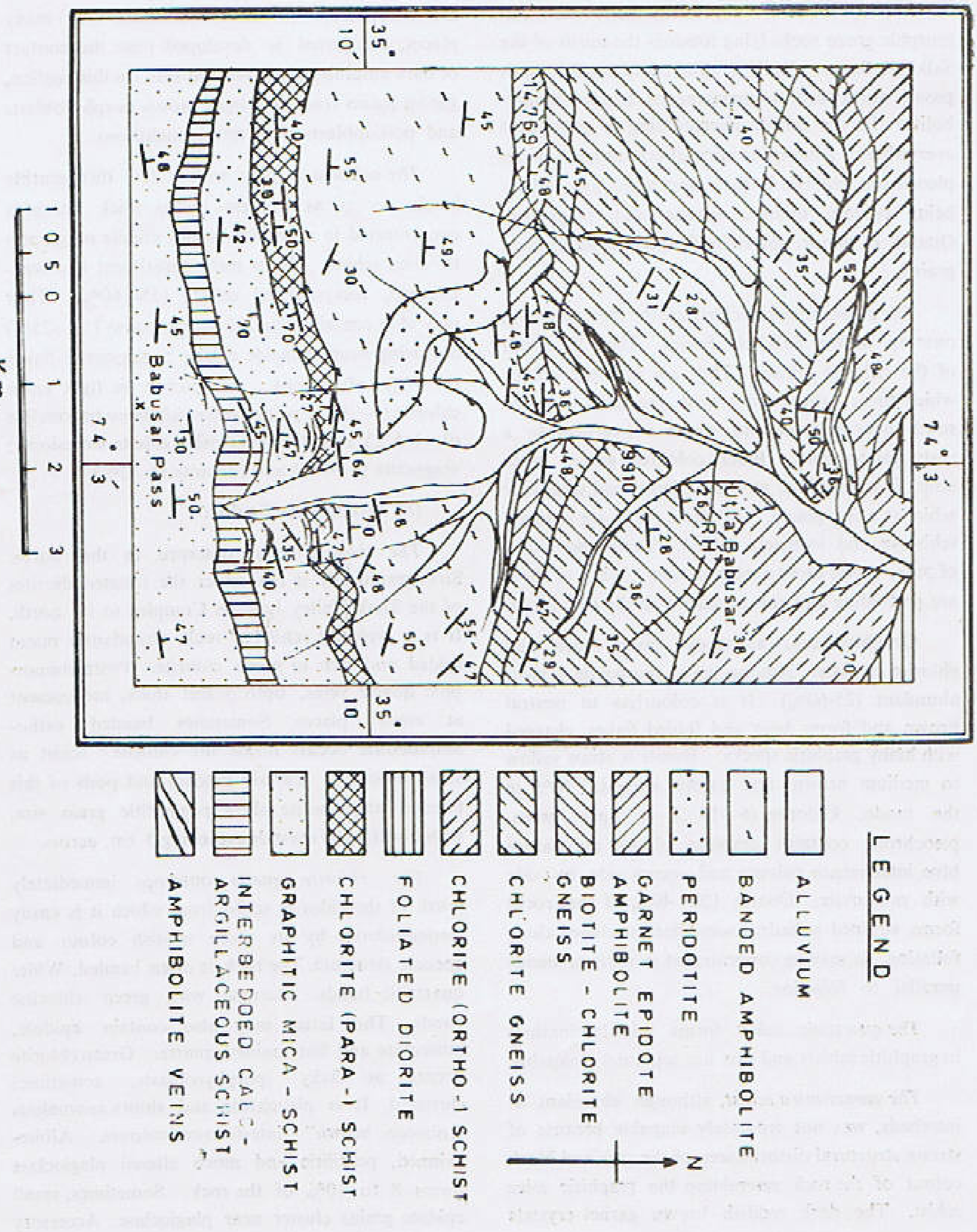

Fig. 2 Geological Map of the Babusar area, Gilgit Agency.

The chlorite schist represents the lowest metamorphic grade rocks lying towards the north of the Salkhala Series. With a thin transitional zone it passes northward to metaigneous banded amphibolite. In the schist, microfolding is prominent everywhere. Among its mineral constituents, green pleochroic chlorite is the most abundant: others being epidote, quartz, sphene and magnetite. Quartz is minor, interstitially present as strained grains.

The graphitic mica schists are the most extensive outcrop of the Salkhala Series. They lie south of the chlorite schists. They are of black colour which turns lighter and greyish gradually towards south (near Babusar top) where it weathers to a rusty yellow rock. Black coloured garnet mica schist is interbedded at many places, and quartzitic schist at a few places. All these rocks are strongly schistose and intensely folded. Veins and lenses of pure, coarse quartz are common. Many of these are prefolding and run parallel with the fold limbs.

Graphite occurs as specks inside mica and chlorite crystals. Among micas muscovite is most abundant (25-60%). It is colourless to neutral brown and forms bent and folded flakes charged with many graphitic specks. Biotite is straw yellow to medium brown and rarely exceeds 10% in the mode. Chlorite (6—19%) is light green, pleochroic, contains graphite, shows anomalous blue interference colours and occurs side by side with muscovite. Quartz (20—40% of the rock) forms strained anhedra, sometimes stretched along foliation. It may be concentrated in veins or bands parallel to foliation.

The quartzitic schist forms thin laminations in graphitic schists and was not separately mapable.

The garnet mica schist, although abundant as interbeds, was not separately mapable because of strong structural disturbances of the area and black colour of the rock resembling the graphitic mica schist. The dark reddish brown garnet crystals are conspicuous in hand specimens. At many places, the garnet is developed near the contact of dark amphibolitic dykes and sills. In thin section, garnet forms fractured, light brown porphyroblasts and poikiloblasts with quartz inclusions.

The calcareous schist with a few thin marble bands, occurs as a few inches thick interbeds concentrated in a horizon in the middle of graphitic mica schists. Their main constituent is a well-twinned, recrystallized calcite (55—60%). They may also contain rounded quartz grains (13—25%) occurring near or inside calcite ; muscovite flakes (5—9%) often bent ; non-pleochroic light green chlorite (2—3%); pale to yellowish green tourmaline (0—1.5%), sometimes enclosing calcite inclusions ; magnetite (3—4%) and limonite (1—2%).

(*b*) **Metaigneous Rocks :**

The chlorite schist outcrops in the north. Stratigraphically it lies under the foliated diorites of the Thak Valley Igneous Complex to its north. It is a typically schistose rock, abundantly micro folded and rich in green chlorite. Postmetamorphic quartz veins, upto 3 feet thick, are present at many places. Sometimes banded ortho-amphibolite occurs inside the chlorite schist as small outcrops. Certain patches and pods of this banded amphibolite show pegmatitic grain size, with hornblende crystals exceeding 3 cm. across.

The chlorite gneiss outcrops immediately south of the chlorite schist from which it is easily distinguishable by its more whitish colour and gneissic structure. The rock is often banded. White quartzitic bands alternate with green chloritic bands. The latter may also contain epidote, muscovite and fine grained quartz. Green chlorite occurs as flaky porphyroblasts, sometimes clustered. It is pleochroic and shows anomalous "tobacco brown" interference colours. Albite-twinned, poikilitic and much altered plagioclase forms 8 to 10% of the rock. Sometimes, small epidote grains cluster near plagioclase. Accessory amounts of anhedral sphene and subhedral magnetite are present.

At places the rock turns less gneissic, poorer in chlorite, and richer in quartz and looks like a semi-gneissic granite. It contains abundant quartz (50 to 60%). Other minerals include clinozoisite, sericite and some chlorite.

Quartzofeldspathic lenses and veins are commonly present in the chlorite gneiss. In addition, simple pegmatites are present in which books of coarse primary muscovite usually exceed 1 cm. in thickness. Quartz is strongly sheared, and plagioclase is sericitized. Twinned albite forms big crystals. Sometimes garnet and calcite are seen in these pegmatites.

The biotite chlorite gneiss lies south of chlorite gneiss where biotite appears, in addition to chlorite which persists in fairly high amounts. Its texture is orthogneissic. Biotite forms small brown flakes which are slightly greenish near contact with chlorite gneiss. Quartz and epidote are consistently abundant, but hornblende varies in amount. Epidote occurs as coarse crystals, needles and fine irregular grains. Untwinned feldspar is often crowded with fine inclusions, albite twinned feldspar is much lesser. Chlorite shows anomalous brown interference colours. Sphene occurs in irregular aggregates of dense brown colour. Sometimes quartzofeldspathic lenses are found.

The garnetiferous banded amphibolite lies to the south of biotite-chlorite gneiss. It terminates gradually in the eastern part, whereas all other metamorphics run across the area and continue beyond its eastern as well as western limits. The rock shows strong lineation due to nematoblastic hornblende. Metamorphic banding is widespread.

The mineral components show a wide variation in relative amounts in different samples. Garnet is pink, often euhedral and transluscent. It is now uniformly distributed and may disappear for some distance and reappear. Sometimes garnetiferous bands alternate with those without garnet. Garnet is often porphyroblastic, fractured and possesses quartz inclusions. Along fractures, chlorite is seen showing anomalous blue as well as brown interference colours, some biotite may be associated with it. Rest of the chlorite is green, flaky, shows brown interference colours and occurs associated with hornblende. Hornblende is strongly pleochroic from light green to bluish green. It forms well developed subhedral to euhedral cystals. Its extinction angle ($c \wedge Z$) ranges from 10 to 18°. Clinozoisite occurs as small grains dispersed as well as aggregated. Quartz is usually abundant and occurs as strained anhedra, their aggregates, or as inclusions in hornblende. Feldspar is usually altered and untwinned, rarely fresh and twinned. Albite twins show a composition of An 5—7%. Anhedral magnetite and sphene are in minor mounts.

The banded amphibolite is well foliated gneissic rock that occurs south of the garnetiferous banded amphibolite and north of the Salkhala Series. The exposure narrows in the eastern part. This amphibolite also shows small outcrops inside chlorite schist and chlorite gneiss in the north, both of which may occur as bands or intercalations inside these small outcrops.

The composition and texture of banded amphibolite is highly variable. This is caused by (*i*) increase or decrease in the relative proportion of dark and light coloured minerals (*ii*) variation in grain size from medium grained to pegmatitic sized crystals. (*iii*) metamorphic segregation into alternate light and dark coloured bands.

Overall, the rock shows nematoblastic and gneissic texture. Bands rich in dark green to black needle like amphibole alternating with those richer in quartz,epidote and feldspar are common, although foliated amphibolite without segregational banding is not uncommon. At many places, both

TABLE 1

Modal Composition of Babusar Rocks

	1	2	3	4	5	6	7	8	9	10
Sample No.	11968	11962	11964	11967	11951	11937	11953	11907	11908A	11909
Hornblende	..	..	..	..	..	22.5	..	13.5	22.3	2.8
Ampbibole (non-pleochroic)	..	..	..	..	..	..	3.3	..	..	..
Epidote	22.4	42.0	1.2	..	..	38.7	33.9	19.4	24.1	18.6 (clinozoisite)
Quartz & untwinned Feldspar	15.2	27.2	39.6	24.7	52.1	28.5	35.0	59.1	42.7	54.4
Plagioclase (twinned)	..	..	..	..	38.7	..	3.0	0.6	2.0	2.8
Chlorite	54.0	13.6	19.1	..	6.0	6.5	8.0	5.1	4.1	13.7
Biotite	..	8.8	1.8	..	..	0.9	6.2	..	..	0.9
Muscovite	..	..	24.0	8.9	..	..	7.2	..	..	..
Graphite	..	.	11.6	..	..	..	..	..	..	..
Calcite	..	..	..	59.9	..	..	..	..	..	..
Garnet	..	..	2.0	..	2.6	..	..	..	1.5	4.2
Magnetite	2.9	1.1	..	3.9	..	2.9	0.5	2.4	1.9	2.0
Limonite	..	0.2	0.7	1.7	..	..	0.4	..	..	0.3
Tourmaline	..	..	..	0.9	..	..	..	..	..	..
Sphene	5.5	7.1	..	..	0.61	0.5	2.5	..	1.5	0.3

Description of samples :

Anal. No	Grid Reference	Description
1.	030394	Microfolded chlorite schist, Salkhala Series.
2.	020396	Biotite chlorite schist, Salkhala Series
3.	031388	Typical garnet mica schist from near basic amphibolite dyke in Salkhala Series.
4.	030384	Calcareous schist, Salkhala series.
5.	047420	Chlorite gneiss, quartz-rich semi-gneissic part
6.	025420	Biotite chlorite gneiss
7.	040420	Biotite chlorite gneiss.
8.	015421	Non banded sample from garnetiferous banded amphibolite
9.	015421	Gneissic variety of garnetiferous banded amphibolite
10.	015421	White band in garnetiferous banded amphibolite.

TABLE I —(*Continued*)

Modal Composition of Babusar Rocks

	11	12	13	14	15	16	17	18	19	20
Sample Nos.	11976	11908	11911	11916A	11916B	11939	11942	11918	11973	11966
Hornblende	0.5	56.0	..	31.0	1.6	37.0	51.7	36.4	..	49.1
Amphibole (non-pleochroic)	..	..	55.6	..	..	..	..	..	..	..
Epidote	15.9 (clinozoisite)	23.2	38.3 (zoisite)	21.2 (clinozoisite)	33.2	33.5	27.1	1.2	..	7.5
Quartz & Untwinned Feldspar	45.2	12.2	2.7	23.8	48.7	18.4	7.8	45.9*	59.5*	19.7
Plagioclase (twinned)	9.7	..	..	..	2.9	..		14.8	33.3	..
Chlorite	5.4	1.4	..	18.0	9.9	7.0	1.6	0.3	..	3.3
Biotite	0.4	..	..	1.2	0.6	..		..	..	1.1
Muscovite	2.9	..	..	..	..	..	..	..	6.5	..
Garnet	18.4	..	..	..	..	..	..	..	0.3	0.9
Magnetite	1.6	3.8	0.9	4.5	2.7	3.4	5.8	0.5	..	3.3
Limonite	..	..	..	0.1	0.4	0.7	..	..	..	0.5
Sphene	..	3.4	1.6	0.2	..	..	6.0	0.9	..	14.6

*Mainly feldspar.

Anal. No.	*Grid Reference*	Description of samples
11.	003421	Garnetiferous banded amphibolite.
12.	015421	Garnetiferious banded amphibolite.
13.	011419	Banded amphibolite with coarse amphibole crystals. Also contains 0.9%calcite.
14.	018399	Green band from banded amphibolite
15.	018399	White band from banded amphibolite
16.	028418	Banded amphibolite
17.	025461	Coarse pegmatitic facies of banded amphibolite.
18.	018399	Banded amphibolite with coarse hornblende crystals.
19.	198433	Pegmatite found inside chlorite schist of Salkhala Series and containing coarse alkali feldspar and 0.4% calcite.
20.	030387	Basic amphibolite dyke, 30 metres thick, inside garnet mica schist of the Salkhala Series.

the banded and non-banded types occur nearby. At a few places massive diorite occurs as boulder size lenses in foliated rock. Many quartz veins run through the rock. They are irregular and ptygmatically folded, and 1 to 30 cm. thick. Much thicker quartz veins, upto 7 metres accross are seen at the contact of dark amphibolitic sills. Also, there are quartzofeldspathic lenses upto 30 cm. wide.

Hornblende is the main mafic constituent. It may form porphyroblasts. It is often strongly pleochroic from light brownish green to bluish green. Extinction angle (c $\wedge$ Z) is 17° to 18°. Colourless epidote is found as dispersed grains and streaks. Quartz may occur as aggregates of anhedra, inclusions in hornblende or as porphyroblasts. Plagioclase is often untwinned and resembles quartz. Green pleochroic chlorite and anhedral sphene and magnetite are seen in minor amounts.

Certain patches and layers in the rock contain euhedral pink garnet, especially in hornblende rich bands.

Dark coloured facies of the rock form patches and inclusions. They are richer in hornblende and iron oxides and poorer in quartz and feldspar.

The compact granoblastic parts of this rock contain in colourless to light brown amphibole as coarse crystals. Its extinction angle ($c \wedge Z$) varies from 8° to 12°. It is often intergrown or replaced by zoisite. Zoisite may also form small independant crystals. Anhedral quartz and plagioclase occur together.

The banded rock is made of white bands richer in finely granular clinozoisite, anhedral quartz and much altered sodic feldspar. The green bands are richer in hornblende and chlorite. Hornblande forms stout prisms pleochroic from light green to bluish green. Chlorite is pleochroic from colourless to light green and shows anomalous brown interference colours. Clinozoisite, strained quartz and sodic feldspar are seen in smaller amounts. Magnetite, biotite and limonite are ubiquitous minor minerals. In some quartz-poor samples, the banded structure is weakly developed.

The coarse grained varieties of this rock are coloured greenish black with white streaks. They are gneissic in texture, and contain much hornblende and epidote alongwith smaller amount of quartz, plagioclase, sphene, magnetite, hematite, biotite and chlorite. Hornblende is strongly pleochroic and forms needles or fibres. Epidote forms discontinuous streaks made of small grains. Quartz is coarse and anhedral. Both twinned and untwinned feldspars occur. Small grains and wedges of sphene occur associated with magnetite. Chlorite also occurs. Some parts show big hornblende crystals, and white veins and patches are found in some.

Basic Amphibolities occur as dykes, sills and veins upto 15 metres thick lying inside the Salkhala Series as well as metaigneous chlorite gneiss. They may be folded, parallel to the folds in the enclosing rock or faulted. Sometimes they enclose lenses of the host chlorite gneiss and may be concordant with pure quartz bands developed along their contacts.

They are semi-schistose rocks made of quartz, epidote, hornblende, chlorite, sphene, biotite, iron oxides and sometimes garnet. Some of these form granoblastic dykes of more than 30 metres width. They may contain brown to medium green pleochroic hornblende (50 - 60%) with $c \wedge Z > 15°$; anhedral, colourless garnet (0 - 2 %) : anhedral quartz plus twinned plagioclase making upto 30% of mode. Sphene (10-14%) is of light brown colour and is cleaved ; epidote, 4-8% ; chlorite, 3-4%; brown biotote, 1-2% ; magnetite, 1-4% ; and limonite, 0-1%.

A few similar granoblastic but strongly sheared rocks are present in chlorite schists. They have faulted contact, and many layers of coarse quartz.

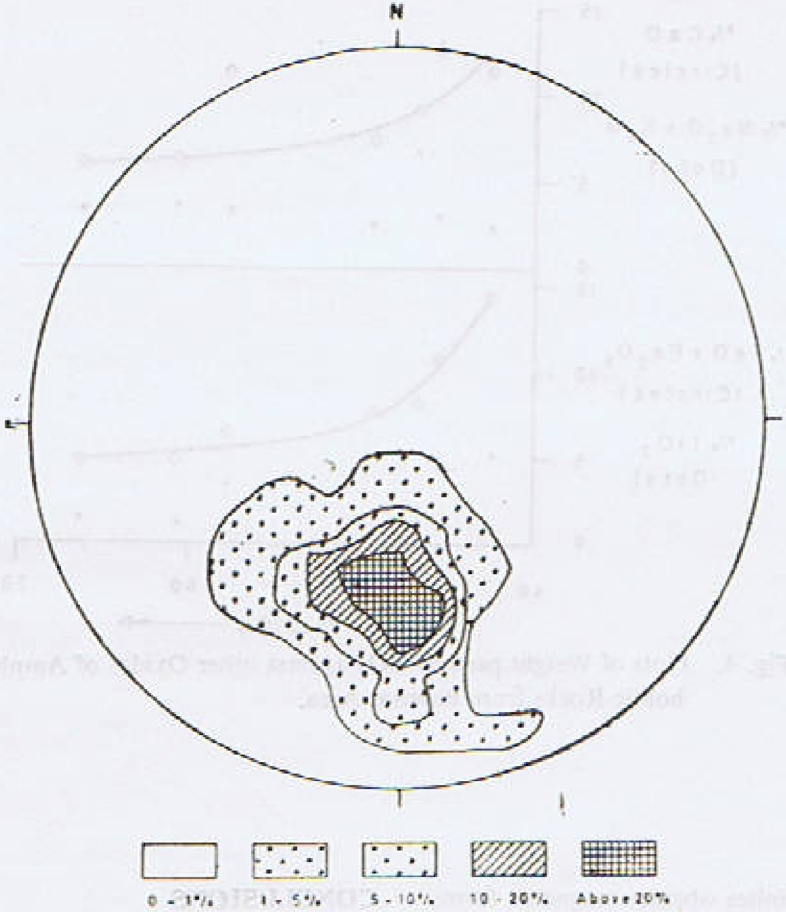

Fig. 3. Contour Diagram of Foliation Readings of Babusar Rocks Plotted on the lower Hemishare of Schmidt Net.

They contain abundant clinozoisite and quartz but very little hornblende. Clinozoisite forms small dispersed non-pleochroic grains of light green colour. Quartz is coarsely crystalline in veinlets parallel to foliation, even when the rock is micro-folded. At such places, quartz tends to concentrate at fold crests. Biotite is pale to brown green, often associated with chlorite, both displaying bent flakes.

Such amphibolites also occur in the garnetiferous banded amphibolite as a massive melanocratic rock with following composition : green, weakly pleochroic hornblende, 45-55%; nonpleochroic light green epidote, 35-35%; dis-dispersed quartz, 5-8%; altered plagioclase, 5% and a little limonite.

(c) *Peridotite* : It is greyish black, compact and coarse grained rock. It is composed of serpentine, augite, olivine, magnesite and magnetite in order of abundance. Serpentine forms radial aggregates and small heaps of flakes, being produced by alteration of olivine and augite. Augite is colourless to faint brown, nonpleochroic, and forms subhedral to euhedral crystals. Magnesite is

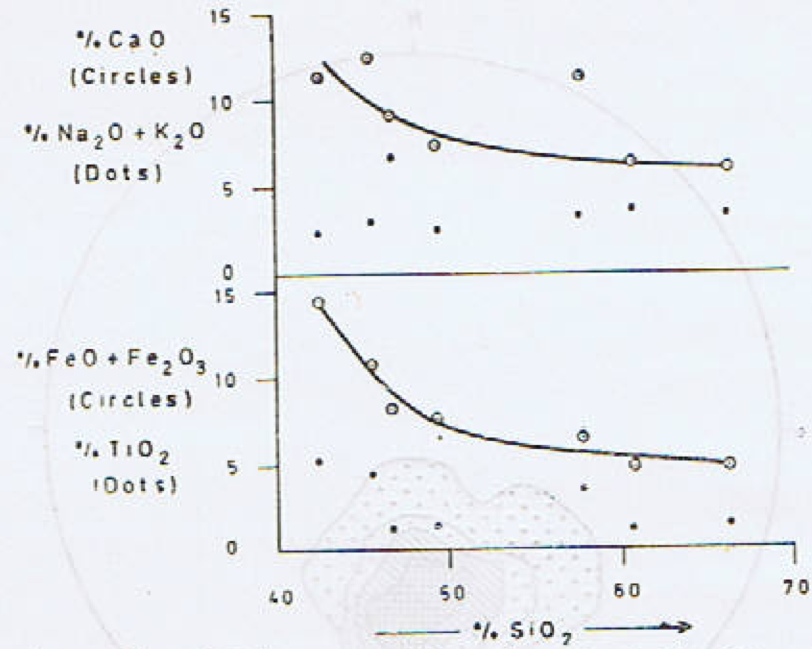

Fig. 4. Plots of Weight percent SiO_2 against other Oxides of Amphibolitic Rocks from Babusar Area.

present in small veinltes whereas magnetite forms both the subhedral scattered grains and the minute specks arranged in straight parallel rows. A little part of magnetite weathers to limonite. Average modal composition may be expressed as follows: serpentine, 45%; augite, 30%: olivine, 10%, magnesite, 8% magnetite, 5% and limonite, 0.1%.

CHEMISTRY

Chemical analyses of ten samples of the area are given in table 2. The metaigneous rocks (anal. 2—9) show variation in SiO_2 content from 42.46 to 66.18 percent. This shows the parent igneous rocks were of acid to basic composition. The plots of weight percentages of TiO_2, $FeO+Fe_2O_3$, CaO and Na_2O+K_2O against SiO_2 are shown in Fig. 4. TiO_2 and CaO display a decreac with increase in silica. Total iron first decreases rapidly then the curve flattens out.

CONCLUSIONS

Major events in the geological history of the area may be summarized as follows: (*i*) Deposition of pelitic, carbonaceous and siliceous sediments in the southern part of the area during Precambrian times. (*ii*) Low grade regional metamorphism of these sediments. (*iii*) Intrusion of intermediate to basic rocks and some simple pegmatites in the northern part of the area. (*iv*) Intrusion of basic dykes and sills, mainly in the south. (*v*) Second episode of regional metamorphism. (*vi*) Intrusion of a peridotite body. (*vii*) Intrusion of ultramafic, basic and intermediate rocks belonging to Thak Valley Igneous Complex just north of the area. (*viii*) Injection of some simple pegmatites.

As shown by the plot of foliations in the metamorphics, the main stress during regional

TABLE 2

Chemical Composition of Babusar Rocks

	11968	11951	11953	11909	11976	11916A	11916B	11942	11918	11973
SiO_2	47.60	64.32	46.72	60.70	66.18	49.22	57.80	42.46	45.44	67.56
TiO_2	2.66	1.06	1.24	1.24	1.59	1.42	3.54	5.32	4.43	0.88
Al_2O_3	23.09	20.26	23.26	19.18	12.67	25.54	14.01	15.39	14.53	18.46
Fe_2O_3	3.20	3.11	6.11	3.08	2.82	5.15	4.33	10.40	7.93	2.23
FeO	0.16	0.61	2.03	1.80	2.16	2.53	2.18	4.02	3.00	0.53
MnO	0.30	0.22	0.30	0.52	0.60	0.30	0.60	0.60	0.28	0.37
CaO	10.88	4.94	9.22	6.20	6.04	7.44	11.38	11.46	12.60	0.96
MgO	7.24	0.41	2.17	2.21	0.96	3.81	1.34	6.08	6.95	0.33
Na_2O	2.43	3.10	5.25	3.40	3.00	2.21	2.90	2.00	2.60	5.20
K_2O	0.35	0.50	1.45	0.20	0.35	0.23	0.50	0.30	0.25	2.10
P_2O_5	0.20	0.14	0.22	0.34	0.54	0.20	0.22	0.19	0.29	0.28
H_2O+	1.42	0.98	1.68	1.10	1.03	1.82	1.21	1.53	1.68	0.87
H_2O-	0.31	0.11	0.23	0.16	0.26	0.15	0.23	0.26	0.13	0.09
Total	99.84	99.76	99.88	100.13	98.20	100.02	100.24	100.01	100.11	99.86

The sample numbers correspond to those in table 1. Analyst. M. Nawaz Ch.

metamorphism was acting in the north-south direction.

The oldest rocks of the area are the Salkhala Series of Precambrian age (Wadia, 1933) represented by the low grade regionally metamorphosed derivatives of mainly pelitic and carbonaceous nature and to a lesser degree, of calcareous and siliceous type.

In the metaigneous as well as metasedimentary suites the general increase of grade of metamorphism is towards south. The metaigneous origin of the amphibolitic rocks of the area is indicated by their sharp contacts with the adjoining pelitic and calcareous metasediments. There are no calcareous or pelitic bands inside the amphibolites. The amphibolites generally have a uniform texture. The banding of the amphibolites may either be original or partly as a result of metamorphic differentiation. The mineralogy of these amphibolites is fairly uniform. Sphene is ubiquitous. The chemical composition of the amphibolitic rocks is fairly close to that of basic igneous rocks, and the titanium content is invariably high.

REFERENCE

Wadia, D.N., 1933 Note on the geology of Nanga Parbat (Mt. Diamir) and adjoining portions of Chilas, Gilgit District, Kashmir. *Rec. Geol. Surv. India*, 66, 212-234.

(Manuscript received, August 1976).

7271 feet. Local relief commonly exceeds 3000 feet. Generally the relief in the northern part is higher as compared with the relief in the southern part.

The drainage is dense, dendritic, and almost homogeneous. There are two main rivers, the Nilum and the Jhelum river. The former is also known as the Kishan Ganga river. The two meet at Domel about $1\frac{1}{2}$ miles south of Muzaffarabad. River Nilum flows throughout the area and many tributaries join it. Most of the streams make 'V' shaped valleys.

Steep slopes are characteristic of the whole area. The slope angle ranges between 35° to 65° degrees. Generally the slopes in the northern part are steeper as compared with the slopes in the south.

Thick alluvial terraces are present along Nilum river and some other major streams. These terraces are relatively flat and are composed chiefly of boulders, gravel, sand and some silt. These terraces are cultivated. The most noteworthy terraces include those of Dhanin, Manjhottar, Bandi Mir Samdani, and Tithwal.

Thick forests like Pir Sahaba forest, Beari forest, Chogali forest, Gratnar forest, and Banjwala forest are present. Elevations above 6000 feet are generally forested.

The area can be said to be passing from the youthful stage toward the stage of maturity.

GENERAL GEOLOGY.

Geologically the Muzaffarabad Nauseri area is very interesting. Lithologically a wide variety of rock types are exposed. Structurally the area is highly disturbed, faulted, and folded.

Most of the rocks exposed in the area are either sedimentary or metamorphic in origin. However, a few doleritic sills of igneous origin were also observed intruding the metamorphics.

The various rock types that have been differentiated and separated on the accompanying geological map are:

Sedimentary	Alluvial Deposits	Recent
	Murree Formation	Miocene
	Nodular Limestone	Eocene
	Muzaffarabad Limestone	Permocarboniferous
Metamorphic	Nauseri Granite Gneiss	Late Cambrian
	Tithwal Garnetierous Schists	Cambrian
	Hazara Slates	Cambrian
	Salkhala Series	Pre Cambrian

A brief description of these rocks is given bellow. Except Hazara Slates which outcrop west and south of Muzaffarabad all other metamorphic rocks are confined to the northern part of the area, i.e. beyond Nauseri. Between Muzaffarabad and Nauseri only the sedimentary rocks outcrop. For the description the stratigraphic sequence is ignored and the formations are described more or less in the order of their occurrence as one moves from Muzaffarabad to Tithwal Via Nauseri.

SEDIMENTARY ROCKS.

The sedimentary rocks in the mapped area are the most dominating. They cover over 65.0% of the toral area mapped. They are much younger as compared with the metamorphics.

Murree Formation. This rock unit is very extensively developed around Muzaffarabad. It starts from Muzaffarabad and continues right upto Nauseri on both sides of the river except in the Chahla—Batmang area where limestone outcrops within this formation. Because of faulted contacts and tight folding the actual thickness is not known.

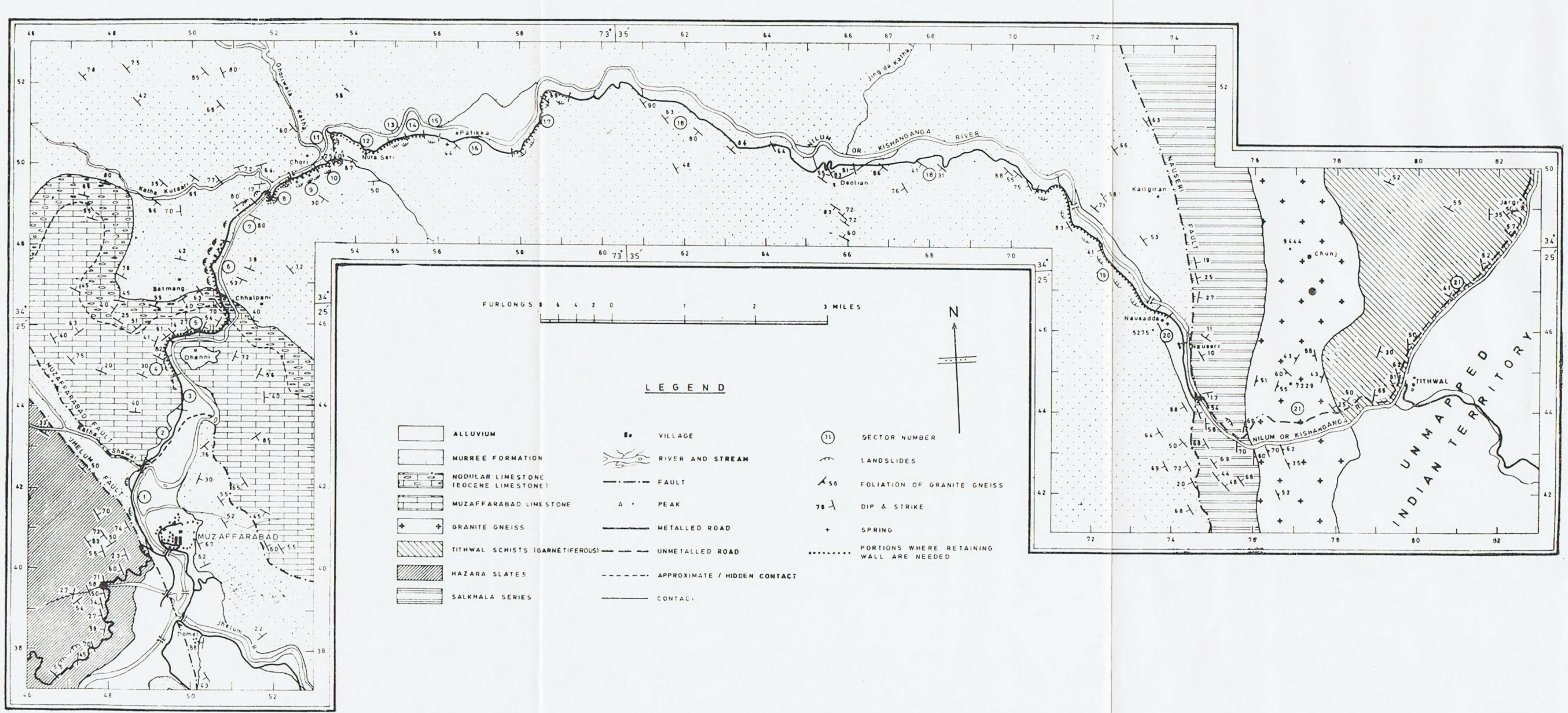

Fig. 1 A. Geological Map of Muzaffarabad-Nauseri Area, Azad Kashmir.

Near Muzaffarabad the Murrees which are sedimentary in origin and Miocene in age are in faulted contact with Hazara slates which are metamorphic and Cambrian in age. This is a long fault which in the south extends beyond Kohala all along the Jhelum river. Calkins and Matin (1968) have named it as Jhelum Fault and the same name is used here. In the north near Nauseri Murrees have been thrusted against the oldest rocks of the area, viz, Salkhalas. This is the largest thrust of Kashmir region. Similarly the contact of Murrees with Muzaffarabad Limestone along Katha Shawai is faulted and this fault is known as Muzaffarabad Fault (Calkins and Matin). The contact with Nodular Limestone is normal but transitional. In the transition zone limestone beds alternate with green, grey, and red shales. The transition zone is about 60 feet thick.

The Murree Formation in this area consists of red, thinly laminated siltstone and shale, thick-bedded to massive clays, and subordinate amounts of fine to medium grained, pale green to grey, and some maroon coloured calcareous sandstone of greywacke nature. The beds of sandstone and the clays and shales alternate with each other. Sometimes the sandstone beds are lens shaped and in a few places beds of conglomerate are interclated with the sandstone. Streaks and veins of calcite are quite common in sandstone and are placed generally at right angles to the bedding.

Petrographically sandstone is fine to medium grained, equigranular, with quartz 58%, calcite 30%, rock fragments 10% and iron ore 2% while the shales and clays are composed mainly of clay minerals 55%, heamatite 20%, calcite 10% and quartz 15%.

The Murrees in Muzaffarabad—Nauseri area are highly folded and well jointed. Local faulting and shearing is quite common. Strike and dip are highly variable.

They represent the weakest formation of the area as far as their engineering properties are concerned. The slopes in Murrees are highly unstable and very vulnerable to sliding. They provide very weak foundations for bridges.

Muzaffarabad Limestone : The grey coloured, unfossilliferous limestone that lies within Murrees close to Muzaffarabad and occupies the core of Muzaffarabad anticline is named as Muzaffarabad Limestone. It is similar to the "Great Limestone" of Wadia and the "Jummu Limestone" of Gansar (1964). Calkins and Matin (1968) have described it as Abbottabad Formation.

Muzaffarabad Limestone is well exposed in Katha Shawai, Chahla and Batmang areas. Because of faulted contacts and tight folding its exact thickness is not known. Approximately it is more than 2000 feet.

Muzaffarabad Limestone is in faulted contact with Murrees along Katha Shawi (Muzaffarabad Fault) and the upper contact with Nodular Limestone of Eocene age is unconformable.

It is thinly bedded, compact, dirty white and dark grey to black, fine grained, unfossilliferous, magnesian limestone which is often cherty. Lower and middle parts are dolomitized while the upper part is characterised by the presence of black siliceous clays and abundance of chert nodules and layers. The chert stands out on weathered surfaces.

Calcite, which occurs both in amorphous and crystallized form, constitutes 95% of the rock. Much of it has been dolomitized. Quartz forms 2% and very fine clay is 3%.

The trend is highly variable because of folding and faulting. Broad as well as tight folding can be seen. The limestone is well jointed and brecciated. Three sets, i.e., NW, NE and the one parallel to bedding are common. The joints are commonly filled with calcite veins.

From an engineering point of view the limestone is generally hard and dense but extensive jointing and shearing has rendered it quite weak. Creep and rock fall are not uncommon.

Nodular Limestone : It has been named as Nodular Limestone because of the very well developed nodular structure. It outcrops between Dhanin and Batmang and occupies a continuous belt of varying width. Where it crosses the Nilum river it is about 1300 feet thick.

The Nodular Limestone is conformable and transitional with the overlying Murree Formation and rests unconformably on the Muzaffarabad Limestone. This lower contact is faulted at some places.

Where the Nodular Limestone is found in beds, it is thinly bedded to massive, grey nummulitic limestone and grey to black carbonaceous shales with subordinate thickness of greenish grey calcareous shales and sandstones. In Batmang area the limestone is marly and highly nodular. The nodules range in size from 8" to 18". The black shally layers curve around the nodules. The graphitic and coaly material is present in high concentrations.

The limestone is generally bioclastic containing abundance of skeletal remains, especially Foraminifera. The fossils present have been identified as Operculina, Miscellanea, Lockhartia Alveolina and Assilina.

Nodular limestone is composed of almost 100% calcite. Small scale local folding and faulting has been observed. Slopes in this limestone are generally unstable.

Alluvial Deposits: These are mostly confined to the river and a few of the main streams. They are mainly composed of boulders and gravel embedded loosely in a matrix of sand and silt. Some of these deposites form very big and very high terraces. The Dhanin terrace on which village Dhanin is located is about 500 feet thick.

METAMORPHIC ROCKS

Hazara Slates : These are fine grained, grey to black coloured, schistose rocks west and south of Muzaffarabad. The name was given by Wadia in 1931. The Dogra Slates, Attock Slates, and Simla Slates are similar to these. They are also referred to as Hazara Slate Formation and Hazara Formation. They are well exposed on Muzaffarabad—Abbottabad road and Muzaffarabad—Kohala road. They represent a very wide spread unit.

Only the northern contact with Murrees lies in the area mapped. As mentioned earlier this is a faulted contact which represents a major thrust known as Jhelum Fault.

Hazara Slates in the investigated area are dark grey to black in colour with some patches of gypsum. They are rusty brown or drark green on weathered surfaces. Lenticular quartz veins are common and quartz partings are present at a few places. The formation also contains some phyllites and graphitic layers. Close to their contact with Murrees the Hazara Slates become highly calcareous in nature. Here they may even be called shaly limestones.

Microscopically they show cryptocrystalline texture. The fissility planes show undulations and microfolding. Quartz (55%), micas and chlorite (40%) and pyrite (5%) are the main constituent minerals.

Bedding in slates is well developed and so is planer structure. They show a perfect oblique cleavage because of which the rock breaks into flat pieces.

Tight folding, at places overturned (Fig. 1) is present in slates due to which strike varies over short distances.

Fig. 1. Tight overturned folding in Hazara Slates. Shearing in the arial zone is quite clear.

From the engineering point of view Hazara Slates represent relatively weaker rock because of the ease with which they break along planes of weakness. Where they are much sheared the slopes are unstable and sliding occurs. A very big slide about 2 miles south of Muzaffarabad on Muzaffarabad–Abbottabad road was observed in this rock formation.

Salkhala Series : This name was applied by Wadia (1931) to a series of alternating rocks which are generally schistose to phyllitic thin quartzites, calcareous schists, soapstone, etc. In the area under consideration this formation is well exposed near Nauseri. Along the Nauseri-Tithwal road they extend for about two miles starting from Nauseri bridge. The exact thickness of this formation cannot be determined here because of its folded nature and because its southern contact is faulted and the northern contact is gradational.

Salkhalas which are Precambrian in age are in a faulted contact with Murrees of Miocene age. This contact marks the biggest thrust in Kashmir region along which Salkhalas have been brought up for thousands of feet. This thrust is shown on the map as Nausaeri Fault. The northern contact with granite gneiss is exposed opposite to Thanda Katha. This is a gradational contact and before the actual gneiss starts there is a transition zone in which both gneiss and schists, which represent Salkhalas, are present. The Salkhalas in the transition zone show the development of coarser quartz and feldspar. The contact is marked by cliffs at some places.

Salkhala series is well bedded, the bedding being medium to thick. Olive green colour is seen on wheahered surfaces due to abundance of chlorite and epidote. The various types of rocks which comprise Salkhala series in this area are :

1. Fine grained, grey coloured, quartizitic schists in which the schistosity is not very prominant.
2. Fine grained greenish looking schists which are chloritic phyllites. Schistosity is poorly developed.
3. Graphitic schists which are dark grey in colour and break into fine pieces.
4. Green stone. Greenish looking schists with a lot of chlorite and epidote.
5. Dark coloured, greenish brown amphibolites which are composed of aluminous hornblende (65%), plagioclase (12%), chlorite (10%), and sphene (3%).
6. Epidosite which is coarse grained pegmatitic and contains 65% epidote. Quartz forms 20%, cholorite 8% and hornblende 7%.
7. White coloured, soft, banded marble or baked limestone. The above rock types indicate a low to medium grade of metamorphism.

The age is Pre-Cambrian because the series underlies the Hazara Slates everywhere.

The Salkhalas are well bedded. The strike as well as the dip is much variable because of folding and local faulting. Tight zig zag folding is the most characteristic feature of this series (Fig. 2). Jointing is quite common.

Salkhalas are hard and dense. Slopes are generally stable but where the rock is much jointed and the slopes are covered with loose overburden rock falls also occur.

Tithwal Garnetiferous Schists : This rock unit is best developed in the Chilhana, Reali, and Tithwal area. The name has been derived from the town of Tithwal which falls in the Indian territory on the other side of the river. This is a very thick unit.

The contact of schists with granite gneiss is gradational. As one moves from schists toward their contact with the granite gneiss one observes that the amount of biotite, feldspars, and quartz increases considerably. With the increase in the amount of these minerals the grain size also increases and the rock starts changing from schists to gneiss. The quartz and feldspar grains develop parallel to the planes of shistosity and the feldspar grains are eye shaped near the contact. This gneissic texture becomes more and more pronounced until the rock becomes truly gneissic. The foliation of gneiss is parallel to the foliation planes of schists.

The various types of schists that comprise this rock unit can be best studied on the road section from Chilhana to Jargi. Quartz mica schists, chlorite schists, and garnet mica schists alternate with each other. On the whole the schistosity is poorly to well developed. Garnet is present in all varieties but its amount as well as size varies widely. A very important characteristic of these schists is the abundance of quartz veins and segregations which frequently show pinching and swelling and at some places are even folded. The schists themselves are well folded and well jointed.

Fig. 2. Tight zig-zag folding in Salkhalas.

Chlorite schists. These are fine grained greenish looking schists in which schistosity is moderately well developed. They are mainly composed of quartz (55%), muscovite (25%), chlorite (15%), garnet (3%), and iron ore (2%). Iron ore is haematite and pyrite. Larger flakes of chlorite give a spotted appearance to these schists at places. Lineation in not present.

Quartz Mica Schists : More prominently developed beyond Tithwal. They are light coloured arenaceous schists consisting chiefly of quartz (75%) and muscovite (15%). Other minerals are biotite (3%), chlorite (2%.), garnet (1%), and magnetite and pyrite (4%). Schistosity is poor to moderate. Bands of poorly developed quartzites are also present.

Garnet Mica Schists : They are silver grey in colour and in them the schistsity and the lineation are well developed. Important constituents are quartz (50%), muscovite (30%), biotite (8%), garnet (5%) and iron ore (7%). Both magnetite and pyrite are present. Garnet, though small in size, is abundantly developed. Folding is common and quartz veins are very abundant. The distinguishing feature in the field is that the garnet can be seen with the naked eye.

Tithwal Schists are stronger as compared with Hazara Slates. The slopes are generally steeper and landsliding is relatively uncommon. Minor rock falls occur where schists are badly sheared.

Nauseri Granite Gneiss : This rock deserves special attention because it has not been mapped and described before. Farooqi of the Pakistan Industrial Development Corporation included it in Nauseri Formation and named it as a syenite porphyry.

The granite gneiss outcrops two miles from Nauseri bridge on Nauseri—Tithwal road where it is in gradational contact with Salkhalas. Because of the Indian border marked by the river at this place the outcrop of the granite gneiss could only be traced on the right hand side of the river. However, it is very extensively developed and some of the highest peaks like Chunj and 7229 are made of this gneiss.

The southern contact of the gneiss is with Salkhalas and the northern with Tithwal schists. Both the contacts are gradational with transition zones. Both Salkhalas and schists near their contacts with the gneiss show gradually increasing development of feldspars, quartz, and biotite. Also in the transition zone the bands of country rock and the gneiss alternate. Veins of quartz and feldspar are quite common in transition zone. The foliation of the gneiss is parallel to the original bedding that can be seen clearly in this rock as well as to the bedding planes of Salkhalas and Tithwal schists. This shows the conformable nature of the contacts.

Nauseri granite gneiss is a light grey coloured, porphyritic and foliated rock (Fig. 3) that consists chiefly of quartz, feldspars, and micas. It is thickly bedded (Fig. 4) to massive and very hard. The phenocrysts of feldspar can be seen even from a distance. The maximum size of the phenocrysts observed is 5" and the general range is from 2"—4".

Fig. 3 The size and abundance of phenocrysts in granite gneiss, the foliation and the jointing.

Fig. 4 Well developed bedding and jointing in granite gneiss between Nauseri and Tithwal.

Some of the phenocrysts are perfectly euhedral and even show carlsbad twinning. Where they are not euhedral they are eye shaped giving rise to a well developed augen structure.

Another very characteristic feature of the gneiss is the abundance of quartz and feldspar veins which show microfolding, microfaulting and pinching and swelling (Fig. 5)

Microscopically quartz amounts 50% which forms small anhderal grains or pocket like segregations. Potash feldspar constitutes 25% and occurs mostly in the form of phenocryst of orthoclase, microcline, and perthite. Alteration of feldspars to muscovite and sericite is common. Euhedral to subhedral grains of plagiolase are 5% in proportion and oligoclase in composition. Muscovite makes up 12% and biotite 5%. Accessories include euhedral sphene (2%) and calcite (1%).

Fig. 5. Abundance of quartz veins and Segregations showing Pinching and swilling and microfolding at the contact between Granite Gneiss and Tithwal Schists.

Structurally the gneiss is well jointed and shows micro folding (Fig. 6)

As far as the origin of the granite gneiss is concerned it is a para gneiss. It is a granitized granite. The gradational and conformable nature of the contacts (Fig. 7), the bedded nature, the parallelism of the foliation and the bedding, very high percentage of quartz, the presence of calcite, the development of microfolding (Photo 6), the absence of chilling at the contacts and the absence of

Fig. 6. Microfolding in Granite Gneiss.

Fig. 7. The conformable contact between the Granite Gneiss (below) and the Tithwal Schists (above) on Nauseri Tithwal road.

xenoliths and dykes and veins intruding the country rock indicate clearly that the gneiss is not a product of magmatic crystallization. It has resulted from the granitization of Salkhalas and Tithwal Schists. Whether the source of granitization is some igneous body nearby or whether it is due to very high temperature and pressure, is yet to be confirmed. Mapping of adjacent areas is needed for this purpose.

It is the strongest rock of the area which forms steep slopes and in which no landsliding was observed.

STRUCTURE

Structurally Muzaffarabad—Nauseri area is characterised by severe tectonics. It is highly folded, faulted, and jointed. This is because the area of study lies in the axial zone of the syntaxial bend of the Hymalayas. The structural pattern of the mapped area is a part of the larger structures of the bend itself and is a result of the same tectonic forces which produced the syntaxis. The structure of the area can be described in two parts :

1. Major structure
2. Minor structures.

Major Structure :

Among the major structural features are included faults, folds, and joints.

Faults : The area is highly faulted but the largest faults are those which also mark the contacts between different formations. They include Jhelum fault, Muzaffarabad fault and Nauseri fault. All are reverse faults and all dip east ward.

Jhelum Fault : It marks the contact between Hazara Slates and Murree Formation and runs west of Muzaffarabad. It is a very big fault which in the northwestern direction extends upto Kunhar river and in the south continues along Jhelum river.

In Muzaffarabad area the fault dips eastwards at steep angles ranging between 60 to 80 degrees. It is a combination of reverse and strike slip faulting. Along this fault plane Murrees have moved south west as well as north-west as compared with the slates. The affect on the surrounding rocks is manifested by tight folding, crumbling, and change of strike and dip of the strata.

Muzaffarabad Fault : This fault has occurred on the overturned southern limb of Muzaffarabad anticline. The names Muzaffarabad fault and Muzaffarabad anticline were first given by Calkins and Matin (1968). This fault separates Muzaffarabad Limestone from the Murrees. It dips at moderate angles towards east with an average of 40 degrees.

Along the fault plane the Muzaffarabad Limestone has moved southwest over Murrees. Because of this fault almost whole of southern limb of Muzaffarabad anticline has gone down.

Nauseri Fault : This marks the largest thrust of the Kashmir region. It extends in the northern direction for many miles beyond the mapped area and continues south of Nauseri and then southeast for hundreds of miles. Like other major faults of the area it dips eastwards at moderate to steep angles with an average of 50 degrees. The Nauseri fault separates the oldest rocks (Salkhalas) from the youngest rocks (Murrees). Along the fault plane the Salkhalas have moved northwards for thousands of feet and also westwards. The rocks on both sides of this fault are tightly folded and sheared.

In addition to these major faults the unconformable contact between Muzaffarabad Limestone and nodular limestone has also been reported faulted at many places (Calkins 1968). Similarly many intraformational faults of small throw and extent were observed in the field.

Folds :

Almost all formations of the area have been folded. Folds are nearly of every known type. Broad as well as tight folding is present. The most intensively folded formations include the Hazara Slates, Muzaffarabad Limestone, Murrees and Salkhalas.

Muzaffarabad Anticline : East of Jehelum fault the Muzaffarabad Limestone, the Nodular Limestone and the Murrees are folded into a large anticline which trends northwest and its western limb is overturned. Muzaffarabad Limestone forms the core of this anticline. The overturned southern limb of this anticline has been faulted (Muzaffarabad fault), therefore only a part of this limb is present. The Nodular Limestone which is over 1000 feet thick in the northeastern limb is almost completely missing from the overturned limb because of faulting.

Superimposed on the Muzaffarabad anticline is another series of subsidiary folds trending north east.

Folds of tight nature, many of them overturned, are present in slates and Salkhalas. Shearing along the axial planes of these folds is a common feature.

Joints :

Most of the rocks of the area are well jointed and there are more than one directions of jointing. Most of the joints are closed and smooth surfaced. Many of them are filled with secondary mineralization. Most of the joints are produced by tensile and shear forces.

Minor Structures :

These include microfolding, foliation, cleavage, lineation and cross bedding. Microfolding is very common in Hazara Slates, Salkhalas and granite gneiss and to a lesser extent in schists. Thin veins also follow the trend of this folding. Axial planes of microfolds are parallel and they show a combination of shear and drag.

Foliation is best developed in granite gneiss while the lineation is present on the schistosity planes of garnet mica schists. Cross bedding is displayed by the Murree sandstones.

Tectonic Forces :

The present sturcture of the area is the result of deformation during the Hymalayan orogeny which began in late Cretaceous. According to Calkins and Matin.in the area under consideration the rocks west of Jhelum fault, i.e. Hazara Slates moved southwards resulting in stresses directed southwest-wards which caused other faults. To counteract these forces stresses were generated in the westward and south westward directions. This resulted in the westward overturning of major folds like Muzaffarabad anticline and also eastern sides were upthrown as compared with the western sides along the fault planes. The refolding of Muzaffarabad anticline is also a result of the westward forces.

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(Manuscript received August, 1976)

GEOCHEMISTRY OF CHROMITES FROM HARICHAND, MALAKAND AGENCY, PAKISTAN

BY

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Abstract : *Chemical analyses of three purified chromite s mples from Harichand area Malakand agency are presented and compared with chromites from Muslimbagh. A number of diagrams have been drawn to present the chemical data. The analysed Harichand chromites are aluminian chromite with tendency towards chromian spinel due to high alumina. Microhardness and specific gravities of all the specimens are presented whereas cell edge dimension and refractive indices of two samples are given.*

INTRODUCTION

Ultramafic bodies, many of which are chromite bearing, are exposed from Malakand agency in the north to the Chagai district in the south. Chromite was discovered in Muslimbagh by Veredenburg in 1902 (Hayden, 1917) and is being mined since then. Workers such as Ahmad, (1972) and Bilgrami, (1963, 68) have worked in detail on the chemistry of purified chromites from Muslimbagh and Fort Sandeman, but no detailed work has been done on the chemistry of purified Harichand chromites.

EXPERIMENTAL

Chromite samples concentrated by magnetic separator and purified by heavy liquids, were analysed following the analytical scheme of Ahmad, (1969). Specific gravities of the purified chromite samples were measured by pycnometer method and a mean of three determinations is given. Microhardness of polished chromite samples was determined in terms of Vickers Hardness Number (V.H.N.) using a G.K.N. microhardness tester at a load of 200 grams. The values given are mean of ten determinations made on each sample. Refractive indices were determined by immersion method and cell edge dimension, using a powder camera with 190 mm diameter and Mo Kα radiation.

RESULTS AND DISCUSSION

The chemical analyses of the three purified chromite samples are given in Table 1. Unit cell contents on the basis of 32 (O) and end member percentages are given in Table 2. Physical properties i.e. specific gravity, microhardness, cell edge dimension and refractive indices are given in Table 3. The chemical data given in tables is presented in the form of five illustrations.

Table 1, shows that these chromites contain high alumina with a maximum value of 28.24%, and low Cr_2O_3 with a lowest Cr_2O_3 value of 39.06% as compared to chromites from Muslimbagh, which have a highest value of Al_2O_3 20.31% and a lowest value of Cr_2O_3 (49.95%) Ahmad, (1972). As compared to Muslimbagh chromites, these chromites are low grade with a Cr/Fe ratio varying from 2.06 to 2.47. RO/R_2O_3 show a variation of 0.96 to 0.98. Table 4 shows that these chromites have a composition variation as Cr_{46-63} Al_{35-49} Mg_{56-71}. Table 2 shows the formula percentages, spinel varies from 35.01 to 49.30%, Magnesio-chromite from 13.74 to 21.83%, Ferro-chromite from 23.89 to 41.78% and Magnetite varies from 2.01 to 4.98%. This table shows that with the increase in spinel,

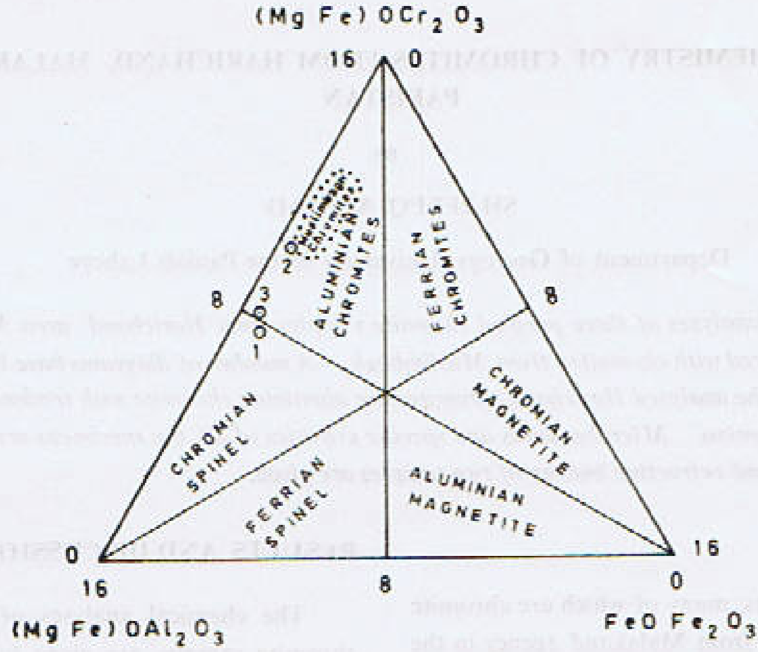

Fig. 1. Triangular Diagram Showing Composition of Analysed Chromites from Harichand.

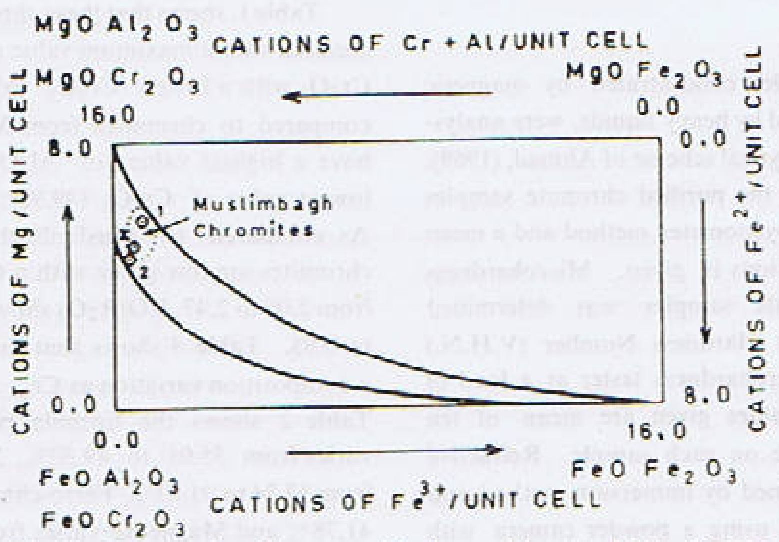

Fig. 2 Rectangular Diagram with Zone of Isomerphism, Composition of Analysed Chromites Shown by Numbers.

TABLE 1

Chemical Analysis of Harichand Chromties

	1	2	3
Cr_2O_3	39.06	50.66	42.05
Al_2O_3	28.24	18.86	26.29
Fe_2O_3	4.48	1.70	3.07
V_2O_5	0.04	Nil	Traces
FeO	11.99	16.49	15.19
MgO	15.52	11.84	12.83
MnO	0.25	0.17	0.26
CaO	0.04	0.06	0.09
NiO	0.06	Traces	Traces
TiO_2	0.14	0.18	0.16
SiO_2	0.23	0.06	Nil
	100.05	100,02	99.94
Cr/Fe	2.21	2.47	2.06
RO/R_2O_3	0.98	0.98	0.96
MgO/RO	0.70	0.56	0.60
Fe_2O_3/R_2O_3	0.05	0.02	0.04
MgO/MgO+FeO	0.58	0.42	0.46
Cr_2O_3/Al_2O_3	0.58	0.73	0.61

Sample No.	Description
1	Brownish yellow chromite with interstitial serpentine
2	Massive brown chromite
3	Massive brownish yellow chromite

TABLE 2

End Member Percentages

	1	2	3
Formula Percentage			
Spinel	49.30	35.01	46.57
Magnesio-chromite	21.83	21.20	13.74
Ferro-chromite	23.89	41.78	36.22
Magnetite	4.98	2.01	3.47
Weight Percentage			
Spinel	39.59	26.38	36.45
Magnesio-chromite	23.71	21.60	14.51
Ferro-chromite	30.21	49.57	44.64
Magnetite	6.49	2.45	4.40

TABLE 3

Physical Properties of Chromites

	1	2	3
Specific gravity	4.245	4.470	4.340
Microhardness	1321	1287	1314
Cell edge dimension	8.231		8.241
Refractive index	1.955		1.963

magnetite increases, whereas ferro-chromite decreases. Same is the case with end member percentages given in terms of weight percentages.

The chemical compositions of chromites plotted in spinel triangle Fig. 1, shows that two chromites

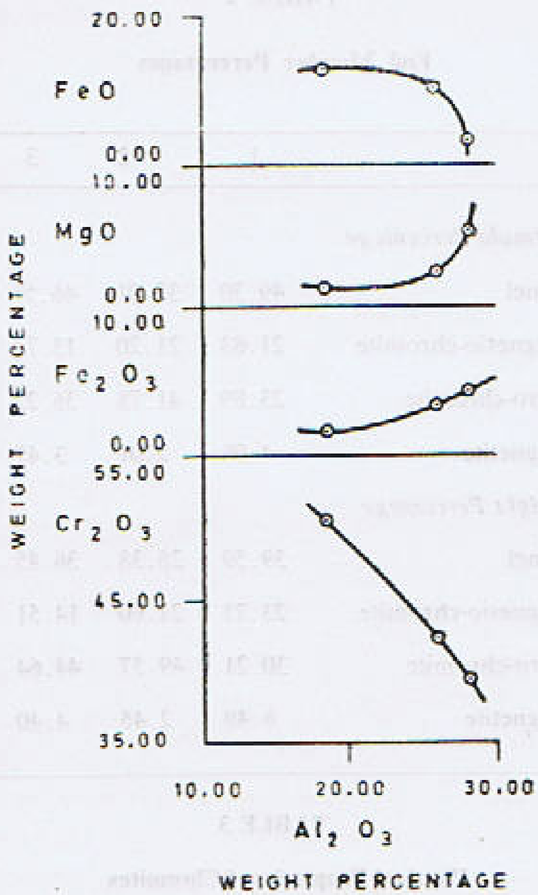

Fig. 3. Relation between Weight Percentages, Al_2O_3 and Cr_2O_3, Fe_2O_3, MgO, FeO in Harichand Chromites.

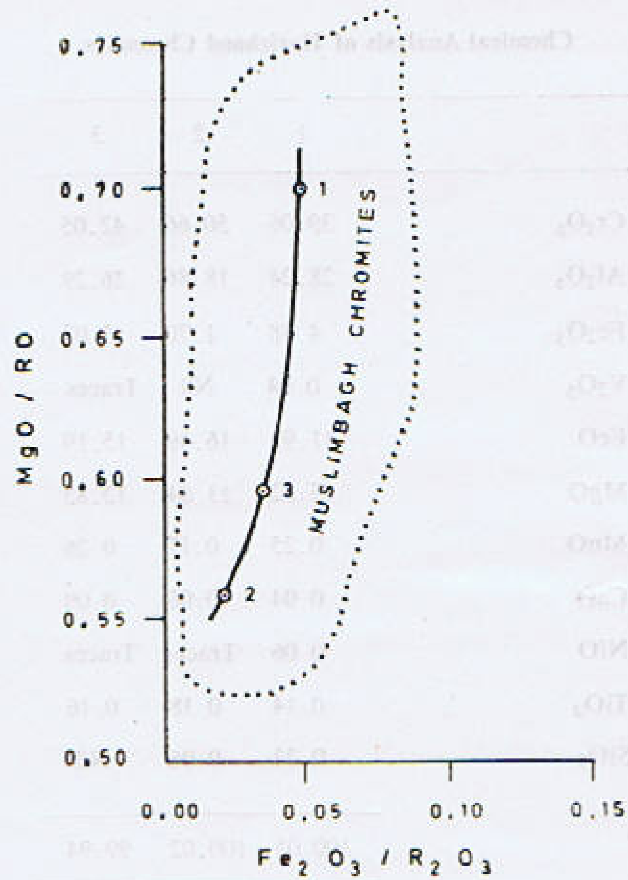

Fig 4. Relation between Fe_2O_3/R_2O_3 and MgO/RO in Harichand Chromites.

with numbers 2, 3 lie in the region of aluminian chromite, whereas one sample number 1 lies in chromian spinel. Sample number 3 is very close to the margin of chromian spinel. This shows that these chromite, due to high Al_2O_3 contents have a tendency towards chromian spinel. To confirm this more detail chemical study of more chromite samples will be required. When compared with Muslimbagh chromites, these chromites lie outside the area occupied by Muslimbagh chromites.

The area occupied by Muslimbagh chromites is also plotted for comparison. Fig. 2, is a plot of these chromites in the rectangular diagrams showing zone of isomorphism. This figure shows that these chromites lie in the zone of isomorphism and in the area covered by Muslimbagh chromites. The curve shows that with the increase in (Cr+Al), the contents of Mg decreases.

Fig. 3, which is a plot of weight percentages of Al_2O_3 aganist weight percentages of Cr_2O_3, Fe_2O_3, MgO & FeO, shows that with the increase in Al_2O_3, the contents of FeO, Cr_2O_3, decreases, whereas MgO & Fe_2O_3, increases.

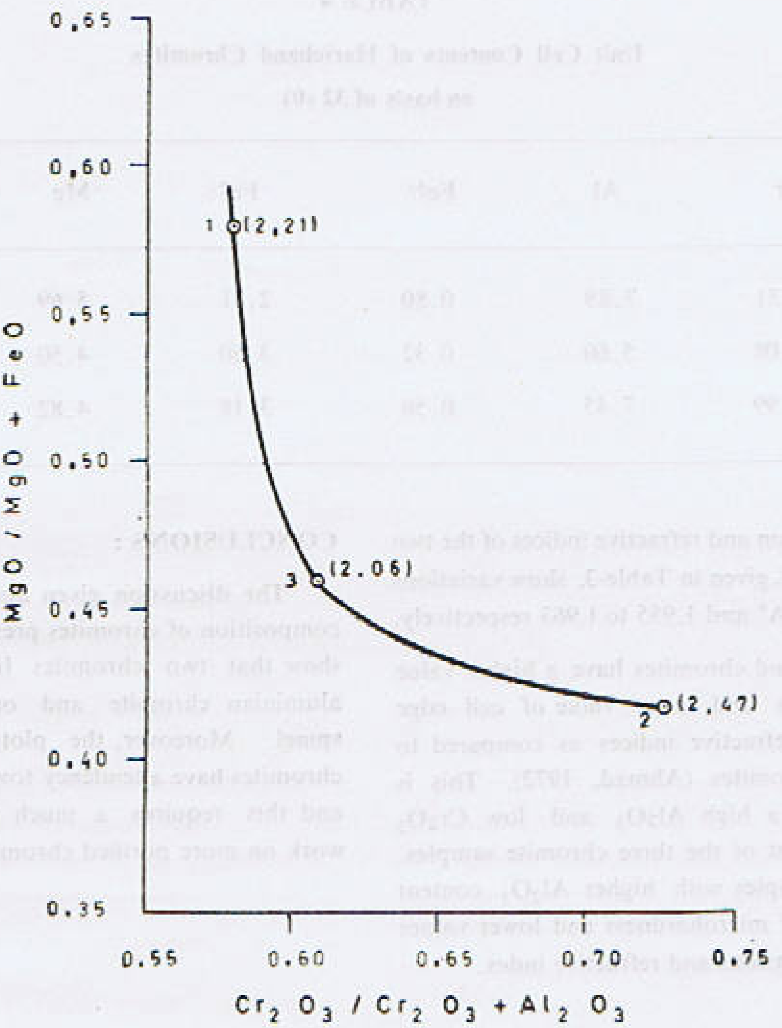

Fig. 5. Relation between $Cr_2O_3/Cr_2O_3+Al_2O_3$ and $MgO/MgO+FeO$ in Harichand Chromites (Cr/Fe Ratio given in brackets)

Fig. 4, is a plot of MgO/RO against Fe_2O_3/R_2O_3 for Harichand chromites and comparison with Muslimbagh chromites. This figure shows that increase in MgO/RO ratio, causes an increases in the ratio Fe_2O_3/R_2O_3. Moreover these chromites lie in the area occupied by Muslimbagh chromites.

Fig. 5, a plot of $MgO/MgO+FeO$ against $Cr_2O_3/Cr_2O_3+Al_2O_3$ show that with the increase of $MgO/MgO+FeO$, the ratio $Cr_2O_3/Cr_2O_3+Al_2O_3$ decreases.

The physical properties given in Table-3 shows a variation in specific gravity from 4.245 to 4.470. Microhardness varies from 1287 to 1321. The

TABLE 4

Unit Cell Contents of Harichand Chromites on basis of 32 (0)

Sample No.	Cr	Al	Fe^{3+}	Fe^{2+}	Mg	Composition
1	7.31	7.89	0.80	2.31	5.69	$Cr_{46}Al_{49}Mg_{71}$
2	10.08	5.60	0.32	3.50	4.50	$Cr_{63}Al_{35}Mg_{56}$
3	7.99	7.45	0.56	3.18	4.82	$Cr_{50}Al_{47}Mg_{60}$

cell edge dimension and refractive indices of the two sample detrmined, given in Table-3, show variations of 8.231 to 8.241A° and 1.955 to 1.963 respectively.

The Harichand chromites have a higher value of microhardness and lower value of cell edge dimension and refractive indices as compared to Muslimbagh chromites (Ahmad, 1972). This is possibly due to a high Al_2O_3 and low Cr_2O_3 contents, since out of the three chromite samples, the chromite samples with higher Al_2O_3 content has high value of microhardness and lower values of cell edge dimensions and refractive index.

CONCLUSIONS :

The discussion given above and the chemical composition of chromites presented in Tables 1—2, show that two chromites lie in the region of aluminian chromite and one in the chromian spinel. Moreover, the plots show that these chromites have a tendency towards chromian spinel and this requires a much more detail chemical work on more purified chromite samples.

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(Manuscript received August 1976).

STRATIGRAPHIC COLUMN OF THE AREA

ERA	Period	Lithostratigraphic Unit	Equivalent Facies	Tectonic classifications
	Recent	Alluvium	—	Freshwater
	Miocene	Murree Formation	—	Fore-deep Unfillings
		............Disconformity..........		
CENOZOIC	Palaeocene	Patala Formation (With) Kotal Member)	—	—
	Palaeocene	Lokhart Formation	—	—
	Palaeocene	Hangu Formation	Huangu Formation (Arenaceous)	
		..........Disconformity marked by laterite..........		
MESOZOIC	Cretaceous	Kawagarh Formation	—	—
		...........Minor Disconformity..........		
	Cretaceous	Lumshiwal Formation.	—	—
	Jurassic	Chichali Formation	Zarghun Khel Formation	
		..........Disconformity..........		
	Jurassic	Samana Sukh Formation (Base not exposed)		

The Zarghum Khel formation is a facies variation of the Chichali Formation. It is, however, much thinner as compared with Chichali and has a thickness of about a few feet to twenty two feet in the area investigated.

Lumshiwal Formation

Hard, compact, quartzose, glauconitic and ferruginous sandstones. Greenish grey to brownish green, at places olive green. May weather to yellowish brown. Lower contact with Chichali Formation is transitional. In the investigated area the formation is poor in megafossils.

Kawagarh Formation

Generally medium to thick bedded, light to medium grey, fine grained limestones. Weathers into dirty grey and yellowish grey. Occasionally thin bedded (beds less than one inch in thickness at places). Lower and upper parts are dolomitic. The lower contact with Lumshiwal Formation represents minor local disconformity marked by dolomitic beds containing pebbles of Lumshiwal glauconitic sandstone.

The thicker dolomitic portions of this limestone frequently wheather in chopboard style.

Hangu Formation

In the Kotal sheet (see below) the formation consists of patchy pissolitic laterite representing a disconformity at the base followed by reddish or brownish sandstone followed by yellowish brown and reddish brown ferruginous shales. At places there are intercalations of marl.

between 41° F to 104°F. The maximum average temperature for any single month is 106.3° F in the month of June. Average annual rainfall is 21.99 inches. Most of it falls in summer.

Darra Adam Khel is a mountainous area with moderate relief. Within the surveyed part the North West Frontier Road more or less follows the main stream Leo Khawr which, starting from Sara Mela, markes a U-shapped valley and then moves north. A number of major streams drain into it from the western side. Those draining into it from the eastern side are comparatively smaller except for the one i.e. Penderi Algada. The major streams are flanked by narrow terraces with across the channel width of a quarter to one mile. These alluvial terraces are low with one or two levels. The terrace systems of the major streams Leo Khawr and Wuch Khawr merge into the larger expanse of alluvium as we move north out of the mountainous area on the Peshawar side.

Drainage is well integrated, dendritic. All streams are intermittent.

Where the rock conditions, relief, and structure permit full development of slope profile one can distinguish an upper convex segment and a lower concave segment.

Predominent lithology being well bedded and well jointed limestones one can distinguish two major modes of weathering, root wedging and solution.

The area is in a mature stage of development.

Vegetation is restrited, generally patchy or open, and reflects the semi-arid conditions. Among the trees are Gorgora, Phlusa, Meinmoona and Ber. The shrubs include Garati, Pustocuoona, Sarazghey, Khapianga and Baaza. Terraces are cultivated for wheat, sugar cane, foodder, etc.

STRATIGRAPHY

Stratigraphically the area resembles the nearby Kala Chitta and Hazara areas. The construction of stratigraphic column of the area, however, presented a great deal of confusion because of the great structural complexity and significant facies changes over very small distance. It was only after the facies changes had been realized and the structure understood that it became possible to construct the given stratigraphic column, relate the different rock formations to their counterparts in Kala Chitta and Hazara and prepare an accurate geological map. (Fig. 1).

A brief description of the stratigraphic units which can be related to the adjacent areas of Kala Chitta and Hazara and a relatively detailed description of the lithostratigraphic facies peculiar to the area follows bellow.

Samana Sukh Formation

Well bedded limestone with occasional marly bands. Medium to dark grey. Yellowish dolomitic patches, occasional dolomite bands. Oolitic at places. Effects of solution weathering, e.g. Karren structure, are pronounced on surface.

Chichali Formation

Black greenish grey or yellowish grey silty shales. Weather into lighter tones and dark on fresh surface. At places intercalated with marl bands and at places iron nodules are present. Base marked by sandy dolomitic beds with ferrugionous encrustations. Fossiliferous Containing belemnites, ammonoids and crinoid spicules.

Zarghun Khel Formation

Yellowish dolomites with bedded chert. Chert is shaded grey on fresh surfaces and rusty brown on the weathered surfaces. At grid reference 55355270 the stratigraphic detail is as follows :

Bedded chert sequence
Yellow dolomitic limestone
Fossiliferous band
Bedded dolomite

98-99

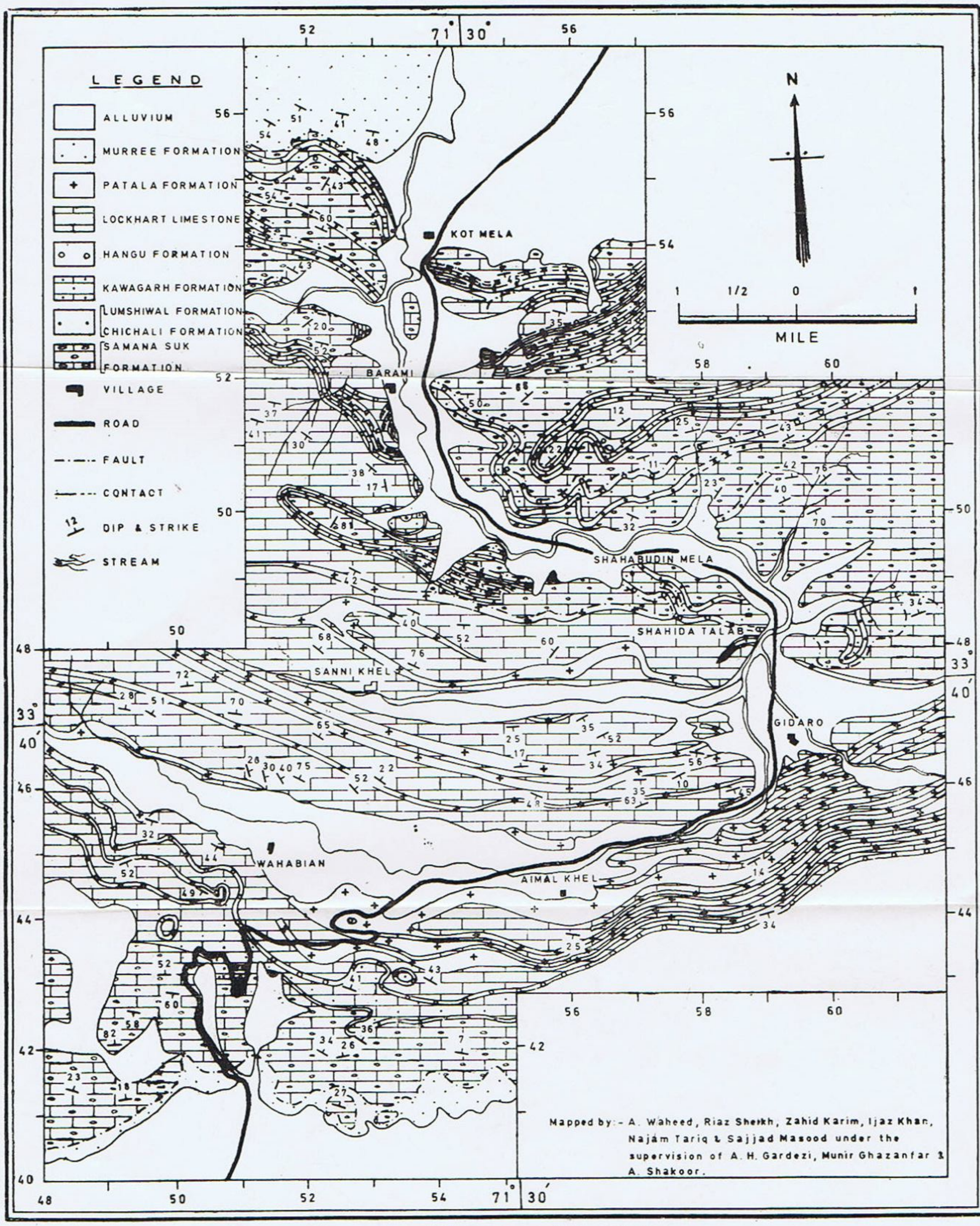

Fig. 1. Geological Map of Darra Adam Khel Area.

GEOLOGY OF DARRA ADAM KHEL AREA, DISTRICT KOHAT, NORTHWEST FRONTIER PROVINCE, WITH OBSERVATIONS ON THE FACIES CHANGES AND THEIR TECTONIC IMPLICATIONS

BY

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Abstract : *Poineer work has been carried out in the geologically unknown tribal territory of Darra Adam Khel. Stratigraphic column has been established. Facies changes of great structural significance have been discovered. Complicated local structure has been unraveled with important bearings on the tectonics of the outer Hymalayas.*

INTRODUCTION

The Locality : Darra Adam Khel is a longest strip of tribal territory with Peshawar on the north and Kohat on the south. Geological investigations, however, were carried out only few miles on both sides (east and west) of the North-West Frontier Road, within longitudes 71° 26′ 20″ to 71° 34′ 35″E and latitudes 33° 36′ 40″ to 33° 45′ 0″N covered by toposheets 38 Q/6 and 38 Q/10 of the Survey of Pakistan.

Working condition and Previous Work : Investigations in the area were first carried out by the writers when a party of six students began mapping the area under their supervision in November 1974. These six M.Sc. students were Messrs Zahid Karim, Ijaz Ahmad, Sajjad Masood, Najam-ul-Huda Tariq, Abdul Waheed and Riaz Ahmad. The students spent nearly three months in the area. The writers supervised them altogether for about three weeks. In addition to the observations made and given below by the writers the students have carried out petrographical studies, fossil identification and detailed stratigraphic observations which are given in their comprehensive M.Sc. theses lying in the library of the Geology Department of the Punjab University. These theses contain explanatory photographs, diagrams, and maps.

No previous work has been done on the geology and structure of this tribal belt.

The tribal area, except for the North West Frontier Road, is not covered by the laws of the Pakistan Government. The Government, however, has a liaison with the tribal administration through a political tehsildar who sits in Kohat. Within the area itself more than one tribal jurisdictions exist. For the purpose of the survey the political tehsildar made available an escort of Khassadars (local Militia).

Physiography : The temperature and rainfall data recorded by the meteorological department at the Kohat Pakistan Air Force Station for the year 1973 is as follows :

The average annual range of temperature is

In the Zarghun Khel sheet (see below) the pissolitic laterite and shale are absent. Here the formation is mainly arenaceous consisting chiefly of dark reddish brown coarse grained ferruginous quartzose sandstone.

Lokhart Formation

Medium to thick bedded, medium to dark grey on fresh surfaces and dirty light grey on weathered surfaces. Foetid smell on freshly broken surfaces. Nodularity is characteristic. Occasionally massive. Foraminiferal microfossils.

Patala Formation

Greenish grey, dominantly khaki, at places shades of purple, splintery shales with subordinate marl and limestone intercalations. Intercalations of nodular limestone towards the lower part. Occasionally sandy and carbonaceous.

Patala shales near Kotal Frontier Constabulary Post in this area have developed a peculiar lithology which has not been quoted from any other area ever before. The Kotal member consists of purplish, reddish brown and reddish grey coarse sandstone, grit, and microconglomerates. The grit occurs in medium to thick beds and is compact and hard. Some beds are medium grained and dominantly of greenish grey colour. Size of the conglomerates varies considerably. Big sized conglomerates are observed near Kotal post.

Murree Formation

Reddish, purple, greenish grey shales, sandstone, clays, with intraformational conglomerates and pseudoconglomerates. Sandstone shows sedimentary structures like cross-bedding.

Alluvial Deposits

The terraces are composed of a wide variety of graine size. In addition to silt and finer grades there is coarse sand, cobbles and pebbles. The material is very poorly sorted, is subangular and, at places, occurs in alternating layers of coarse and fine.

Facies Changes

A look at the geological map shows that the stratigraphic position of the Chichali Formation (arenaceous shales) is occupied at other places by Zarghum Khel Formation (cherty dolomite). The two formations are so radically different that they confused the stratigraphy for quite some time. Kotal member of Patala Shales too contributed to this confusion. Some facies change has also been described under the Hangu Formation. Facies variation is also present in Kawagarh Formation at different places. The existence of lithofacies along with associated variations in thicknesses suggest more than one isopic zones of deposition for the same stratigraphic horizon. Moreover the facies belonging to these different isopic zones occur side by side in the area. This observation helped to understand the complex structure and map the area accurately.

STRUCTURE

The Jurassic to Palaeocene sequence of Darra Adam Khel is flanked on both south and north i.e., Kohat and Peshawar sides by extensive Murree deposits of Miocene age. The older formations in the middle have faulted contacts in the form of low angle thrusts with Murrees on both sides. This situation could be explained in two ways :

(*i*) One explanation would be that the area has suffered block faulting with the central massif having moved upwards exposing older rocks. It was then followed by gravity gliding on both sides from top of the uplifted block. This in turn led to the bending of the otherwise vertical fault planes in the form of low angle thrusts.

(*ii*) The second explanation could be that when the uplift of the miogeosynclinal sediments began because of the northward movement of the Indian plate the sediments on the south facing side of the rising Hymalayas became loose and slided downwards. After having undergone long distance translational movement they landed up on top of the fore-deep infillings of the Murree Formation. This was repeated again with another slice from higher up the rising Hymalays, detaching and after long distance translational movement coming to rest on top of the first slice. The two allochthonous slices belong to two different isopic zones and hence the facies changes.

Now the existence of radically different facies side by side along with the difference in thickness cannot be explained by the first hypothesis of block faulting. This could be explained only by long distance translational movement and the existence of nappes. Again, this alone could explain the total absence of Murree Formation from the superimposed nappes. Thirdly even the mode of deformation between the various sheets is different. The lower, Kotal nappe is more intensively deformed (faulting main structural element) than the upper Zarghun Khel nappe (folding main structural element).

The structure of the area was thus worked out as consisting of two allochthonous nappes resting upon the autochthonous Murree sediments. The thrust separating the lower nappe from the Murree sediments is termed the "Kotmela thrust" after the village Kotmela in Akhurwal. The upper nappe is separated from the lower nappe by a second major thrust called the "Qasim Khel thrust" after the village Qasim Khel in the Zarghun Khel area. The upper nappe has been called the Zarghunkhel nappe and the lower as the Kotal nappe.

Tectonic Characteristics	Name of the Sheet	Isopic Characteristics
Allochthonous (Miogeosynchinal)	Zarghun Khel nappe	Contains Zarghun Khel Formation facies. Formations have lesser thicknesses. Hangu is the youngest formation.
..........Qasim Khel Thrust..........		
Allochthonous (Miogeosynchinal)	Kotal nappe	Contains Chichali Formation facies. Formations have greater thickness. Patala Shales with Kotal member is the youngest formation.
..........Kotmela Thrust..........		
Autochthonous (Foredeep infillings)	Murree deposits.	

The structure given above is further confirmed by a large fenester northeast of village Qasim Khel in the Zarghun Khel area (about the middle of the mapped area). Here the Kotal nappe with Kotmela thust at its base is seen through an eroded portion of the Zarghun Khel nappe.

The detachement of the two nappes appears to have taken place on the "decollement" style. The decollement requires the presence of a soap layer or plastic horizon which provides mobility for the overriding mass. In this case the Shinwari Formation (which occurs below Jurassic Samana Sukh in other areas) must have acted as the soap layer for the Kotal nappe. The Shinwari Formation consists of limestones and marl in the lower half and red shales and clays with intercalated marl in the upper half. It is Lower Jurassic in age.

For the second detachment i.e., for the Zarghun Khel nappe both Shinwari Formation and the Hangu Formation seem to have acted as the decollement horizon.

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(Manuscript received September, 1976).

NOTICES, ABSTRACTS AND REVIEWS

ORIGIN OF MYRMEKITE OF THE ACID MINOR BODIES OF MANSEHRA AND BATGRAM AREA, HAZARA DIVISION

INTRODUCTION

The acid minor bodies occur as rocks in the form of albitites, aplites, pegmatites and albitized rocks (Ashraf, 1974). They are in the form of lensoid, lenticular and tabular bodies emplaced in the fissures along the foliation of granitic and metasedimentary rocks. The granitic rocks have been studied by Shams (1969).

Myrmekite was amongst the last phase to form in the granitic rocks (Shams, 1967). It showed a continued activity of soda towards the later stages of the plutonic evolution of the granitic bodies. This activity of soda is also thought to be responsible for the development of some soda aplites and albitites.

THE MYRMEKITE

The myrmekites occur in the granites abundantly, and particularly in the older granites and gneisses. A detailed account of its occurrence in these rocks has been given by Shams (1967). In the case of acid minor bodies myrmekite occurs in the unzoned pegmatites having mineral composition mainly microcline-albite or albite-microcline-pegmatites of the interior marginal zone. It also occurs rarely in some equivalent aplites. The important character of the myrmekite is the vermicular habit of its quartz and association with K-feldspar in a plug-like form Fig. 1. It is sometimes not associated with K-feldspar (here myrmekite might had completely replaced the K-feldspar.) Myrmekite is most common in the sheared rocks.

Various theories have been put forward by Becke (1908) who thinks that internal chemical activity of solution causes replacement of potash in feldspar by soda lime and releasing free quartz. Sarma and Raja (1959) arrived at the conclusion that unstable portions of plagioclase break down under stress and release quartz which goes to form myrmekite intergrowth. Shelley (1964) thinks that exsolved albite from orthoclase incorporates recrystallization with quartz of the sheared groundmass. According to Shams (1967) the textural relations show that the growth of myremkite is essesntially a post magmatic and post shearing phenomenon. He thinks that hydration of SiO_2 is

Fig. 1. Vermicules of Quartz in Microcline showing Myrmekite Habit.

possible to give rise to Si $(OH)_4$ which may absorb some sodium forming an unstable $NaOSi(OH)_3$ complex reacts with potassium feldspar of the rock and gives rise to the following reaction :

$$KAlSi_3O_8 + Na\text{-}O\text{-}Si(OH)_3 = NaAlSi_3O_8 + SiO_2 + H_2O + KOH$$

this shows that the complex will allow easy incorporation of potassium into the solution phase and will produce a release of silica which in the form of quartz will be intergrown with albite to give rise to myrmekite.

Anyhow, whatever is the theory of the formation of myrmekite, the replacement of microcline by some sodic phase is responsible in the formation of myrmekite, as in almost all the cases the replacement is on the boundaries of microcline or along the cracks of the fractured grains of microcline. Shams (1967) considers that myrmekitization is post shearing but in the case of pegmatites shearing is later than the myrmekite development as seen in some thin sections (Fig. 2) that the myrmekite developed as older or contemporaneous with shearing as it has been much effected along shearing zones. In other cases vermicular quartz move out of the albite grains partially and emplaced around the grain and the albite becomes well twinned. These albite grains are anhedral to subhedral usually.

Fig. 2. Development of Myrmekite as older or Contemporaneous with shearing.

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Shelly, D., 1964 On myrmekite. *Amer. Mineral.*, 49, 41.

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NOTICES, ABSTRACTS AND REVIEWS

A BRIEF NOTE ON THE METAMORPHISM AND PRE-EXISTING STRUCTURES OF THE SECTION BETWEEN THAKOT AND SHATIAL BRIDGE.

The traverses across Haramosh, Nanga Parbat and Swat-Hazara Kohistan (Fig. 1,) have provided a good grasp of variation of metamorphism in the area. It has been observed in general that metamorphism on the whole gradually decreases away from the central line connecting the above mentioned ranges (Fig. 2). It indicates that the metamorphism is mostly, as also in other parts of Pakistan, related to tectonics of the area.

It is further observed that these ranges form a mega-anticlinorium the core of which is more

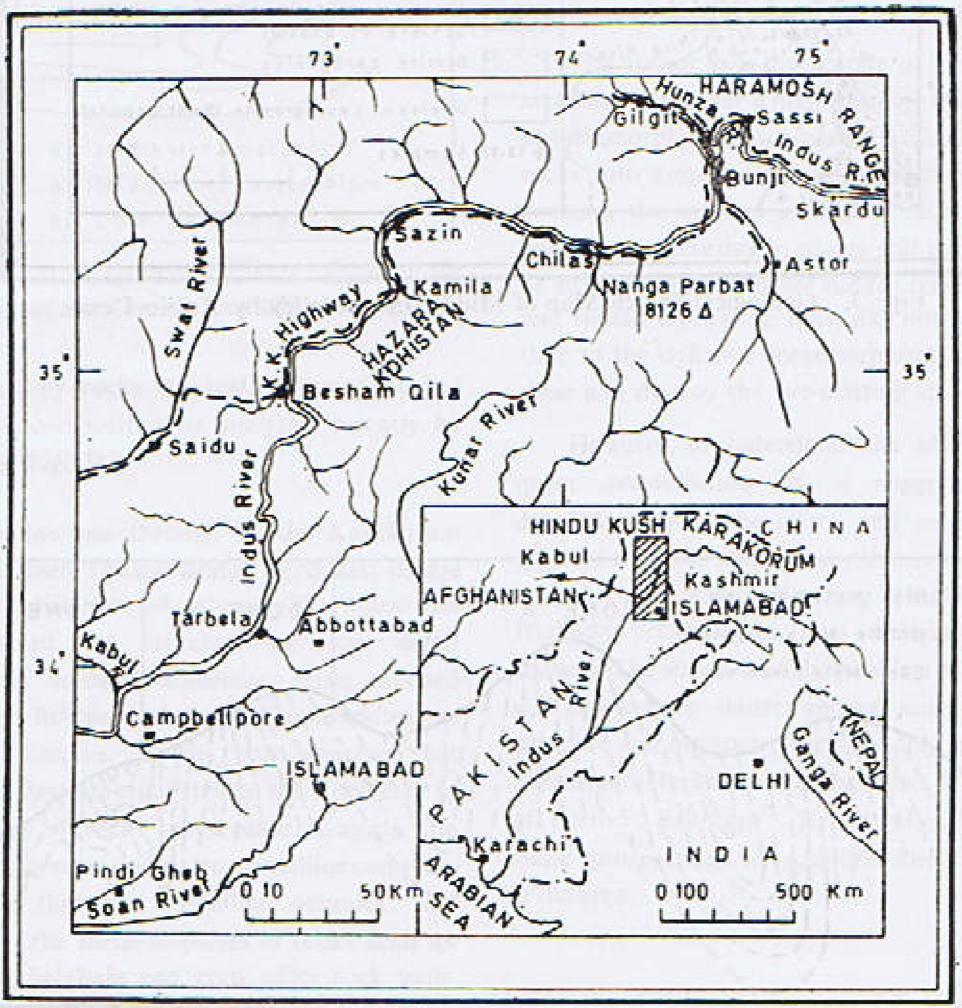

Fig. 1. Showing the location of the area.

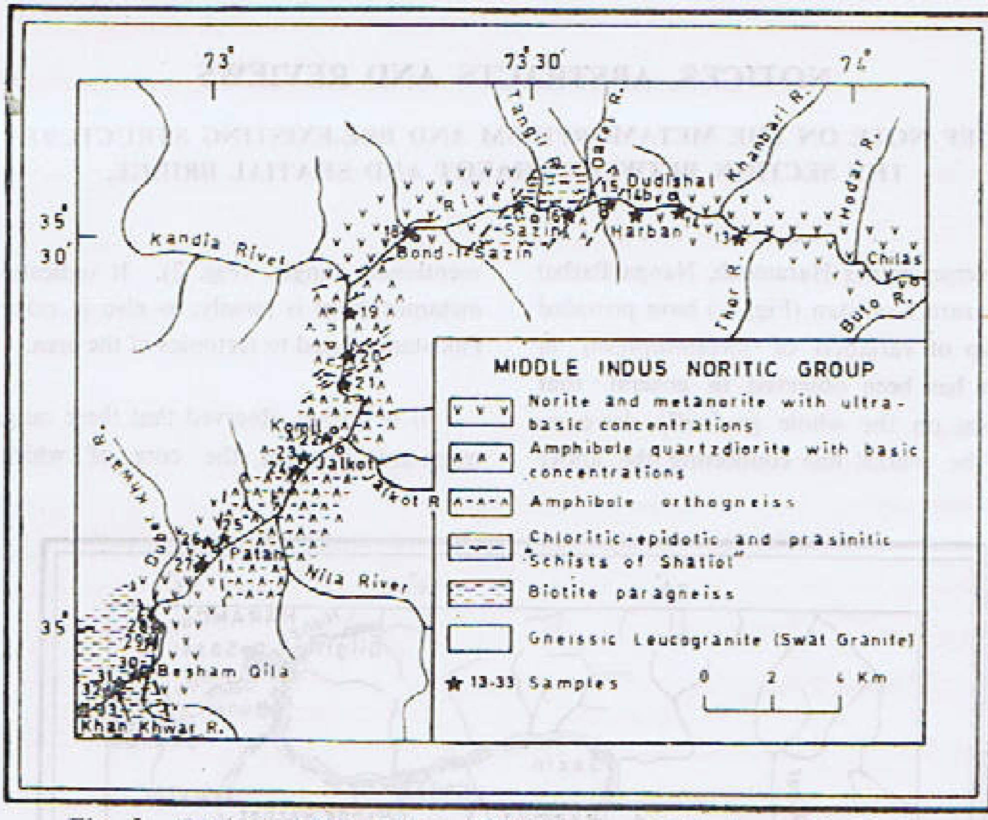

Fig. 3. Geological Sketch-Map of Middle Indus Valley by Ardilo Desio.

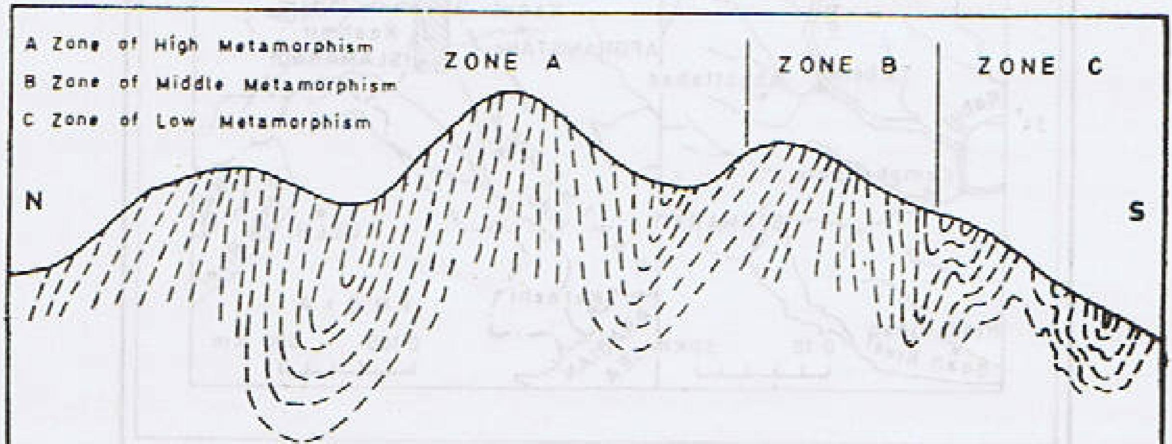

Fig. 4. Diagramatic Section showing the Flexures in Section Examined.

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Dr. Shamim Akhtar Arif.	Mathematics	

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Mr. Shahid Hameed, B.Sc.	Structure	October, 1975.

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Mr. Mahmud Ahmad, Geological Illustrator	January, 1967.
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Mr. Khurshid Ahmad, Librarian	June, 1959.
Mr. A. Latif, Office Assistant	February, 1949.
Mr. Mohammad Riaz, Stenographer	February, 1965.
Mr. Ghulam Mohyuddin, Store-Keeper-cum-Senior Clerk (Accounts)	November, 1964.
Other Staff	21

1. On leave without pay to Attock Oil Co. Since November, 1975.
2. On leave without pay to Zambia since November, 1973.
3. On leave without pay to Algeria since April, 1975.

STAFF LIST OF THE DEPARTMENT OF GEOLOGY UNIVERSITY OF THE PUNJAB, NEW CAMPUS LAHORE PAKISTAN AS IN OCTOBER 1976.

Name and Qualifications	*Subject*	*Appointed*
Chairman :		
Mr. Munir Ghazanfar, M.Sc. M.A. (Pb.), M.Sc. (Sheffield)	Gemorphology, Photogeology, Remote-Sensing	January, 1965
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Dr. F. A. Shams, M.A. (Cantab), M.Sc. Ph.D. (Pb.).	X-Ray Crystallography Petrology, Mineralogy	November, 1956.
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Mr. Zahid Karim Khan, M.Sc. (Pb.)	Engineering Geology	October, 1975
Mr. Riaz Ahmad Shaikh, M.Sc. (Pb.)	Structure, Petroleum Geology	November, 1975
Mr. Umar Farooq, M.Sc. (Pb.)	Geophysics	November, 1975
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