The

GEOLOGICAL BULLETIN

of the

PUNJAB UNIVERSITY

Number Ten *November* 1974

CONTENTS

A CAMBRIAN AGE FOR THE ABBOTTABAD GROUP OF HAZARA, PAKISTAN

BY

M. A. LATIF

Department of Geology, University of the Punjab, Lahore, Pakistan

Abstract: *The Lower Himalayas all along are dominantly composed of a thick sequence of quartzites, sandstones and dolomites overlying what are known as Slate Series named variously at different localities. One such sedimentary sequence mapped earlier* (1970) *by the author as Abbottabad Group is the subject of study in this article. Like similar other rock sequences in other parts of Indo-Pakistan the age has been unknown for want of fossil evidence. The majority of previous workers have for reasons of glaciated Tanakki Conglomerate proposed a post Carboniferous age for the problematic sequence. The rock sequence has been described starting with the Hazara Group followed by the Tanol Formation. These are considered to be from Eo-Cambrian to Basal Cambrian. Abbottabad Group follows after a break marked by Tanakki Conglomerate followed by Sangargali Member, Mahmdagali Member and Mirpur Member all belonging to Kakul Formation. These are followed by a dolomite sequence, the Sirban Formation, which in upper parts is cherty and phosphatic. After a break, said to be gradational in few sections* (?), *the Abbottabad Group is followed by Tarnawai Formation composed of Galdanian and Hazira members, known to be facies equivalents of each other. Galdanian Member is composed of red haematitic mudstones, clay-stones etc. and Hazira Member of yellowish sandstone and siltstone rich in glauconite in lower parts. The Tarnawai Formation is followed by the Thandiani Group of Jurassic age.*

Fossil, Hyolithes and Chencelloria have been recorded from the Hazira Member and a Cambrian age is assigned to the rock sequence lying above Tanol Formation and below Hazira Member. The sequence has been correlated partly with the Cambrian sequence of Salt Range and Iran. The lithologically similar sequences in other parts of Indo-Pakistan are suggested to be the possible equivalents of Abbottabad Group.

INTRODUCTION

Hazara is one of the northern mountain districts of Pakistan situated in the north of Rawalpindi and Campbellpur districts and bounded on the north by the Indus River (Fig. 1).

The first publication of any significance on the Geology of Hazara is Albert Vercheres paper read before the Asiatic Society in Calcutta in 1866-67. This deals with Kashmir, Western Himalayas and the Afghan Mountains. In this paper Verchere gives a brief outline of the north-eastern end of the Sirban Mountain near Abbottabad. He recognised Carboniferous Limestone resting upon volcanic rocks. The beds above these he referred in a general way to the "Jurassic Formation", and the highest strata on the north-eastern side of the mountain to the Nummultic Limestone. The detailed descriptions of the rocks, and construction of the section given by him are inadequate.

Waagen and Wynne (1872), for the first time mapped Mount Sirban situated to the south of

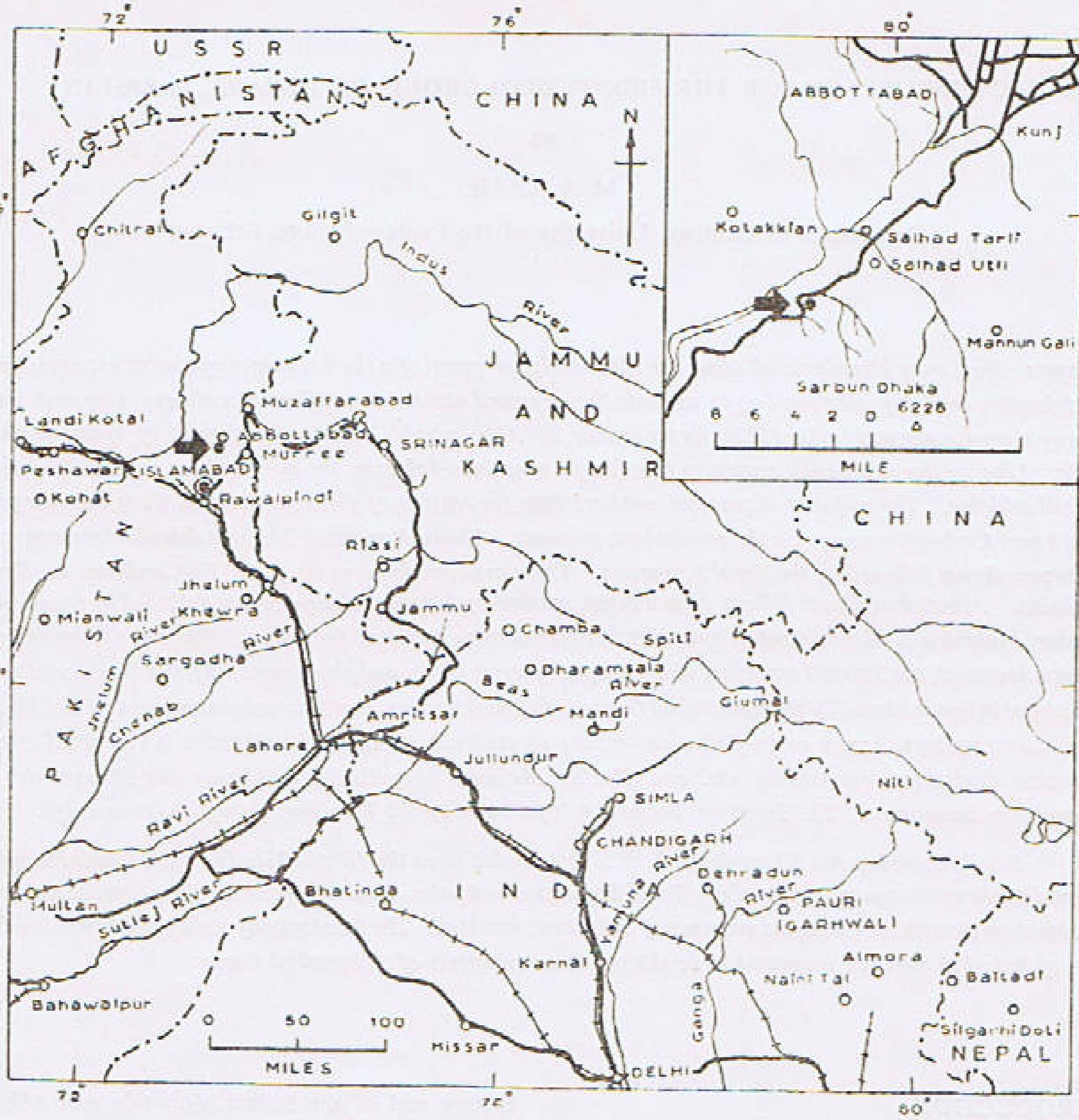


Fig. 1. Locality Map

Abbottabad. A description of the rocks was accompanied by a geological map of Sirban Mountain on a scale of one inch to a mile, the first of its kind for the area. Most of their rock identifications and the few suggested correlations with those in other areas, have proved correct.

The information provided by Wynne, with the assistance of Waagen, in a series of papers during the late seventies of the last century is still the soundest basis for solving the geological problems of the area. He is considered as the first geologist to bring order to the ill defined rock units of the area and to map Hazara on a scale of a quarter inch to a mile, which unfortunately remained unfinished and unpublished. Some workers, having affiliations with different government departments, took part in later work. Their reports submitted to the respective departments generally remained unpublished.

It fell to the lot of Middlemiss to collect all the scattered pieces of information, complete or incomplete, published or unpublished and present in an orderly form. His is the only comprehensive account of the Geology of Hazara published so far, alongwith a map of the area on a scale of half an inch to a mile.

None of the later workers could match the excellent pioneer work done by Waagen, Wynne and Middlemiss. Later publications are mostly restricted to the appreciation and/or criticism of the work done by them. Wadia (1929) discovered glacial striations on the Tanakki boulders and confirmed an Upper Carboniferous age, doubtfully assigned by Middlemiss. Marks and Mohammad Ali (1961 and 1962), challenged the age of the Triassic series of Middlemiss and thought they might well be Jurassic at least in the upper horizons. Latif (1962) assigned a Cretaceous age to the Grey limestones previously placed at the base of the Eocene by Middlemiss and confirmed the views expressed earlier by Waagen and Wynne. Davies and Gardezi (1965) considered the age of the basal part of the Triassic Series as Jurassic, on the basis of fossils. Nothing of any significance has been published since the work of Middlemiss some 77 years ago. With the passage of time, a revision of the stratigraphy of Hazara became a necessary basis for any future academic and/or economic activities, particularly after the idependence of the sub-continent.

The author's inclination to work in the area goes as far back as the Spring of 1953, when he paid his first private visit to Abbottabad, Nathiagali and Murree. The present study was initially suggested in 1956 by N. R. Martin, then UNESCO advisor and Head of the Department of Geology, University of the Punjab, Lahore. A few roadside reconnaissance trips were made by the author during the summer months of 1956. Some important localities like the Havelian-Abbottabad and Murree-Barian road sections, described by earlier workers, were visited. A few independent trips were also made in the early Spring and Summer of 1957. The nature of these did not go beyond reconnaissance and photography for an unpublished field report submitted in 1957.

The reconnaissance was started in 1959 for sedimentary rocks occupying the southeastern part of Hazara as well as parts of the Rawalpindi and Muzzaffarabad districts situated between 73°.00′ and 73°.30′ E and 33°.43′ and 34°.20′N. The mapping was completed by 1967. While improvement was made in the nomenclature, the map and the dating of various rock units, the pre Jurassic unfossiliferous succession, (Fig. 2) remained a challenge even after submission of my thesis on Hazara in June 1969. Immediately after my return to Pakistan in 1969 a fossil hunt was launched and in late 1969 was rewarded by the

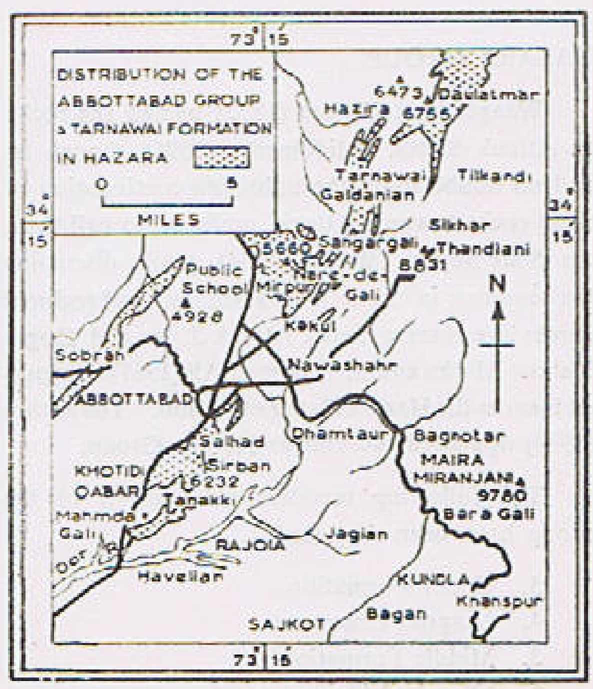


Fig. 2.

discovery of fossils in Hazira Shale near Salhad 2 miles south of Abbottabad. The present article is devoted to outlining the significance of this fossil find on the geology of Indo-Pakistan subcontinent particularly in respect of undated dolomite sequences all over the Himalayan arc.

STRATIGRAPHY

Stratigraphic succession of Pre-Toarcian Rocks in Hazara, is as given below:

Group	Formation	Member	Age
Thandiani	Maira		Lower Jurassic
— —	— — —	unconformity	— — —
	Tarnawai	Hazira Galdanian	
— —	— — —	disconformity ?	— — —
	Sirban — —		
Abbottabad	Kakul	Mirpur Mahmdagali Sangargali Tanakki	Under discussion in this article
— —	— — —	Unconformity	— — —
	Tanol		
Hazara	Upper Langrial Limestone. Middle Miranjani Limestone Lower		

HAZARA GROUP

Waagen and Wynne (1872) named the rocks as Attock Slates. Middlemiss (1896), though he had no doubt about the unbroken continuation of these rocks towards Attock, preferred to call them the Slate Series. Wadia (1934), while discussing the sequence in north West Kashmir, used regional names like Hazara Slates, Attock Slates and Dogra Slates. Marks and Mohammad Ali (1961) recognised them as the Hazara Slate Formation. The author (1970) upgraded the unit as Hazara Group.

The following tentative subdivisions of the group have been suggested.

5. Upper Formation
4. Langrial Limestone
3. Middle Formation
2. Miranjani Limestone
1. Lower Formation

The group is composed of low grade slates, silty shales, subgreywacke sandstones and siltstones interbedded with calcareous slaty shales, algal limestone bands and gypsum. On the basis of lithology and sedimentary structures, two distinct environments of deposition, a shallower one in the south-east and a deeper one in the north-west are recognised. There is a significant increase in the metamorphic grade northwards. It is suggested that the Saline Series facies of Salt Range may extend to Hazara and some of the metamorphic rocks further north may actually be the metamorphic equivalents of the Hazara Group. The Formation is considered to be homotaxial with Dogra Slate of Kashmir, Simla Slate of Simla and Kumaon, India and Western Nepal.

415

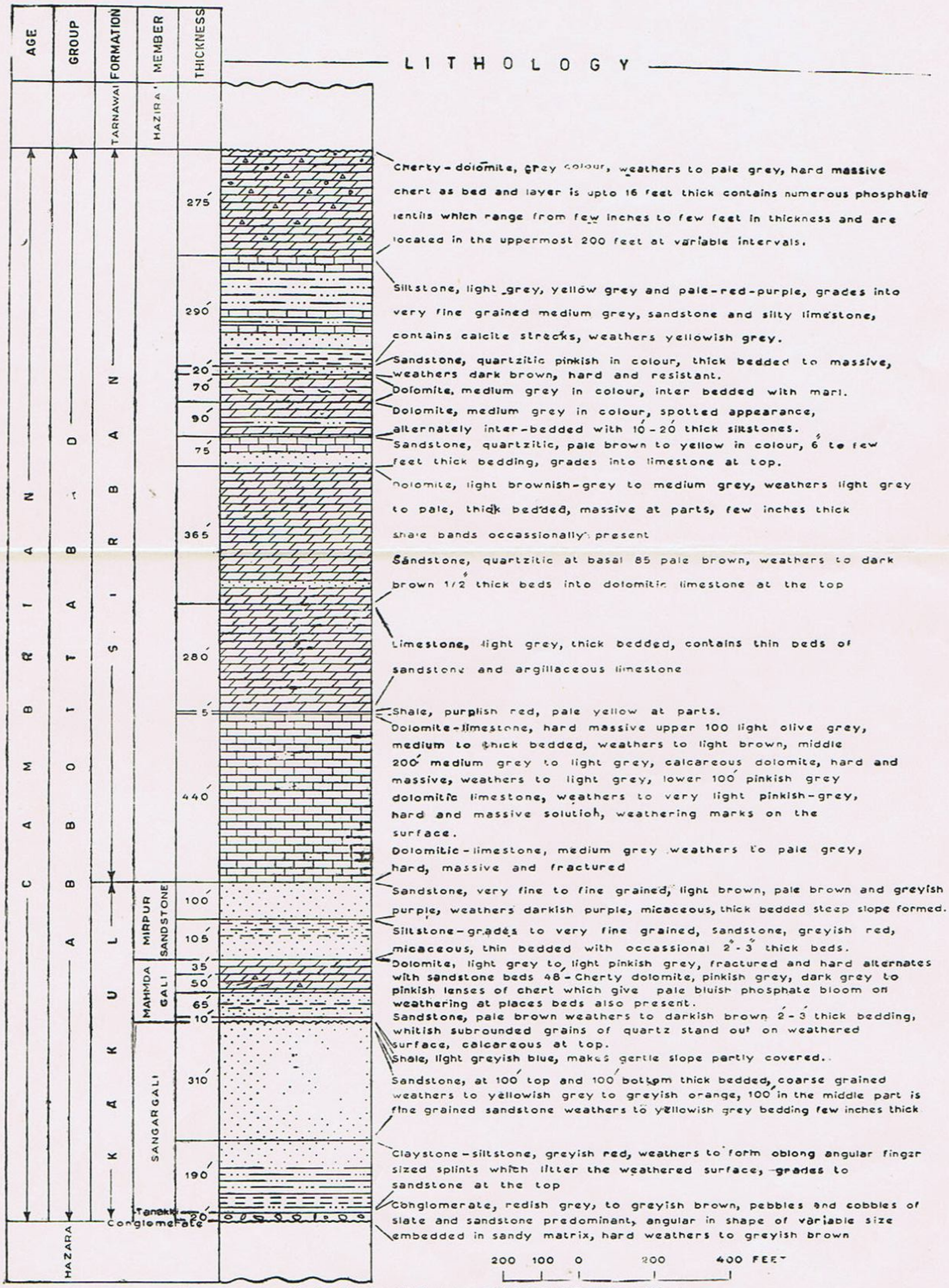


Fig. 3. Stratigraphic Sequence of Abbottabad Group near Mirpur.

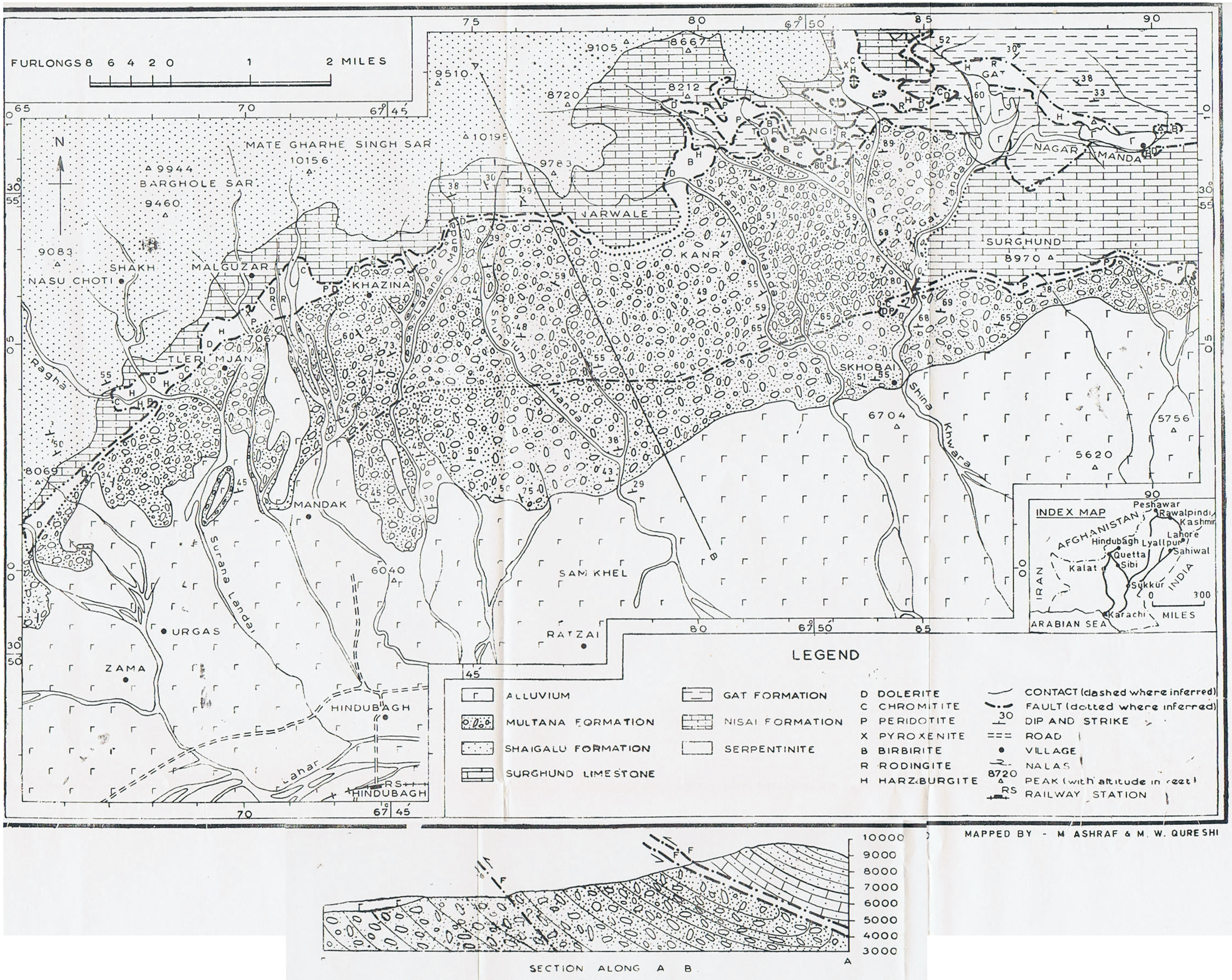


Fig. 1. Geological Map of the Area North of Hindubagh

TANOL FORMATION

The name Tanol was first given by Wynne (1879) to "a series of unfossiliferous, partly metamorphosed slates, conglomerates, schists and quartzites, carbonaceous and arenaceous shales and phyllites, found in Hazara, overlying the Attock Slates." Wynne (1879) and Middlemiss (1896) considered the formation as a part, of the 'Infra-Trias', now Abbottabad Group, but experienced difficulties in constructing a map and sections on the basis of this assumption. Recent studies of the formation by Mohammad Ali (1962) show them to be underlying the Infra-Trias Group. The Formation is composed of well bedded to flaggy, light grey to yellowish and sometimes faintly reddish quartzites which are cross bedded and contain ripple marks. Siltstones and pebbly layers are common. The upper contact is disconformable. The Formation is considered to be homotaxial with Tanawals in Kashmir, Chandpur and Nagthat in Simla, India, Khaira Quartzite of Gharwal, India, Chails of Kumaon, India, Chandpur and Nagthat in Western Nepal and Dalings in Sikkim, Fuchs (1970).

ABBOTTABAD GROUP

The stratigraphic unit was first described by Waagen and Wynne (1872) as "Below the Trias". Middlemiss (1896) named the unit as the Infra-Trias Series. Marks and Mohammad Ali (1961) preferred to call the unit, the Infra-Trias Group divided into a lower and upper formation. In the following year (1962) however, the same authors decided to rename the Infra-Trias Group as Abbottabad Formation divisiable into five members. Gardezi and Ghazanfar (1965) added the Haematite and Hazira formations to the Abbottabad Formation of Marks and Mohammad Ali and named them together the Abbottabad Group. The author (1970) provisionally accepted the definition given by Gardezi and Ghazanfar for the purposes of the mapping though suggested that "the upper two formations namely the Galdanian and Hazira Formations, may be grouped to be known as Tarnawai Group, in any later regrouping." For the present purposes therefore the Abbottabad Formation of Marks and Mohammad Ali (1962) is upgraded as Abbottabad Group, which is a sound basis nomenciaturally.

The following are the two subdivisions of the Abbottabad Group, Fig. 3.

2. Sirban Formation
1. Kakul Formation.

I. KAKUL FORMATION

The formation is divided into the following members.

(*iv*) Mirpur Sandstone
(*iii*) Mahmdagali Member
(*ii*) Sangargali Member
(*i*) Tanakki Conglomerate

I/*i*. Tanakki Conglomerate

Originally described as a breccia by Waagen and Wynne (1872), this was later referred to by Middlemiss (1896), as a basal conglomerate, homotaxial with the Talchir Boulder Bed of the Salt Range. Wadia (1929), discovered striated boulders in this basal conglomerate. Marks and Mohammad Ali (1961) grouped this conglomerate along with the shale and sandstone as the Lower Formation of their Infra Trias Group. In the following year (1962) however, they revised their earlier view and recognised it as a definite member. The author named it as Tanakki Member (1970). However since it is dominantly composed of conglomerate with a wide lateral distribution identified even beyond the limits of the present work as a distinct easily mappable, lithological unit, it has been recognised as Tanakki Conglomerate. The name Tanakki, for the unit has already found its way in the geological literature and is retained to suit the requirements of nomenclature. Sangargali section near Thandiani is however considered as a principle reference section.

The lower part of this member is composed mainly of a conglomerate, with ill-sorted fragments ranging in size from a fraction of an inch to more than two feet in diameter, (Fig. 4). These fragments appear to be derived essentially from the underlying Hazara Group of rocks. The pebbles and boulders are angular to sub-angular in Sangargali and Sobrah areas respectively. These are embedded in a sandy to silty matrix varying in colour from grey, greenish to purplish. There is a significant decrease in the size of the pebbles upwards, as well as a general transition in the matrix from silt to clay. Ultimately there is a gradual passage to the next higher member. No trace of bedding has been recorded. Definite evidence of glacial striations in Sangargali section have been observed to confirm the views expressed earlier by Wadia. The thickness of the member varies from almost absent in south eastern regions to 180 feet in the north western.

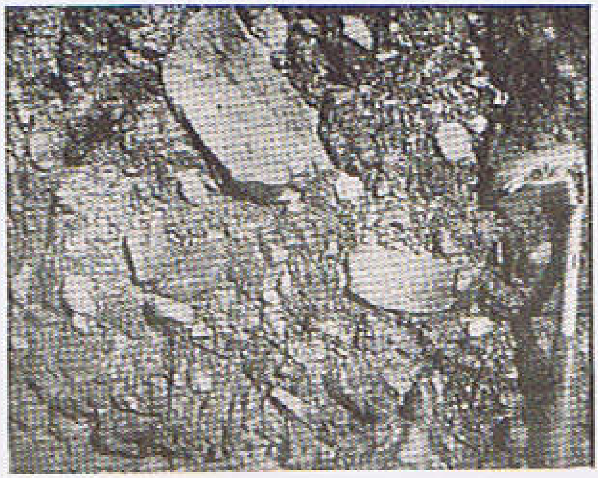


Fig. 4. Tanakki Member near Khoti-di-Qabar.

1/ii Sangargali Member

These rocks were first reported by Waagen and Wynne (1872) as lithologically resembling the Purple Sandstone, Lower Cambrian of the Salt Range. They were later named by Middlemiss (1896) as "The lower sandstones and shales" constituted the 2nd or the middle stage of the "Infra Trias Series". Marks and Mohammad Ali (1961), identified them along with the lower conglomerate as the "Lower member" of the Infra-Trias Group. However they recognised the unit in 1962 as a full member of their Abbottabad Formation.

Because of its distinctive lithology and wide distribution and that it is an easily mappable unit it was recognised as a member by the author (1970). The name is after its typical occurrence at Sangargali, near Thandiani.

The Tanakki Conglomerate becomes well sorted and with a gradual transition passes upwards into purple colour, well sorted shales and claystone frequently containing very thin greyish and greenish partings followed by sandstones and quartzites. The thickness of the shales and claystone as noticed near Sangargali, is 195 feet. The shales claystones are well laminated and fissile and show cleavage oblique to the bedding, (Fig. 5). They break into sharp splinters which are particu-

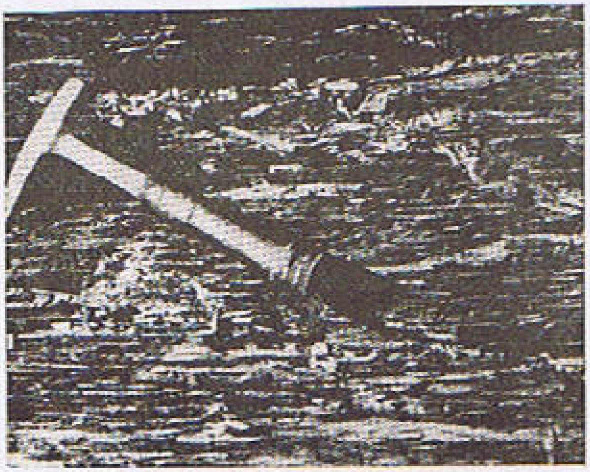


Fig. 5. Splintary Shales Sangargali Member near Thandiani.

larly note-worthy near Sobrah. Thin micaceous sandstone bands upto 10" in thickness are interbedded with the shales and increase in frequency upwards ultimately merging into purple coloured siltstones and sandstones. The maximum thickness of these siltstones and sandstones as seen near Sangargali is about 114 feet. The massive sandsstones weather rusty brown. Cross bedding is common and low amplitude ripple marks have also been observed. The sandstone is fine grained compact, hard and breaks with a conchoidal fracture. The purple sandstone becomes lighter in colour upwards and gradually passes into the orthoquartzites, (Fig. 6), with a thickness of 89 feet near Sangargali. The lower part is of light purplish colour while the topmost portions are pure white. The joints are commonly seen. The absence of unstable minerals and spherecity of the grains suggests significant transportation prior to their deposition in shallow water conditions. The total thickness of the member at Sangargali section is 398 feet while near Mirpur it is nearly 500 feet with over 300 feet of orthoquartzite.

The unit is also well exposed near Khote di Qabar 5 miles south of Abbottabad, near Public School, 5 miles north of Abbottabad and Sobrah about 10 miles west of Abbottabad. The most conspicuous features noticed in all the sections are (*i*) persistence of a purplish colour for most part of the unit (*ii*) ending up with a white quartzite band and (*iii*) the top of which shows a slight break in deposition.

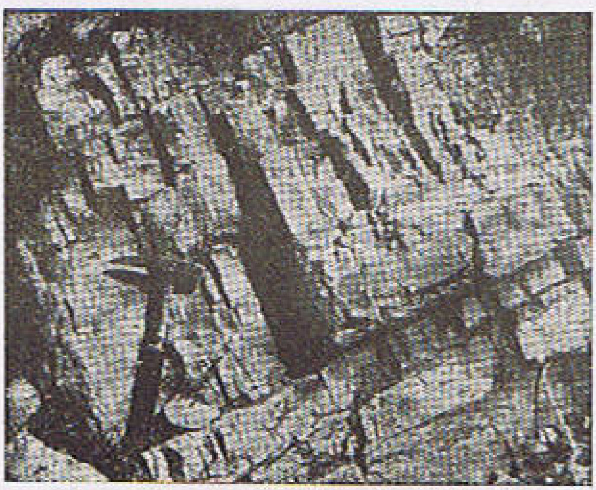


Fig. 6. Well Bedded Orthoquartzite of Sangargali Member near Thandiani.

I/*iii* Mahmdagali Member

The rocks included in this member were first identified by Waagen and Wynne (1872) as dolomites. On the basis of chemical analysis of a few samples, carried out by Middlemiss (1896), he preferred to call them limestones rather than dolomites. He grouped this formation with the overlying 'limestones' (now Sirban Formation) as the Upper Limestone unit of his Infra Trias Series. Marks and Mohammad Ali (1961), recognised it as the Upper Limestone Member of the Lower Formation in the Infra-Trias Group. The following year (1962) however, they identified it as a lower dolomite member of the Abbottabad Formation (previously called Infra-Trias Group).

On the basis of wide lateral distribution and distinct lithological upper and lower boundaries, this unit was recognised as a member by the author (1970) in order to suit the nomenclatural requirements, and has been named as the Mahmdagali Member after its occurrence near Mahmdagali, 1½ miles north of Havelian.

The basal beds are conspicuously coarse grained sandstones with quartz grain littered weathered surfaces. The sandstone is pale red to purplish red in colour, with a gradual increase in the calcareous content, the unit passes into pale red to purplish red calcareous dolomite weathering pale to purple grey. Chert bands ranging from an inch to 9 inches in thickness occur in the form of lenses and lenses fused together to form beds in the upper dolomite part of the member. The chert bands vary in colour from pale blue, blue, grey, pinkish grey and greyish pink. The rock is very compact and well bedded though jointing is frequent. The solution weathering of the calcareous dolomite is a conspicuous feature and has produced butcher chop board type weathering of the bedding planes and sharply cut surfaces. The thickness of the member near Khoti di Qabar and Public School 5 miles south and 5 miles north respectively of Abbottabad is nearly 150 feet.

I/iv Mirpur Sandstone

The rocks included in this formation were identified by Marks and Mohammad Ali (1961), as the "Lower sandstone and shale member" of the Upper Formation in the Infra Trias Group. In 1962 however they recognised it as the "Upper shale and sandstone member" of their newly introduced Abbottabad Formation. The name Mirpur was proposed by the author (1970).

Since the lithology of the member is uniform in general and it has wide lateral distribution, distinct lithologic boundaries with the underlying member and the overlying formation, it is recognised as Mirpur Sandstone. The name has been derived from the type exposure near Mirpur about four miles N.N.E. of Abbottabad.

The formation is composed of red or variegated shales at the base, followed by purple coloured sandstones. This member differs from the Sangargali Formation in the presence of variegated shales, as compared to the monotonous purple colour of the later; the complete absence of orthoquartzite, complete absence of cleavage, relatively soft nature of the sediments, an increasing content of calcareous matrix and at places gradual inter-bedding of thin dolomite bands. The member is over 110 feet in thickness.

The Mirpur Sandstone in its type locality consists of thinly bedded calcareous sandstone. In the lower part, the member is thinly bedded fine grained sandstone of greyish red colour while in the upper part it is relatively thickly bedded and of variegated colours, light brown, greyish red etc. The lower part forms gentle slopes while the upper the steep ones. In type area it is over 200 feet in thickness. The contact with the overlying Sirban Formation is transitional.

2. SIRBAN FORMATION

The rocks included in this formation were identified by Waagen and Wynne (1872) as the second division of 'Below the Trias'. composed of dolomites of a light colour and occasionally siliceous. Middlemiss (1896) recognised them as 'upper limestone' belonging to his 'Infra-Trias Series'. Marks and Mohammad Ali (1961, 1962) identified these rocks as the 'Upper Dolomite Member' of the Infra-Trias Group, later named by them as the Abbottabad Formation.

The unit has been identified here as a formation by the author (1970) because of its distinct lithologic characters as compared to the overlying and underlying rocks, it's fixed position in geological sequence, it's enormous thickness, wide lateral distribution in the area, occurrence of identical rocks in the adjoining areas and distinctive weathering, (Fig. 7).

The Mirpur Sandstone passes into Sirban dolomite with a gradual change of material. The lower part consists of light greenish grey dolomites, weathering pinkish, when freshly broken show yellow patches. This is followed by dull grey coloured dolomites weathering buff and light patches bearing dolomite weathering dark grey. Grey orange and pink colours dominate the lower part which consists of massive thick bedded scarp forming dolomites. This is followed by light brownish grey and grey dolomite beds intercalated with recurrent sandstone, shale and limestone beds. This is followed by pale brown and pinkish to medium grey quartzitic sandstone and dolomite. The upper part is composed of grey to light grey medium to thick bedded cliff forming

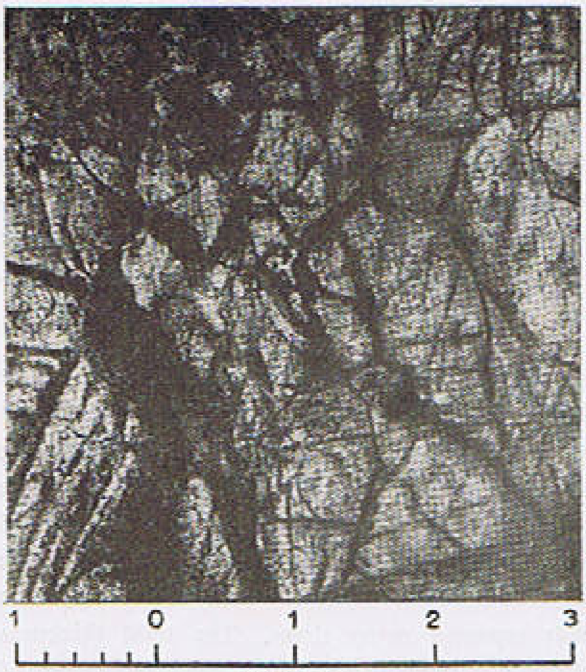


Fig. 7. Solution Weathering of Dolomites of Sirban Formation near Abbottabad.

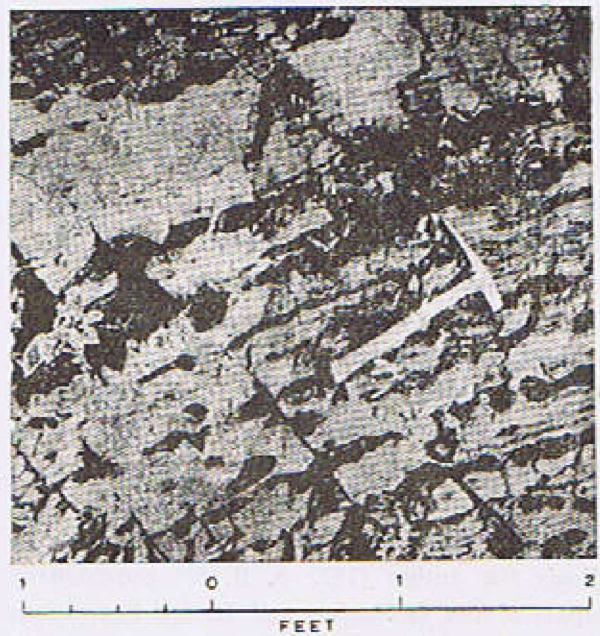


Fig. 8. Chert and Phosphate Lenses and beds in Dolomites of Sibren Formation near Mirpur.

hard dolomite with interbeds of chert upto one foot in thickness and beds of phosphate ranging from few inches upto 12 feet in thickness, (Fig. 8). The formation ranges from 800 to over 1600 feet in thickness.

The upper contact of the formation with Galdanian/Hazira members varies from one locality to the other. It may be gradational as in the case of Salhad (?) and para conformable as in Naredi Gali.

TARNAWAI FORMATION

The unit was first identified as volcanic by Verchere (1867). Waagen and Wynne (1872) recognised an upper division lower part of the Haema.itic Series consisting of heamatitic rocks and quartz breccias. They however failed to recognise the volcanic nature of part of this unit and placed it provisionally as the uppermost part of the Infra-Trias. Middlemiss (1896) not only confirmed the presence of volcanic materials, but also observed the presence of some yellow shales near Tarnawai. He, however, considered the unit associated with the base of the overlying Triassic series, rather than the top of 'Infra-Trias.' Marks and Mohammad Ali (1961) recognised a Rhyolite Member, Lower Formation at the base of their 'Triassic System'. Gardezi and Ghazanfar (1965) described this unit under Haematite Formation and a Hazira Formation. Because of the presence of a gradational passage(?) with the underlying dolomite, they favoured the association of the above two units with the underlying sequence rather than the overlying 'Triassic Series' and as such upgraded the Abbottabad Formation of Marks and Mohammad Ali (1962) as Abbottabad Group to include Haematite Formation and Hazira Formation. The author (1970) followed the above grouping for the purposes of map finalised in 1968. However it was suggested in the text (1970, p. 12) that "three distinct environmental subdivisions of the Abbottabad Group can be noticed (a) a basal conglomerate (b) an orthoquartzite, dolomite and (c) a volcanic, oolitic haematite, siltstone. Though the name Abbottabad Group is retained for the time being, a fresh regrouping seems necessary. The upper two formations namely the Galdanian and Hazira Formations, it is suggested, may be grouped to be known as Tarnawai Group in any later regrouping." Moreover Galdanian and Hazira Formations can not be incorporated as a part of a group upgraded from Abbottabad Formation which as described by Marks and Mohammad Ali were not included in the original definition. It was further noticed by the author that the lower contact in some localities was not gradational with dolomites but paraconformable as near Naredigali. Accordingly the author (1972 p. B. 51) provisionally separated the Galdanian and Hazira Formations from the Abbottabad Group as 'Tarnawai? Group'. Since the Galdanian and Hazira Formations of author (1970) are partly the facies equivalents of each other and in general either one or the other, are overlying the Sirban Formation, it is felt that they do not fulfill the required definition of a formation and as such it is suggested that both Galdanian and Hazira Formations may be downgraded as members of a Tarnwai Formation.

I. GALDANIAN MEMBER

The unit was first identified as volcanic by Verchere (1867). Waagen and Wynne (1872) recognised an upper division lower part of the Haematitic Series, consisting of haematitic rocks and quartz breccias. They, however, failed to recognise volcanic nature of part of this unit and placed it provisionally as the uppermost part of the Infra-Trias. Middlemiss (1896) not only confirmed the presence of volcanic materials, but also observed the presence of some yellow shales near Tarnawai. He, however, considered the unit associated with the base of the overlying Triassic Series, rather than the top of 'Infra-Trias'. Marks and Mohammad Ali (1961) recognised a Rhyolite Member, Lower Formation at the base their 'Triassic system'. Gardezi and Ghazanfar 1965 referred to the unit as the Haematite Formation. The author (1970) proposed the name Galdanian Formation after its development, at Galdanian 9 miles northeast of Abbottabad which was also suggested as a type locality. The Galdanian Formation is downgraded here as a member for reasons given in the description of Tarnawai Formation.

The Galdanian Member at Galdanian can be divided into a lower part consisting of manganese oxide followed by purple coloured quartzitic siltstone and then by a thin bed of manganese oxide. The total thickness of this part is about 23 feet. This is followed by red nodular haematitic claystone, oolitic haematite and oolitic claystone beds repeated many times. The total thickness of this unit is about 132 feet. The topmost bed of about 7 feet thickness is composed of white claystone. In other areas it is described to consist of volcanic rocks, haematitic mudstone and sandstones and quartz breccias. The total thickness of the member is about 162 feet.

II. HAZIRA MEMBER

Waagen and Wynne (1872) recognised sandstones and shales in the upper division of the Haematitic Series of their 'Below the Trias' above haematitic rocks and quartz breccias. Middlemiss (1896) in the descriptive part of his Memoir, p. 124, while describing a section east of Kakul, pointed to the presence of some 'brownish to greenish siltstones and shales, apparently conformably overlying the cherty limestone of Infra Trias'. The rocks were studied in detail by Gardezi and Ghazanfar (1965) who recognised the unit as Hazira Formation. The unit is downgraded to the status of a member for reasons given in the description of Tarnawai Formation.

The formation is composed of dirty grey and yellowish brown calcareous siltstones and sandstone containing earthy concretions, and a few quartzite bands. The member is conspicuously glauconitic in the lower parts and phosphatic in the middle. The yellowish brown colour is replaced by a red tinge at places. The lower contact with Sirban Formation at Naredigali is marked by a dark brown layer of sandstone representing a disconformity. However the Salhad section about 2 miles south of Abbottabad shows a gradational contact (?) with the underlying Sirban Formation. The hyolithids figured and described in this article were collected from the lower glauconitic part of the Hazira Member from Salhad section.

THANDIANI GROUP

The contact of the Thandiani Group with the underlying rocks is unconformable. The group overlaps the eroded surfaces of the various formations/members of the older sequence. It overlies the Tarnawai Formation at Nare di gali; Sangargali Member of Kakul Formation at Sangargali; Tanakki Conglomerate near Thandiani and Hazara Group near Baragali. The overlap is more pronounced in a south easterly direction.

The basal beds consist of an orthoquartzite, grey shales and marls with limestone intercalations, followed by a thick limestone sequence with infrequent marl and shale bands. The Maira Formation and the lower part of the Sikhar Limestone are markedly arenaceous, gradually passing upwards into a purer oolitic limestone. The total thickness of the group is of the order of 1000 feet.

I. DISCUSSION, AGE AND CORRELATION OF THE ABBOTTABAD GROUP

The age of the rocks belonging to the Abbott abad Group, has long been a matter of controversy due to the absence of fossil evidence. The Tanakki Conglomerate was first referred by Oldham, (see Middlemiss 1896, p. 19) as homotaxially related to the Talchir Boulder Bed, of the Salt Range. Waagen and Wynne (1872) found a striking resemblance of the overlying sandstone, the Sangargali Member of the Kakul Formation, with the Purple Sandstone (Khewra Sandstone), Cambrian, of the Salt Range. Middlemiss (1896) compared the two conglomerates of Hazara and the Salt Range situated about 100 miles apart, (Fig. 9), and suggested a possible Carboniferous age, for Tanakki Conglomerate of Hazara, based on the following points of similarity.

Fig. 9. Generalised Geological Map of the Salt Range and Northern Mountain Regions of Pakistan.

1. Both the conglomerates represent an unconformity.

2. Both the conglomerates consist of subangular boulders with great variation in size and coarseness decreasing upwards.

3. Both the conglomerates gradually pass upwards into sandy beds.

4. No other conglomerate of the kind is exposed at any other horizon, in both the areas, except at the base of the Nahan Stage (Miocene) in the Salt Range.

Wadia (1929) confirmed a Carboniferous age for the conglomerate in Hazara, based on his claim to have noticed glacial striations on the Tanakki boulders near Garhi Habibullah Khan.

Marks and Mohammad Ali (1961, p. 53) noted that the striated boulders occurring near Khote di Qabar, close to Tanakki, were in actual fact slickensided by the movements of pebbles during the deformation of the beds.

During the course of the present work, the following facts have been noted.

1. The conglomerate is almost entirely com posed of rocks derived from the underlying Hazara Group as against the Talchir Boulder Bed which is composed of rocks derived mainly from the crystalline rocks of Peninsular India.

2. The break in deposition is not restricted to the Tanakki horizon only but has also been recorded at the following levels :—

(*a*) Between the Sirban and Tarnawai formations (age under discussion in this article).

(*b*) Between the Tarnawai Formation and Thandiani Group (Toarcian).

(*c*) Between the Thandiani and Hothla groups (Oxfordian).

(*d*) Between the Hothla and Galis groups (Maestrichtian).

(*e*) Between the Galis and Rawalpindi groups (Burdigalian).

(*f*) Between the Rawalpindi and Havelian groups (Lower/Middle Pleistocene).

3. The conglomeratic and/or brecciated rocks occur at other horizons, as well, like the quartz breccia of the Galdanian Member; at the base of the Maira Formation as a micro-conglomerate; at the base of the Murree Formation as the Fatehjang Member, and as part of the Havelian Group.

4. The striations of the Tanakki Conglomerate in the area under investigation are of glacial origin.

5. The red and purple sandstones, quartzites and dolomites belonging to Kakul and Sirban Formations are always found to be younger than Tanakki Conglomerate as compared to Salt Range where a similar sequence is always older than Talchir Boulder Bed (Tobra Formation), Permian.

6. The fossilliferous *Productus* Limestone of Salt Range, overlying the Talchir Boulder Bed is completely absent above the Tanakki Conglomerate in Hazara.

The above facts go to prove that the Tanakki Conglomerate and Talchir Boulder Bed represent two different geological horizons and that the former is probably older than the latter.

The volcanic activity Kashmir has been noticed by Wadia, as ranging from the Upper Carboniferous to the Triassic. In Hazara it has not been noticed in the sequence underlying Tarnawai.

All this goes to show that if the volcanic activity dated as Upper Carboniferous in Western Kashmir is applied to Hazara, the pre-Tarnawai Formation sequence is Hazara is older than Upper Carboniferous and not younger.

In the Simla, India, some 300 miles south east of Abbottabad, the Simla Slates are followed by the

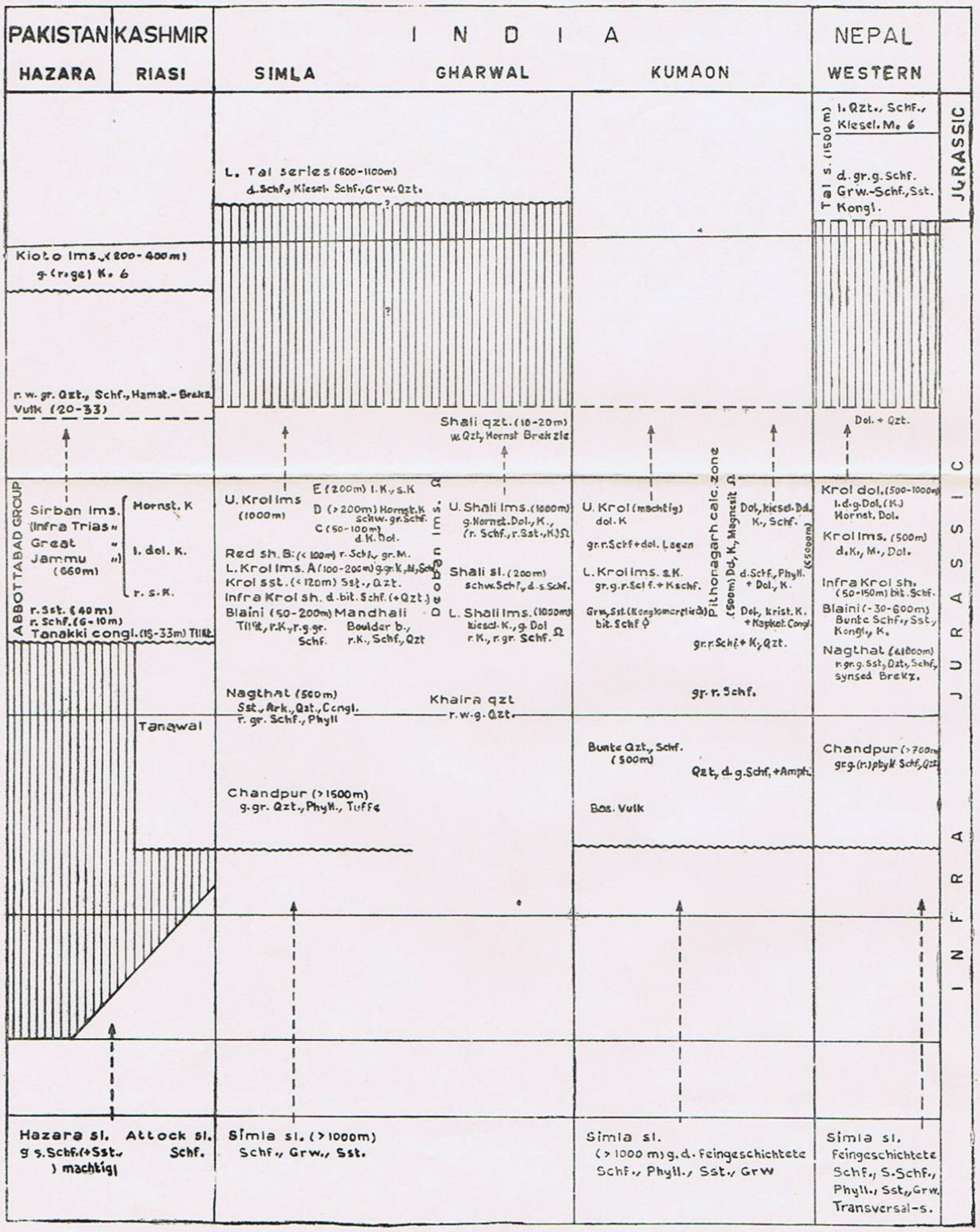


Fig. 10. Correlation Chart of the Unfossiliferous Infra-Jurassic Rocks of the Indo-Pakistan Subcontinent compiled after G. Fuchs (1970).

12/13

Jaunsar Series (Chandpur and Nagthat) consisting of quartzites, grits, conglomerates, and arkoses, which have been definitely considered younger than the Simla Slates and older than Blaini Conglomerate (see Pascoe 1959, Vol. 2, p. 670). The lithological details of Jaunsar Series and their stratigraphic position are identical with the Tanol Formation of Hazara (Fig. 10). These rocks are followed by the Blaini Conglomerate, Infra Krol Shale, Krol Sandstone and Quartzite, Lower Krol Limestone, red shale, and Upper Krol Limestone, overlapped by Lower Tal Series of Jurassic age.

In Gharwal, India, Khaira Quartzite, Lower Shali Limestone, Shali Slate, Upper Shali Limestone followed by Shali Quartzite is considered homotaxial to the Nagthat. Upper Krol Limestone sequence with the addition of Shali Quartzite sequence of rocks similar to that in Simla area has been identified and named as such in Kumaon area of India. In Western Nepal the Simla Slates are followed by Chandpur, Nagthat, Blaini, Infra Krol Shale, Krol Limestone and Krol Dolomite. No fossils have been reported from these rocks, which for every lithological detail resemble those found in Hazara. Fuchs (1970 a. p. 21 and 22) while commenting on the article by the author (1970) says that "The Abbottabad Group (former "Infra Trias" Middlemiss, 1896) apparently shows so many similarities to the Nagthat—Blaini—Krol (Shali) succession and that we cannot doubt their equivalence". Fuchs (1970 b.p. 59 footnote) observes that "In 1969 a joint excursion of M. A. Latif and G. Fuchs has substantiated the equivalence of the Abbottabad Formation and the Blaini—Krol (Shali) sequence". Such a correlation has also been suggested by earlier workers who mainly based their correlation due to the glacial nature of Blaini and Tanakki, which were considered to be of Upper Carboniferous age on the basis of glacial nature of Talchir Boulder Bed. Though there is no doubt about the glacial nature of Blaini and Tanakki their dating as Upper Carboniferous simply on the basis of glacial nature and as such correlating with Talchir is certainly questionable, as glaciation is found no more restricted to Upper Carboniferous level. Though a long range correlation based entirely on the lithologic grounds is not safe, the striking resemblance with the rocks in Hazara and their close proximity to the identical fossiliferous sequence in the Spiti Gharwal, Kumaon and Western Nepal favours such a correlation, (Fig. 10).

It is therefore concluded that

(*a*) Abbottabad Formation may not be post Upper Carboniferous but rather pre Upper Carboniferous.

(*b*) Abbottabad Group may be homotaxial to the identical post Blaini sequence of Simla, Gharwal, Kurmaon India and Western Nepal.

(*c*) Tanakki Conglomerate may not be homotaxial with the Talchir Boulder Bed (Tobra Formation) of Salt Range.

With this basis in mind the author made at thorough search for fossils in late 1969.

Fossil like objects in the Hazira Member were first observed at Salhad near Abbottabad, (Fig. 11, 12) by the author and G. Fuchs in late 1969. These were sent to Seilacher of the University of Tubingen, West Germany in January 1971 and were examined by Seilacher and Gocht in July 1971, the latter also having prepared the drawings, (Fig. 13). They reported as the following :—

"1. There is no doubt that we deal with true fossils.

2. Two morphological types are observed in the sample.

(*a*) Conical bodies up to 12 mm. in length, which resemble Hyolithid shells through their being somewhat flattened on one side.

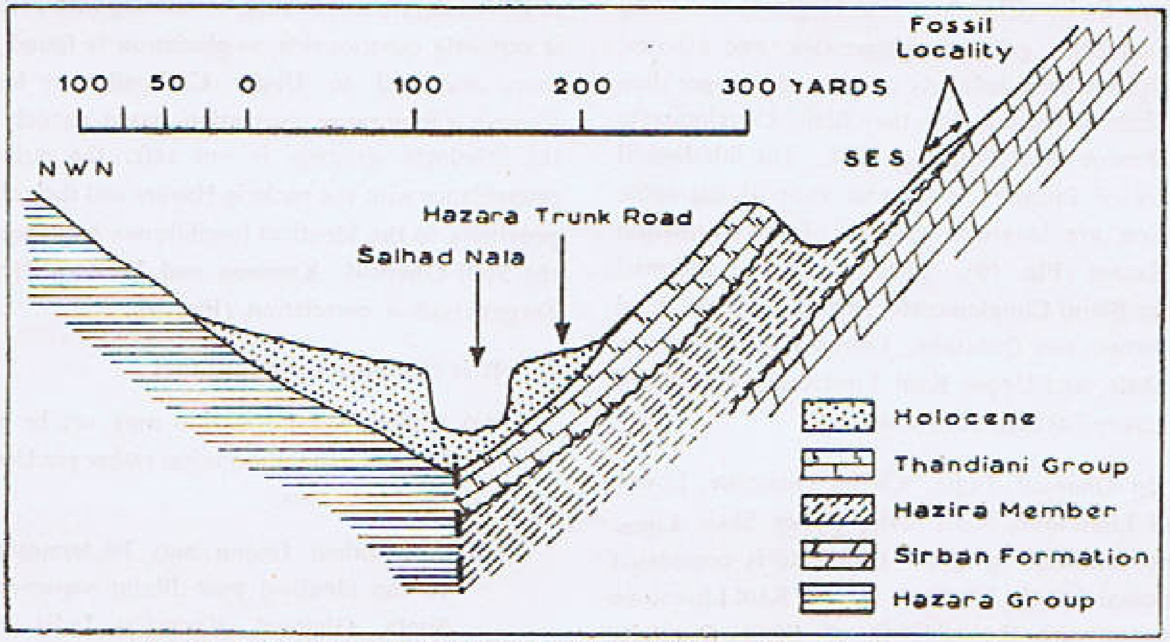


Fig. 11. Section Drawn near Salhad, Abbottabad, Mile Stone 69, on the Hazara Trunk road.

(*b*) Smaller, slender rods, (up to 3 mm and more), sometimes with ends thickened like articulated elements of axial endoskeletons (melanosklerites of fossil hydrozoa; bryozoa; echinoderms).

3. In this section most of the conical fossils reveal concentric rings expressing a "cone in cone" structure. Similar structures have been described by Yochelson (U. S. Geol. Survey Profess. paper 593-F, 1968) in the enigmatic fossil Polylopia from Middle Ordovician limestones. This genus, however, has a circular cross section. Its "cone in cone" structure was earlier interpreted as an original feature but I tend to agree with Yochelson that it is due to post-morten "nestling" of shells during transport. In this case the similarity with polylopia has no significance as to geologic age but only to the biostratinomic situation.

4. All fossils are massive, consisting of a brown homogeneous substance different from the matrix. This substance is somewhat less soluble in acetic acid than the matrix and more resistant to weathering. The initial suspicion that we deal with phosphatic material could not be analytically corroborated: No luminescence in ultraviolet light; no phosphorous to be detected with the vanadium-molybdate test. As a result we tend to consider the fossils as Hyolithid shells derived from a primary deposit where high turbulence or wave action had produced multiple "nestling" of dead shells before the stacks became sediment-filled and imbedded. Reworking brought the steinkerns into the present secondary deposit, where they became

Fig. 12. Hyolithes fossils littered Weathered surface of Hazirah Shale Member.

stirred up by extensive bioturbation which destroyed most of the depositional structures, and caused the obvious mottling of the rock. Frequent fracturing of the fossils may be due partly to transport or to compactional stress."

According to Moore, Lalicker and Fischer (Invertebrate Fossils), Hyolithes is widely distributed in Cambrian rocks, recorded at many places in Ordovician and Silurian strata, and occurs sparingly in younger Palaeozoic deposits as high as Permian. This, I would say, practically rules out a Permian—Triassic age for the beds, as was formerly assumed and confirms the views of the author expressed in 1969 and 1970 that the Abbottabad Group may not be of post Upper Carboniferous age. A palynological examination of Infra-Krol and Blaini rocks (verbal communication with G. Fuchs) has yielded primitive globular forms as are described from several Algonkian sequences. If the Blaini Krol (Shali) correlation with Tanakki-Abbottabad Group, (see Fuchs 1970 page 59), is accepted, it further rules out the possibility of post Upper Carboniferous age for Tanakki Conglomerate and post Tanakki deposits. The Hyol thes bearing Hazira Member is rich in glauconite. Similarly the Hyolithes bearing Kussak Formation, formerly Neobolus Beds, late Early Cambrian to early Middle Cambrian of Salt Range, Pakistan, is also distinctly glauconitic. In Iran, Hyolithes is very common in Cambrian beds but has not been recorded from any younger beds, see Stocklin et. el. 1964. This and the lithological similarities of the profile with the Cambrian sections of Salt Range and Iran, particularly the high glauconite content (glauconite being almost a "guide-mineral of the Cambrian of North Iran), lead us to at any rate the most reasonable assumption of a Cambrian age of the Hazira Member.

There are however a few questions which must be answered before reaching a final conclusion.

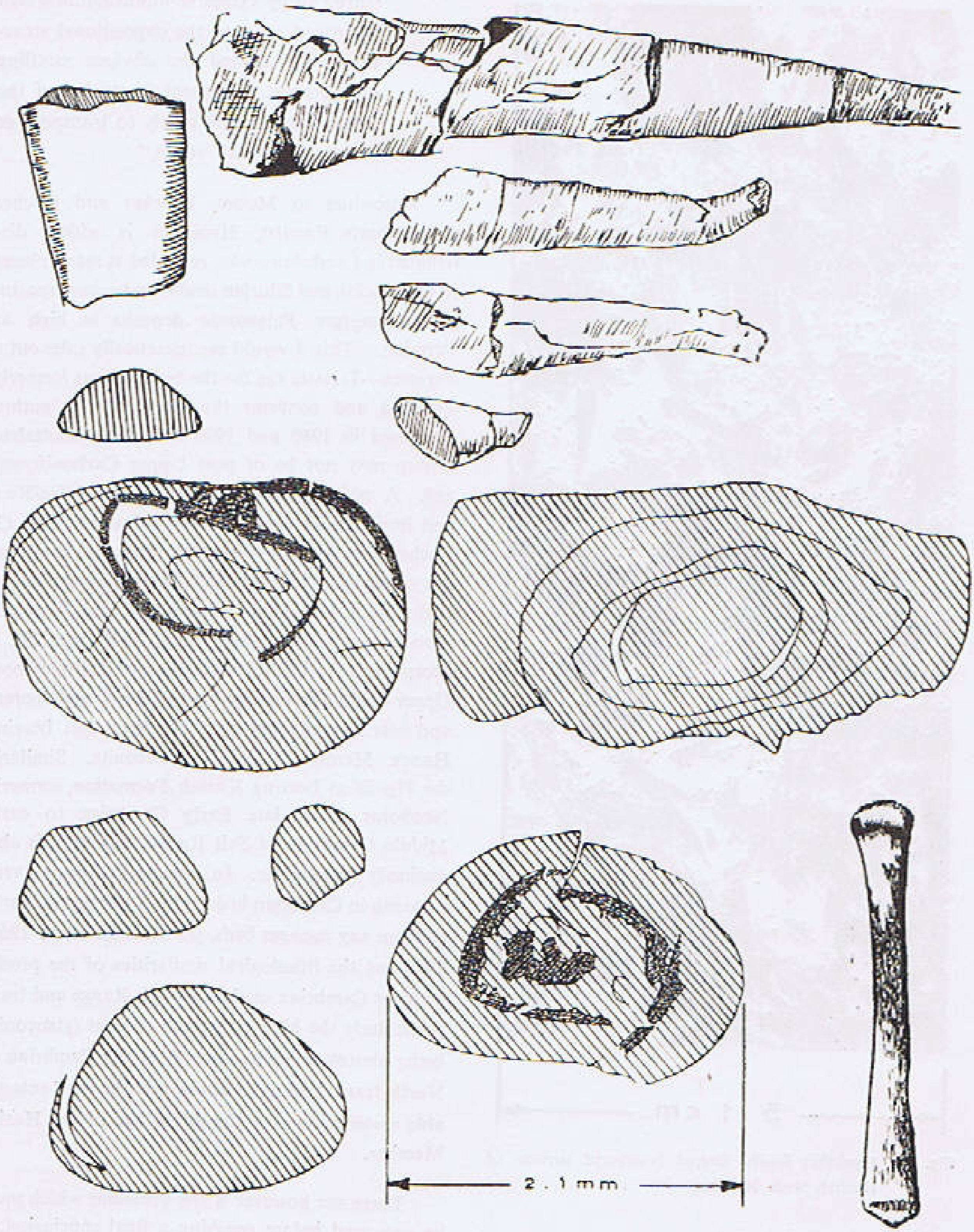


Fig. 13. Various Sections of Fossil Hyolithes (Drawing by H. Gocht)

1. Seilacher considers that the Hyolithes shells have undergone reworking from a primary deposit into the present secondary deposit.

2. The Upper parts of Sirban Formation and certain parts of Hazira Member are phosphatic.

3. The glauconitic, Kussak Formation, Cambrian, of Salt Range is underlain by Khewra Sandstone (Purple Sandstone) and overlain by Jutana Dolomite. In Hazara, Hyolithes bearing Hazira Member is separated from Sangargali Member which is mainly purple coloured sandstone and quartzites, by a thick dolomite and sandstone sequence and not followed by dolomites as in the Salt Range.

Stocklin, written communication, has the following comments on the questions posed above. "Hyolithids being most abundant in Cambrian beds the world over there is a high probability that the Hazira Member is Cambrian. I do not quite understand why Seilacher considers them as reworked; if they are reworked, I would say that they have been reworked very shortly after primary deposition. Otherwise I could not understand why they occur at one stratigraphic level and only at this level, and why they are not mixed with various other fossil debris. The assumption of a Cambrian age is supported by: a) the presence of abundant glauconite as in the Cambrian of the Salt Range and of North Iran, b) the presence of a red sandstone unit (Sangargali) farther down-section, as is the case in the Salt Range and over a great part of the Middle East, and of stromatolitic beds below the red sandstone.

The Sangargali Member, because of its stratigraphic position below beds with *Hyolithes*, must be assumed to be Lower Paleozoic or older. Because of this, the lithological similarity with the Purple Sandstone and the Lalun Sandstone and the proved great persistence of the later make stratigraphic identity highly probable; the Sangargali Formation can thus be safely assumed to be correlative with the Purple Sandstone and the Lalun Sandstone and to be Lower Cambrian.

The the glauconitic Kussak Formation of the Salt Range is underlain by the Purple Sandstone, thus pointing out the difference with Abbottabad, where thick dolomites separate the glauconitic beds from the suggested Purple Sandstone equivalent. Comparing with Iran, I think that the presence of the dolomites at Abbottabad rather support than contradict a Cambrian age of the Hazira. It is very important to know that the Cambrian fossils of Kussak are older (Lower or Lower Middle Cambrian) than those of the Iranian sections to which you refer (Stocklin and Rutner, 1964); these range from Middle Cambrian to Ordovician (see revisions in the Iranian Lexican), and they are like at Abbottabad underlain by 200 m. thick dolomite unit (Member 1 of the Mila Formation) in North Iran and 1000 m thick (Kalshaneh Formation) in East Iran, separating the fossil beds from the Lalun Sandstone. We have now some good evidence that these (unfossiliferous) dolomites correlate with dolomite limestones occurring in the same stratigraphic position further south in Iran (in the Zagros and at Kerman) and containing there similar trilobites as those of the Kussak Formation *i.e.* Lower or Lower Middle Cambrian. It is thus well possible that the Hazira fossil beds correspond not to the Kussak but to the North Iranian (Middle Cambrian to Ordovician) *trilobites/hyolithes* beds, which are also highly glauconitic. The Kussak equivalents at Abbottabad in this case would be present in the post Tanakki Abbottabad members, not in the Hazira. I had always this correlation in mind, but as a Pakistani you had of course more concern for a comparison with the Salt Range. All this is suggested in the following correlation.

Seilacher has however pointed out that the Hyolithid shells have been reworked into their secondary present deposit, the Hazira Member, which is also found to be phosphate rich. The

North Iran	*East Iran (Tabas)*	*SE Hazara*
Mila Formation, Members 2,3,4.	Derenjal Formation	Hazira Formation
Mila Formation, Member 1	Kalshaneh Formation	Sirban Formation Mirpur Member Mahmdagali Member
Lalun Sandstone	Lalun Sandstone	Sangargali Member

possibillity of reworking howsoever of limited duration cannot be ruled out as the contact between the Sirban Formation and Hazira Member is generally marked by a break in deposition. The phosphate bearing rocks in Iran are found in the Geirud Formation, Devonian.

Since the sequence from Tanakki Conglomerate to Sirban Formation except for a short break above Sangargali Member is generally normal and transitional and that since the contact between Sirban Formation and Hazira Member is both gradational (?) as well as disconformable varying from region to region, the sequence from Tanakki Conglomerate to Sirban Formation in all probabillity is pre-reworked, the hyolithid faunae bearing Hazira Member. Whereas the age of the post Sirban Formation sequence is left open, that of the Abbottabad Group from Tanakki Member to Sirban Formation in all probabillity is Cambrian.

The samples examined by Seilacher and Gocht were sent to Rushton who reported in March 1973 as follows:

"Preparation of Latif's material not only confirmed the presence of Hyolithids (*circotheca* and *Linevitus*?) but yielded spicules of Heterectinellid sponge *Chancelloria* Walcott. *Chancelloria* is known from the Middle Cambrian of North America, the Ordian of Australia and from Lower Cambrian in England. A Cambrian age for the Hazira Shale is therefore fully confirmed".

It is therefore concluded :

(*a*) That Tanakki to Sirban sequence of Abbottabad Group is of Cambrian age.

(*b*) That Sangargali Member of the Kakul Formation is homotaxial with the Khewra sandstone (Purple Sandstone) of Salt Range and may be homotaxial with the Lalun Sandstone of Iran.

(*c*) That the Post Tanakki sequence of the Abbottabad Group of Hazara may be equivalent to the identical post Blaini sequence is Simla, Gharwal, Kumaon, India and Western Nepal. Perhaps a search for fossils in Shali Quartzite in Gharwal area, in India may prove to be interesting.

ACKNOWLEDGEMENTS

The writer is thankful to Dr. J. Stocklin for his inspiring discussions, and for his request to Prof. Seilacher for examining the sample and suggesting improvements in the draft. Without his personal interest this publication might not have been possible. I am thankful to Prof. A. Seilacher and Dr. H. Gocht of the University of Tubingen for the identification of fossils. I am also thankful to Dr. A. W. A. Rushton for confirming the Identification and age. Thanks are also due to Prof. W. D. Gill for fruitful discussions and to Mr. D. J. Carter for his kind help in providing facilities in initial stages which made this study possible.

REFERENCES

ALI, C. M., 1962 The Stratigraphy of the South-Western Tanol area, Hazara, West Pakistan. *Geol. Bull. Punjab. Univ.*, **2**, 31–38.

AVAL, M. MOVAHHED, NAMIN, M. SAMINI AND GHASEMIPUR, R., 1966 Recent phosphate discoveries in Iran, *Geol. Surv. Iran Report*, 10, 1–84.

FUCHS, G., 1970 The significance of Hazara to Himalayan Geology. *Jb. Geol. B.A. Sond.* **15**, S 21–23 **Wien.**

FUCHS, G., 1970 The Geology of West Nepal between the Rivers Kali Gandaki and Thulo Bheri. *Jb. Geol. B.A. Sond.*, **18**, S 1–103, Wien.

GARDEZI, A. H., AND GHAZANFFAR, M., 1965 A change of facies at the base of the Jurassic in district Hazara, West Pakistan. *Geol. Bull. Panj. Univ.*, **5**, 53–54.

GEE, E. R., 1944 The age of Saline Series of the Punjab. *Nat. Acad. Sci.* India, Sec. B., **6.**

Bakr, M. A. and Jackson, R.O., 1964 Geological Map of Pakistan. *Geol. Surv. Pak.* (Scab. 1 : 2,000,000).

HOLLAND, T. H., 1908 On the occurance of striated boulders in the Blaini Formation of Simala with a discussion on the geological age of beds. *Rec. Geol. Surv. India*, **37**, 120–135.

KHAN, M. H., 1956 Lexique Strat. Internat. 3. facs. 8, a India, Pakistan, Nepal, Bhutan, 1–404.

LATIF, M. A., 1969 The stratigraphy of South East Hazara and parts of the Rawalpindi and Muzaffarabad, districts of West Pakistan and Kashmir. Ph.D. thesis, London Univ., London.

———, 1970(*a*) Explanatory notes on the geology of South Eastern Hazara, to accompany the revised Geological Map. *Jb. Geol. B. A. Sond*, **15**, S 5–20 Wien.

———, 1970(*b*) Lower Carboniferous Rocks near Nowshera, West Pakistan. *Goel. Soc. Amer. Bull.*, **81**, 1585–1588.

———, 1972(*a*) An occurrences of Palaeozoic phosphate rock in Hazara district, West Pakistan. *Trans. Sec. Inst. Min. Met., B.* **81**, 50–53.

———, 1972(*b*) Lower Palaeozoic, Cambrian (?) Hyolithids from Hazira Shale, Pakistan. *Nature Phys. Sci.*, **240**, 100, 92.

MARKS, P., AND ALI, C. M., 1961 The geology of Abbottabad area with special reference to Infra Trias *Geol. Bull. Panj. Univ.*, **1**, 47–55.

———, 1962 The Abbottabad Formation, a new name of Middlemiss 'Infra Trias. *Goel. Bull. Punjab. Univ.*, **2**, 56.

MIDDLEMISS, C. S., 1896 The geology of Hazara and the Black Mountain. *Mem. Geol. Surv. India*, **26**, 10–29 and 88-177.

MOORE, R. C., LALICER, C. G., and FISCHER, A. G., 1952 Invertebrate fossils. MacGraw Hill Book Co. Inc. New York, 329.

PASCOE, E. H., 1950–1959 A manual of the geology of India and Burma Vol. I and II.

STOCKLIN, J., RUTNER, A., AND NABAVI, M., 1964 New data on the Lower Paleozoic and pre-Cambrian of North Iran. *Geol. Surv. Iran report* 1—36.

Stratigraphic Committee of Pakistan, 1962 Stratigraphic Code of Pakistan. *Geol. Surv. Pak. Mem.* **4**, pt. **1**, 1—7.

VERCHERE, A., AND DEVERNEUIL, 1866—67 Kashmir the Western Himalaya and Afghan Mountains a geological paper with a note on fossils. *Journ. As. Soc. Beng.*, t. **35**, pt 289—133, 159—203 and t. 36 pt 2, 9—50, 83—115, 201 10 pt.

WAAGEN, W., AND WYNNE, A. B., 1872 The geology of Mount Sirban in the Upper Panjab. *Mem., Geol. Surv. India*, 9, 331—350.

WADIA, D. N.. 1929 North Punjab and Kashmir. *Rec. Geol. Suvr. India*, **62**, 152—156.

Wadia, D. N.. 1934 The Cambrian—Trias sequence of North Western Kashmir (Parts of Muzaffarabad and Baramula districts). *Rec. Geol. Surv. India*, 68, Pt. **2**, 128—176 with map.

WADIA, D. N., 1053 Geology of India. MacMillan and Co. London.

WEST, W. D., 1931 Hazara Simla Hills correlations. *Rec. Geol. Surv. India*, 65 125—132.

(Manuscript received March, 1973)

GEOLOGY OF THE SERPENTINITE BELT AND ASSOCIATED ROCKS NORTH OF HINDUBAGH (MUSLIMBAGH) ZHOB VALLEY, BALUCHISTAN, PAKISTAN

BY

FUZAIL A. SIDDIQUI

Department of Geology, University of the Punjab, Lahore

and

MOHAMMAD ASHRAF

M. WAHEED QURESHI

Glass and Ceramics Division, PCSIR Laboratories, Lahore

Abstract : *Geological map of about 120 sq. miles area at a scale of $2\frac{1}{2}''=1$ mile was prepared which has been reduced for publication to a scale of one inch to one mile. The rocks present include serpentinite associated with Palaeocene and younger sedimentary rocks.*

Two sub-parallel thrust faults striking roughly east-west and separated by about $2\frac{1}{2}$ miles are the important structural elements in the area. Serpentinites are associated with dolerite, rodingite, and pyroxenite outcrop where Eocene or Palaeocene strata are thrust over Siwaliks.

Previously the contact of Shaigalu Formation (Oligocene) and Nisai group (Eocene) was thought to be a thrust fault but this could not be confirmed in the present survey.

No contact metamorphism appears to be associated with serpentinites and they appear to have been emplaced tectonically.

Regarging the vesuvianite deposits of Tleri M. Jan these occur in rodingite formed by metasomatism of dolerite.

Near Tor Tangi and elsewhere in the area silica rich residual rock has been formed by weathering of the serpentinites. The rock is very similar to birbirite rock from Yubdo, Ethiopia. Similar rocks south of Hindubagh have been erroneously called 'laterite'. Chemical composition of the various zones of the residual cap is also presented.

Chromite, generally of refractory grade, occurs in the area. Chromite from a few occurrences in the eastern part of the area, are of metallurgical grade.

INTRODUCTION

Scope of the Paper

The paper presents the main features of the geology of the area north of Hindubagh but places special emphasis on the ultramafic igneous rocks. The latter outcrop mainly in the form of a narrow belt, some 15 miles long, along the northern flank of the Zhob Valley. The geology of the area formed the basis of field reports of two of us (M.A.

& M.W.Q.) which were submitted to the University of the Punjab in 1966 in partial fulfillment of the requirements of M.Sc. degree. The work was supervised by Siddiqui. Chemical analyses, except where otherwise stated have been done by Qureshi. A geological map of the area at a scale of 2½"=1 mile was prepared which has been reduced for publication (Fig. 1). About 300 rock specimens were collected, of which about 100 were studied in thin section. Petrography of various serpentinites, dolerites and related rocks is described in some detail. Brief comments are offered on the lithology and stratigraphic palaeontology of Tertiary sedimentary successions, between which the serpentinite is sandwiched. The presence of volcanic rocks, probably not previously recrorded from the area, is briefly described. Aspects of the structure of the area, bearing upon the emplacement of the serpentinites, are dealt with at some length. Also discussed is the relationship of the serpentinite belt to the main mass of ultramafic rocks of the Hindubagh Igneous Complex, to the south of Zhob Valley. Some chemical analyses of rodingite and the birbirite cap developed on portions of serpentinite are presented and the petrogenesis of birbirite and rodingite is discussed.

Location and Field Work

The area investigated lies immediately north of Hindubagh town, situated at about 74 miles north-east of Quetta. The boundaries of the area mapped are represented by long. 30° 45′ 03″ – 30° 56′ 46″N and lat. 67° 40′E – 67° 54′ 50″E enclosing an area of some 120 square miles of mountainous territory (Fig. 1).

The major villages of the area namely Ragha Sultan Zai, Tleri Muhammad Jan, Khazina, Tor Tangi and Gat, are connected to Hindubagh town by unmetalled fair-weather roads. Hindubagh, in turn, is connected to Quetta by metalled road and railway.

Field work was spread over two field seasons viz May-June 1965 and July-August 1966. The mapping was carried out from camps located first at Khazina, then Tor Tangi and finally at Gat.

The mapping was done using photographic enlargements at 2½" to a mile, prepared from Survey of Pakistan 1" topo-sheets No. 34 N/9 and 34 N/13. Field mapping was supplemented by interpretation of aerial photographs.

Physiography

The area is a portion of the northern flank of the Zhob Valley which runs approximately ENE-WSW in the vicinity of Hindubagh. Geomorphologically the area consists of precipitous and rugged mountains to the north bordered by the low laying old terraces of the Zhob Valley to the south. The altitude of the area increases gradually from just under 6000 ft. to 7500 ft. in about six miles, as one proceeds from Hindubagh towards north. From here onward, the slopes abruptly steepen and the altitude increases to the highest peak of the area-Mate Ghare Singh Sar (10156 ft.) within 3 miles.

The topography is markedly controlled by geology. The northern high cliffs and steep mountainous area consists of compact and hard Shaigalu Sandstone and Nisai Limestone. Sheared serpentinite forms low rounded hills. Locally, portions of serpentinite, which have escaped shearing and are consequently less prone to erosion, stand out as steep pillars, as for instance at Urgasai, east of Tleri M. Jan and West of Gat. (Fig. 2). The low lying southern area consists of semi-consolidated clay and sandstones of Multana Formation unconformably overlain by horizontally bedded sub-recent alluvium and conglomerates (Fig. 3).

The major stream flow is to the south. None of the streams is perennial. A few *Karezes* (rows of wells connected by underground channels) such as at Ragha Sultan Zai, Khazina, Kanr and Gat and a few springs provide the water requirements .

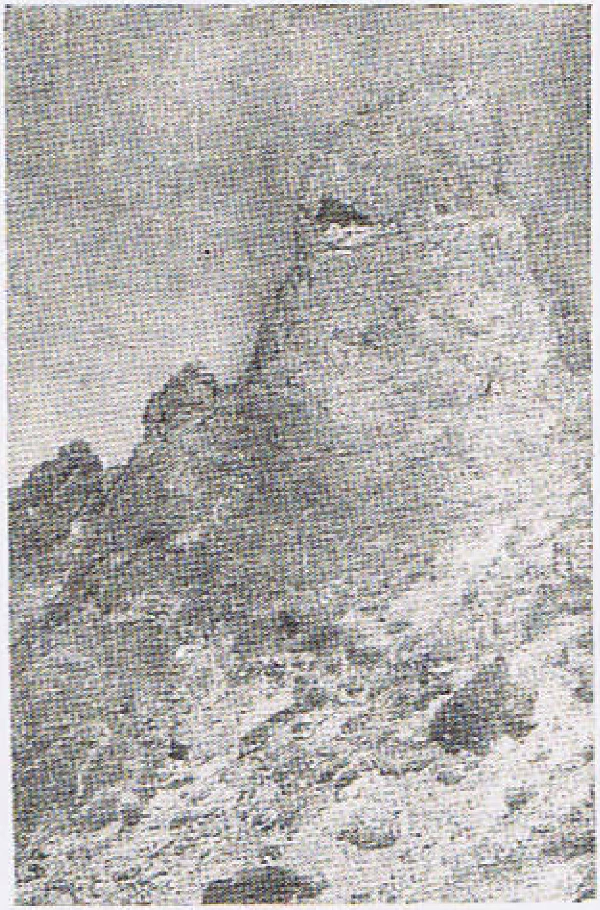


Fig. 2 Pinnacles in Serpentinite.

of the area. A spring with saline water emerges from an outcrop of pyritous clay at Grid Ref. 721.5, 068.5. The climte is arid, hence there is little vegetation. The exposures, throughout much of the area are excellent, except where covered by scree.

Previous Work

Few references exist in the literature mentioning geological aspects of the area. The ultramafic infrusions of Hindubagh have attracted a great deal of attention owing to their chromite deposits. However, most of the work appears to have been done on the ultramafic and associated igneous rocks to the south of Hindubagh. Bilgrami (1960) described the vesuvianite bearing rock of Tleri M. Jan and considered it to be metamorphosed stoped limestone block in enclosing serpentinite. Later, he published a correction and the same rocks were called rodingite (Bilgrami 1963). The same conclusion was reached by the authors independently.

Geologists of the Hunting Survey Corporation Limited (1960) mapped the region geologically on

Fig. 3 Sub-recent Alluvium lying Unconfirmablly on Tilted beds of the Multana Formation.

a reconnaissance basis. The area forms part of the sheet No. 26 accompanying their report. They pointed out the possible existence of a low dipping fault named the Hindubagh thrust fault, along the north edge of Zhob Valley and considered that the thrust fault existed along the top of the Nisai group (early Eocene-early Oligocene) and that Nisai group rested unconformably on serpentinite. Shams (1955) described the mineralogical properties of vesuvianite of Tleri M. Jan. Ashraf et al. (1970) have described the mineralogy of serpentinite from Tleri M. Jan.

REGIONAL GEOLOGICAL SETTING

The present account of the regional geology is largely based on the report of Hunting Survey Corporation Limited (1960). From the Permo-Carboniferous to the Pliocene time the Baluchistan region was the site of a structural trough occupied by one arm of the ancient sea "Tethys". The trough known as the Baluchistan Geosycline, was the site of deposition of thousands of feet of sedimentary strata, mostly of shallow marine environment. From at least Jurrasic period onward longitudinal geanticlinal ridges began to form in the basin. The main positive structure of this type, as inferred from the study of present day exposures, is called the central geanticline.

The geanticlines emerged from the sea at various time and at various places along their lengths. The conditions of the crest and flanks of the geanticlines remained shallow marine or continental and gave rise to an assemblage of sedimentary rocks called the "Axial Belt" that are distinct from the deposits elsewhere in the basin. These deposits are characterised by (*i*) prevalence of pre-orogenic conglomerate (*ii*) sedimentary features of shallow water environment (*iii*) unusual variety of colours.

The geanticlines were also the site of igneous activity of both extrusive and intrusive type. Along the central geanticline, volcanic (spilitic basaltic lavas with pillow structures) and related pyroclastics and intrusive ultramafic rocks of Cretaceous age were emplaced on the northern flank at two places i.e. Hindubagh and Fort Sandeman (Fig. 4). The serpentinite belt described in the present paper forms the northern-most outcrop of Hindubagh intrusion. Younger doleritic dykes and sills intrude both the igneous as well as the older sedimentary rocks, surrounding the Hindubagh intrusion.

The geanticlines probably began as simple folds which in their later stages developed into complex anticlinoria combining the effects of multiple folds and reverse faults.

GENERAL GEOLOGY OF THE AREA

The most prominent feature of the area north of Hindubagh is a narrow, pinching and swelling belt of serpentinite sandwiched between early and late Tertiary sedimentary stratea.

The serpentinite belt consists of serpentinized dunite, harzburgite and peridotite. In addition some pyroxenite dykes are present in the serpentinite. Small isolated blocks of dolerite measurable into tens of yards, are enclosed in serpentinite at several places. Some of these blocks are altered to rodingite. Serpentinite is locally sheared and granulated into a friable mass and may contain net work of veins of chrysotile asbestos and fibrous dolomite. A number of isolated chromitite lenses occur in the serpentinite and it is interesting to note that all the lenses are localized a few feet below the top of the serpentinite belt.

The upper faulted contact of the serpentinite body is with Palaeocene/Eocene limestone and is characterised by the occurrence of a breccia consisting of angular fragments of serpentinite or talc cemented by carbonate material. The lower contact, also faulted, is mainly with arenaceous and argillaceous sediments. Red coloured fault gouge is encountered all along the lower contact of serpentinite.

The various rock types and their field relations

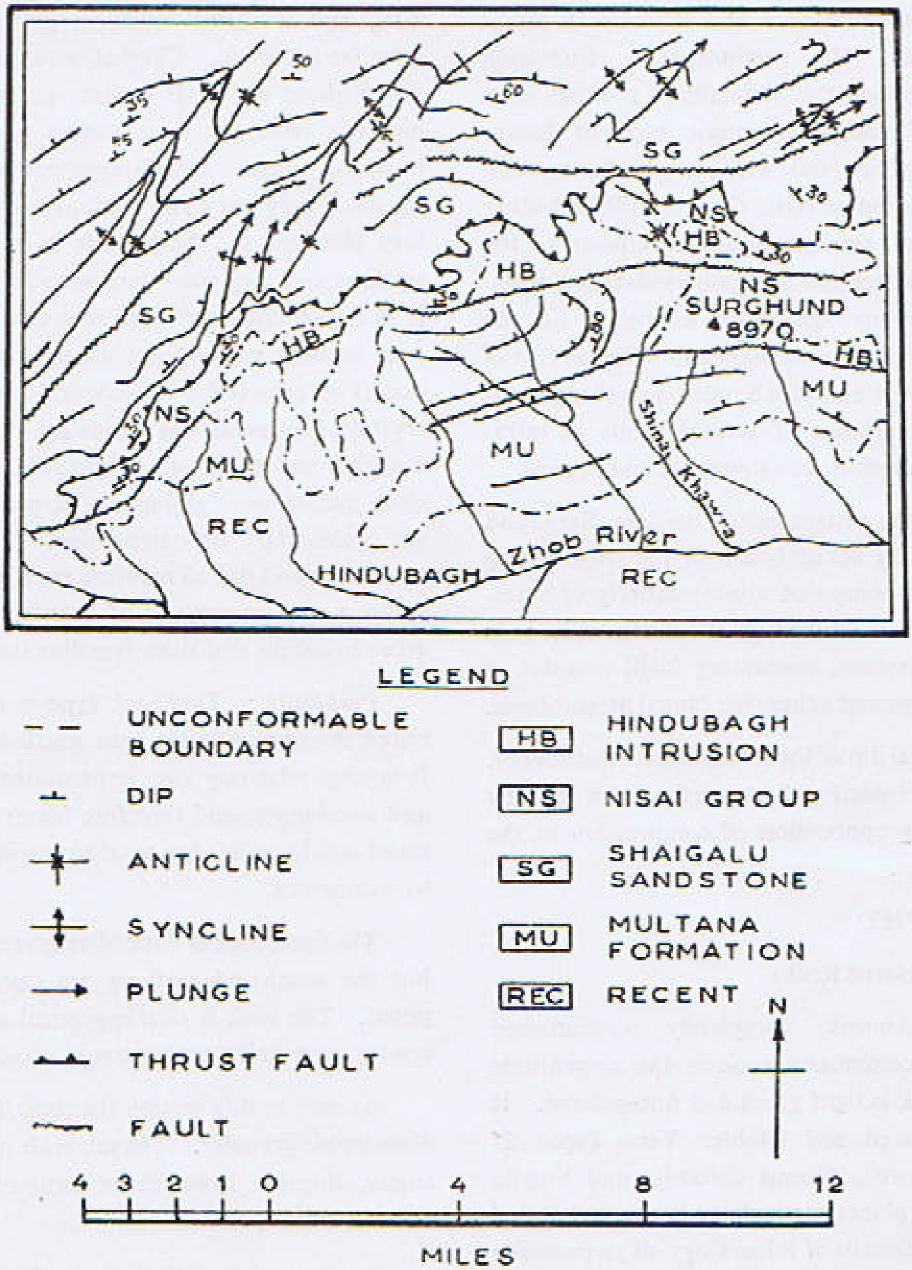


Fig. 4. Portion of the Geological map of Zhob Valley showing Location of main Outcrops of Ultramafic Rocks (after Hunting Survey Corporation 1960).

may be described with the help of the Section (Fig. 1) The stratigraphic nomenclature of Hunting Surveys Corporation (1960) is adopted for the purpose of this paper.

The strata below the serpentinite belt consist of undifferentiated Oligocene and younger beds called Multana Formation. These are a succession of strongly coloured (red, orange, yellow, olive, grey) conglomerates, sandstones and shales with minor limestone beds. The sedimentary formation immediately above the serpentinite consists of a succession of mainly limestone beds of Lower Tertiary age called Nisai Group. At the western end of the outcrop of Nisai Group, tuffs and other volcanic rocks are encountered. Upwards, the Nisai Group passes into Shaigalu Sandstone Formation of Oligocene age which continues till the northern edge of the area mapped. The contact of Nisai Group and Shaigalu Sandstone is characterized by the occurrence of several bands of intra-formational limestone conglomerate and breccia.

Towards the eastern end of the area, Surghund Hill, which rises abruptly above the surrounding topography, is composed almost entirely of limestone. The hill is flanked on the north with beds of reefoid limestone, containing fossil colonies of Coral and Algae and other rich faunal assemblages.

The general dip of the formations is northward. The strata are folded and reverse faulted a tectonic style indicating application of compression as the dominant stress.

PETROGRAPHY

Igneous and Related Rocks

Dunite : Almost completely serpentinized dunite is the commonest rock in the serpentinite belt. The rock is light green and fine-grained. It is locally sheared and friable. Veins (upto 2" thick) of asbestos, fibrous dolomite and brucite occur at many places particularly in the vicinity of Tleri M. Jan: Details of mineralogy of serpentinite body have been given by Ashraf et al. (1970).

As seen in thin sections the rock is composed almost entirely of colourless, pale green to green serpentine minerals with occasional crystals of chromite. Box work texture is common. Antigorite content varies from almost 100% to about 10% and it forms anhedral grains or a fibro-lamellar net work. Chrysotile content varies from nil to about 55%. It occurs as cross fibres in bipartite veins. It is colourless to pale green or brownish green. Interference colour is normally the usual grey but some sections exhibit an anomalous blue colour. Serpophite is present in a few sections and may constitute upto 25% of the rock. It is fine-grained and typically colourless. Chromite content varies from about 1 to 10% and it occurs as euhedral to subhedral reddish brown crystals. Frequently the grains are altered along the margins and cracks to maghemite. Some grains show inclusions of globules of serpentine. Magnesite is secondary after serpentine. It locally occurs as veinlets and fine to medium sized grains. A few sections contain crystals of bastite which are pale green in colour and show lamellar structure.

Peridotite : This rock type is of rather restricted occurrence in the area north of Hindubagh. It is also relatively less serpentinized than dunite and harzburgite and therefore forms outcrops that stand out in relief due to their superior resistance to weathering.

The fresh rock is dark olive green and compact but the weathered surfaces are rusty brown and pitted. The rock is coarse-grained with pyroxene crystals over half a centimeter in cross-section.

As seen in thin section the rock is coarse hypidiomorphic granular. The minerals present include augite, diopside, hypersthene, antigorite, chrysotile and olivine.

Augite may constitute upto 30% of the rock and occurs as subhedral to anhedral grains ($C \wedge Z = 60°$). Some grains are twinned (No. 8551)*. Alteration along cleavage and cracks to chrysotile is common. In some specimens the clinopyroxene present is diopside. Orthopyroxene is bronzite or hypersthene in composition and may constitute

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

upto 15% of the rock. Chrysotile (upto 35% modal content) is present as a network of veins enclosing fine-grained aggregates of antigorite. The latter may comprise upto 30% of the rock. Some specimens (e.g. No. 8248) contain iddingsite and bowlingite in addition to chrysotile and antigorite. Antigorite also occurs in late stage veins. Early antigorite has slightly anomalous blue interference colour. Remnants of olivine occur as clusters of angular grains. In one specimen (No. 8551) olivine comprises 5% of the volume of the rock.

Ore minerals are generally absent in peridotite. Fig. 5 is a photomicrograph of a typical thin section of peridotite from the area.

Harzburgite : Serpentinized harzburgite is present as concordant layers in serpentinized dunite (Fig. 1). Three sub-parallel layers are present in the Tleri M. Jan area, and continue upto the Ragha Nala. The other main exposures are in the Gat area. Outcrops of serpentinite east of Gat consist almost entirely of harzburgite with occassional dykes of dolerite. The harzburgite layers vary in length from a few feet to almost a mile. The width is also variable, attaining a maximum of 300 feet in the eastern part of the area. At places blocks of dunite are enclosed in harzburgite. In hand specimen the rock is easily distinguished from dunite by its dark olive green colour and shining crystals of pseudomorphed bronzite set in a matrix of partially or completely serpentinized olivine. At places white carbonate veins cut across the rock. In thin section subhedral crystals of bastite are found to be randomly distributed in antigorite and crysotile.

Bastite comprises upto 40% of the rock. The crystals are light green anhedral to subhedral and show fine lamellar structure probably inherited from the lamellar twinning of the original orthopyroxene. Dusty opaque inclusions may or may not be present. Replacement by carbonate along margins and cracks is common.

Fig. 5. Photomicrograph of Peridotite (8551).

Chrysotile (15-55%) and antigorite (0-60%) are present in the usual box work structure in which light green chrysotile veinlets form a network enclosing colourless antigorite. In some specimens the ground mass is composed of iddingsite and bowlingite. Serpophite (0-30%) occurs in the form of patches of very fine-grained material of a faint greenish colour and very low birefringence. A late stage colourless chrysotile occurs in fine-veinlets which cut across all other grains. In some of these veins chrysotile is replaced by carbonate and a late stage chlorite crystallized along the middle of the veins.

Unaltered olivine grains (30%, in specimen No. 8600) are seen in an outcrop near Gat. The grains are coarse to medium, anhedral to subhedral and have irregular cracks lined with chrysotile. Spinel group minerals constitute upto 10% of harzburgite. This composition varies considerably from specimen to specimen. Most samples contain chromite (dark reddish brown to almost opaque grains) which are usually altered to an opaque mineral, probably maghemite. Some specimens contain brownish yellow picotite while one specimen (8610) contains a light green spinel, possibly pleonaste, with partial alteration to chrysotile along irregular cracks.

Pyroxenite: Dykes of pyroxenite are present at three places in the area. Two of these dykes occur in the Malguzar nala while a third occurs west of Gat (Grid Ref. 8350,1100). The first two dykes are 400-500 feet long and about 100 feet in width. The third is smaller with a length of about 100 feet and width of 30 feet.

The rock is green, turning to blackish green on weathering. It is coarse to very coarse grained granular with crystals upto 2 cm across in the Malguzar outcrops. Bronze like lustre is shown by pyroxene cleavage surfaces.

Diopside or diopsidic augite is the chief constituent of the pyroxenites with a modal percentage of 70-80%. In thin section it is colourless to pale green, grains are anhedral to subhedral. The range of extinction angle ($C \wedge Z$) as observed in four thin sections of pyroxenite is $40° - 45°$ (+ve) while 2V in the some sections ranges from $58° - 70°$ (+ve). Simple twinning is present and parallel to (100) and (010) may be well developed.

One specimen (No. 8277) from Malguzar contains orthopyroxene, crystals of which are enclosed in clinopyroxene. Orthopyroxene crystals are completely pseudomorphed by bastite. Traces of original multiple twinning are visible. Amphibole is also present in this specimen in the form of hornblende grains and as uralite replacing pyroxene crystals.

Serpentine minerals, chrysotile and antigorite develop at the expense of pyroxene and may in turn be replaced by carbonate. Serpophite characterised by its low birefringence is found in specimen No. 8227.

Chromitite : With rare exceptions chromite concentrations (chromitites) are present in dunite as is also the case in the ultramafic roks south of Hindubagh. The location of the chromitite bodies is shown in Fig. 1.

Chromitite occurs as podiform bodies of generally massive granular texture or as disseminations in serpentinite. Near Tleri M. Jan one ore body contains bands of oval globules of serpentine (diameter 3-10 mm) in chromite. In some bodies chromite rich layers alternative with layers of serpentine with little chromite. In thin section the chromite is seen as euhedral to subhedral grains of brown colour. Mostly the chromite grains are altered along margins and cracks to opaque maghemite. The matrix consists of antigorite and chrysotile. Serpentine globules in chromite consist of antigorite. In one specimen (No. 8494) the matrix consists of carbonate rather than serpentine. In another specimen (No. 8298) the cracks in chromite are occupied by chlorite and such grains are further traversed by thin veinlets of chlorite showing anomalous interference colours. Tiny inclusions of an unidentified strongly birefringent mineral probably olivine occur enclosed in chromite in the same specimen.

Dolerite : A number of dolerite dykes are enclosed in serpentinite. These may be seen protruding above the relatively easily eroded serpentinite. The dykes are upto 40 feet wide and 100 to 300 feet long. Most of these dykes are confined to the middle portion of the serpentinite belt. Their contact with serpentinite is quite sharp and dolerite is chilled against serpentinite indicating the younger age of the dykes. Some of the dykes have been partially or completely altered to rodingite. Unaltered dolerite is dark greenish black, medium to fine-grained. Mostly the rock is hornblende dolerite.

In thin section the texture is seen to be subophitic to ophitic. Fresh dolerite is composed of plagioclase and pyroxene or hornblende. Accessory minerals include ilmenite and sphene.

Hornblende content varies from 40 to 60% Crystals are subhedral to euhedral. At places crystals are indistincty zoned. Hornblende is pleochroic from green to brown. Alteration is normally into a chlorite with anomalous blue interference colour. In one specimen where hornblende occurs associated with albite (No. 8481) the former is altered to talc. In most specimens anorthite content of plagioclase is An_{46-48}. In some specimens (e.g. No. 8609) plagioclase crystals are zoned. Alteration to sericite and kaolinite is common.

In few specimens (e.g. Nos. 8568 and 8580) pyroxene is present and is of augitic composition ($C \wedge Z = 50°$). Some grains show hour glass structure. Accessories consist mainly of ilmenite whose content may be upto 5%. It occurs as fine to medium-grained anhedral to subhedral or skeletal crystals. It alters to leucoxene and may occur intergrown with sphene and hornblende. An unidentified brown radiating mineral occurs as an accessory in specimen No. 8617.

Rodingite : Many of the dolerite blocks in the serpentinite belt are partially altered to rodingite. Two of the blocks i.e. the ones near Tleri M. Jan are completely altered where the original minerals and texture has been completely replaced. The rodingite occurs as resistant blocks of rock protruding above the enclosing serpentinite (Fig. 6).

The rock is green to buff in colour, lightness of colour increases with the degree of alteration. The rock is tough and closely joined. Veins of green idocrase, white prochlorite and honey coloured grossularite traverse the rock. Xenoliths of serpentine are also seen at a few places.

In the thin section identification of constituent minerals is difficult owing to the very fine-grain size. Idocrase and prochlorite occur in the veinlets as euhedral to subhedral crystals growing with the largest dimension perpendicular to the walls. Carbonate fills the interstices, cracks and the space left in the middle of the veins. Properties of idocrase and prochlorite have been described by Bilgrami (1960). Prehnite is present at places and

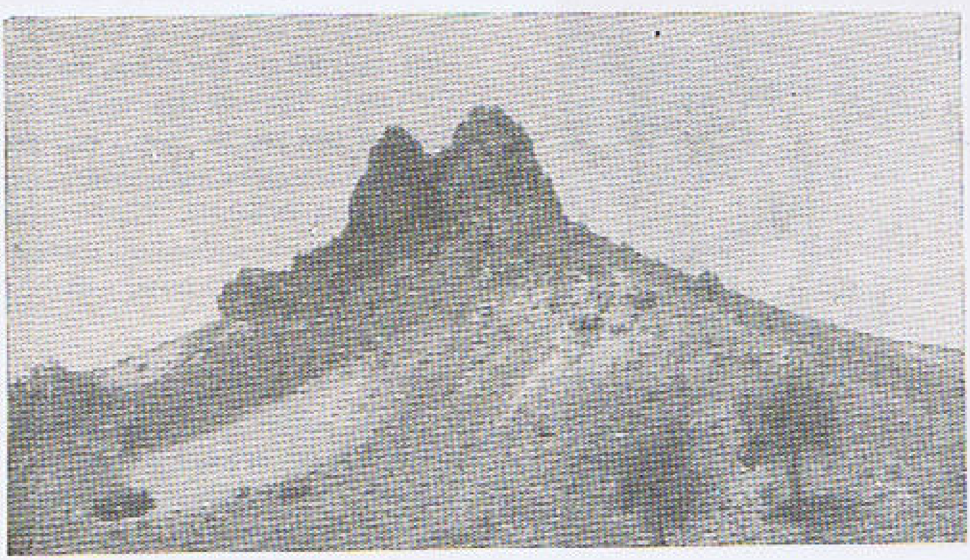


Fig. 6. Outcrop of rodingite at Tleri M. Jan.

may constitute upto 50% of the rock. Fine euhedral to subhedral grains of magnetite are scattered throughout the rock.

Garnet-Pyroxene rock : At Tleri M. Jan also occurs a pocket of a light green, medium-grained, massive rock composed almost entirely of clinopyroxene and grossularite. Clinopyroxene (55-65%) is diopsidic—augite in composition and occurs as subhedral, coarse to medium sized, pale green grains with strongly developed parting. Grains may be altered to serpentine along cleavage cracks which may also be filled with carbonate. A few grains are twinned. Grossularite (upto 35%) occurs as isolated grains and clusters of garnet crystals enclosed in serpentine. Also garnet veinlets with non-parallel walls cut across serpentine. In some specimens (e.g. Specimen No. 8235) only garnet occurs alongwith pyroxene without any serpentine (Fig. 7). Garnet occurs as pale to yellowish grey grains with irregular cracks and well developed parting on (111).

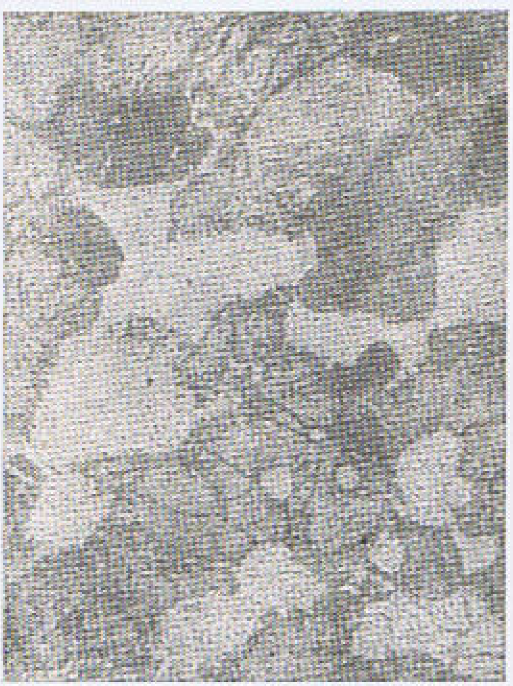


Fig. 7. Photomicrograph of Garnet-Pyroxene Rock.

Volcanic Rocks : Pyroclastic and volcanic rocks occur in the extreme west of the area but the exposures are poor and much more work is required to delineate their aerial axtent. Boulders of vesicular basalt are found in the nalas and red tuff outcrops are encountered. The vesicular basalt (Specimen No. 8518) has a fluidal texture and consists of pigeonite (15%) and feldspar which is altered beyond recognition to kaolin and sericite. Vesicles (upto 2 mm across) are lined with chalcedony while the central portion is filled with carbonate. Albite is present in some vesicles.

Fault Breccia : The rock occurs in a zone upto 10 feet thick along the contact of serpentinite and Nisai Limestone where it indicates the tectonic nature of the contact between Nisai Formation and serpentinite.

In hand-specimen the rock is brown with angular and sheared fragments (upto 4 cm across) of bluish talc or serpentinite set in a matrix of siderite or calcite. Carbonate veins are also common. In thin section talc is colourless with a fine-grained or curved lamellar aggregate. Grains of chromite are scatteered throughout the rock.

Birbirite : Weathering of serpentinite has resulted in the formation of a red residual cap of a silica rich rock at a few places, particularly around Tor Tangi. The rock also occurs in Nagar Manda. Study of thin section reveals that the rock has developed mainly by replacement of serpentinite by silica and/or carbonate. On the basis of colour, structure and composition the residual cap may be divided into three horizons, namely, top, middle and bottom horizons.

The bottom horizon which lies immediately above the unaltered serpentinite is light brown to yellowish brown in colour and is traversed by white magnesite veins 1-2 cm and rarely upto 10 cm thick (Fig. 8). In thin section the rock is found to consist of a net work of magnesite veins enclosing areas of limonite and carbonate (in the ratio of

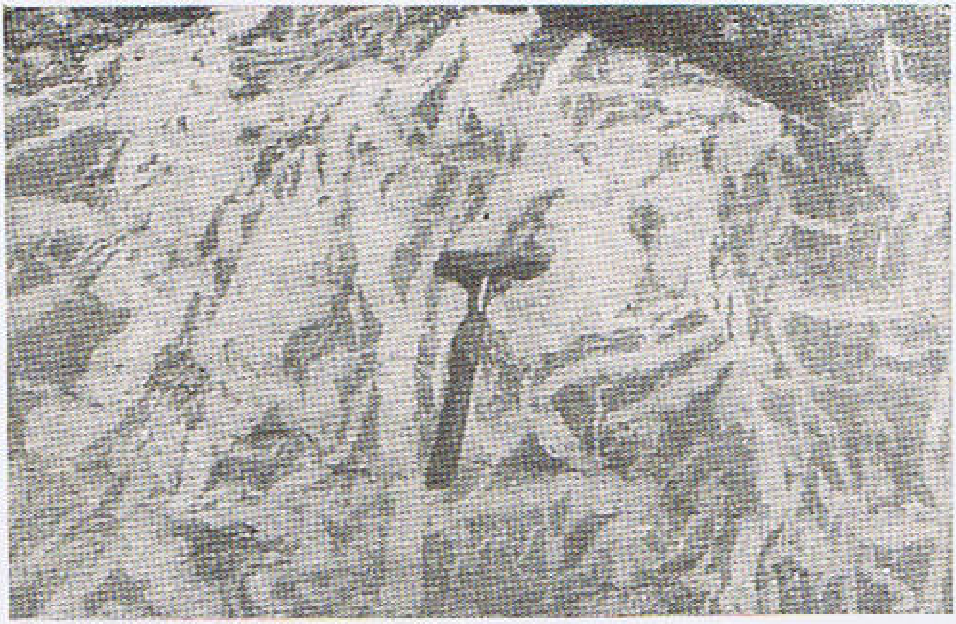


Fig. 8. Viens of Magnesite in Bottom Zone of the Weathered Top of Serpentinite at Tor Tangi.

1 : 4). By comparison with unaltered serpentinite it is evident that chrysotile has been replaced by fine-grained mixture of limonite and magnesite while the original pyroxene of the serpentinite has been replaced by an aggregate of chlorite flakes.

The middle horizon is dark brown to dark red in colour with veins of yellow coloured magnesite upto 1 cm thick. In thin section the rock is found to consist of very fine-grained quartz, probably recrystallized chalcedony in a matrix of limonite. Scattered grains of magnesite and chromite are present.

The top horizon is a red, hard silica rich rock in which the boxwork texture of the original serpentine is still preserved locally, as indicated by trails of dust like opaque inclusions in colourless quartz. A few veinlets of magnesite are also present. Relict chromite grains also betray the genesis of the above silica rich rock from alteration of ultramafic rocks.

SEDIMENTARY ROCKS

Nisai Group

The stratigraphy and palaeontology of Nisai Group has been described in Hunting Survey Corporation Report (1960) and it is not intended to report the same here. Only brief comments are offered for the sake of completeness and some new information is given.

Aerial Extent and Lithology: The strata of this group underlie the Shaigalu Formation and are exposed through the entire length of the area overlying the serpentinite belt. The thickness of Nisai Group ranges from 1500-3000 feet. Limestone is the predominant rock type with subordinate shales. Limestone is generally grey coloured and weathers to brown. Giant Forams (Nummulites) upto 2 cm or more in diameter are found near Khazina. Southwest of Ragha nala the lithology changes laterally to shale to such an extent that limestone remains only as intercalating layers. The shale is green or buff. At places it is strongly fissile and may be of slaty structure.

At the eastern end of the area also, the limestone gradually passes along the strike into shale mapped seperately as Murgha Faqirzai Formation.

Age : on the basis of fossil content the Nisai Group is assigned an Eocene—Oligocene age by Hunting Survey Corporation (op. cit).

In the present survey a dark grey to black argillaceous fossiliferous limestone bed was located at the base of Nisai Group in the Khazina nala. The following fossils were identified in this limestone by Farshori (personal communication, 1965) who assigns a Palaeocene (equivalent to Dunghan L.St.) age to the assemblage.

Miscellanea miscelia
Lockhartia Conditii
Discocyclina ranikotensis
Ranikotalia nuttalli

Thus the strata of Nisai Group appear to include Palaeocene beds in addition to those of Eocene age.

Surghund Limestone: This limestone is exposed in the form of the isolated Surghund Hill in the eastern part of the area. The limestone is generally light grey and brownish grey. It is massive and hard and generally without appreciable bedding except in the uppermost part where algal, coral and formainiferal limestone outcrop. Richly fossiliferous, nodular limestone outcrops near Nagar village. The limestone is without appreciable impurities. A specimen gave the following results on analysis :

SiO_2, 0.64; Al_2O_3, 0.03; Total iron, 0.08; MgO, 0.10; CaO 55.40; Loss on ignition, 43.55%.

Surghund Limestone is overlain by Multana Formation but the contact is obscured by the alluvium of the Gat nala. Hunting Survey Corporation reported the contact to be unconformable.

Ashraf reports giant forams at the base of Surghund limestone identical with those seen in Nisai Group near Khazina. Specimens from coral colonies at the top of Surghund Limestone were sent to Rizvi of Karachi University who reported the following species (Rizvi personal communication, 1967) and suggested a Nari (Oligocene) age.

Stylophera cf. confusa
Favia cf. *pedunculata*
Hydnophora (probablly a new species)
Favites cf. *tenuiseptata*
Pocillopora cf. *densa*
Platygyra cf. *latimaeandra insignis*

It may be concluded that while the base of the Surghund Limestone is of Eocene age the top beds are of Oligocene age and pass upward into the sandstone and shale of Multana Formation.

Murgha Faqirzai Formation : The name is given to a distinctive argillaceous formation equivalent the Nisai Group. The formation makes its appearance at Tor Tangi wherefrom it extends and thickens eastward to a maximum of 1000' in the area mapped.

The formation is dominated by shales and subordinate limestone and sandstone layers. The shales are pale grey, grey green or white. The shales are calcareous and silty, fissile and weather to clay forming a low topography of rounded bills. They are typically splintery. Limestone which is richly fossilliferous is argillaceous and dark brown to light grey in colour. Sandstone is grey green, fine-grained and calcareous. Lignitic shales interbedded with green shales are found in the upper portion of the formation at Tor Tangi and Gat.

The limestone layers yield fossils of Ecocne age (personal communication Butt, 1966) and the formation is regarded as equivalent the Nisai Group as was done by Hunting Survey Corporation (op. cit).

Shaigalu Sandstone Formation :

Nisai group is overlain by Shaigalu Sandstone which occupies the higher elevations in the northern part of the area. At the top of the Nisai Group there are several conformable layers of limestone conglomerate or breccia alternating with beds of sandstone which increase in frequency and thickness upward, finally passing into Shaigalu Sandstone which consists of alternating beds of sandstone and shales.

The sandstone is dark greyish green with brown and black specks and weathers light grey. Shaigalu Sandstone is thick bedded without much crossbedding or ripple marks. Flute casts are observed at some places. In thin section the rock is found to consist of the following; plagioclase biotite, jasper, chalcedony and fragments of quartzite, phyllite (?) and limestone. The sandstone is quite impure and is classified as sub-greywacke. The associated shale is pale green and strongly crosscleaved. The shale is pale green and strongly crosscleaved. The shale is generally equal to or greater than sandstone in amount. Quartz - carbonate veins filling joint planes are wide spread.

Multana Formation :

The formation occupies the low hills immediately north of the Zhob Valley and occur in the form of a tectonic window. The rocks are rather brightly coloured and consist of a succession of buff, purple and grey sandstones, red orange and green shales and claystones and conglomerate beds.

Hunting Survey Corporation (1960) recognized these beds as Oligocene in age.

Recently Sarwar of Zoology Department Punjab University provided information on the fauna and flora of these beds. On the road from Hindubagh to Tleri M. Jan the following strata are noted. The low hills adjacent to the alluvium of Zhob Valley consist of boulder conglomerate and mudstones with leaf impressions and worm burrows. A few unrecognizable bone scraps were found which are still not completely petrified. The beds are possibly Upper Siwaliks. Further north, the Upper Siwalik(?) beds are overlain by bright red shales characteristic of Chinji Beds of Lower Siwaliks. A few fragments of *Gaindatherium* and *Trilophodon* were found in these Beds indicating a Lower Siwalik age. It would, therefore appear that Middle Siwalik is missing in this area.

Still further north, the Chinji Beds are overlain by light grey sandstone indicating Nari as the age of these beds. Petrified wood is present in abundance in this sandstone.

The succession, therefore appears to be overturned. More work would be required to decide whether the overturning is only apparent i.e. due to faulting or is it indeed due to overturning of a fold limb.

STRUCTURE

The present survey confirms the presence of the "Hindubagh Thrust". The existance of this fault has been postulated by the Hunting Survey Corporation (op. cit) and the conclusion reached by them of the structure of Baluchistan and Sind is that "the tectonic style every where is unquestionably the result of continued compression along unvarying regional directions". The present area is no exception to the above general observation on the regional structure. Folding and reverse and thrust faulting are the main components giving rise to the present structure of the area. Normal faults are absent or insignificant.

Folds

Synclines and anticlines with steep to vertical axial planes and steep limbs are common in the northern part of the area i.e. in Shaigalu Formation and Nisai Group outcrops. Shaigalu Formation being mainly hard greywacke and shale, has been folded in a competent manner compared to the underlying Nisai Group which is composed mainly of limestone and shale. In both successions the folding has occurred in response to the same tectonic stress as indicated by a parallelism of orientation of fold axes which trend NE-SW and plug NE. The folds are open and of concentric type (Fig. 9). In the eastern part of the area, near Gat the fold axes in Nisai Group trend NW-SE but this is contrary to the regional trend and may be regarded as due to a local flexure. Over folds with axial planes dipping northward are present in Murgha Faqirzai Formation on the eastern side of the valley of Gat nala near Gat village.

Multana Formation is more simply folded and forms a broad fold having a NE-SW trending fold axis with a steep plunge to SW. The Syncline is truncated to the north and south by ENE-WSW trending faults.

Faults

A number of reverse faults striking ENE-WSW parallel to the bedding and dipping northwards are encountered in the area. Many of them are high angle reverse faults but at least two of them are of relatively low angle of dip (approximately)30° and may be termed a trust faults. The outcrops of the thrust faults can be traced for several miles along their strike. The serpentinite out-crops described in this paper are confined to the trust faults.

Hindubagh Thrust : One of the thrust faults, hereby called the Hindubagh Thrust, is the most significant structural feature of the area and it is described in some detail below. Hindubagh thrust persists through the entire length of the area. Along this fault Nisai Group has been thrust over the Multana Formation. Slicken-sides at the base of the hanging wall indicate that the latest movement was an overthrusting from a general NW direction. Almost all along its exposed length a belt (upto 1000 feet thick) of serpentinite intervene between the hanging and the footwall. Where there is no intervening serpentinite, the fault plane is occupied by red fault guoge. In the extreme east, near Nagar Manda, the fault plane is occupied by dolerite blocks of four inches. Some of these blocks have a thin highly polished ultramylonitic surface layers.

There is evidence to conclude that the contact between Nisai Group and serpentinite is the thrust

Fig. 9. Folding in the Nisai Group near Tleri M. Jan.

and not the contact between Shaigalu Formation and Nisai Group as envisaged in the hunting Survey Corporation Report (1960). The evidence is summarized below.

1. That, as mentioned earlier there is a passage into the underlying Nisai Group at the base of Shaigalu Formation. Three layers of conglomerate alternating with sandstone or limestone intervene between Shaigalu Formation and Nisai Group. On the basis of the presence of pebbles of only one or two uniform kinds of limestone, the conglomerate beds are thought to be intraformational and not basal conglomerates. According to the Hunting Survey Corporation Report (page 40) such "intra-formational layers of limestone conglomerate and breccia are ubiquitous and characteristic of many sedimentary assemblages in parts of the axial belt that flank the calcareous zones".

2. That at the contact with Nisai Group, serpentinite is highly crushed and pieces cemented by calcareous material.

3. Ultramylonitic material is found coating the surface of rounded pieces of dolerite immediately below Nisai Group.

4. Silckensiding is found at the base of limestone of Nisai Group at its cantact with serpentinite.

Age of Hindubagh Thrust : The youngest strata truncated by the thrust in the area mapped are those of Multana Formation of Oligocene and younger age. The thrust is, therefore, of post-Oligocene age. The thrusting is one of the younger geological events to have occured in the area.

Surghund Fault : Another major fault—the Surghund fault truncates the southern limb of the syncline in Multana Formation. The fault strikes parallel to the Hindubagh thrust but is of relatively higher angle of dip (about 45°).

In the east, the Surghund fault seperates the Surghund Limestone (Eocene) and the Multana Formation whereas west of the Shina Khwara the fault intervenes between different strata of Multana Formation. Serpentinite slices are found emplaced almost entirely below the Surghund Limestone along this fault.

Uptilted Siwalik beds make the foot wall of this fault and the fault is thought to be post Siwalik in age. Assuming that Hindubagh thrust and the Surghund thrust are both products of the same tectonic event, it may be concluded that the Hindubagh thrust also is of Post-Siwalik age.

PETROCHEMISTRY

Chemical analyses of two rock types of the area, namely rodingite of Tleri M. Jan and birbirite zones of Tor Tangi was carried out to help understand their genesis.

Rodingite

Analyses of Tleri M. Jan rodingite and dolerite are given in Table I. Analyses of rodingites from Byne Hill and Roding river are also given to show the chemical similarity of the there occurrences.

Assuming formation of rodingite by the alteration of dolerite, the chemical changes can be understood by comparison of the chemical analyses of the two rocks. The alteration is accompanied by a reduction of SiO_2, total iron and MgO contents of dolerite. On the positive side, increase in Al_2O_3 and strong enrichment in CaO is noticed.

Birbirite

Three specimens one each from (A) unaltered serpentinite (B) middle and (C) top horizons of the birbirite cap were analysed chemically. The analyses are presented in Table II. Variation of contents of the major constituents i.e. SiO_2, MgO, Fe_2O_3 and Al_2O_3 in the three specimens is graphically presented in Fig. 10. From the unaltered serpentinite to the top horizons, SiO_2, Fe_2O_3, Al_2O_3 increase while MgO shows a sharp decline. FeO, Cr_2O_3 and CaO are small in amount and do not show a systematic variation.

Discussion

As mentioned above, the Tleri M. Jan rodingite appears to be chemically very similar to the rodingites from Roding river (New Zealand) and Byne Hill (Ayrshire). The mode of occurrence is also similar as they all occur associated with ultramafic rocks. Following are the chief hypotheses advanced to account for the genesis of rodingites.

(*i*) Primary products of crystallization [Marshall (1911)]

(*ii*) Crystallization from basic magma enriched in lime by digestion of limestone [Finlayson (1969)]

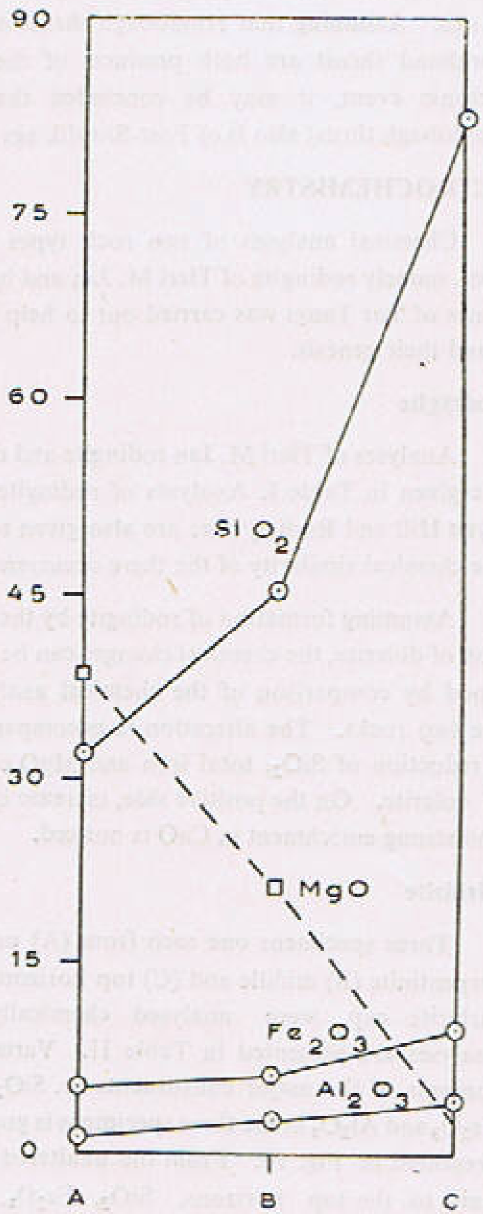


Fig. 10 Variation Diagram showing Changes in Composition of Serpentinite during Alteration to Birbirite.

TABLE I

Chemical Analyses of Rodingite

	A	*B*	*C*	*D*
SiO_2	39.62	33.95	38.04	51.23
TiO_2	0.12	0.42	0.82	n.d.
Al_2O_3	23.29	19.91	15.07	15.73
Fe_2O_3	2.26	1.28	1.78	7.94
FeO	4.56	6.98	3.02	5.65
MnO	0.18	0.28	0.21	n.d.
MgO	2.50	5.23	9.62	6.02
CaO	23.15	26.95	25.84	9.78
Na_2O	n.d.	0.15	0.04	n.d.
K_2O	n.d.	—	—	n.d.
H_2O^+	—	4.85	4.19	—
H_2O^-	—	—	1.15	—
P_2O_5	n.d.	—	0.24	—
Loss on ignition	4.08	—	—	3.50
	99.76	100.00	100.02	99.85

A. Rodingite, Tleri, M. Jan, North of Hindubagh, Zhob valley Pakistan.

B. Rodingite, Roding River, Dun Mountain, New Zealand. P. Marshall, 1911, p. 33.

C. Rodingite, Byne Hill, Ayrshire. T. W. Bloxau 1955, p. 527.

D. Dolerite, north of Hindubagh.

(*iii*) Alteration and metasomatism of gabbros Source of lime is ascribed to serpentinization of lime bearing pyroxene in the adjacent ultramafics [Grange (1927); Miles (1950)]

TABLE II

Chemical Analyses of Serpentinite and its Silica Rich Residual Cap (Birbirite)

	A	*B*	*C*
SiO_2	32.37	45.19	79.80
TiO_2	n.d.	traces	traces
Al_2O_3	1.13	2.59	3.87
Fe_2O_3	5.21	6.11	9.51
FeO	2.29	0.73	1.04
Cr_2O_3	1.90	0.73	1.25
MgO	38.96	21.28	2.13
CaO	0.58	1.38	0.69
MnO	0.06	nil	nil
Loss on ignition	17.20	21.80	1.80
	99.70	99.81	100.09

A. Serpentinite
B. Middle horizon of residual cap
C. Top horizon of residual cap

n.d. = not determined

(*iv*) garnetization of gabbroic rocks by concentrated magmatic waters acting at high pressures.

(*v*) For Byne Hill rodingite Bloxam (1955) concluded that the lime introduced in gabbro could not have been derived from serpentinization of ultramafics since the latter are dominantly harzburgites. i.e. without Ca-pyroxene. Some lime may have been derived from alteration of pyroxene and plagioclase in gabbro itself but would be quite subordinate in amount. He thought that lime rich hydrothermal solutions and CO_2 responsible immediately post - dating serpentinite were for the alteration of gabbro.

Further work is necessary in order to find out the source of lime for formation of Tleri M. Jan rodingite. However, the source is unlikely to be any hydrothermal solutions from a source outside the ultramafics as no igneous instrusions other than the dolerites themselves or serpentinite are located in or near the area. Serpentinization of pyroxenites, peridotites as well as alteration of pyroxene and plagioclase of dolerites themselves, could have provided the necessary lime for the genesis of rodingites of present area. Regarding birbirite, field and microscopic mineralogical studies point to its derivation from serpentinite.

Chemical analyses of various alteration zones overlying the serpentinite indicate strong leaching and migration downward of MgO which is fixed as magnesite in the middle and bottom zones. SiO_2, Al_2O_3 and Fe_2O_3 tend to be left behind in the top layers, the last being responsible for the red colour of the top and middle zones.

The top zone has marked lithological similarity with birbirite from Yubdo/Birbir, W. Ethiopia which is defined as "a rock consisting of fine quartz, limonite, chromite and sperrylite a derivative of dunite. No sperrylite has so far been notice in the Tor Tangi occurrence but the rest of the minerals indicate a close petrographic as well as genetic similarity with the Yubdo occurrence. According to Augustithis (1965) birbirite develops by hydration alteration of dunite. In the advanced stages of serpentinization free silica in the form of chalcedony is deposited by leaching out of MgO from olivine and serpentine.

To explain the origin of birbirite, Augustithis refers to the theoretical consideration of Pieruccini

(1962). The latter postulated that leaching and seperation of elements from a mineral compound is dependent upon the mass energy that can be absorbed by a specific element. The sialic components are less inclined towards energy saturation than the femic and as a result sialic components tend to be residual while the femic are more easily leached out.

The mineralogical changes as seen in birbirite in the present area also show that femic components Mg more than Fe-having been mobilized, silica has tended to remain as a residual cap. Due to strong hydration, silica passed through a gel condition before deposition. Solution channels in the original serpentine are lined with silica-crystal size being larger towards the centre of the cavity (Fig. 11) where abundant free space was available. The presence of the silica rich layers as the topmost layer indicates that the source of hydrating fluids was surface water which also provide CO_2 necessary to fix MgO as magnesite in the middle and lower zones.

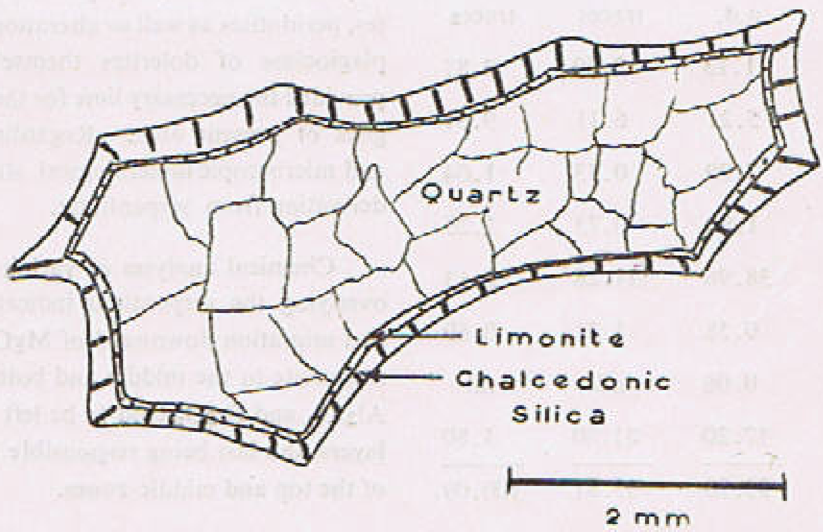


Fig. 11. Cavities lined with Silica and Limonite in Birbirite.

It may be mentioned here that similar rocks have been noted capping portions of ultramafic rocks south of Hindubagh. These have been termed laterite (Zulfiqar and Nawaz, 1969). However the chemical analyses presented by the above authors do not support the use of the term "laterite" in this case. Laterite is defined as "Red residual soil developed in humid tropical and sub-tropial regions. In the analyses of four zones of "laterite", presented by the above authors the iron content is barely 10% or less while silica is persistently high reaching a maximum of 67.44% in the uppermost zone 'A'. The birbirite rocks of Hindubagh area have only a superficial resemblance with 'laterite'.

ECONOMIC GEOLOGY

The area under reference does not have any large economic mineral deposits. Only chromite, serpentine, magnesite and asbestos are of some interest. Of secondary interest are deposits of vesuvianite, and soapstone.

Chromite : Lenses and bands of chromitite occur at sevral places in the area. More than 20 different occurrences have been noted. One of the largest of these deposits, near Tleri M. Jan, is 2-4 ft. thick and about 50 ft. long. The occurrences are shown on Fig. 1.

Chemical analyses of samples from chromite deposits indicate that a majority of them have poor Cr/Fe ratios and non-metallurgical grade of the ore. However the material is suitable for making refractory bricks. A few occurrences are of metallurgical grade and merit further exploration. Table III gives the Cr_2O_3 content and Cr/Fe ratio of purified chromites from some of the chromitite occurrences of the area.

TABLE III

Cr_2O_3 Content and Cr/Fe Ratios of Purified Chromites from North of Hindubagh

Specimen No.	Locality/Grid. ref.	$Cr_2O_3\%$	Cr/Fe ratio
8625	Surghund 903.0,065.0	58.89	3.61
8586	Gat 842.5,058.5	58.25	3.43
8569	Tor Tangi 809.0,101.0	49.95	2.70
8571	Tor Tangi 811.0,099.5	54.63	2.45
8572	Tor Tangi 812.0,008.0	55.43	2.35
8560	Tor Tangi 789.5,1020	50.66	3.1
—	North of Khazina	53.95	2.36

Analyst : Shafeeq Ahmad

Serpentine : The Serpentinite belt may be more than a 1000 ft. thick at places. The serpentine is at places mixed with magnesite. Thus MgO content is high (38-96%) and SiO_2 content varies from 32-37% in the specimens analyzed. The serpentine, particularly around Tleri M. Jan, is of a composition which, in conjuction with dead burnt magnesite, can be used for making forsterite bricks.

Magnesite : Deposits of this mineral in Tleri M. Jan Area have been evaluated (Ahmad, 1969) and several thousand tons are estimated to occur in the form of intimate mixture with serpentine. The mixture can be used for manufacture of forsterite bricks as both the minerals are required for their fabrication. On the eastern side of the area, near Tor Tangi magnesite is in bigger veins upto 3 or 4 feet thick.

Asbestos : Chrysotile asbestos intergrown in parallel growth with fibrous dolomite and brucite occurs in the form of intersecting veinlets in serpentinite at Tleri M. Jan.

Vesuvianite : In addition to the outcrop at Tleri M. Jan, from which vesuvianite has already been extracted, new occurrences of the mineral have been located in the present survey. Crystals upto 1 cm long have been noted in dolerite blocks in serpentinite west of Gat on the path to Tor Tangi. Vesuvianite has been used as a semi precious gemstone and the outcrops west of Gat merit further explorations as a source of the mineral.

Soapstone : Talcose rocks are scattered widely along the serpentinite belts. All the occurrences are small and most contain abundant impurities. One occurrence, partly quarried, contains a few hundred tons of a green massive soapstone., (Grid ref. 6530,0020).

SUMMARY & CONCLUSIONS

The serpentinite belts north of Hindubagh are overlain by Eocene (locally Palaeocene) and underlain by Oligocene or younger sedimentary rocks. Two major thrust/reverse faults striking roughly ENE-WSW divide the area into three structural blocks. The southern-most block adjacent to the alluvium of the Zhob valley consists of a succession of conglomerates, sandstones and shales of Multana Formation, dipping generally northwards. The middle block consists mainly of beds of Multana Formation folded to form a syncline with a roughly E-W fold axis. Older beds of limestone (including reefoid limestone) of Oligocene and Eocene age crop out in the Surghund Hill at the eastern end of this block. The contact of Multana Formation and the limestone of Surghund hill is obscured by the alluvium of Gat nala. Both the northern and southern limbs of the syncline of the middle block are truncated by thrust/reverse faults.

The northern most block consists of limestone of Nisai Group at the base, overlain by subgreywackes and shales of Shaigalu Formation. The contact of Nisai Group and Shaigalu Formation is not a thrust fault as envisaged by previous workers.

The so-called "Hindubagh Thrust" has brought up the limestone of Nisai Group to overlie rocks of Multana Formation. The serpentinite belts north of Hindubagh occupy the two major thrust/reverse faults. Along Hindubagh Thrust almost the entire fault zone is occupied by serpentinite. In case of Surghund fault, serpentinite is confined to the eastern part of the area where limestone of Surghund Hill is thrust over beds of Multana Formation.

The serpentinite belts consist of partially or completely serpentinized dunite, harzburgite and peridotite. Isolated blocks and dykes of dolerite occur in the middle of the serpentinite belt. Many dolerite blocks, particularly around Tleri M. Jan, are altered to rodingite with veins of vesuvianite, grossularite and prochlorite.

A series of outcrops of relatively unaltered dolerite have been located in the present survey in the serpentinite belt between Khazina and Gat. Some of these outcrops (e.g. at Grid Ref. 8310,0940) contain veins of vesuvianite identical to the ones found at Tleri M. Jan.

Geological History : Regarding the geologic history of the area it appears that in the Palaeocene-Lower Oligocene period dominantly calcareous sediments were being deposited in the basin, north of Hindubagh. Coral and algal colonies flourished in parts of the Lower Oligocene shoreline. In later times basin conditions changed and deposition of argillaceous and arenaceous sediments took place. In the vicinity of the axial belt where terrestrial or shallow marine conditions were present, brightly coloured and coarse grained sediments of Multana Formation were deposited. Towards north, in the deeper portion of the basin, the sediments deposited consisted of a succession of sand and clay giving rise, on consolidation, to subgreywackes and shales of Shaigalu Sandstone Formation which are partly equivalent to Multana Formation. Compression from a general NW direction resulted in folding of the starta and upthrusting of Shaigalu Formation/Nisai Group over Multana Formation. The same compression also mobilized the serpentinites of Hindubagh intrusion which were tectonically emplaced along the faults.

Emplacement of serpentinite : Any theory of emplacement of serpentinite north of Hindubagh must explain the following facts.

1. Identity of lithology with the larger serpentinite outcrops (Hindubagh intrusions) of late-Cretaceous-early Eocene age, south of Hindubagh.

2. Presence of disrupted blocks of dolerite instead of the regular dykes as seen in serpentinite south of Hindubagh.

3. Absence of any contact metamorphic or metasomatic effects on the adjoining sediments.

4. Presence of fault breccia at the contact of serpentinite and adjoining sediments.

5. Sheared and even pulverized structure of serpentinite with chrysotile-dolomite-brucite veins.

All the above chracters point to a tectonic and not magmatic emplacement of serpentinite north of Hindubagh. The compression which ultimately caused the development of Hindubagh and Surghund thrusts also mobilized the serpentinite of Hindubagh intrusion which was plastically squeezed into the thrust planes and acted as a lubricant in the movement of the fault blocks. In the process, the serpentinite was sheared producing chrysotile—fibrous dolomite-brucite veins by shearing along joint planes. Dolerite dykes, being brittle, were broken up into large blocks. Hydrothernal solutions capable of altering dolerite to rodingite and crystallizing vesuvianite and grossularite invaded the dolerite blocks. Locally serpentinite also became unstable and grossularite developed at its expense, ultimately producing the peculiar garnet-pyroxene rock.

ACKNOWLEDGEMENTS

The authors are most grateful for the hospitality of Dr. S. A. Bilgrami and Mr. M. A. Faruqi of Pakistan Chrome Mines Ltd., during the course of the field work at Hindubagh. Geological Survey of Pakistan kindly provided the camping equipment. We are thankful to Dr. A. N. Fatmi, Mr. M. W. A. Iqbal of Geological Survey of Pakistan and M. Sarwar of Zoology Dept. University of the Punjab, Lahore for a useful field discussion on the stratigaphy of the area. The laboratory work was carried out at the Laboratories of Department of Geology, University of the Punjab and the P.C.S.I.R. Laboratories, Lahore.

REFERENCES

Ahmed, Z., 1969 Directory of mineral deposits of Pakistan. *Geol. Surv. Pakistan.*

Ahmed, Zulfiqar and Chaudhry, M.N., 1969 Geology of the Palaklara Area, Splaitorgharh, Hindubagh, Zhob District, West Pakistan. *Geol. Bull. Punjab Univ.*, **8**, 61-72.

Ashraf, M., Qureshi, M.W., and Faruqi, F.A., 1970 Mineralogy of the serpentinite from the Tleri Mohammad Jan Area, North of Hindubagh, Pakistan. *ibid.*, **9**, 29-36.

Augustithis, S.S., 1965 Mineralogical and Geochemical studies of platiniferous dunite-birbirite-pyroxenite complex of Yubdo/Birbir, W. Ethiopia, Zeitsch. *Fur Chem. Min. Pet. Bodenk.*, *Geochemie und Meteortenkunde*, **24**, 2, 159-196.

Bilgrami, S.A., 1960 Serpentinite-limestone contact at Tleri Mohammad Jan, Zhob Valley, West Pakistan. *Amer. Mineral.*, **45**, 1008-1019.

Bilgrami, S.A., and Howie, R.A., 1960 The mineralogy and petrology of rodingite dyke, Hindubagh, Pakistan. *ibid.*, **45**, 791-801.

Bilgrami, S.A.. 1963 Serpentinite-limestone contact a correction. *ibid.*, **48**, 1176-77.

Bloxam, T.W., 1955 Rodingite from the Girvan-Bellantrace complex, Ayrshire. *Min. Mag.*, **30**, 525-528.

Hunting Survey Corporation, 1960 Reconnaissance of geology of part of West Pakistan.

Marshall, P., 1911 The geology of the Dun Mountain sub-division, Nelson, New Zealand. *Geol. Survey Bull.*, **12**, 31-35.

Pierucinni, R., 1962 Einige in der theorie und proxis gewonnene geochemische Erkentinisse uber das Verhalten des Wassers bei der metamporphitischen Unwandluug von vulkanischen Tuffen und Sediment questeinen. Berichte der Geologischen Gesellischaft (Sediment. I) Vortrog, gehaltan auf dem achten Traffen des Fachverbandes Mineralogie der geologische Gesellischaft in der DDR, 117-144.

Shams, F.A., 1955 Vesuvianite from Hindubagh (Baluchistan). *Pak. Jour. Sci. Res.*, **7**, 35-37.

(Manuscript received August, 1973)

GEOLOGY AND PETROLOGY OF THE MALAKAND GRANITE AND ITS ENVIRONS

BY

M. NAWAZ CHAUDHRY

Department of Geology, University of the Punjab, Lahore

SADAQAT ALI JAFFERI

AND

BASHIR AHMED SALEEMI

Geological Survey of Pakistan, Islamabad

Abstract: *A detailed geological map on the scale of 3.8" to a mile of about 50 square miles of the area around the Malakand Pass is presented on a reduced scale. Detailed petrology and geology of the Malakand granite and the associated argillaceous, calcareous and arenaceous metamorphic rocks is being presented here for the first time. Five chemical analyses of the Malakand granite, one analysis of the pegmatite vein and one analysis of the Malakand granite gneiss along with their mode and norm are given. The metamorphics range in grade from biotite to garnet grade of the regional metamorphism. Malakand Granite has been derived from the Malakand Granite Gneiss but has undergone reconstitution and silicification.*

INTRODUCTION

The area investigated is about 50 square miles. It lies between longitudes 71°50′ to 72°05′ E and latitudes 34°30′ to 34°37′ N. The area was mapped on 3.8" to a mile scale. The area has a moderate relief. The maximum and the minimum heights are 4970′ to 1600′ above sea level.

Tipper (1906) noted the rocks penetrated by the Malakand Tunnell and described them as mica schists on either side of the Tunnell and uniform granite in the middle. Hayden (1915) described the rocks between Dargai and Malakand as chiefly the hornblendic schists, much foliated, crushed and full of quartz veins. These rocks he said are replaced by granite on the road to Chakdara. Hayden's hornblendic schists are in fact chiefly chlorite-mica schists. Gulzar Ahmad (Personal communication 1964) studied the area briefly. According to him the Malakand granite is surrounded by schistose rocks which include garnet-mica schists with bands of pure coarse grained limestone and hornblendite in E and mica gneisses in SW and N. The intrusive body contains xenoliths and inclusions of mica calcareous schists.

REGIONAL GEOLOGY

No accurate account of the regional geology of the area is available. However the following rough picture of the regional geological setting of the area can be formed from the available information from the various sources and author's own (still unpublished) work to the north of the area.

The area falls in the southern part of the Attock Hazara Area of Pakistan folded arc. This area is most probably a part of the external flank of the Himalayan meganticlinorium. It is composed of Attock Slates of early Palaeozoic (?) age, with a few lime-stone and sandstone horizons at places. The area is cut by a number of intrusions (Wadia, 1953; 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 Landikotal towards west. However Ahmad et al. (1969) believe that the slates extend far into Afghanistan. If the above authors are correct then the Malakand Metamorphics represent higher grade Metamorphic facies of the Attock Slates.

Towards north the Malakand Metamorphics extend upto River Swat. Here they are quartzites and quartzitic schists. Beyond River Swat and into Dir the Metamorphics i.e. quartzite, quartzitic schists, marbles and a little graphitic schists extend for about 20 miles north of Chakdara. Beyond this point the Dir Amphibolites and Intermediate and Basic Complex starts and continues till Bibiore, a small village about 10 miles south of Dir. Further north occur marbles and low grade schists of Tertiary Age. Towards the west and northwest the Malakand granite gneiss extends over a large area. Towards Southwest is located the Harichand ultramafic complex. This complex has been described by Ijaz Hussain Uppal (1972).

GENERAL GEOLOGY

Diagonally located and in the middle of the area mapped **Fig. 1** lies roughly oval shaped non-porphyritic and compact Malakand Granite. This body which trends NE-SW is roughly 5 miles by 3.3 miles. It is a mica epidote bearing microcline ablite granite. Towards the south and southeast of the Malakand Granite lies NE-SW trending biotite muscovite schist, garnet mica schist, graphitic and calcareous schists with minor veins of amphibolites. Towards extreme northeast, the Malakand Granite is surrounded by quartzites and quartz-mica schists. Towards west and northwest occurs the Malakand Granite Gneiss. It is muscovite and biotite rich gneiss. In the north the Malakand granite is partly covred by alluvium.

Following rock units of the area were established and mapped.

Metamorphic Rocks

1. Biotite Chlorite Schist
2. Garnet Mica Schist (including intercalations of Calcareous Schists and Amphibolite bands)
3. Calcareous Schists and Marble
4. Quartzite and Quartz Mica Schist.

Igneous Rocks

1. Malakand Granite
2. Malakand Granite Gneiss

METAMORPHIC ROCKS

The regionally metamorphosed rocks were divided into the following units.

1. Biotite Chlorite Schist
2. Garnet Mica Schist
3. Calcareous Schist and Marble
4. Quartzite and Quartz Mica Schist.

The above units correspond to three lithologies i.e., pelitic (units 1 and 2), calcareous (unit 3) and arenaceous (unit 4). The above units will be described in the following.

Pelitic Rocks

The pelitic rocks occur in the southern and southeastern part of the area. They trend NE-SW. Towards north they come in contact with the NE-SW trending Malakand granite. Towards south and extreme southeast they are replaced rather abruptly by calcareous schists and marbles. The pelitic rocks are blackish to grey due to graphite in the south and are greenish in the north due to higher content of chlorite and paucity of graphite.

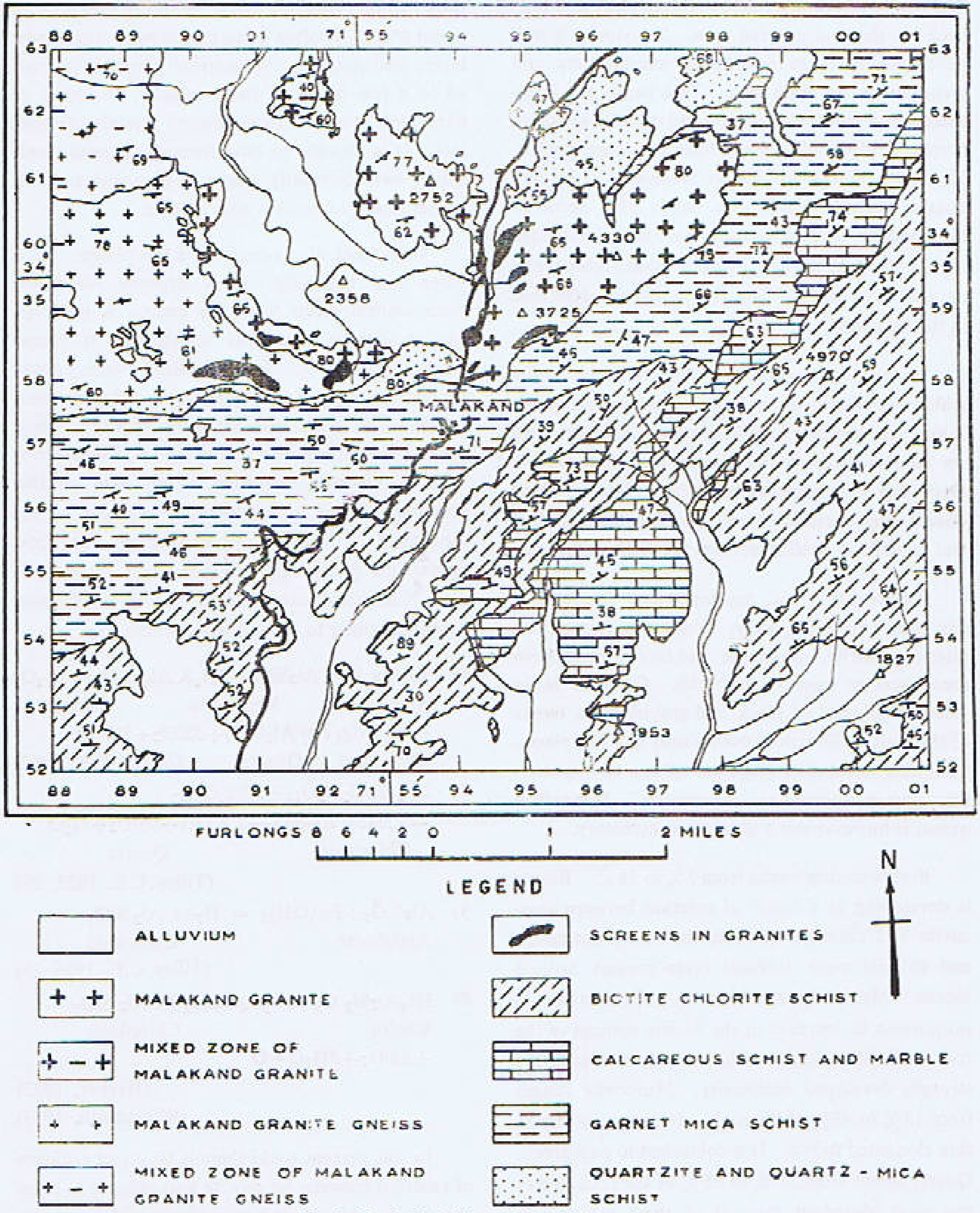


Fig. 1 Geological Map of the Malakand Area

The pelitic metamorphics form steep cliffs and high peaks in the southeastern area. Schistosity is well developed in these rocks and microfolding and crenulations are often seen. Thin bands and intercalations of calcareous schists and marbles are often present. Most of these bands are unmappable. The pelitic metamorphics are profusely cut by thin quartz veins. Amphibolite bands also occur in these rocks. The pelitic rocks have been subdivided into two grades i.e. chlorite-biotite-schist and garnet-mica schist. The two units are described in the following.

1. *Biotite-Chlorite-Schists* : The chlorite-biotite schists are varied in colour. The serpent green colour is however predominant. Locally they are reddish to brownish due to iron and gray to black due to concentration of graphite. Folded quartz veins are ubiquitous. Mullion, microfolding and pinch and swell structures are fairly common.

Schistosity is well developed and the schistosity planes are often wavy. Under the microscope quartz, chlorite, muscovite and biotite have been recognised as essential minerals. Graphite is an essential mineral of black and grayish black bands of this unit. Chloritoid occurs only at a few places. Limonite, haematite, graphite, sphene and spessertine garnet occur as accessories. Spessertine garnet is however not a ubiquitous accessory.

Biotite content varies from 7% to 18%. Biotite is developing as a result of reaction between muscovite and chlorite. This is shown by muscovite and chlorite poor aureoles often present around biotite. Muscovite and chlorite both decrease in proportion to increase in the biotite content of the rock. Biotite along with muscovite marks the strongly developed schistosity. Muscovite ranges from 13% to 45% of the rock. It occurs mostly as thin elongated flakes. It is colourless to pale green. Quartz forms from 20% to 65% of the rock and is the most abundant mineral of these schists. It shows strain extinction and is biaxial having a 2V of about 6°-8°. It often occurs as segregated bands, layers and patches. Spessartine garnet is restricted to a few bands in these schists. It occurs as light pink euhedral to subhedral crystals of small size. It is thought to have formed in those bands which were originally richer in manganese. This garnet does not mark a new isograd.

Chloritoid also occurs at a few places. It is green and prismatic. It is strongly pleochroic from neutral green to bluish green. It generally lies at various angles to schistosity. It ranges from 2% to 3.5%. The chloritoid bearing rocks are generally poor in chlorite and richer in muscovite. The rock also contains biotite. These rocks show strong iron colouring i.e., haematite as well as limonite colouring. They also contain graphite. There is considerable evidence of the movement of iron solutions through the rock. Spessrtine garnet and graphite occur as accessories. Chloritoid can develop in the argillaceous rocks according to the following reactions.

1) $H_2(Mg, Fe)_2 Al_2SiO_9 + 2H_2K Al_3Si_3O_{12} + Fe_2O_3 =$
Amesite — Muscovite — Haematite
$4 H_2 (Mg, Fe) Al_2SiO_7 + 3SiO_2 + 2KOH$
Chloritoid — Quartz (Shams F.A. 1967)

2) $2H_2 KAl_3Si_3O_{12} + 3 Fe(OH)_2$
$= 3 H_2Fe Al_2SiO_7 + 2 KOH + 3SiO_2 + H_2O$
Chloritoid — Quartz
(Tilley C.E. 1925, 26)

3) $Al_2SiO_5 + Fe(OH)_2 = H_2Fe Al_2 SiO_7$
Andalusite — Chloritoid
(Tilley C.E. 1925, 26)

4) $3H_4Al_2Si_2 O_9 + Fe_3O_4 = 3H_2 Fe Al_2 SiO_7$
Kaolin — Chloritoid
$+ 3SiO_2 + 3H_2O + O$
(Harker, 1932)
(Williamson, 1953)

In the present rocks there is no direct evidence of reaction between muscovite and chlorite to form chloritoid. Also there is no evidence of the presence of either andalusite or kaolin. In view of these facts reactions 1, 3 and 4 can be ruled out. Therefore it is thought that reaction 2 applies and that chloritoid formed as a consequence of reaction between mica and iron bearing solutions. The formation of chloritoid was facilitated due to the presence of carbonaceous material which produced reducing conditions and convertion of Fe^{+++} into Fe^{++}. Relatively bigger lenses of marble and calcareous schist beds occur in chlorite—biotite schist.

Graphitic-Schists : By increase in the amount of graphite chlorite biotite schists rapidly grade into grayish black to black graphitic schists. Graphite forms layers, streaks and films along the schistosity plane. It also occurs as disseminated grains. Quartz ranges from 20% to 45%, muscovite from 25% to 45%, biotite from 6% to 17 % and graphite from 3% to 17%. Besides, chlorite, limonite and spessertine garnet occurs in small amounts. The graphitic schists differ from the ordinary chlorite-biotite schist in having higher total mica and graphite and lower chlorite.

Garnet-Mica-Schist : The garnet-mica schist is not a uniform unit. It contains intercalated calcareous schists and minor amphibolite bodies. In the south and southeast it comes in contact with biotite chlorite schist. In the extreme NE it envelopes the Malakand granite and also comes in contact with the quartzites and quartz mica schist unit. In the E.E.N. it forms the southern contact with the marble. The schists trend NE-SW. The garnet mica schist varies in colour from greenish brown to brown. The schistosity is well developed and reddish brown almandine garnets of almost uniform size can be easily identified.

Quartz, muscovite, biotite, garnet and potash feldspars are the essential minerals and tourmaline, limonite, magnetite and graphite are the accessories. The garnet is reddish brown almandine. It forms subhedral to euhedral crystals which thrust apart the schistosity planes. Garnet crystals contain quartz inclusions. Garnet forms from 2% to 6% of the rock. It tends to form sharply bounded prophyroblasts and encloses spiral train of quartz and mica inclusions which indicate rotation of garnet during growth. The bigger garnet crystals thrust apart the folia of micaceous minerals thus assuming an eye shaped configuration the corners of which are filled with quartz. The garnet seems to have formed as a result of the following reaction.

$$\underset{\text{Biotite}}{KFe_3\,Si_3AlO_{10}\,(OH)_2} + \underset{\text{Muscovite}}{KAl_3\,Si_3O_{10}\,(OH)_2} + 3SiO_2$$

$$= \underset{\text{Orthoclase}}{2KAlSi_3O_8} + \underset{\text{Almandine}}{Fe_3Al_2Si_3O_{10}} + 2H_2O$$

This is because muscovite and biotite poor haloes are often present around garnet crystals. Also orthoclase which is a by product of the above reaction makes its appearance in this grade although it is seldom encountered in the biotite grade. Also the garnet does not seem to have formed directly from chlorite because as the biotite zone grades into garnet zone chlorite diminishes in amount rapidly.

Muscovite as thin scales forming continuous bands marks the schistosity along with biotite. Muscovite make up from 20% to about 40% of the rock. Biotite is yellowish brown and strongly pleochroic from light yellow to yellowish brown. It constitutes from about 6% to 12% of the rock. Small anhedra of orthoclase constitute from about 0.5 to 2.5% of the rock. Quartz occurs as small lenses, streaks and bands. The quartz anhedra generally show strong strain extinction. It forms from about 25% to 40% of the rock. Graphite occurs as shreds and veinlets and varies from 0.3% to a maximum of 5%. Tourmaline occurs as small anhedra. It is pleochroic from neutral yellow to yellowish brown. It generally varies from 0.2% to about 1%. Limonite and magnetite are the other accessory minerals.

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

Calcareous Rocks

Calcareous-Schist and Marble : Calcareous schist and marble is extensively developed in the south-eastern part of the area. Main body of massive compact and non-foliated marble lies in the north of the village of Dobandi and extends towards northeast with north-south trend. It becomes thinner as it extends towards northeast and shows pinching and swelling.

Marbles are black, greenish black, gray to almost white in colour. Its surface gives rusty appearance due to weathering. White to grayish white marbles are confined to the vicinity of Sarbaba (G.R. 983583). Marbles are mostly compact and non-foliated. In hand specimen calcite and quartz are the only recognisable minerals.

Marbles are predominantly granoblastic. Calcite anhedra make up from 85% to 95% of the rock. They show perfect rhombohedral cleavage. In black varieties graphite encloses calcite grains as well as occurs within the calcite crystals. Quartz makes up from 3% to 8% of the rock. Small flakes of muscovite are distributed randomly in the rock. It constitutes upto 1% of the rock. Magnetite may make upto 1% of the rock.

There is no qualitative difference between the mineralogy of marble and the calc-schist. Calc-schist however contains larger amount of mica and magnetite.

Actinolite Schist: A narrow zone of actinolite schist is developed within calc schist (G.R. 977618) in the northeast of the area, near the granite contact. The microscopic study shows that the rock is composed of calcite, biotite, muscovite, actinolite with subordinate amounts of magnetite, garnet and epidote. Muscovite marks the schistosity of the rock. Actinolite makes from 3-8% of the rock. It is green in colour and pleochroic from light green to dark green. Its $2V=82^\circ$ and sign is negative. Actinolite could form as a result of the following reactions.

1. $$2\,Ca\,CO_3 + 5\,Fe\,CO_3 + H_2O + 8\,Si\,O_2 = \underset{\text{Actinolite}}{Ca_2\,Fe_5\,Si_8\,O_{22}\,(OH)_2} + CO_2$$

(Ramberg, 1952)

2. $$Ca\,CO_3 + 5\,Fe_3\,O_4 + 8\,SiO_2 + H_2O = \underset{\text{Actinolite}}{Ca_2\,Fe_5\,Si_8\,O_{22}\,(OH_2)} + 5\,Fe_2\,O_3 + 2\,CO_2$$

Actinolite has developed as a reaction between $Ca\,CO_3$ of the calcareous rock and introduced silica, water and iron. There is considerable evidence to suggest that silica, water and iron were in fact introduced. There is from 16-25% quartz, 23-31% muscovite, 25-37% calcite, 3-8% actionlite and about 1% sphene in this rock. So not only water and silica but titanium has also been introduced in the rock. Of the above two reactions the first reaction seems more likely since haematite is not the end product of the reaction. This schist has developed as a result of superimposed piezothermal metamorphism-metasomatism on calcareous schist at the contact of Malakand granite.

Arenaceous Rocks

Quartzites and quartz-mica schists are the arenaceous metamorphics. They have been mapped as a single unit in the field.

Quartzites: Quartzites are confined mostly to the northern part of the area mapped. To the south they form irregular contact with granite and schists and towards north they are burried under alluvium, except at one place where they come in contact with granite. The weathered surfaces of quartzites are brown to reddish brown due to iron staining. The colour of quartzites ranges from brown, reddish brown, rusty gray, greyish white to dirty white. Quartzite is granoblastic and from massive to poorly schistose. Quartz, K-feldspar, muscovite and plagioclase are essential minerals and biotite, limonite and epidote are accessory minerals. Quartz ranges from 65% to 85%. It occurs from sub-rounded to elongate grains which may often show sutured boundries. Both microcline and orthoclase occur in the rock. They form about 6-13% of the rock. Microcline occurs as anhedral crystals showing cross-hatched twinning. Orthoclase also occurs as small anhedral crystals. Muscovite ranges from 6% to 20% of the rock. Muscovite is generally interstitial to quartz. In some cases well crystallised muscovite flakes are irregularly distributed whereas in other cases, specially where the muscovite content is higher they are arranged in preferred orientation thus marking schistosity. Biotite ranges from 0.2% to about 2%, epidote from 0.3% to about 2% and limonite is from 0.5% to 1.5%.

Quartz-Mica-Schist : With increase in the amount of muscovite the quartzites grade into quartz-mica schists. It differs from quartzite in having well developed schistosity and microfolding. Quartz mica-schist occurs in the northwest of the area along with the granite contact. The contact is sharp, conformable and concordant. The general trend is NE-SW and the beds dip south at angles ranging from 40°-65°. The rock is composed chiefly of quartz, mica and feldspar. Biotite, garnet, epidote, sphene, graphite, magnetite and limonite occur as accessories. Some fluorite occurs in the schist near the contact with granite. Quartz occurs as rounded to enlogated grains. Muscovite marks schistosity of the rock and its aggregates often show microfolding. Biotite lamellae and graphite may some-times occur along its cleavage. Quartzites and quartz mica schists are also often interbedded.

Meta Igneous Rocks

Amphibolite: Amphibolite occurs in the from of sills, rarely as dykes, which generally range from six feet to 30 feet in thickness. They are confined close to the granite contact and lie within calcareous schists and garnet mica schist. The general trend of these bodies is from northeast to southwest and they dip towards northwest at angles ranging from 50° to 65°. Their contact with the surrounding metamorphics is sharp and generally concordant. No gradation was seen between the amphibolite and the surrounding schists.

Amphibolites are green coloured, medium to coarse grained foliated bodies. The green colour is due to the abundance of hornblende. Brown almandine garnet crystals are often clearly visible on the weathered surfaces. Foliation is fairly well developed due to alignment of hornblende crystals.

Hornblende is the predominant mineral and calcite, plagioclase and garnet are important subordinate minerals whereas sphene, magnetite, zoisite and orthoclase are accessory minerals. Green coloured prisms of hornblende constitute from about 82% to almost 90% of the rock. It shows strong pleochroism from light green to dark green. Small amounts of cummingtonite have been encountered in some cases.

Calcite ranges from 3% to 6% of the rock. It forms anhedral elongated grains which are generally elongated parallel to the foliation. Garnet constitutes from 2% to 4% of the rock. It occurs as subhedral to anhedral porphyroblasts which contain rather large amount of inclusions of quartz and calcite and sometimes also sphene. The bigger crystals tend to form augens. Andesine constitutes from 3% to 5% of the rock. It is generally subhedral to anhedral and often poorly twinned. Magnetite, sphene, zoisite and orthoclase are accessories, each of which generally constitutes less than 1% of the rock.

The amphibolite bodies have most probably formed as a result of metamorphism of basic to ultrabasic intrusions. Since they, sometimes do occur as dykes in the metasediments, therefore their intrusive nature is clear. Even when they occur as sills, minor discordance can often be observed. The fact that they contain sphene and leucoxene further supports an igneous parentage of these rocks. These bodies occur both in the garnet-mica schist as well as in the calcareous schists. It is obvious that they could not have been derived by the metamorphism of the pelitic schist. But where they occur in the calcareous rocks there is considerable evidence to suggest that they did not form as a result of metamorphism of these rocks.

PETROGENESIS OF THE METAMORPHICS

The area covered by the metamorphics originally consisted of a sequence of pelitic, arenaceous and calcareous rocks. They have been regionally metamorphosed from chlorite grade to garnet grade of regional metamorphism. But the garnet grade appears to be piezothermal rather than regional in character because it has developed close to the Malakand granite and Malakand granite gneiss. When traced along strike away from the granites it disappears. The regional metamorphism is older than the granite gneiss. In terms of facies the the rocks fall in the green schist facies. Part of the garnet grade however falls in the garnet amphibolite facies. This fact has been confirmed by the study of the composition of plagioclase in the garnet grade. Most of the amphibolites, specially the garnet amphibolites fall within the garnet amphibolite facies. But again this facies has developed as a result of piezothermal metamorphism close to the contacts of granite and granite gneiss. The amphibolites were originally sills and dikes of a basic to ultrabasic rocks.

The Malakand metamorphics are most probably higher grade equivalents of the Attock Slates which occur south of the area.

IGNEOUS ROCKS

Malakand Biotite Granite Gneiss: In the west and northwest of the area lies the Malakand granite gneiss. It is a darker coloured rock compared with the Malakand granite. To the NW it is rich in inclusions and screens. It is from medium to coarse grained and well foliated rock. It contains a large number of quartz veins which may often show folding. Its contact with the Malakand granite is irregular and apophyses of the Malakand granite extend into the granite gneiss. It shows considerable mixing with the metamorphic rocks, mostly schists, in the northwest of the area. As a result of this mixing a thick mixed zone is developed where migmatization and granitisation is taking place.

The Malakand granite gneiss is composed of quartz, plagioclase, biotite, microcline and orthoclase. Sphene, epidote and magnetite are the accessory minerals. Garnet and calcite are often present as accessories in the rock. Plagioclase ranges from 20% to 40% of the rock. It occurs from subhedral to anhedral crystals. It is almost invariably an oligoclase. It shows alteration to muscovite and epidote. Orthoclase constitutes from 14% to 25% of the rock. It generally contains inclusions of quartz and shows alteration to sericite. Microcline anhedra ranges from 3% to 8% of the rock. Quartz makes up from 28% to 40% of the rock. It occurs as subhedral crystals which invariably show strain extinction. It also occurs as inclusions in plagioclase as well as in orthoclase and microcline. Biotite makes up from 0-50 % to 30% of the rock. It is strongly pleochroic from light brownish green to dark brownish green. It along with muscovite forms parallel layers with feldspars and marks the well developed gneissic structure. Muscovite makes up from 2% to 18% of the rock. When primary it is associated with biotite and when secondary it occurs as alteration product of the feldspars. Magnetite grains range from 0.5% to about 3% of the rock, calcite goes upto 25% of the rock, garnet upto 3% and sphene upto 2% of the rock.

The biotite granite gneiss of the area is older than the Malakand granite. It is gneissic and therefore syntectonic. It has not been studied in detail and therefore cannot be dealt with at length. Its petrogenesis and origin are not the theme of this paper.

Malakand Granite : The Malakand granite is a roughly oval shaped body. It trends NE-SW and is 5 miles by about 3.4 miles. In the south and south-east of the Malakand granite lies NE-SW trending biotite-muscovite schist, garnet mica schists, graphitic schists and calcareous schist and marbles. Towards extreme NE lie quartzites and quartz-mica schists. Towards west and northwest lies the Malakand granite gneiss.

It is non-porphyritic fine to medium grained granite. When fresh it is white, while its weathered surfaces are light brown in colour. It is invariably criss-crossed by simple pegmatite and aplite veins. Xenoliths and screens of the country rock are generally confined to the contact. The screens are generally baked, hornfelsed and granitised.

The contact between granite and metamorphics is very sharp. Evidence of chilling at the contact is also present. Although the contact is generally conformable, minor discordance is very common. Apophyses of granite extend both into metamorphices as well as the granite gneiss. At a few places the contact schists have been somewhat hornfelsed although no characteristic thermal metamorphic minerals appear. The schists change their attitude near the contact suggesting forceful intrusion. Pegmatites develop in abundance near the contact.

TABLE 1

Modal Analyses

	11712*	11645	11409	11710	11687	11725	11561**
Albite ..	39.87	54.30	21.30	30.77	32.33	29·00	8.88
Quartz ..	28.02	18.72	49.04	32.74	32.63	34.09	42.37
Microcline ..	16.04	6.95	18.70	24.38	27.88	26.91	33.38
Muscovite ..	11.23	16.35	5.65	12.11	5.03	5.44	14.39
Epidote ..	2.25	2.51	0.58	0.00	2.13	1.14	0.98
Sphene ..	0.00	0.67	0.00	0.00	0.00	0.00	0.00
Calcite ..	1.82	0.00	1.33	0.00	0.00	0.00	0.00
Biotite ..	0.87	0.33	2.20	0.00	0.00	2.17	0.00
Garnet ..	0.00	0.00	0.18	0.00	0.00	0.00	0.00
Apatite ..	0.00	0.17	1.02	0.00	0.00	0.80	0.00

* Malakand granite gneiss.

** Pegmatite vein.

Malakand granite is fine to medium grained compact rock. It is non porphyritic hypidiomorphic granular. Quartz, plagioclase, microcline and muscovite (except in a very few cases) are the essential minerals whereas epidote, magnetite, biotite, sphene and calcite are the accessory minerals Table 1. The texture of the granite is non-uniform. There is considerable evidence of replacement. At places replacing minerals are quartz and mica and at quite a few places also megacrysts of both microcline and albite.

Plagioclase makes up from 21.30% to 54.30% of the rock. Its composition varies from A_{n4} to a maximum of A_{n14}. In most cases however it is an albite, sometimes it is anti-perthitic. It often occurs in two generations. One generation, the earlier one consists of small euhedral to subhedral laths. The plagioclase is poor in inclusions. The second generation occurs as megacrysts. This generation is subhedral to anhedral. The crystals have often a rugged outline, enclosing and replacing minerals at the margins. The inclusions range from 2% to almost 30%. The inclusions consist mainly of bits of quartz, sometimes in optical orientation, but sometimes also of muscovite and even smaller crystals of albite and epidote. In some cases microcline is being clearly replaced by the megacrystic plagioclase. The replacement may be so advanced that only small pieces of the replaced mineral are left. This shows that the megacrysts formed in a solid state, after minerals like albite, quartz, microcline and mica had already crystallized.

But this is not to say that phenocrysts do not occur. They occur at a few places. They are subhedral and poor in inclusions. Plagioclase shows ubiquitous alteration to muscovite. Sometimes it also shows alteration to kaolin. Other alteration products are muscovite-calcite, and muscovite epidote. Plagioclase alters much more readily.

Microcline makes up from 6.95% to 27.88% of the rock. It also often occurs in two generations. One generation, the main generation is composed of subhedral to anhedral microcline of smaller size. Its outlines are rather rough but more or less regular. It is poor in inclusions and visibly from very poorly perthitic to non-perthitic. The perthitic growths, which are poorly developed, can be seen in only a few cases. The second generation consists of the megacrysts of microcline. They are from well twinned to poorly twinned. They enclose other minerals and their outlines are irregular and rugged. The microcline of this generation contains inclusions mostly of quartz but also of muscovite as well as albite. At places the quartz bits in microcline are in optical orientation. Sometimes the cracks in microcline are filled with a fine grained aggregate of either muscovite, or calcite or both. The second generation is, more often than not perthitic. All forms of perthite lamellae from stringer lamellae to vein lamellae to band lamellae occur. Patch lamellae are very rare. The distribution of the perthite material is not uniform. Some parts of the crystals, may be more perthitic than the others. In some cases the perthitic lamellae show good twinning.

Quartz occurs as anhedral crystals, mostly of small to medium size. It occurs both as distinct crystals as well as aggregates and small patches. Sometimes recrystallisation seems to have produced bigger crystals of quartz by coalescence. Occasionally a few megacrysts of quartz can be seen. They may enclose albite and mica. Quartz also occurs as inclusions in orthoclase, plagioclase and mica. Quartz almost invariably shows strong strain extinction. It varies from 18.72% to 49.04%.

Both muscovite and biotite occur in the Malakand granite, but the former is ubiquitous, whereas the latter may or may not occur. Biotite may occur either independently or as intergrowths with muscovite. In the latter case it generally occurs as small growths and patches along the cleavage of muscovite. Muscovite varies from 5.03% to 16.35% whereas biotite reaches a maximum of 2.20%.

Muscovite is a light green variety. It is pleochroic from colourless to light green. It has the following three modes of occurrence.

1. Primary muscovite occurring as well formed crystals of a fair size, generally euhedral to subhedral. It may contain, occassionally, a little biotite along the cleavage.

2. As an alteration product of feldspars. It is an alteration product of both albite (plagioclase) as well as microcline. Generally muscovite is the only alteration product, but occasionaly some epidote and rarely some calcite may also occur.

3. As a product of greisenisation in certain parts of the Malakand granite. This greisenisation takes places both on a megascopic as well as microscopic scale. This greisenisation is not very common and when it does occur it is restricted to the sheared zones.

Biotite is less common than muscovite. Biotite is either an accessory or a very minor constituent of the Malakand granite. The colour of biotite is greenish brown. It is strongly pleochroic from almost light greenish brown to greenish brown. Biotite is closely associated with muscovite.

Colourless to light green clinozoisite is an important accessory mineral. It occurs independently as subhedral crystals. There is no evidence to suggest that it is an alteration product of feldspar. Textural evidence shows that it is younger than the first generation of plagioclase and microcline. It is older than or contemporaneous with the megacrysts. The second generation of clinozoisite occurs as very small grains associated with altered feldspar. It is secondary and has formed as a result of alteration of feldspars.

Calcite occurs as an accessory mineral in a few cases. It occurs in some sheared rocks. It has been introduced in the rock after consolidation. Occasionally calcite and muscovite are associated with altered plagioclase. Here it appears to be forming as an alteration pair with muscovite. Poikiolitic, pink garnet occasionally occurs near the contact within the granite or as a relic of xenoliths of garnet mica schist within granite.

Myrmekites : Myrmekitic growths are encountered in a number of cases in the Malakand granite. These growths are generally confined to the relatively coarser parts of the granite. The myrmekite bearing rocks are generally free of shearing effects. The myrmekite growths are present at contact between plagioclase and microcline. These growths extend into microcline. In cases where the microcline is strongly perthitic, the perthite lamellae continue across the myremekitic growths undisturbed.

Pegmatites and Aplites: The Malakand granite and the associated metamorphics and the Malakand granite gneiss are cut by light coloured pegmatites and aplites. Pegmatite and aplite bodies show extensive cross cutting. In majority of the cases aplites cut the pegmatite veins. However a few rather poorly developed pegmatite veins cut aplite veins. Most of the pegmatites are filling the joints in granite and other country rock. Patchy, irregular replacement pegmatites are also seen. The pegmatites generally range in size from a few inches to about 15 feet in thickness and from a few feet to about 40 feet in length. The aplites range in size from less than an inch to about 3 feet in thickness and from a few inches to about 20 feet in length. Almost all the pegmatite and aplite bodies (except the replacement bodies which are irregular) are tabular. The pegmatites may be divided into the following three types.

1. Feldspar—quartz—pegmatites
2. Mica-feldspar—quartz—pegmatites
3. Tourmaline—fluorite bearing pegmatite

The feldspar—quartz pegmatites occur either as patches or as thin veins. They are most abundant in the Malakand granite. The patchy bodies are indefinite in their outline and show evidence of replacement. Even when these pegmatites occur as veins their margins are irregular and show replacement relation with the surrounding rock. These pegmatites are composed essentially of microcline, plagioclase and quartz with minor mica and epidote.

The mica-feldspar-quartz pegmatites are mostly tabular bodies filling joints and fractures of granite and the contact rocks. They are most abundant near the contact. At places the walls are muscovitised. They consist of microcline, plagioclase and muscovite.

The 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 pegmatites contain tourmaline, fluorite and sphene. These pegmatites almost invariably contain amazonite. They mostly occur along joint surfaces. Their contacts with the host rock are sharp.

The aplites occur as veins. They have typical saccharoidal texture. They are composed of 33% to 45% quartz, 17% to 28% plagioclase, 14% to 27% K-feldspar, 2% to 6% muscovite, 0.5% to 2.5% epidote and 0.3% to 1.5% sphene. Aplite veins generally cut the pegmatites but sometimes a few of them are cut by pegmatites.

CHEMISTRY

Five chemical analyses of the Malakand granite one analysis of the Malakand granite gneiss and one analysis of the pegmatite are given in Table 2. Variation diagrams are given in Fig. 2. In this figure Na_2O, K_2O and Al_2O_3 are plotted against SiO_2. With increase in the amount of SiO_2, K_2O increases whereas Na_2O, CaO and Al_2O_3 decrease. Since SiO_2 increases with the progress of crystallisation, therefore as the crystallisation progresses the amount of SiO_2 and K_2O increases, whereas the amount of Na_2O, CaO and Al_2O_3 decrease with progressive crystallisation; total alkalies also decrease. The chemical analysis also show that there is a fairly complete transition in composition from granite gneiss to the late pegmatite vein.

ORIGIN AND PETROGENESIS OF GRANITES

The Malakand granite is a minor intrusive of Rastall (1945). It is a discordant intrusion. The discordance is supported by the field mapping as well as the geophysical work carried out by Saleem Ullah and Rizvi (1964). Both geological as well as geophysical evidence suggests it to be a laccolithic body. Its contacts with the country rock are sharp and discordant. The exchange of material across the contact is hardly appreciable. Baking and hornfelsing has been observed at many places. Near the contact screens and xenoliths are fairly common. Apophyses of granite are often seen in the country rock. Petrographically the body is rather uniform and compact. The normative composition Table 2 of (Ab+Or+Qtz)=100% when plotted on petrogeny residua shows that almost all samples (except pegmatitic vein) fall in or very close to the petrogeny residua showing that the granite is a product of crystallisation from a melt. The texture is typically hypidiomorphic granular. The chemical study shows progressive evolution of composition in keeping with crystallisation in a silicate melt of appropriate granitic composition. The variation diagrams show a complete transition from the granite gneiss to the Malakand granite to late pegmatite veins. This suggests that the Malakand granite has been directly derived from Malakand granite gneiss through progressive crystallisation. The above facts clearly suggest that the Malakand granite is a late tectonic minor pluton of magmatic origin.

After its evolution from the Malakand granite gneiss and emplacement of the magma itself there ensued progressive crystallisation. This resulted in progressive increase in SiO_2 and along with it a progressive increase in K_2O and decrease in Na_2O CaO and Al_2O_3. This progressive change in composition is reflected in progressive increase in the amount of quartz, potash feldspar, and mica and decrease in the amount of soda feldspar.

Towards the close of crystallisation in the granite magma a rest magma formed which was comparatively richer in K_2O, H_2O, F_2 and SiO_2. It resulted in the formation of aplites as well as pegmatites.

At the end the Malakand granite underwent pneumatolytic metamorphism. Water, silica and fluorine were the main metasomatic fluids. This resulted in the local enrichment in quartz and mica of the Malakand granite and formation of quartz and quartz mica veins.

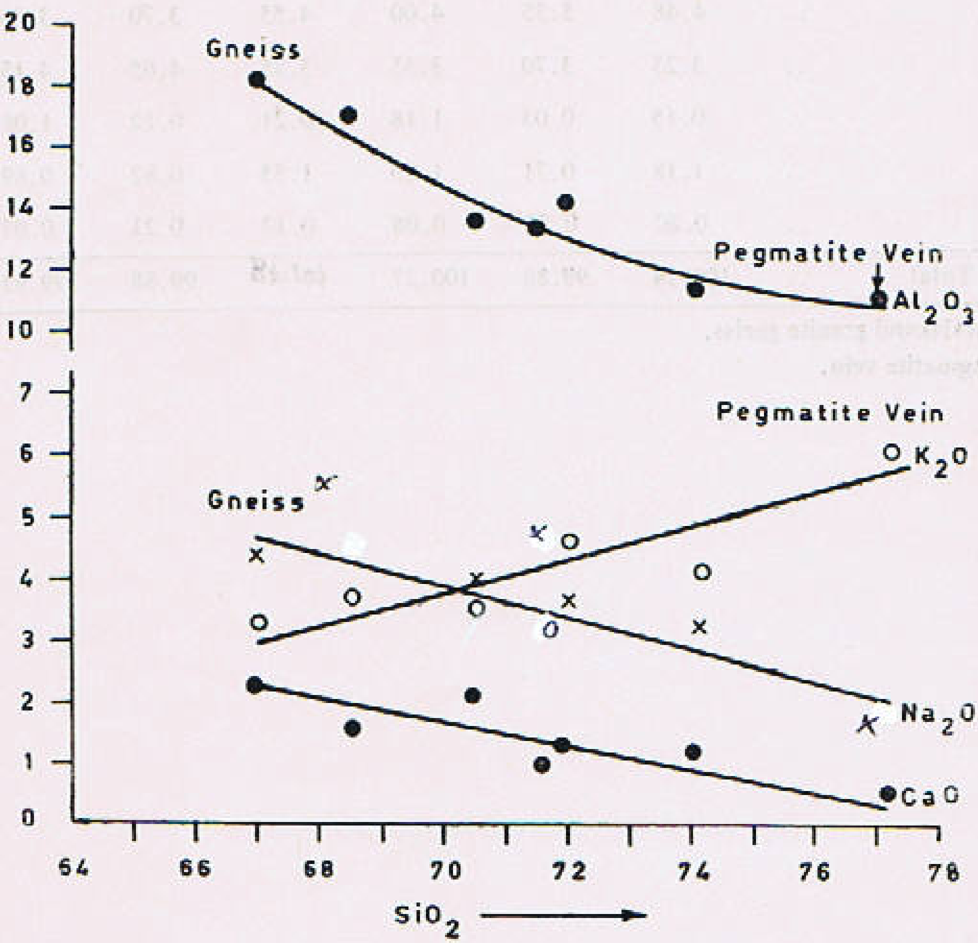


Fig. 2 Diagram showing Variation of CaO, Na_2O, K_2O and Al_2O_3 with Variation in SiO_2

TABLE 2

Chemical Analyses of the Malakand Granite

	11712 *	11645	11409	11710	11687	11725	11561**
SiO_2 ..	66.91	68.48	70.46	71.56	71.86	74.04	77.01
TiO_2 ..	0.13	0.28	0.18	0.71	0.35	0.53	0.10
Al_2O_3 ..	18.19	17.03	13.84	13.39	14.35	11.54	11.02
Fe_2O_3 ..	2.59	1.40	2.51	3.53	2.06	2.31	1.57
FeO ..	0.35	0.44	0.16	0.14	0.11	0.21	0.26
MgO ..	0.41	0.00	0.99	1.17	0.35	0.61	0.33
MnO ..	0.05	0.50	0.02	0.05	0.00	0.00	0.18
CaO ..	2.25	1.54	2.10	0.86	1.30	1.20	0.62
Na_2O ..	4.48	5.55	4.00	4.55	3.70	3.30	1.09
K_2O ..	3.25	3.70	3.55	3.35	4.65	4.15	6.16
P_2O_5 ..	0.15	0.03	1.18	0.21	0.12	1.08	0.08
H_2O^+ ..	1.18	0.71	1.20	1.53	0.82	0.89	1.38
H_2O^- ..	0.20	0.22	0.08	0.13	0.21	0.07	0.11
Total ..	100.14	99.88	100.27	101.18	99.88	99.93	99.91

* Malakand granite gneiss.

**Pegmatite vein.

TABLE 2 (Contd.)

Normative Composition

	11712*	11480	11409	11710	11687	11725	11561**
Albite ..	38.25	41.39	34.06	38.25	31.44	27.77	9.43
Anorthite ..	10.56	3.89	3.89	3.89	5.56	0.00	2.22
Orthoclase ..	18.90	35.03	20.57	25.58	27.24	24.46	36.70
Quartz ..	23.22	16.56	30.54	25.26	29.70	38.34	45.30
Corrundum ..	3.37	0.00	1.94	3.47	1.12	1.63	1.63
Hypersthene ..	1.00	0.80	2.50	2.90	0.90	1.50	0.80
Magnetite ..	1.16	1.86	0.00	0.00	0.00	0.00	0.70
Haematite ..	1.76	0.00	2.56	3.52	2.08	2.24	1.12
Ilmenite ..	0.15	0.15	0.30	0.15	0.15	0.61	0.15
Rutile ..	0.00	0.00	0.08	0.64	0.24	0.24	0.00
Apatite ..	0.34	0.00	2.69	0.34	0.34	2.69	0.34
Normative (Ab+Or+Qrtz recalculated to 100%)							
Plagioclase ..	53.67	46.74	42.61	45.32	39.39	30.66	12.44
Orthoclase ..	20.79	36.16	23.10	27.51	29.00	27.01	39.19
Quartz ..	25.54	17.10	34.29	27.17	31.61	42.33	48.47

*Malakand granite gneiss.

**Pegmatite vein.

REFERENCES

Ahmad, M., Ali, K.S.S., Khan, B., Shah, M.A., and, Ullah, I., 1969 The geology of Warsak area, Peshawar, West Pakistan. *Geol. Bull. Univ. Peshawar*, **4**, 44.

Bakr, M.A., and Jackeon, R.O., 1964 Geological Map of Pakistan. *Geol. Surv. Pak.* (Scale 1 : 2,000.C00).

Hyden, H., 1918 General report of the Geological Survey of India for the year 1916. *Rec. Geol. Surv.* India, **48**, 12.

Harker, A., 1939 Metamorphism 2nd Edition, Methun, London.

Rastall, R.H., 1945 The granite problem. *Geol. Mag.*, Vol. **82**, 28.

Ramberg, H., 1952 Origin of metamorphic and metasomatic rocks. Chicago Univ. Press.

Saleem Ullah, M., and Rizvi., 1963-64 Field report, *Geophys.* M.Sc. *Punjab Univ.*, Lahore.

Shams, F.A., 1963 The petrology of some chloritoid and staurolite bearing schists from the Mansehra-Amb State area, Northern West Pakistan. *Geol. Bull. Punjcb Univ.*, **1**, 57.

Tipper, M.H., 1905 Report on penetration of Malakand tunnel. *Rec. Geol. Surv.* India, **35**, 35.

Tilley, C.E., 1925 Petrological notes on some chloritoid rocks. *Geol. Mag.*, **62**, 309.

Uppal, I.H., 1972 Preliminary account of the Harichand Ultramafic Complex, Malakand Agency N.W.F.P. Pakistan. *Geol. Bull. Punjab Univ.*, **9**, 55.

Wadia, D.N., 1953 Geology of India 3rd Edition. MacMillan and Co. London.

Williamson, D.H., 1953, Petrology of chloritoid and staurolite rocks, north of Stonehaven, Kincardineshire. *Geol. Mag.*, **90**, 353.

(Manuscript received September, 1973)

GEOLOGY OF DADAR PEGMATITES, MANSEHRA AREA, HAZARA DISTRICT, PAKISTAN

by

MOHAMMAD ASHRAF

Glass and Ceramics Division P.C.S.I.R. Laboratories, Lahore

and

M. NAWAZ CHAUDHRY

Department of Geology, University of the Punjab Lahore

Abstract : *Six complex pegmatite bodies have been located in the Dadar area. They are zoned. Most of the zones have been completely reconstituted. It is conceived that they are granite pegmatites which have been derived from sodic solutions with gradual enrichment in potassic phase. The reconstitution occurred at pneumatolytic stage forming cleavelandite, muscovite and beryl. Replacement by tourmaline is local. In one of the pegmatites the replacement by cleavelandite is so extensive that small islands of microcline perthite are left as relicts in the intermediate zone, even the outermost zone (wall zone) has also not survived replacement.*

INTRODUCTION

Many pegmatite occurrences have been noted in the Mansehra and Batgram area both in the granites and the associated metamorphics. Various facies of granites have been recognized by Shams (1969) and Ashraf (unpublished work), they are the Susalgali granite gneiss, a thoroughly gneissic variety covering about 55% of the granitic complex; the Mansehra granite, a porphyritic granitoid facies of the complex; the Hakle tourmaline granite, a later non-porphyritic granitoid with tourmaline as an essential mineral; the Chailsar microgranite, is perhaps later facies than the Hakle tourmline granite and is more sodic. The metamorphics of the area consist of pelitic to psammatic schists and quartzites which have suffered Barrovian type regional metamarphism upto the kyanite grade (Shams, 1967). The Dadar pegmatites have been emplaced in the metamorphics along the foliation plane and also along the joints. They have been classed as interior marginal pegmatites (Ashraf, unpublished work).

Dadar is located at a distance of about 20 miles from Mansehra. It is connected by an all weather metalled road. From Dadar the pegmatite deposits are located at a distance of about one mile, near Basala village at an altitude of about 5000 feet above sea level. The granite occurs at a distance of about two furlongs from the pegmatites.

GEOLOGY OF THE PEGMATITES

Six pegmatite bodies have been found in this area. Mining for microcline was in operation in the past which has exposed partially to fully the internal sturucture of the bodies. Zonation is well-developed in all of them, and the pneumatolytic replacement has modified the pegmatite zones giving rise new mineral assemblages in them. Practically all of them are complex since rare mine-

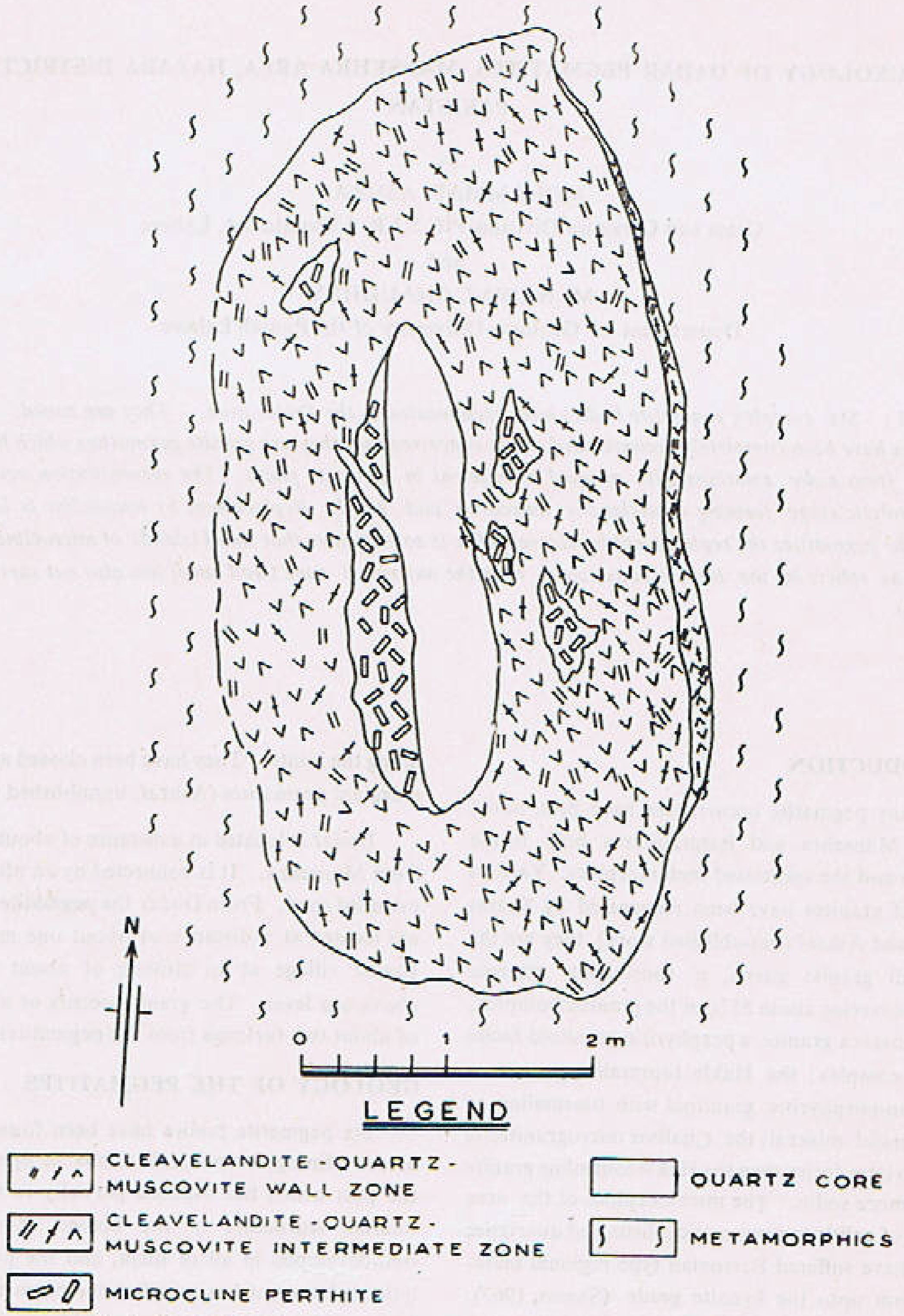


Fig. 1 Sketch Map of Dader Pegmatite Showing Wall, Intermediate Zones, Core, and the Super mposed Replacements.

rals like beryl and cleavelandite are present (5 to 50 mm long crysals). Such beryl and cleavelandite bearing pegmatites have been described by Shaub (1937), Fisher (1968), Reedman and Lowenstein (1971) and Rao (1972) where both these minerals are closely associated. In the present case beryl is also closely associated with cleavelandite, a radiating and fibrous white albite. In three pegmatites boron was also very active in depositing tourmaline in all the zones except the core. One of the best exposed pegmatite is about 6 metres in length and its maximum exposed width is about 3 metres in the middle. Zonation is perfect in it as wall zone, intermediate zone and core are well marked (Fig. 1). Later on, both the wall and the intermediate zones were extensively replaced by soda fluids to form cleavelandite. The replacement is so evident that islands of microcline perthite are still present in the hanging wall side in the intermediate zone and this zone was also narrowed near the footwall side. The core has been slightly effected by replacement and only near the contact with the intermediate zone. Here quartz is being replaced by cleavelandite.

Following zones are, therefore established in the field in all the pegmatites as defined by Jahns (1955) and Rodes (1964) and will be discussed in respect of the pegmatite shown in Fig. 1. (*i*) Wall zone (*ii*) Outer and inner intermediate zones (*iii*) Core. In the following one representation will be discussed (Table 1, Fig. 1). As replacement has modified this pegmatite therefore, modal compositions of the replaced outer intermediate zone, the relict microcline perthite in the inner intermediate zone and contact zone of the core are presented in Table 1.

(*i*) *Wall zone*. It is thin, about 10 to 30 cm thick, irregularly developed in the hanging wall and missing in the footwall side due to blasting by the miners. The minerals as studied under the microscope are from 1 to 2 mm with occasional 3 mm and 0.2 to 0.5 mm. The rock is crushed badly. This zone has been completely replaced and no relict of potassic phase is seen.

Cleavelandite is the dominant mineral of this zone usually 1 to 2 mm with occasional finer, and coarser grains upto 3 mm. It is twinned on albite law. It shows partially fibrous radial structure in most grains (Fig. 2). The composition of cleavelandite is An_4. Grains are crushed and appear as if they are replacing quartz and are being replaced by garnet.

Quartz grains from 1 to 1.5 mm in size with occasional 0.2 to 0.5 mm grains are associated with albite of the same size. Quartz is anhedral in shape.

Fig. 2 Photomicrograph of a Rock Sample from the Wall Zone, Showing Radial Pattern of Cleavelandite, (X. 27).

Muscovite occurs as 0.1 to 0.4 mm flakes. Muscovite exsolves biotite at places along cleavage traces.

Biotite is 0.2 to 0.6 mm in size and is in the form of flakes and tablets. It is sometimes exsolving from muscovite. It also occurs as an alteration product of garnet. Biotite is pleochroic in light brown to brown colours.

Garnet occurs in the form of anhedra 0.2 to 2.5 mm. It alters to biotite along cracks and on the surface. It exsolves magnetite and replaces albite.

Apatite is in the form of subhedra 0.1 to 0.4 mm in size.

Ore is magnetite exsolving from garnet as 0.2 to 0.4 mm grains.

(*ii*) *Outer Intermediate Zone* : This in its present form is a completely replaced zone with relicts of K-feldspar at a few places. The mineral grains are 1.5 to 30 mm in size, though finer grains of the order of 0.1 to 0.5 mm are not uncommon. Like wall zone the mineralogy is almost the same but with larger size of the grains and the presence of beryl. The latter has not been detected in the wall zone.

Cleavelandite is relatively more fibrous and radiating having anorthite one percent (An_1.) Beryl is in the form of anhedral to subhedral grains from 0.8 to 2.5 mm in size. It contains inclusions of muscovite. In another pegmatite the outer most part of this zone shows extensive development of myrmekite.

(*iii*) *Inner Intermediate Zone* : In this zone relict islands of microcline perthite are present near the core. The microcline islands are being surrounded by the cleavelandite-quartz-muscovite rock of almost the same composition as in the outer intermediate zone. Under the microscope the entire rocks of the islands of this zone consist of microcline perthite traversed by micro-aplitic veinlets (Fig. 3) composed of microcline, albite and sometimes quartz. This aplitic phase might have been formed from and within the host microcline perthite.

Fig. 3 Photomicrograph of Microcline-perthite from Inner Intermediate Zone showing patch of Albite and Microaplitic Veinlets, (X. 27).

Microcline covers the entire thin section. It is crushed at places and the fractures are filled by microcline and albite from 0.1 to 0.25 mm subhedra. It is perthitic with albite lamellae very fine to 1 mm thick.

Quartz occurs from 0.1 to 0.6 mm anhedra in minor amount.

Albite occurs as fine perthitic lamellae from 0.2 to 1 mm with composition An_{3-5}. It has well-developed twinning. It also occurs in aplitic veinlets.

Muscovite is in the form of very fine needles and tablets (0.1 mm).

Ore grains are of magnetite and limonite. They occur as very small grains.

(*iv*) *The Core* : It consists mainly of quartz (Fig. 4) which is being replaced by cleavelandite at places near the contact with inner intermediate zone. The width of the core is from 0.25 to 0.5 metre. In the following lines only the composition of the core near the contact zone is described.

Cleavelandite is 1 to 5 mm in size, fibrous radiating, well twinned with composition A_{n2}. A small amount of it alters to sericite. Cleavelandite fibres are sometimes traversed by biotite veinlets.

Quartz occurs as 1 to 3.5 mm grains with some finer grains around 0.3 to 0.5 mm which occur quite welded together and are being replaced by cleavelandite.

Muscovite is in the form of 0.1 to 0.3 mm tablets replacing cleavelandite.

Sericite is an alteration product of cleavelandite. Biotite occurs in veinlets of cleavelandite as light brown to brown pleochroic flakes. Veinlets are 0.1 to 0.2 mm thick.

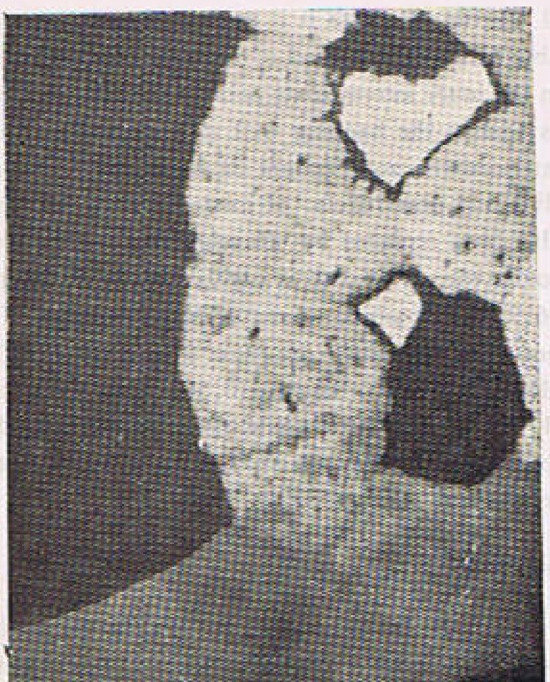


Fig. 4 Photomicrograph of a Rock Sample from Quartz Core Showing Dominant Quartz Grains, (X. 54).

TABLE I

Modal Analyses

	Outer Intermediate Zone	Inner Intermediate Zone	Core
Cleavelandite (albite) ..	64.68	21.19	5.20
Microcline ..	1.29	76.39	0.00
Quartz ..	21.15	0.15	93.15
Muscovite ..	6.85	2.11	1.35
Sericite ..	0.00	0.00	0.20
Biotite ..	0.23	0.00	0.10
Apatite ..	0.36	0.00	0.00
Sphene ..	1.47	0.00	0.00
Beryl ..	3.96	0.00	0.00
Ore ..	0.00	0.15	0.00

CHEMISTRY

Three chemical analyses of the representative samples from outer intermediate zone, inner intermediate zone (microcline perthite) and core were done according to routine classical methods (gravimetric) for SiO_2 and R_2O_3. Fe_2O_3 and FeO were determined titrometrically, CaO and MgO by EDTA, TiO_2 and P_2O_5 by spectrophotometry, Na_2O and K_2O by flamephotometry. H_2O^+ was determined by penfield tube method. H_2O^- was determined at 110° C. Following (Table II) is the composition of different zones analysed.

TABLE II

Chemical Analyses

	Outer Inter-mediate Zone	Inner Inter-mediate Zone	Core
SiO_2 ..	68.90	63.06	96.96
TiO_2 ..	1.23	0.00	0.00
Al_2O_3 ..	18.80	20.37	2.53
Fe_2O_3 ..	0.02	0.11	0.00
FeO ..	0.12	0.04	0.07
MgO ..	0.35	0.00	0.00
CaO ..	0.49	0.00	0.00
Na_2O ..	6.53	3.37	0.41
K_2O ..	3.37	13.05	0.08
P_2O_5 ..	0.00	0.16	0.00
H_2O^+ ..	0.62	0.21	0.04
H_2O^- ..	0.09	0.05	0.04
Total ..	100.52	100.42	100.13

Table III shows the norms based on the chemical analyses of the different zones. The methods used for the calculation are after Johanssen (1939) and Homes (1930).

From the chemical analyses and normative composition of different zones it is clear that the outer intermediate zone is highly rich in Na_2O due to the presence of about 55.02% normative albite. K_2O is 3.7% which is mainly in microcline relicts. In the norm calculation this much K_2O has given rise to 20.02% orthoclase. The source of anorthite (2.5%) is from cleavelandite. In this zone corundum could be expressed due to muscovite in the mode. In the inner intermediate zone K_2O is very high 13.05% and Na_2O 3.37%. These two oxides when recalculated in normative form give

TABLE III

Normative Composition

	Outer Inter-mediate Zone	Inner Inter-mediate Zone	Core
Ab ..	55.02	23.82	3.14
Or ..	20.02	76.73	0.56
An ..	2.50	0.00	0.00
Q ..	16.56	0.00	94.38
C ..	3.47	0.00	1.84
Mt ..	0.02	0.00	0.00
Ru ..	1.06	0.00	0.00
il ..	0.15	0.00	0.00
Hy ..	0.80	0.00	0.13

orthoclase 76.73% and albite 23.82%. The amount of other oxides is meagre as shown in Table II. From this data it is evident that the greatest abundance of K_2O and of normative orthoclase is in the inner intermediate zone in the footwall side as against the hanging wall side where the inner intermediate zone (might be consisting of microcline and now relicts of microcline are left) has also been replaced by cleavelandite, quartz, muscovite etc. The core is highly rich in SiO_2 upto 96.96% with minor amount of Na_2O and K_2O. The normative amount from these is quartz (94.38%), albite (3.14%), orthoclase (0.56%) and corundum (1.84%). The latter could again be expressed due to muscovite and some Al_2O_3 replacing SiO_2 in the tetrahedral position.

GENESIS

The Dadar pegmatites are granitic pegmatites which have been formed in such conditions in which water vapour pressure of the granite increased more than 10 Kbs (as found by Jahns, 1964; Hall

1972, 73). But after the release in local vapour pressure in the granites due to presence of fissures albitites were formed (Ashraf unpublished work). Thereafter as the vapour pressure decreased further enrichment in K_2O started with the upward movement of alkalic solutions in the batholith which deposited albite-(microcline)-aplites and pegmatites, albite-microcline-aplites and pegmatites, microcline-albite-aplites and pegmatites as composite as well as independent bodies. Finally true pegmatitic solutions came into being to deposit complex zoned pegmatites near marginal and marginal-exterior zones with almost all the properties of a rest magma, becoming richer in aqueous fluids in association with silicate melt in a closed system.

In the present cases three stages of their formation have been observed (*i*) pegmatitic (*ii*) pneumatolytic and (*iii*) hydrothermal. The pegmatitic stage is the initial zonal consolidation of the pegmatite in a closed system. This view has been put forward by Kemp (1924), Landes (1933), Cameron et al. (1949), Flawn (1951), Jahns (1953) and Jahns and Burnham (1969). The zonal structure has been attributed to fractional crystallization and incomplete reaction between successive crops of crystals and rest liquids. The zones developed in the Dadar pegmatites are wall zone, outer intermediate zone, inner intermediate zone and core. In some pegmatites the wall zone and outer intermediate zone have been completely replaced by cleavelandite, myrmekite, quartz, muscovite ± tourmaline. The outer intermediate zone otherwise developed as mainly microcline perthite. The inner intermediate zone in most cases consists dominantly of microcline perthite, the relicts of which are also evident in some highly replaced bodies. And lastly quartz core was formed. After the development of zones of the pegmatites the pneumatolytic fluids were very active in replacing the pegmatites. The replacement in most cases started from wall zone inward. Thereby replacing completely wall zone, sometimes outer intermediate zone, partially to fully inner intermediate, and part of the core. The pneumatolytic solutions were rich in Na, Si, B, Be and F at the early pneumatolytic stage. And they deposited cleavelandite, quartz, tourmaline, beryl and muscovite in the outer and inner intermediate zones. While at late pneumatolytic stages Na and F, bearing solutions were responsible in forming cleavelandite and muscovite in replacing the microcline and quartz (from core). The hydrothermal stage is represented by last phase of activity in the formation of pegmatites. The most pronounced minerals belonging to this group are kaolinite and sericite. These two minerals are formed as an alteration product of feldspars and beryl. The amount of these minerals is very small which shows that the hydrothermal solutions must have escaped. This is why the amount of kaolinite and sericite is meagre in the pegmatites.

ACKNOWLEDGEMENTS

The first author (Ashraf) is grateful to Dr. F.A. Faruqi, Head of Research Division and Director P.C.S.I.R. Laboratories, Lahore-16 for arranging field trip. Thanks also go to former Head (Prof. F.A. Shams) and also present Chairman (Dr. M.A. Latif) of the Department of Geology, University of the Punjab, Lahore for providing laboratory facilities to carryout this work in the department.

REFERENCES

Cameron, E.N., Jahns, R.H., McNair, A.H., and Page, L.R., 1949 Internal structure of granitic pegmatites. *Econ. Geol. Mon.*, **2**, 115 p.

Fisher, D.J., 1968 Albite vs. cleavelandite and the signs of its optic directions. *Amer. Mineral.*, **53**, 1968.

Flawn, P.T., 1951 Pegmatites of the Van Horn Mountains, Texas. *Econ. Geol.*, **46**, 163.

Hall, A., 1972 Regional geochemical variation in the Caledonian and Variscan granites of Western Europe. 24th IGC, 171.

Hall, A., 1973 Geochemical control of granite compositions in the Variscan orogenic belt. *Nature Phy. Sci.*, **242** (118), 72.

Homes, A., 1930 Petrographic methods and calculations. Thomas Murby & Co. New York.

Jahns, R.H., 1953 The genesis of pegmatites : 1. Occurrence and origin of giant crystal. *Amer. Mineral.*, **38**, 563.

Jahns, R.H., 1955 The study of pegmatites. *Econ. Geol.* 50th Anniversary Volume, 1025 p.

Jahns, R.H., and Burnham, C.W., 1969 Experimental studies of pegmatite genesis : I.A model for the derivation and crystallization of granitic pegmatites. *Econ. Geol.*, **64**, 843.

Johannsen, A., 1939 A descriptive petrography of the igneous rocks: I. The University of Chicago Press, Chicago.

Kemp, J.F., 1924 The pegmatites. *Econ. Geol.*, **19**, 697.

Landes, K.K., 1933 Origin and classification of pegmatites. *Amer. Mineral.*, **18**, 33 : 95.

Luth, W.C., Jahns, R.H., and Tuttle, O.F., 1964 The granite system at pressure of 4 to 10 Kilobars. *Jour. Geophys. Res.*, **69**, 759.

Rao, K.B., 1972 Beryl and cleavelandite from Bihar, India. *Min. Mag.*, **38**, 896.

Reedman, A.J., and Lowenstein, P.L., 1971 Economic geology of the beryl-bearing pegmatites of southwest Uganda. *Trans. Inst. Mining. Metall.*, **80**, B4.

Rode, K.P., 1964 On the nature of mica pegmatites. IGC (6), 38.

Shams, F.A., 1967 Granites of the Mansehra-Amb State area and the associated metamorphic rocks. Unpublished Ph.D. Thesis Punjab University, Lahore.

Shams, F.A., 1969 Geology of the Mansehra-Amb State area Northern West Pakistan. *Geol. Bull. Punjab Univ.*, **8**, 1.

Shaub, B.M., 1937 Contemporaneous crystallization of beryl and albite *vs.* replacement. *Amer. Mineral.*, **22**, 1045.

(Manuscript received October, 1973)

QUARTZ, QUARTZ-ILMENITE AND QUARTZ-KYANITE VEINS IN THE MANSEHRA-BATGRAM AREA OF HAZARA DISTRICT.

BY

MOHAMMAD ASHRAF

Glass and Ceramics Division, P.C.S.I.R. Laboratories, Lahore

and

M. NAWAZ CHAUDHRY

Department of Geology, University of the Punjab, Lahore

Abstract : *Simple quartz, quartz-ilmenite and quartz-kyanite veins have been found in the area. Simple quartz veins occur both in the metamorphics as well as in the granites. But quartz-ilmenite and quartz-kyanite veins have only been found in the metamorphics so far. They range from mere stringer to many hundreds of feet in dimensions. They are lensoid, lenticular and lenticular branching type. They are thought to be products of hydrothermal solution and metamorphic differentiation.*

INTRODUCTION

Wide-spread occurrences of quartz bearing veins have been noted in the Mansehra and Batgram area of Hazara District (Topographic Sheets $43\frac{F}{2}$, $43\frac{F}{3}$, $43\frac{F}{6}$ and $43\frac{F}{7}$ of the Survey of Pakistan). The area consists of pelitic to psammatic schists and quartzites which have suffered Barrovian type regional metamorphism upto the kyanite grade (Shams, 1967) in which granites of various types have been emplaced.

The quartz veins are abundantly present in the Mansehra granite and they progressively decrease in abundance in the other types of granites namely Susalgali granite gneiss, Hakle tourmaline granite and Chail Sar microgranite. In the metamorphics of all types quartz veins are present in fair numbers but in pelitic to psammatic metasedimentaries the veins are much more abundant. Quartz veins have been described previously by Calkins et al. (1968) and kyanite pseudomorphing andalusite in schists has been discussed by Shams (1964).

SIZE, SHAPE, FORM AND EXTERNAL STRUCTURE:

The quartz bearing rocks occur as veins, lenses and tabular bodies in granites and also as lenticular, and folded bodies (Fig. 1), in the metamorphics. They have always very sharp contact with the host rocks. Usually the quartz veins and lenses are from stringer to six feet thick. But a body occurring in Mansehra granite near village Chitta Batta (Fig. 2) on Hazara Trunk Road is quite sizeable. It is about 34 feet wide (near this village) and about one mile long and branches into two or three bodies while entering the metamorphics having widths from 5 to 15 feet. Their contact with the surrounding granites and metasediments is sharp.

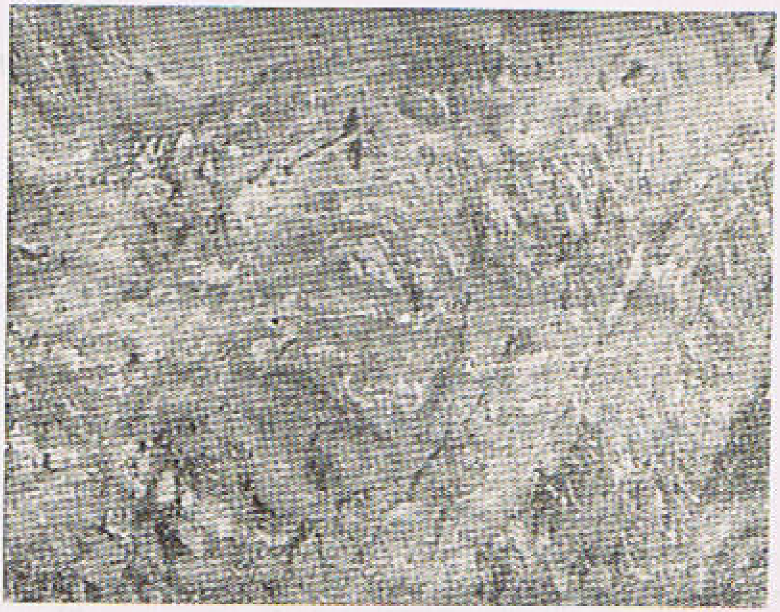


Fig. 1 Veinlets of Quartz in Metamorphics near Balakot.

Fig. 2 Sizeable (34 feet × 1 mile) Quartz Dyke near Chitta Batta.

The quartz-ilmenite veins occur as lensoid to tabular veins and lenses about 4 to 6 feet wide and about 6 to 50 feet in length.

Lensoid quartz-kyanite bodies 3 to 5 feet wide and 8 to 20 feet in length occur as discontinuous bodies.

DISTRIBUTION:

The quartz veins are very wide spread in the area. They occur as stringer like veins in tension gashes, in joints and along the foliation planes. One of the most important quartz vein occur near Chitta Batta. This vein is quite extensive as described above. Other smaller important quartz veins occur near Giddarpur, Arab Khan, Battal, Dadar, and Shaikhabad.

The ilmenite bearing quartz veins occur in the metamorphics near Giddarpur and Khabbol.

The qurartz-kyanite pegmatitic veins occur in the metamorphics. Generally along the foliation plane near Shahidpani, Tatar Bala, Battamori and Gajbori.

Quartz veins occur as mineralogically uniform bodies. The quartz-ilmenite veins are similar to quartz veins but have non-uniform distribution of ilmenite in the quartz bodies. In some of the quartz-kyanite veins there is partial development of the zones. In the outer zone there are quartz-kyanite-muscovite and chlorite minerals relatively more than the inner zone where quartz is much more abundant.

PETROGRAPHY

Those bodies which contain more than 90% quartz are termed as quartz veins. These bodies fall in two size ranges; One from 1″ to 8″ and the other from 3 to 40 feet wide. Those quartz bodies are considered here which are emplaced dominantly in granite as well as in metamorphics. In addition those quartz bodies are also discussed which contain ilmenite or kyanite etc. in addition to dominant quartz. These bodies are lensoid mostly and may branch out in some cases. They have sharp contact with the enclosing rocks. The mineral compositions of some typical quartz bodies are given below in Table 1.

TABLE 1

	A-78 Quartz Chitta Balta	A-21 Quartz ilmenite Giddarpur	A-35 Quartz kyanite Shahidpani
Quartz	98.88	95.10	65.90
Muscovite	0.62	0.75	4.20
Biotite	0.00	0.00	5.05
Chlorite	0.00	0.00	3.19
Apatite	0.00	0.00	0.90
Kyanite	0.00	0.00	20.12
Sphene	0.00	0.00	0.11
Magnetite	0.00	0.00	0.52
Ilmenite	0.00	3.40	0.01
Inclusions	0.50	0.75	0.00

The thin simple quartz veins occur in the Mansehra granite along the foliation and joint planes. The one quartz vein located near chitta Batta on Hazara Trunk Road consists of several en echelon veins ranging in thickness from 10 to 34 feet and cut both the Mansehra granite and the metamorphics. These quartz veins contain about 98 to 99% (Fig. 3) quartz with grains ranging from about 0.5 to 1 mm and sometimes upto 3 mm anhedral and quite welded together to give hard and compact rock. The impurities are of very fine muscovite and inclusions.

The ilmenite-quartz veins occur near Giddarpur and Khabbal. These veins are 3 to 10 feet thick

Fig. 3 Photomicrograph of Quartz Showing Quartz Grains in Different Orientation, (X. 27).

and 6 to 20 feet long. These are just like simple quartz veins but, in addition, there is ilmenite developed in them. The extensive development of ilmenite is usually very local within an area of 12 to 20 inches at its maximum. In thin section quartz occurs usually as 0.5 to 2 mm anhedral grains quite welded together, with minor muscovite and inclusions. The ilmenite occurs as scaly mass blue grey with metallic lustre in reflected light. The scales of ilmenite are from 1 to 3 cm in most cases.

Quartz-kyanite bodies are found near Shahid-pani as lenses in an area of about one square mile. More than 10 bodies have been recorded in the area. The size of lenses is 1.5 to 3 into 10 to 20 feet. The rock is generally coarse-grained as anhedral crystals of quartz are 4 to 8 mm and euhedral kyanite blades are 3 to 6 cm in size, but in some bodies about 15 cm long crystals of kyanite have also been observed. The quartz is transparent to translucent whereas kyanite is distinctly bluish in handspecimen. Muscovite is slightly brownish, transparent biotite is brown and, chlorite is greenish. In thin sections quartz grains are anhedral strained and have crenulated boundaries. The quartz sometimes encloses fine muscovite flakes. The kyanite is colourless and is in the form of tabular and bladed grains. Muscovite occurs as flakes needles and tabular grains about 0.2 to 3 mm in size. It replaces kyanite along cleavage plane and on boundaries. Biotite is light brown to brown pleochroic. Chlorite is closely associated with both muscovite and biotite as tabular and radiating grains ranging from 0.5 to 3 mm. It exsolves ore. Accessories include apatite and ore (fig. 4). In one rock section (Tatar Bala) the kyanite is pseudomorphed after andalusite where relict anda-

Fig. 4 Photomicrograph of Quartz-Kyanite Rock showing Kyanite, Chlorite (rediating), Muscorite and Quartz (finegrained material), (X. 27).

lusite is also present. The Battamori quartz-kyanite body show strongly mylonized texture where kyanite and andalusite are coarser than quartz grains (0.05 mm).

ORIGIN OF QUARTZ VEINS

Tolman (1931), Landes (1937) and Bowen (1933) think that quartz veins would be formed from the highly aqueous residum after the crystallization of pegmatites. The quratz veins present in the granitic rocks in the interior zone, in this case are not formed as suggested by Tolman, Landes and Bowen, rather they are the differentiation product of some other hydrothermal activities sufficiently later, may be after the release in vapour pressure in the granitic complex. Because the pegmatites occur in the marginal and exterior zones and obviously at quite a high structural levels where no quartz veins have been observed in the granites. Therefore the hydrothermal silica rich solutions cannot move down to form quartz veins, rather it is found that the hydrothermal solutions derived from pegmatites were meagre. It is therefore concluded that in the interior zone of the granitic complex the formation of quartz veins is from an indipendent source, i.e. silica rich phase not directly connected with the formation of pegmatites.

The occurnce of quartz veins in the pelitic schist is possibly a product of metamorphic differentiation as also advocated by Chapman (1950). According to Chapman the well known concretion principle of Eskola (1932) could have been operative during metamorphism of pelitic rocks thereby causing the more siliceous layers to become still richer in silica. Such a process would in general promote the formation of relatively thin but uniform quartz layers or veins. Moreover it is suggested that during folding which accompanied metamorphism fissures like openings developed parallel to bedding at the nose of the folds. Silica being most mobile flowed from the flanks of the folds to the noses i.e. from high pressure areas to the low pressure areas.

The quartz-ilmenite and quartz-kyanite muscovite etc. veins are present in the metamorphics and they have not been found in the granites. These rocks may have been originated either from hydrothermal solutions or by metamorphic differentiation. Heinrich (1949) has described quartz kyanite microcline muscovite apatite etc. bearing pegmatites of magmatic nature, while Read (1932) advanced a metamorphic origin, a process of endogenous secretion during the period of metamorphism, to the quartz-kyanite rocks. In the present case metamorphic origin is also possible for the quartz-ilmenite and quartz-kyanite veins. As during the secretion process along with quartz, ilmenite or kyanite may be derived and deposited in the cavities and in the weak zones. It is also possible that hydrothermal solution may have dissolved some of the ilmenite and kyanite from the metasediments while passing through them and deposited them along with quartz, an idea also postulated vaguely by Heinrich (1949). Due to the absence of felsic minerals in the present rocks, purely magmatic origin can be ruled out rather hydrothermal solutions rich in silica (as is found in case of pure quartz bodies in granite) may have assimilated with the metasediments to form quartz-ilmenite or quartz-kyanite veins. The kyanite after andalusite in the present case is thought to have been formed as a result of shearing stress (as was also postulated by Tilley, 1935 and Dike, 1951). This phenomna of shearing stress is wide spread in the area. As the shape of the pseudomorphs is that of andalusite and the minerology is dominantly muscovite and kyanite it is therefore thought that following reaction must have taken place.

$$3Al_2SiO_5 + 2H_2O + K_2O + 3SiO_2 \rightarrow 2KAl_3Si_3O_{10}(OH)_2$$ (after Rose, 1957).

but no corundum was found as mentioned by Rose (1957) because the enviroments were silica rich. The above reaction forms muscovite while kyanite was formed at higher values of $\Delta P/\Delta T$ under stress conditions.

ACKNOWLEDGEMENTS

The first author (Ashraf) in indebted to Dr. F.A. Faruqi, Head of Research Division for arranging the finances from the Director P.C.S.I.R. Laboratories Lahore to carry out the field work. Thanks also go to former Head and also present Chairman of the Department of Geology University of the Punjab Lahore for providing facilities to carry out this work in the Department.

REFERENCES

Bowen, N.L., 1933 The broader story of magmatic differentiation, briefly told, in ore deposits of the Western States. *Amer. Inst. Min.* and *Metall. Engg*. New York, 106.

Calkins, J.A., and Matin, A.S.A., 1968 The geology and mineral resources of the Garhi Habibullah quadrangle and the Kakul area Hazara District, West Pakistan, U.S.G.S., PK-38.

Chapman, C.A., 1950 Quartz veins formed by metamorphic differentiation of aluminous schists. *Amer. Mineral*., **35**, 693.

Dike, P.A., 1951 Kyanite pseudomorphs after andalusite from Delaware County, Pennsylvania. *Amer. Jour. Sci*., **249**, 457.

Eskola, P., 1932 On the principles of metamorphic differentiation. *Commgeol. Finlande, Bull*., **97**, 68.

Heinrich, E.W., 1949 Pegmatites of Montana. *Econ. Geol*., **44**, 307.

Landes, K.K., 1937 Pegmatite and hydrothermal veins. *Amer. Mineral*., **22**, 551.

Read, H.H., 1932 On quartz-kyanite rocks in Unst, Shetland Islands, and their bearing on metamorphic differentiation. *Min. Mag*., **23**, 317.

Rose, R.L., 1957 Andalusite and corundum—bearing Pegmatites in Yosemite National Park, California. *Amer. Mineral*., **42**, 635.

Shams, F.A., 1964 Kyanite psuedomorphing andalusite in hornfelsic pelitic schists of Amb State, West Pakistan. *Geol. Bull. Punjab Univ*., **4**, 23.

Shams, F.A., 1969 Geology of the Mansehra Amb State area Northern West Pakistan. *Geol Bull. Punjab Univ*., **8**, 1.

Tilley, C.E., 1935 The role of kyanite in the "hornfels zone" of the Carn Chuinneag granite (Ross Shire) *Min. Mag*., **24**, 92.

Tolman, C., 1931 Quartz dikes. *Amer. Mineral*., **16**, 278.

(Manuscript Received October, 1973)

GEOLOGY OF SAHIBABAD - BIBIOR AREA, DIR DISTRICT, N.W.F.P.

BY

M. NAWAZ CHAUDHRY,
AFTAB MAHMOOD
Department of Geology, University of the Punjab, Lahore
and
MOHAMMAD SHAFIQ
Geological Survey of Pakistan, Islamabad

Abstract : *Fifty square miles of Bibior—Sahibabad area, a part of Hindukush Range and situated ten miles south of the town of Dir, was mapped on 3"=1 miles scale. A map on the reduced scale is presented.*

The area is composed of igneous and metamorphic rocks. Igneous rocks include granodiorite and some minor granitic intrusions. The metamorphic sequence is represented by calcareous schists and amphibolites. Calcareous schists are the oldest rocks of the area. Study of fossils recovered from a marly band in them show Eocene age. Amphibolites are formed as a result of regional metamorphism of calcareous pelitic rocks.

Granodiorite is intrusive into amphibolite. It is a massive granitoid of igneous origin. A mixed zone ranging from 100 to 250 yards in width is formed due to interaction of the granitic magma and the amphibolite.

Seventy two thin sections of various units were studied. Sixteen modal analyses of leuco amphibolites, twenty three of the mela amphibolites, nine of the mixed zone, six of the granodiorite, four of the calcareous schists and two of the minor veins and bodies are presented.

INTRODUCTION

Location and Accessibility : The Sahib-abad Bibior area of Dir District is located to the north of Peshawar in North Western Frontier Province of West Pakistan. The main access to the area is by Dergai-Mingora road, from which at Chakdarra the road leading to the area branches towards west over the Swat river bridge. The only road in the area studied is the main Dir road, which is unmetalled and passes through the area.

Physiography: The area has high relief, the highest peak is 10685 feet. The lowest height is 3508 feet. The total relief of the area is 7177 feet.

Main stream in the area is Panjkora river and tertiary streams are joining with the Panjkora river in a dendritic pattern.

Previous Work : H. H. Hayden (1914) was the first geologist to carry out a reconnaissance survey of Dir. His main aim was to determine a relationship between stratigraphic provinces of Chitral and Pamirs. For this reason he confined his studies to the rock types exposed along the now main Dir road. He named the Bibior granodiorite as granite and called the mixed zone as hornfelses.

Davies (1965) considered the rocks of the area similar to diorites of Khawazkhela and Kalam, as the trend of the latter suite is towards Dir.

GENERAL GEOLOGY

The area has been divided into the following rock units.

1. Calcareous Schists
2. Leuco Amphibolite
3. Mela Amphibolite
4. Granodiorite
5. Mixed Zone
6. Garnet Bearing Quartz-o-Feldspathic Rock
7. Hornblendites
8. Pegmatites

1. *Calcareous Schists :* Calcareous schists cover about 10% of the investigated area. These rocks occur in the extreme northwest of the area mapped. The strike of these rocks is northeast southwest and dip towards south-east. Calcite, quartz and muscovite can be easily recognized in hand specimen. These are grey coloured rocks which on weathering give reddish brown colour. The calcareous schists are poorly foliated. These are profusely cut by calcite and quartz veins. A fossiliferous marly bed containing Nummulities and Assilina is found in these rocks, proving an Eocene age.

2. *Leuco Amphibolite :* These rocks cover about 35% of the mapped area. These rocks occur in the northern part of the area mapped. The strike of these rocks is towards northeast-southwest and dip towards southeast. Hornblende, epidote, quartz, feldspar and muscovite can be easily recognised in hand specimen. These are greenish grey coloured rocks which on weathering give brown to reddish brown colour. Generally these rocks are massive but at some places give a banded appearance. These rocks are micaceous and foliated near the contact with calcareous schists. Veins of epidote, quartz, granite and pegmatite are present at some places.

3. *Mela Amphibolites :* These rocks cover about 40% of the mapped area. They occur towards the southern side of the area mapped. The dip of these rocks is south and southeast, while the strike is towards northeast. Hornblende, epidote, quartz and feldspar can be easily recognized in hand specimen. The mela amphibolites are green to greenish black in colour. The weathering colour of these rocks is brown to reddish brown. These rocks are banded (Fig. 1) but at some places, these rocks give a massive appearance. Bands of epidote and hornblende are present. Veins of granite, epidote, quartz-o-feldspar and pegmatites are also present. At some places coarse quartz veins occur. Boudinage structure is well developed in these rocks. Most of the boudins are of epidote. Intrusion of granite in mela amphibolite is shown in Fig. 2 Foliation in mela amphibolite is shown in Fig. 3.

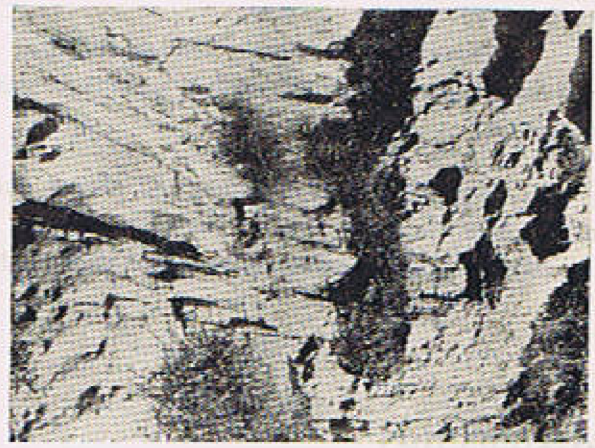
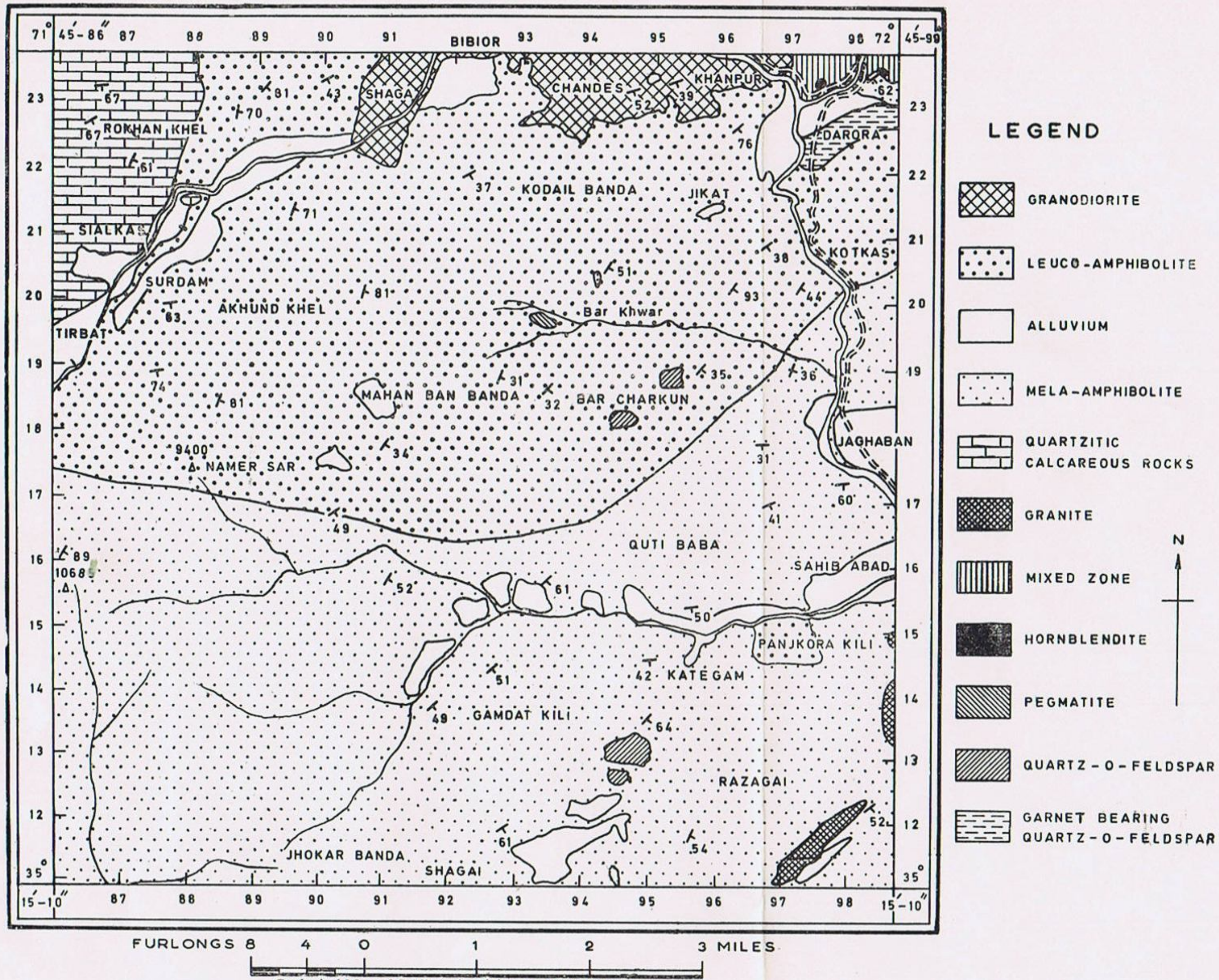


Fig. 1 Banding in mela Amphibolite.

4. *Granodiorite* : These rocks cover about 10% of the mapped area. These occur towards the northern side of the map. The dip of these rocks is towards south and south east, while the strike is towards north-east south-west. Quartz, feldspar, muscovite and biotite can be easily recognised in hand specimen. These rocks are of white colour with dark brown biotite flakes in them. The

74175



Geological Map of Sahibabad - Bibior area (Dir District).

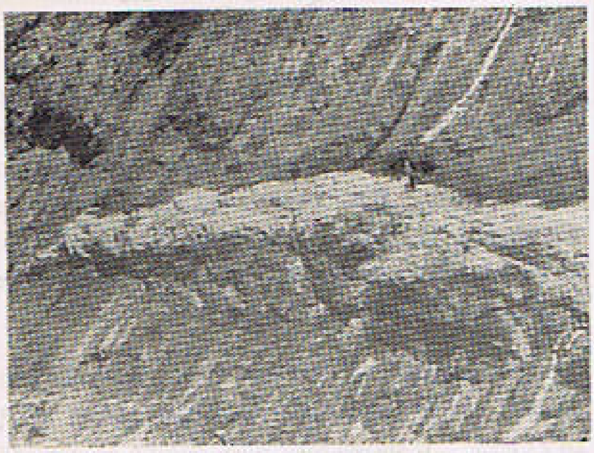


Fig. 2 Granite Intrusion in mela Amphibolite.

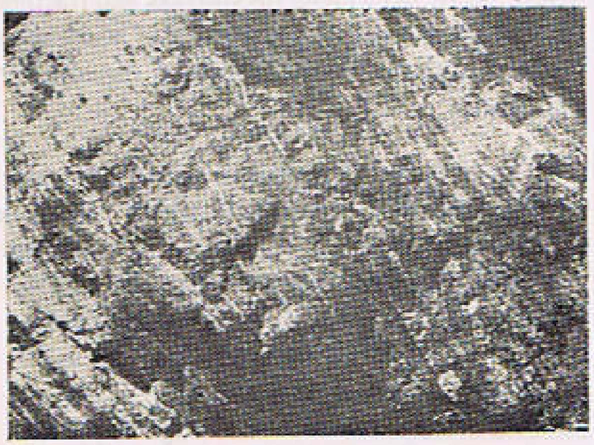


Fig. 3 Foliation in mela Amphibolite

Fig. 4 Spheroidal Weathering in Granodiorite.

weathering colour of these rocks is grey and brownish grey. These are massive rocks. Veins of epidote and quartz-o-feldspar are present. Spheroidal Weathering is common in these rocks (Fig. 4).

5. *Mixed Zone* : These rocks cover about 5% of the mapped area. They occur towards the north eastern corner of the map. The strike of these rocks is towards NE-SW while the dip is towards south east. Hornblende, epidote, quartz, feldspar and muscovite can be easily recognised in hand specimen. The colour of these rocks is greenish black while the weathering colour is brown and grey. These are massive rocks. Veins of epidote, granite and quartz-o-feldspar are present.

6. *Garnet Bearing Quartz-o-Feldspathic Rocks* : These rocks cover about 2% of the mapped area. These rocks occur towards the north eastern side of the map. The strike of these rocks is towards northeast-southwest, while the dip is towards southeast. Garnet, quartz and feldspar can be easily recognised in hand specimen. These rocks are of white colour with highly weathered brown garnet in it. The weathering colour of these rocks is grey. Minor intrusions of granite are present in them.

7. *Hornblendites*: These occur as a few patches in mixed zone. These are black coloured rocks. The weathering colour of these rocks is brownish grey. Hornblende and epidote can be easily recognised in hand specimen. Veins of epidote and quartz-o-feldspar are present. Boudinage structure is well developed. Boudins of epidote are present.

Amphibolites are divided into two types here, those having high colour index are named here as mela amphibolites. Those having lower colour index are named here as leuco amphibolites.

PETROGRAPHY

Mela Amphibolites

The mela amphibolites can be divided in field on the basis of internal structure into two types.

1. Layered
2. Non-layered

Non layered mela amphibolites can be further divided into three types.

1. Highly Foliated
2. Poorly Foliated
3. Massive

The Mutual Relationship of the Various Types and Their Distribution :

In the layered mela amphibolites two types of layers are present. Dark coloured and light coloured layers. Dark layers are more prominent than the white layers. Thickness of individual layers varies from 5 m.m. to 15 m.m. The dark layers are rich in hornblende while the light layers are rich in quartz, feldspar and epidote. The layers are mostly parallel to each other.

10

In non layered mela amphibolites, the highly foliated types are present as conformable bodies in strike and dip with layered amphibolites. In poorly foliated, foliation planes are not well developed and in massive amphibolites, the foliation planes are not developed. All these types are so intermingled with one another that they cannot be mapped separately.

These are medium to coarse grained rocks. Myrmekite like texture in epidote is common. Xenoblastic texture is also common because all grains are anhedral to subhedral. The modal analyses of the mela amphibolites are presented in Table 1.

Hornblende and epidote are the main constituents, while chlorite, sphene, quartz, plagioclase and iron ore are accessories.

The amount of hornblende varies from 40.00 to 60.03% in dark bands and in light bands from 1.96 to 12.09%. It is yellowish green to bluish green in pleochroism. Interference colours are of lower 2nd order. Quartz grains are embedded in it. It is mostly altering to chlorite.

The amount of epidote varies from 6.77 to 11.12 % in dark bands while in light bands from 24.66 to 50.31%. It shows varigated colours in crossed nicols. Both zoisite and clinozoisite were recognized. Zoisite shows anamolous colours. The grains are euhedral to sub-hedral. Magnetite and haematite inclusions are present.

The amount of chlorite varies from 3.52 to 32.22% in light bands and in dark bands from 11.41 to 23.63%. It shows inky blue colour in crossed nicols. It shows grey interference colours of lower order. It develops along the cleavage and fracture planes and around the boundries of hornblende crystals. Chlorite is an alteration product of hornblende.

Out of twenty three modal analyses of mela amphibolites, four do not contain sphene and six contains less than 1% sphene. A few samples containing abnormal amount of sphene are adjacant to the granite intrusions. The amount of sphene in dark bands varies from 1.09 to 6.77% and in light bands varies from 0.00 to 11.64%. It is earthy coloured in crossed nicols. It is wedge shaped with well developed rhombic cleavage. The grains are euhedral to subhedral.

The amount of quartz varies from 5.60 to 20.93% in dark bands and in light bands it varies from 2.51 to 19.92%. It shows greyish white interference colours. The grains are subhedral to anhedral and rounded in outline. Inclusions of epidote are seen in quartz.

The amount of plagioclase varies from 2.89 to 3.01% in dark bands and from 4.82 to 24.89% in light bands. It is prismatic, columnar and lath shaped. Mostly it is altering to Kaolin. Inclusions of quartz are present in these grains. Big grains of quartz and plagioclase are in light bands of mela amphibolite.

TABLE 1

Banded Mela Amphibolites

Minerals	15252	15299	15282	15257	15250	15318
Hornblende ..	58.76	54.30	57.57	37.50	34.59	61.06
Quartz ..	0.00	10.06	6.73	3.97	9.11	25.81
Epidote ..	16.69	17.24	13.04	19.76	26.59	3.80
Plagioclase ..	2.95	0.00	0.00	0.00	3.35	0.91
Sphene ..	2.25	0.00	8.89	4.62	5.65	2.13
Chlorite ..	17.75	9.79	12.38	16.60	0.96	0.00
Magnetite ..	1.60	0.00	0.00	0.00	0.00	0.00
Kaolin ..	0.00	8.61	1.19	17.54	19.75	6.27
Muscovite ..	0.00	0.00	0.00	0.00	0.00	0.00
Haematite ..	0.00	0.00	0.20	0.00	0.00	0.00

Veins in Mela Amphibolite

Minerals	From Leuco amphibolite Patch 15279 (Massive)	Hornblende bearing Qtz-0 feldspar vein 15276	15288	15273
Hornblende ..	20.45	12.97	30.23	3.68
Quartz ..	42.89	9.38	57.35	56.39
Epidote ..	5.59	8.88	0.00	2.64
Sphene ..	0.61	1.94	0.00	0.15
Plagioclase ..	2.56	21.23	3.13	23.18
Chlorite ..	7.76	5.34	0.00	0.90
Muscovite ..	14.16	8.09	0.00	0.00
Kaolin ..	4.79	16.35	2.94	1.57
Magnetite ..	0.00	4.46	0.00	0.00
Haematite ..	1.19	0.00	0.99	0.00
Orthoclase ..	0.00	10.36	6.34	11.49

Table 1 (Cont.)

	Dark	Light	Dark	Light	Dark	Light	Dark	Light
Minerals	15299	15299	15250	15250	15257	15257	15282	15282
Hornblende ..	60.03	12.09	46.51	11.17	49.27	1.96	40.00	5.00
Quartz ..	5.60	19.56	20.93	19.92	10.62	2.51	16.37	8.13
Epidote ..	6.77	24.66	11.12	40.74	2.09	50.31	6.96	41.12
Plagioclase ..	3.01	24.89	2.89	4.82	0.00	0.00	0.00	0.00
Sphene ..	6.77	0.00	4.02	0.91	1.09	11.64	5.45	5.05
Chlorite ..	17.04	18.80	11.41	9.37	21.24	3.52	23.63	32.22
Magnetite ..	0.78	0.00	3.12	2.75	0.00	0.00	0.00	0.00
Kaolin ..	0.00	0.00	0.00	10.32	15.69	30.09	7.57	8.50

Non-Layered

Mela Amphibolites LEUCO PATCHES

Minerals	15300	15293	15290	15308	15253
Hornblende ..	59.56	71.62	55.81	29.10	17.65
Quartz ..	9.81	18.85	20.57	33.07	7.46
Epidote ..	2.54	3.45	3.10	8.97	17.24
Plagioclase ..	3.20	5..23	1.38	8.18	33.33
Sphene ..	1.09	0.20	0.42	0.00	0.44
Chlorite ..	23.80	0.00	12.76	20.67	5.73
Magnetite ..	0.00	0.65	0.00	0.00	6.07
Kaolin ..	0.00	0.00	0.00	0.00	12.03
Muscovite ..	0.00	0.00	5.96	0.00	0.00

Magnetite, haematite and limonite are frequently scattered throughout the rock, Magnetite gives steel grey, limonite gives yellowish brown colour in reflected light. Amount of it varies from 0.78 to 3.12% in dark bands and from 0.00 to 2.75% in light bands.

In massive mela amphibolites the amount of hornblende varies from 55.81 to 71.62%, while in the banded types it varies from 34.59 to 61-06%.

The amount of quartz varies from 9.81 to 20.57% in the massive types while it is from 0.00 to 25-81 % in the banded types.

The amount of epidote varies from 2.54 to 3. % in the massive types and 13.04 to 26.59% in the banded types. The amount of plagioclase varies from 1.38 to 5.23% in the massive types and from 0.00 to 3.35% in the banded types.

The amount of sphene varies from 0.20 to 1.09% in massive types and from 0.00 to 8-89% in banded types. Only one sample of the banded amphibolites contains sphene. The amount of chlorite varies from 0.00 to 23.80% in the massive types and from 0.96 to 17.75% in the banded. The amount of muscovite varies from 0.00 to 5.96% in massive types The amount of iron ore varies from 0.00 to 1.60% in banded types. Fine grained mela amphibolite is shown in (Fig. 5), Medium grained mela amphibolite is shown in Fig. 6. Coarse grained mela amphibolite is shown in Fig. 7. Porphyroblasti in mela amphibolite is shown in Fig. 8.

Leuco Amphibolite

Those amphibolites having low colour index are named here as leuco amphibolites. These rocks have medium to coarse grained xenoblastic and porphyroblastic texture. Sixteen modal analyses of this unit are presented in Table 2.

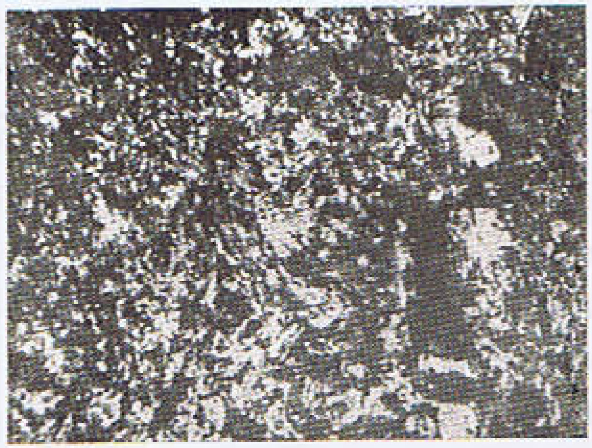


Fig. 5 Fine-Grained mela Amphibolite.

Fig. 6 Medium-Grained mela Amphibolite.

Fig. 7 Coarse-Grained mela Amphibolite.

TABLE 2

Banded

Leuco Amphibolite

Minerals	15798	15861	15863	15865	15868	15848	15271	Bands of Leuco amphibolite *Dark band*	*Light band*
Hornblende ..	23.74	40.36	27.91	21.98	21.39	26.94	21.60	48.67	11.05
Quartz ..	50.44	23.15	28.13	56.70	32.40	19.25	20.60	42.30	55.91
Epidote ..	4.62	0.00	14.26	0.20	18.55	1.13	0.80	6.15	28.76
Chlorite ..	2.60	30.43	3.38	0.00	0.48	23.05	1.81	1.87	1.59
Kaolin ..	14.30	3.83	21.82	4.33	23.89	28.00	29.49	0.00	0.00
Plagioclase ..	1.55	0.49	0.65	14.62	0.48	0.00	3.23	0.00	0.00
Muscovite ..	1.16	0.00	0.96	0.00	0.00	0.50	0.00	0.00	0.00
Garnet ..	1.60	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
Sphene ..	0.00	1.12	0.39	0.97	0.48	0.50	2.73	0.71	0.00
Magnetite ..	0.00	0.64	2.23	0.81	0.35	0.62	19.73	0.30	1.73
Orthoclase ..	0.00	0.00	0.35	0.00	1.98	0.00	0.00	0.00	0.93
Sericite ..	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.03

Massive

Leuco Amphibolite

Mineral	15269	15847	15854	15846	15852	15867	15839
Hornblende	23.21	38.52	38.49	33.35	28.08	21.24	26.35
Quartz	22.73	32.03	30.34	21.31	26.27	27.00	32.06
Epidote	3.14	22.34	0.00	0.00	0.00	0.30	3.24
Chlorite	15.93	0.00	9.22	23.13	18.05	0.38	3.90
Kaolin	0.00	0.00	0.00	0.00	27.60	33.77	27.43
Plagioclase	0.00	0.00	13.11	5.29	0.00	0.00	0.00
Muscovite	16.09	0.00	7.10	4.20	0.00	12.88	5.96
Garnet	0.00	4.84	0.00	0.00	0.00	0.00	0.00
Sphene	3.98	0.00	0.49	1.83	0.00	0.00	0.15
Magnetite	1.57	0.00	0.00	0.00	0.00	2.95	0.00
Orthoclase	0.00	2.27	1.25	2.94	0.00	1.48	0.66
Sericite	0.00	0.00	0.00	8.04	0.00	0.00	0.00
Calcite	13.34	0.00	0.00	0.00	0.10	0.00	0.25

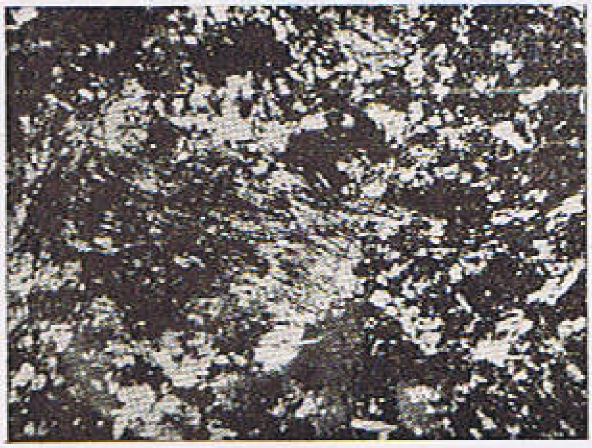


Fig. 8 Porphyroblasts in mela Amphibolite.

Hornblende, quartz and plagioclase are the main constituents while chlorite, garnet, epidote muscovite, orthoclase, sphene, calcite and iron ore are the accessories.

The amount of hornblende varies from 21.04 to 40.36 %. It is light green in colour and pleochroic from green to bluish green. Quartz grains are embedded in it. Iron ore inclusions are present in hornblende. It commonly alters to chlorite.

The amount of quartz varies from 20.60 to 56.70%. The grains are euhedral to subhedral and rounded in outline. Inclusions of epidote are present in it.

The amount of plagioclase varies from 0.00 to. 14.62%. It is prismatic, columnar and lath shaped. Composition of plagioclase is from oligoclase to andesine. Mostly it is altering to Kaoline. In some sections it is altering to epidote Quartz, epidote and orthoclase inclusions are common.

The amount of chlorite varies from 0.00 to 30.43%. It is light green in plane polarized light and gives inky blue colour in crossed nicols. The grains are subhedral to anhedral. It develops along the cleavage and boundries of hornblende. It is an alteration product of hornblende.

The amount of epidote varies from 0.00 to 22.34%. It shows varigated colours in crossed nicols. The grains are euhedral to subhedral. Both zoisite and clinozoisite were found, clinozoisite shows normal second order interference colours whereas zoisite shows anomalous colours. Inclusions of quartz are common in epidote.

The amount of garnet varies from 0.00 to 4.84%. Garnet occurs in six sided idiomorphic crystals. Quartz and epidote inclusions are common in it.

The amount of muscovite varies from 0.00 to 16.09%. It fills fractures of quartz in some sections. It is the alteration product of feldspar. But also occurs as primary crystals.

The amount of orthoclase varies from 0.00 to 2.94%. It gives cloudy appearance due to incipient alteration in contrast with quartz. Some inclusions of orthoclase are observed in hornblende.

Out of sixteen modal analysis of this unit, five do not contain sphene and seven have less than 1% sphene. The amount of sphene varies from 0.60 to 3.98%. It is earthy coloured in crossed nicols. It is wedge shaped with well developed rhombic cleavage. The grains are eudhral to subhedral.

The amount of calcite varies from 0.00 to 13.34%. It shows well developed rhombic cleavage. The grains of calcite are embedded in quartz.

The amount of iron ore varies from 0.00 to 19.73%. Magnetite, haematite and limonite are frequently scattered throughout the rock.

Mixed Zone

The term mixed zone is applied to that zone in which mixing of two rocks (granodiorite and amphibolite) takes place. These rock types are intermingled with each other but they can be recognized in the field, because of their structure and composition. However they cannot be mapped as seperate units, since they are intimately associated and intermixed on a very small scale. Five modal analysis of the mixed unit are presented in Table 3.

These rocks have medium to coarse grained granular texture.

Hornblende, quartz, plagioclase and orthoclase are the main constituents while sphene, chlorite, biotite, epidote, muscovite and iron ore are the accessories.

The amount of quartz varies from 8.48 to 16·67 % in amphibolite layer while in granitic layer 20·24 to 41.99%. Inclusions of sericite are present in it.

The amount of hornblende varies from 12.15 to 19.34% in granitic layer and 34.10 to 55.68% in amphibolite layer. Quartz and iron ore inclusions are present. It commonly alters to chlorite.

The amount of plagioclase varies from 31·75 to 34.29% in granitic layer and 1.91 to 14·50% in amphibolite layer. The composition of plagioclase is andesine. Quartz inclusions are common.

The amount of orthoclase varies from 5·80 to 7.15% in granitic layer and 4.58 to 6.92% in amphibolite layer. Inclusions of sericite are present in it. The amount of sphene varies from 1·30 to 3.73% in amphibolite layer

It gives earthy colour in crossed nicols.

The amount of chlorite varies from 2·87 to 14·73 % in amphibolite layer

It is alteration product of hornblende. It develops along cleavage and fracture planes of hornblende.

TABLE 3

Mixed Zone

Minerals	Hornblendite 15804	15805	15806	15266	15284	15286
Hornblende ..	75.42	55.68	34.10	12.15	44.78	19.34
Quartz ..	13.32	14.39	16.67	41.99	8.48	20.24
Chlorite ..	3.98	3.88	14.73	0.00	2.87	0.00
Epidote ..	0.00	11.06	1.79	0.00	6.61	0.00
Sphene ..	1.91	1.30	1.78	1.08	3.73	0.00
Kaolin ..	0.00	3.84	7.39	2.69	21.22	15.34
Plagioclase ..	2.99	2.23	14.50	34.29	1.91	31.75
Orthoclase ..	0.69	6.92	6.18	7.15	4.58	5.80
Muscovite ..	0.00	0.00	2.81	0.22	2.28	4.29
Magnetite ..	1.38	0.67	0.00	0.00	3.53	3.22
Biotite ..	0.00	0.00	0.00	0.42	0.00	0.00

The amount of biotite varies from 0.00 to 0.42% in granitic layer. The grains are euhedral to subhedral. It develops along the boundries of muscovite.

The amount of epidote varies from to 1.79% to 11.06% in amphibolite layer. Epidote inclusions are present in hornblende.

The amount of muscovite varies from 0.00 to 25.81% in amphibolite layer and 0.22 to 4.29% in granitic layer. It fills fractures of quartz. It alters to biotite on its boundries.

The amount of iron ore (magnetite) varies from 0.67 to 3.53% in amphibolite layer and 0.00 to 3.22% in granitic layer. Iron ore inclusions are present in quartz.

Hornbendites

The hornblendites occur as a few scattered patches in the mixed zone. Their contact with the surrounding rocks is not sharp. They have medium to coarse grained idioblastic texture. One modal analysis of this unit is presented in Table 3.

Hornblende is the major constituent while chlorite, orthoclase, sphene, quartz, plagioclase and iron ore are the accessories.

The amount of hornblende is 75.42%. It is light green to dark green in colour. The grains are mostly subhedral. They range from 1/2 cm to 5 cm. in length. The amount of chlorite is 3.98%. It shows inky blue colour in crossed nicols. It is an alteration product of hornblende. The amount of sphene is 1.91%. It is earthy coloured in crossed nicols.

The amount of quartz is 13.32%. The grains are subhedral to anhedral. It occurs either as inclusions or as an intersticial grains. The amount of plagioclase is 2.99%. It is prismatic and lath shaped.

The amount of orthoclase is 0.69%. It shows alteration to kaolin. The amount of iron ore (magnetite) is 1.38%. The magnetite grains occur as inclusions with hornblende.

Granodiorite

It is a typical granitoid having a hypoidiomorphic granular texture. Six modal analyses of granodiorite are presented in Table 4.

Plagioclase, orthoclase, quartz and biotite are the main constituents while muscovite, chlorite, sphene and iron ore (magnetite) are the accessories.

The amount of plagioclase varies from 11.41 to 56.87%. The composition of plagioclase is andezine. The grains are prismatic, columnar and lath shaped. It is colourless in thin section. The grains are euhedral to anhedral. Inclusions of quartz are common. It is mostly altering to Kaolin.

The amount of orthoclase varies from 14.38 to 34.48%. It gives cloudy appearance due to incipient alteration to clay. The grains are subhedral to anhedral.

The amount of quartz varies from 8.73 to 39.90%. The grains are anhedral.

The amount of biotite varies from 4.80 to 11.38%. It forms platy pseudohexagonal crystals. The grains are brown to reddish brown in colour and euhedral to subhedral.

The amount of muscovite varies from 0.44 to 3.96%. These are platy pseudohexagonal crystals. In some sections it fills fractures of quartz. It is altering to biotite.

The amount of chlorite varies from 0.00 to 6.22%. The grains are light green in plane polarized light and inky blue in crossed nicols. The grains are subhedral to anhedral. It is the alteration product of hornblende.

TABLE 4

Granodiorite

Minerals		15809	15810	15826	15928	15829	15815
Quartz	..	34.70	30.00	19.32	8.73	33.42	39.90
Plagioclase	..	16.20	11.21	56.87	49.59	33.07	23.84
Orthoclase	..	34.40	18.04	14.38	19.67	22.75	21.93
Biotite	..	4.80	11.12	4.48	8.89	5.46	11.38
Muscovite	..	3.20	3.45	0.44	1.22	3.96	1.82
Magnetite	..	6.70	0.00	0.73	1.10	0.20	0.23
Ch'orite	..	0.00	6.22	0.00	0.00	0.00	0.00
Kaolin	..	0.00	18.72	3.58	10.82	1.14	0.87
Sphene	..	0.00	1.22	0.20	0.00	0.10	0.00

The amount of sphene varies from 0.00 to 1.22%. The grains are euhedral to subhedral. The grains are wedge shaped with well developed rhombic cleavage. These are earthy coloured in crossed nicols.

The amount of magnetite varies from 0.00 to 6.70%. The grains are euhedral to subhedral. It gives steel grey colour in reflected light.

Contact between granodiorite and leuco amphibolite is shown in (Fig. 9).

Calcareous Schists

These rocks have granular to myrmekite like texture. Four modal analysis of this unit are presented in Table 5.

Quartz and calcite are the main constituents while sphene, chlorite, hornblende, muscovite, biotite and iron ore are the accessories. The amount of quartz varies from 15.13 to 41.33%. The grains are subhedral to anhedral and rounded in outline. Calcite inclusions are present in it.

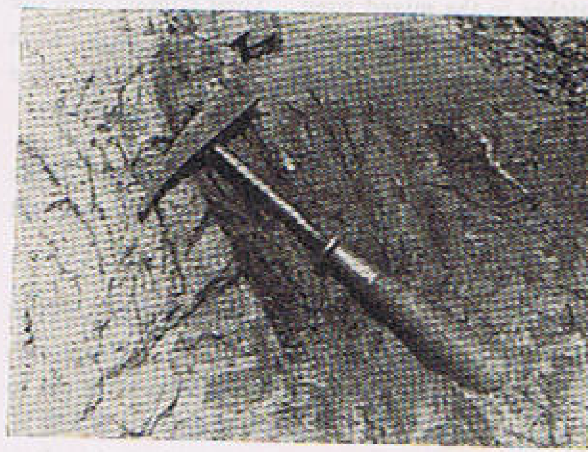


Fig. 9 Contact between Granodiorite and Leuco Amphibolite.

The amount of calcite varies from 14.83 to 21.63%. The grains are subhedral to anhedral. Very fine grained calcite is also present. Inclusions of calcite are present in quartz.

The amount of sphene varies from 0.00 to 2.06%. It gives earthy colour in crossed nicols.

TABLE 5

Calcareous Schists

Minerals	15816	15820	15822	15823
Hornblende	29.95	40.26	0.00	7.24
Quartz	26.37	15.13	41.33	40.21
Muscovite	3.58	6.96	25.72	6.58
Calcite	17.60	18.89	14.50	21.63
Haematite and limonite	0.00	2.81	0.68	0.00
Kaolin	0.00	8.08	0.00	0.00
Chlorite	9.51	7.81	0.00	14.65
Biotite	12.90	0.00	17.88	0.00
Sphene	0.08	0.00	0.00	2.06
Magnetite	0.00	0.08	0.00	7.63

TABLE 6

Garnet Bearing Quartz-o-Feldspar vein

Minerals	15869	15870
Quartz	37.18	20.60
Orthoclase	27.28	13.11
Muscovite	4.67	6.60
Biotite	2.28	7.13
Magnetite	0.71	10.16
Plagioclase	18.93	33.75
Garnet	8.94	8.65

The grains are euhedral to sub-hedral. Inclusions of sphene are present in quartz.

The amount of hornblende varies from 0.00 to 60.26%. Hornblende is present near the contact of these rocks with leuco amphibolites. It is light green to dark green in colour. The grains are euhedral to sub-hedral. Inclusions of calcite and quartz are present in it.

The amount of chlorite varies from 0.00 to 14.65%. It is light green in plane polarized light and gives inky blue colour in crossed nicols. Inclusions of calcite and quartz are present. It is the alteration product of hornblende.

The amount of biotite varies from 0.00 to 17.88%. The grains are euhedral to subhedral. The amount of muscovite varies from 3.58 to 25.72%. The grains are subhedral to anhedral.

The amount of iron ore varies from 0.00 to 7.63%. Magnetite gives steel grey colour in reflected light. The grains are euhedral.

Garnet Bearing Quartz-o-Fledspathic Rocks

These rocks have medium to coarse grained granular and myrmakite like texture. Two modal analys s of this unit are presented in Table 6.

Quartz, orthoclase and plagioclase are the main constituents while muscovite, biotite, garnet and iron ore are the accessories.

The amount of quartz varies from 20.60 to 37.18%. The grains are euhedral to subhedral.

The amount of orthoclase varies from 13.11 to 27.28%. It gives cloudy appearance. The grains are subhedral to anhedral. Inclusions of sphene are present.

The amount of plagioclase varies from 18.93 to 33.75%. The grains are prismatic, columnar and lath shaped. The composition is oligoclase to andesine. It alters to Kaolin.

The amount of muscovite varies from 4.67 to 6.60%. The grains are colourless to pale green in colour.

The amount of biotite varies from 2.28 to 7.13%. The grains are euhedral to subhedral.

The amount of garnet varies from 8.65 to 8.94%. The grains are colourless in plane polarized light and dark brown in crossed nicols. The crystals are six sided.

The amount of iron ore (magnetite) varies from 0.71 to 10.16%. The grains are euhedral to subhedral. It gives steel grey colour in reflected light.

PETROGENESIS

Amphibolites

Amphibolites can form by the metamorphism of both intermediate and basic igneous rocks as well as pelitic calcareous sediments. The distinction between the amphibolites formed from the metmorphism of igneous rocks i.e. orthoamphibolites and the amphibolites formed from the sedimentary rocks i.e. para amphibolites is a difficult one. Various field, textural, structural and chemical criteria have been proposed by various authors to distinguish between the two types. Banded nature of amphibolites has been suggested as an evidence of meta sedimentary origin. Wilcox and Poldervaart (1958) and Walker et al. (1960) have laid great emphasis on the banded nature of amphibolites as an evidence of meta-sedimentary origin. Other authors have laid emphasis on the association of amphibolite with marble in the field as a proof of meta-sedimentary origin. For example Heier (1962) has placed great emphasis on this criterion. But others think that neither evidence is conclusive of a meta-sedimentary origin. Evans and Leake (1960) and Leake (1964) regard such evidence as inconclusive. These authors place great emphasis on the chemical differences between the two types. Leake (1964) thinks that chemical distinctions are possible between the two types He suggests that higher contents of Ni, Cr and Ti are fairly distinctive of ortho amphibolites. He however thinks that of much more value is the distinction between igneous and sedimentary trends of variation for the distinction between the two types. According to Leake (1964) much of the previous chemical work has been aimed at discovering differences in the abundance levels of certain elements between the two groups of amphibolites. According to him it was soon apparent that all the major elements would be similar in concentration, whether the rocks have formed by the metamorphism of basic igneous rock or by metamorphism of a dolomitic or calcareous clay.

Attention has also been focused on the trace elements by Angel and Angel (1951) and by Walker et al. (1960).

In the foregoing a brief review has been presented of the various criteria proposed by various authors to distinguish between Ortho and para amphibolites. It is considered that no single criterion is conclusive. Field, structural, textural, mineralogical and chemical (all criteria must be used to decide the origin of a given amphibolite. Field and mineralogical evidences should not be under rated. In the case of the amphibolites of Bibior area the field, mineralogical, textural and structural criteria will be considered to decide the origin of these rocks.

Field Evidence : In field there is considerable evidence to suggest that amphibolites have formed as a result of progessive regional metamorphism of the calcareous rocks. There is no clear cut and sharp contact between the calcareous rocks and the amphibolites. In the transitional zone there is admixture of the minerals of the calcareous rocks and the amphibolites. In this zone patches, lenses bands and stringers of amphibolite cut the calcareous rocks. But here the calcareous rock itself contains some amphibole epidote, coarse mica and some plagioclase. Calcite veins are abundently present in this zone.

Textural and Structural Evidence : There is considerable variation in both structure and texture of amphibolites. The grain size is variable. Banding and layering is fairly common. All these characteristics, though not conclusive, suggest, when looked at with field evidence a metasedimentary origin for these rocks. Whereas in the case of orthoamphibolites, the texture and structure is generally uniform and banding is less common.

Mineralogical Evidence : The Bibior amphibolites are composed mainly of amphibole and quartz with lesser amount of epidote, chlorite and mica. Plagioclase is only a minor constituent of these rocks. Titaniferous magnetite and sphene are rare. When sphene occurs in notable amounts, it is due to granitic intrusion. Potash bearing minerals like mica, clay and orthoclase are more common than plagioclase. Cummingtonite is absent suggesting a sedimentary origin. All these factors strongly suggest that these amphibolites have not formed from gabbros, norites or diorites. For in that case there should have been ubiquitous sphene or titaniferous ore, considerable plagioclase or its equivalents and much less quartz. The quantitative mineralogical evidence clearly suggests that these rocks have not formed by the metamorphism of igneous rocks.

Comparison With Other Amphibolites : These amphibolites are very different from the amphibolites occuring in the Southern Dir. They have been studied by the authors. They are rich in plagioclase or its equivalents. They contain ubiquitous sphene and also contain cummingtonite. They are further more poor in quartz and micas. These amphibolites are considered to be of igneous origin. These differences further suggest a meta sedimentary origin for these rocks.

Mixed Zone

The mixed zone has formed as a result of the action of the granitic magma on the pre-existing amphibolites. Small dykes, apophysis, veins and stringers of granite intrude at the contact. As a result sphene, plagioclase, orthoclase, quartz and micas have been introduced in this zone. Due to the heat, stresses and volatiles at the contact, mineral seggregation took place. Amphibole of the amphibolites was segregated in patches giving hornblendites within the mixed zone. As a result of these processes some quartz-o-feldspathic patches were also formed. In the mixed zone banding was oblitrated and the amphibolite was deformed. It became hardened and boudinaged. Deformation, folding and wraping of the bands also took place. The granodiorite intrusions within this zone became rich in amphibole and poor in quartz.

Hornblendites

The hornblendites have formed as a result of metamorphic differentiation in the aureole of the Bibior granodiorite. The aureole has been called here as a mixed zone. It was originally an amphibolite, which has undergone reconstitution due to the influx of heat, volatiles and stresses. Due to this reason the hornblende of the amphibolites was concentrated and segregated at places in the form of small patches forming hornblendites, leaving hornblende poor aureoles at places.

Granodiorite

It is a typically granitoid rock. Foliation is poor, the rock is fairly uniform. It has discordant contact with the country rock and shows chilling at places at the contact. Dykes and apophysis of granodiorite are found extending into the country rocks. Although at the contact within the amphibolites a mixed zone has developed but the mixing is megascopic and often lit-par-lit. All these factors suggest a magmatic origin for the granitoid granodiorite.

Calcareous Schists

The calcareous schists have formed as a result of low grade metamorphism in the green schist facies of the arenaceous calcareous sediments. In terms of grade they are from chlorite to biotite grade. Sericite has recrystallized to muscovite, clay minerals have also recrystallized to form mica minerals. Chlorite and muscovite have reacted to form biotite. With the increase in the grade of metamorphism these rocks grade into amphibolite.

AGE OF THE COMPLEX

Wadia (1932) included the Sulkhala series occuring in the north of Nanga Parbat in the precambrian age. He further suggested that the volcanics overlying this series are of uppermost Cretaceous to lower Eocene age.

Gansser (1964) regarded norites and diorites of slightly younger age than volcanics occuring near Chilas.

Bakr and Jackson (1964) regarded intrusions of diorites and granodiorite of early Tertiary age. The rocks occuring in Dir District are a continous series of these rocks occuring in Chilas.

Aftab, Shafiq, Muzaffar and Shaukat (1972) found fossils Nummulites and Assilina in a fossiliferous bed in calcareous schists near Chukiatan, four miles from Dir. These fossils are of Eocene age. So the age of calcareous schists is proved to be Eocene. Therefore the age of the amphibolites as well as later intrusives is post Eocene.

REFERENCES

BARTH, T. W. F., 1952 Theoretical Petrology. John Willey and Sons, Incorporated New York.

BOWEN, N. L., 1922 The behaviour of inclusions in igneous rocks. *Jour. Geol.*, **30**, 513-567.

ENGEL, A. E. J., AND ENGEL, C. G., 1951 Origin and evolution of hornblende andesine amphibolites and Kindred facies. *Bull. Geol. Soc. Amer.*, **62**, 1435.

EVANS, B. W., AND LEAKE, B. E., 1960 The composition and origin of striped amphibolites of connemarra, Ireland. *Jour. Pet.*, I, 337-363.

HEIER, K. S., 1962 The possible origin of amphibolites in an area of high metamorphic grade. *Norsk. Geol. Tidsskr.*, 42, 157-65.

LEAKE, B. E., 1964 The chemical distinction between ortho and para amphibolites. *Jour. Pet.*, **5**, 238-254.

SHELLEY, D., 1967 Myrmekite and myrmekite like intergrowth. *Min. Mag.*, **36**, 498—503.

TURNER, F. J., AND VERHOOGEN, J., 1960 Igneous and metamorphic petrology. McGraw Hill Book Co,. Inc. New York.

WILCOX, R. E., AND POLDERVAART, A., 1958 Meta-dolerite dike swarm in Bakersville-Roan Mountain area. North Carolina. *Bull. Geol. Soc. Amer.*, **69**, 1323-68.

(Manuscript received November, 1973)

NOTICES ABSTRACTS AND REVIEWS

A REVIEW OF THE STUDY OF PHOSPHATIC ROCKS IN HAZARA DISTRICT PAKISTAN.

In a G.S.P. information release No. 51 on the phosphorite deposits of Kakul-Mirpur area Hazara District NWFP Pakistan by Nasir Ali Bhatti et al., at page 2, the following observation has been made.

"A reconnaissance photo geological map on the scale 1. 63360 covering South Eastern Part of Hazara District was prepared in 1970 by Latif of the Punjab University. He has claimed that he made the first report of occurrences of phosphatic rocks at Kakul Mirpur area (Verbal communication October 1971). But it was not disclosed before 1971 when the occurrence of phosphatic rock in Kakul area was a subject of excitement in certain quarters."

Since the observation is contrary to the factual situation it is imperitive that facts may be brought to light before it becomes a controversy.

The field work for the revision of the Geology of South Eastern Hazara was undertaken by the author from July 1959 to August 1967. This was followed by laboratory studies carried out at the Post Graduate Training Centre of Geology Vienna. 1967-68 and Imperial College of Science & Technology London 1968-69. Definite evidences of the presence of phosphate rock in the Sirban Formation were found by the author in early 1968 based on X-ray analysis, spectrographic analysis and thin section studies. The high P_2O_5 content was later confirmed by the chemical analysis carried out by Dr. F.A. Faruqi of West Regional Laboratories Lahore and communicated by him to the author, then at Vienna, vide letter No. C & G/FAF 21613 dated 1.4.1968 as below :

	Sample No. 4	*Sample No. 2*
L/I	1.30	2.70
SiO_2	46.80	4.68
Al_2O_3	18.435	39.43
Fe_2O_3	0.275	0.45
P_2O_5	30.62	45.62
CaO	2.92	5.61
MgO	0.84	0.68

The work on Hazara was submitted by the author to the University of London for a Ph.D. in June 1969. The presence of phosphate was recorded in the Ph.D. thesis part I at page 73 to 76 showing P_2O_5 content of 6 rock samples as 3.32, 0.75, 42.00, 45.62, 27.80 and 30.62. The thin sections showed the presence of callophane varying from 20% to over 35%. The cherty dolomites of Sirban and 3 thin sections showing pseudo oolites of callophane were illustrated in Part II of the thesis as plates 5/5 and 5/6. Later the map with explanatory note on the geology of Hazara was published by the Geological Survey of Austria in February 1970. In September 1970 the author discussed the possibility of a joint collaboration, between Punjab University and Geological Survey of Pakistan, with Dr. A.N. Fatmi who visited Lahore in September 1970 in connection with discussions on the stratigraphic nomenclature of Hazara. This discussion was later confirmed by Dr. Fatmi vide his letter No. GSP/P & S/70 dated 22nd October 1970 addressed to the author as under.

"I also gave a note to the Director General and Mr. J. M. Master regarding the possibility of your cooperation in phosphorite investigation of Hazara area. Possibly Mr. Asrarullah might discuss this in detail in near future. I have recommended your name plus one geologist from Stratigraphy & Palaeontology branch and one from the Economic Geology branch. I have not yet received any reply to my note, but it seems the matter is being taken up quite seriously."

In another letter No. GSP/P & S/71 dated 14th September 1971 from Dr. Fatmi to the author the former confirms it further in the following words:

"I am in receipt of a copy of your letter dated 28th August, 1971 addressed to the Director General. I may mention that a note, based on our discussion in September last (1970) on the phosphate occurrences in Hazara, was submitted to the Director General in October, 1970. As I was not aware of the horizon or locality, I just mentioned that you have showed me some phosphate rock specimens from Hazara and that in your opinion the area should be investigated in detail, and that you will be happy to participate in case a joint venture is decided. Since then I had been very busy in many other things and further I was not directly involved in these investigations, I left the matter with the senior officers concerned to decide the future course of action. I do not know what steps have been taken in this direction. I may, however, assure you that due acknowledgement and recognition of your work has been made wherever such work has been referred in the reports. Please rest assured that there is nothing to worry regarding omission of your work in any report." The letter dated 28th August 1971 referred by Dr. Fatmi above was addressed by the author to Mr. A.M. Khan Director General Geological Survey of Pakistan Quetta. It gave authors apprehension of attempts to deprive the author of the credit of the discovery of phosphate in Hazara.

Whe.e as Dr. A.N. Fatmi readily acknowledged the communications from the undersigned, Mr. A.M. Khan did not reply to my above communication for reasons better known to him inspite of my request made at Islamabad in the presence of Mr. Asrarullah in 1971 at the time of the visit of first CENTO Phosphate Group to Pakistan.

A note by the author entitled "An Occurrence of Palaeozoic Phosphate Rock in Hazara District West Pakistan" appeared in the Transactions Section B of the Institution of Mining and Metallurgy London Volume 81, 1972.

The Ph.D. thesis submitted by the author in 1969 was consulted by Dr. A. Notholt of the Institute Geological Sciences London, a coordinator from U.K. on the CENTO Phosphate Working Group and referred it in his article published in Transations Section B of the institution of Mining and Metallurgy London Volume 81 at page B 161 as below :

"The phosphatic nature of Palaeozoic rocks near Abbottabad in the Hazara District of northern Pakistan was reported in 1969, 28". It was referred again on page B 163 of the same publication.

Dr. R.A.K. Tahirkheli in the information release No. 5 published by the Directorate of Industries Commerce and Mineral Development, Government of NWFP Peshawar entitled as "Phosphate occurrences in Hazara and other contiguous areas of NWFP and tribal areas" on page 4 records as follows :

"The first mention of phosphate rock in Hazara district has briefly been made in a Ph.D. thesis submitted by M.A. Latif from the Department of Geology Punjab University."

Fossils were collected from the contact zone of Sirban Formation with Hazira Shale in late 1969 by the author in collaboration with Dr. G. Fuchs of the Geological Survey of Austria. These were identified by Professor A. Seilacher & Dr. H. Gocht of the University of Tubingen, West Germany in 1971 and the information published in Nature London in November 1972 as "Cambrian? Hyolithids from Hazira Shale". The identification of fossils and age was confirmed later by Dr. A.W.A. Rushton of Institute of Geological Sciences London S.W. 7 in Nature London, June 1973.

The facts refered above prove beyond any doubt that (*a*) Studies in Hazara were carried out by the author since 1959 (*b*) The occurrence of phosphate rock was known to the author as early as 1968 later recorded in 1969 (*c*) the senior officers of the Geological Survey of Pakistan knew about the discovery of the phosphate in Hazara by the author as early as September 1970. I wish there was more coordination and exchange of ideas between various branches and officers of the Geological Survey of Pakistan to avoid repetition of such remarks as given by (Bhatti et. el.) in the prepublication referred above.

M. A. LATIF
Department of Geology
University of the Punjab, Lahore
November 1973

REFERENCES

Bhatti, N.A., 1972 Phosphorite deposits of Kakul-Mirpur area Hazara district, NWFP Pakistan *Geol. Surv. Pak. Inf. Rel.* 51, 2.

Latif, M.A., 1969 The stratigraphy of South Eastern Hazara and parts of the Rawalpindi and Muzaffarabad districts of West Pakistan and Kashmir. Ph.D. Thesis Univ. of London Part I, 73-76 and Part II plates 5/5 & 5/6.

———, 1970 Explanatory notes on the Geology of South Eastern Hazara to accompany the revised geological map. *Jb. Geol.* B.A. Sond **15**, S 5-20, Wien.

———, 1972 An occurrence of Palaeozoic phosphate rock in Hazara district, West Pakistan. *Trans. Sec.* B. *Inst. Min. Met.* London **81**, B 50-53.

———, 1973 Lower Palaeozoic (? Cambrian) Hyolithids from the Hazira Shale, Pakistan. *Nature Phy. Sci.*, **240**, 100, 92-93.

Notholt, A.J.G., 1972 Palaeozoic phosphate rock in southwest Asia and the Near East. *Trans. Sec. B. Inst. Min. Met.*, **81**, B 158-163.

Rushton, A.W.A., 1973 Cambrian fossils from the Hazira Shale Pakistan. *Nat Phy. Sci.*, **243**, 130, 142.

Tahirkheli, R.A.K. Phosphate occurrences in Hazara and other contiguous areas in NWFP and tribal areas. *Dir. Ind. Com. Min. Dev.* NWFP *Inf. Rel.* No. 5, 4.

(Manuscript received December, 1973)

A NOTE ON COPPER MINERALIZATION NEAR BALDHER, HARIPUR, DISTRICT HAZARA, N.W.F.P., PAKISTAN.

INTRODUCTION

Rare copper staining of the Hazara Slates has been known for some time but only in 1971 worthwhile zone of mineralization was located near Baldher (Long. 73°6'; Lat. 33°59') about 9 miles N-E of Haripur (Fig. 1). The place was visited by authors in April, 1972.

The mineralized zone represents a belt of fault breccia in the Hazara Slate Formation of Palaeozoic age. The latter are represented by khaki to steel grey coloured fine-grained slates that texturally show a status near to phyllites. Thin bands of greenish and purplish slates are sporadically present. Mineralogically, these are composed of varying proportions of quartz, muscovite, bleached biotite, chlorite, feldspar, tourmaline and ore grains etc. No detailed account of petrography of these rocks is available in literature, nevertheless, it is of no direct bearing to present problem in its restricted sense.

The fault breccia zones are recognisable due to the presence of rock rubble and conspicuous ochery colour of limonite. The angular rock fragments are strongly fractured and stained by limonite while the central portion of the breccia zone is occupied by greyish white, coarse quartz-rich material; copper mineralization is generally associated with the latter rocks. In thin section, the quartz rich breccia-zone rocks show strong cataclastic texture, composed of large strained quartz grains bordered by fine-grained strain free quartz. Wherever fractures run through the rock, quartz shows growth outward from its margins; the fractures themselves are generally healed by limonite. In addition to dominant quartz, irregularly distributed angular fragments of slate are present, which show a weak preferred orientation in specimens sampled near walls of the breccia zones. General coarsening of the rock fragments along fractures running through them is frequently seen. Such fractures, both in

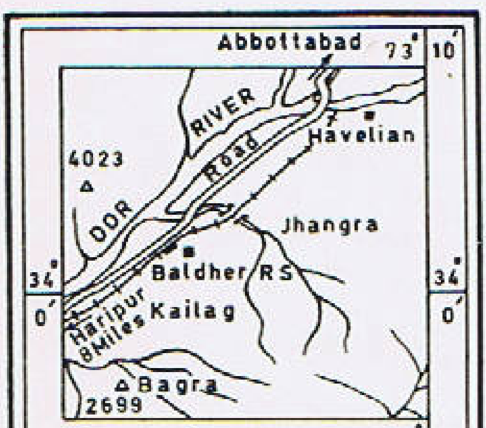


Fig. 1 Locality Map

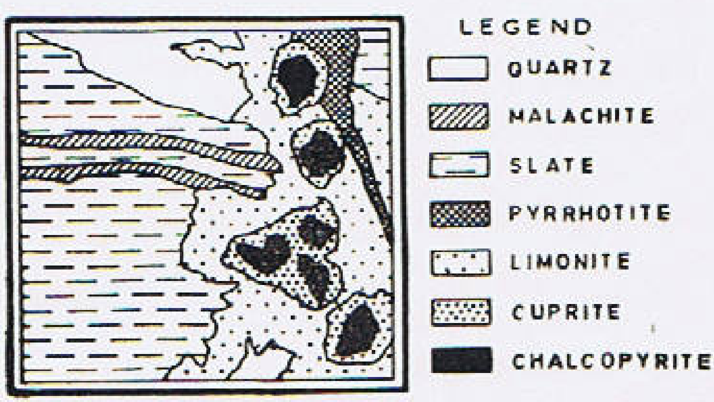


Fig. 2 Mineral Paragenesis

quartz-rich areas as well as in rock fragments, are occasionally filled by bright green malachite, lined outwardly by limonite.

COPPER CONTENT AND MINERALOGY

The elemental copper content of 5 representative specimens ranges from 0.34% to 2.35% (determined by dithizone method). The primary copper mineral is chalcopyrite which alters to cuprite to malachite. Pyrrhotite is generally associated and makes veins and bands that contains tiny chalcopyrite grains. The chalcopyrite areas show boxwork alteration to reddish limonite with a thin marginal zone of pyrrhotite around chalcopyrite (Fig. 2). The malachite is associated with ore minerals in such a manner that its thin veins appear issuing from alteration zones and penetrating the host material. The malachite preferably fills openings in slate fragments parallel to foliation and fractures in large quartz grains; occasionally intergranular spaces as well carry malachite. In frequent cases, galena is associated although it shows tendency to occur separately from copper mineralized areas of the breccia zone rocks.

It appears that chalcopyrite is the primary ore and its content will increase with depth, as has been supported by exploratory digging to a vertical depth of about 10 feet. Further work is in progress.

The authors are grateful to their colleague, Mr. Shafeeq Ahmad, for help in identifying opaque ore minerals.

F.A. SHAMS,
FAZAL-UR-REHMAN
Department of Geology
Punjab University, Lahore,
Pakistan.

(Manuscript received December, 1973)