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CONTENTS

A NEW EVIDENCE TO SOLVE THE CONTROVERSY OF PALEO GLACIATION IN INDO-PAKISTAN

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Abstract : *Evidences show that unconformity is not restricted to Tanakki Member horizon; the conglomerate occurs at levels other than Tanakki Member; the Tanakki Member is composed entirely of rocks of local origin, mainly sedimentary, as against Talchir Boulder Bed where these have been transported from far off distances and are mainly composed of crystalline rocks; the red and purple sandstones, quartzites and dolomites always occur younger than Tanakki Member whereas lithologically identical rock units always occur older than Talchir Boulder Bed; fossil Hyolithes, Chancelloria etc. of Cambrian age are found to occupy a younger position in sequence than Tanakki Member and there is a possibility of the presence of globular organisms of Algonkian affinities in the Blaini Beds of Simla India. It is suggested that Tanakki Member and Talchir Boulder Bed belong to two different phases of glaciation, the former being older, possibly Cambrian or topmost Pre-Cambrian.*

Blanford et al., 1856, first suspected the action of ice in the production of the Talchir boulder bed of Orrisa, India. Striated boulders resting on a grooved and striated floor of Vindhyan Limestone in the Godaveri Valley were the first definite evidence of glaciation recorded and described by Blanford, 1872. He further called attention to the significant resemblence between the boulder bed under Karroo System in South Africa and that at the base of the Lower Gondwana System in India, a character which was pointed out by Oldham, 1861, in the coal bearing systems of New South Wales where he discovered the first striated boulder in 1885. The subsequent general recognition of glacial phenomena in India, Australia, South Africa and northern Europe, at a similar horizon, gave rise to the idea of a contemporaneous glaciation in various parts of the world.

The above general inference of a contemporaneous glaciation, naturally led the geologists to age accordingly, any subsequent finds of glacial boulders in the Indo-Pakistan sub-continent. When Oldham, 1888, pointed to the glacial nature of the Blaini Boulder Bed and correlated it with the Talchir Boulder Bed of Orrisa and Salt Range, it was not only, then, accepted but also considered as a reliable horizon for correlation of unfossiliferous rock sequences in Indo-Pakistan.

Middlemiss, 1896, suggested a correlation between the Tanakki Boulder Bed of Hazara and Talchir Boulder Bed of Salt Range, based on the following points of similarity:

1. The two conglomerates are conincident with great unconformity and overlap.
2. Both are sub-angular and ill sorted.
3. The Tanakki Conglomerate and the Upper part of Talchir Boulder Bed gradually pass into an overlying purplish and pinkish sandstones respectively.

4. There is no other conglomerate exposed at any other horizon both in Hazara and Salt Range.

The correlation of the Blaini Boulder Bed of Simla with the Talchir Boulder Bed of Orrisa led to certain difficulties in correlating the unfossiliferous post-Blaini sequence of the outer Himalayas with a similarly, unfossiliferous pre-Talchir sequence of peninsular India, a sequence which due to the unfossiliferous nature of sediments had no visible similarity with the highly fossiliferous sequence on the Tibeten side of Himalayas. Holland 1908, suggested that Blaini Beds represented an older glaciation than the Talchir, and referred them tentatively to the Purana or Pre-Cambrian Group. He further cited the occurrences of pre-Upper Carboniferous glaciations in other parts of the world to substantiate his point of view. In this connection he pointed to the occurrence of Pre-Lower Cambrian Verigian, glaciations in South China, South Australia and Norway. In South Africa, two periods older than Talchir were marked by glacial phenomena; that in which the Table Mountain Sandstone was formed in Lower Devonian or possiblly pre-Devonian and other much earlier in pre-Cambrian, Huronian, in which period the Griquatown series was formed.

Pilgrim and West, 1928, hesitated to reject the view put forward earlier by Oldham, of an Upper Palaeozoic age and similarity of Blaini and Talchir horizons. Except for suggesting that the Jaunsars and Chails may well partly fill the gap in the unfossiliferous sequence in case the Blaini Boulder Bed is accepted as of Upper Palaeozoic age, they had no other solid evidence to support the Blaini-Talchir correlation and contradict Holland's other objection.

Wadia, 1929, discovered glaciated boulder bed at the base of Infra-Trias in Hazara. Later, 1931, he showed reasons to believe that the Tanakki Boulder Bed was to be correlated with the Blaini Boulder Bed, the former regarded at the base of Infra Trias of Hazara which in turn was homotaxial with the Agglomeratic Slate and with Talchirs.

Marks and Mohammad Ali, 1961, considered that the striations on boulders from Khotedi Qabar section near Tanakki are slickensides formed by the movements of the pebbles during the deformation of beds.

Since the publication of Pilgrim and West's paper, in 1928 a great number of studies of glacial deposits have been made all over the world, which show that the glaciation is not restricted to the Permo-Carboniferous. Blanford, who originally discovered the Permo-Carboniferous tillites appears again to have been the first to suggest occurrence of glaciation in pre-Paleozoic period. Since his work, Pre-Cambrian glacial beds have been recognised from various parts of the world and include the Chuos Tillite of South West Africa ; the Reef Series Glacials, Griquatown Tillite and Numees Tillite of South Africa ; the Karagwe System of East Africa and Katanga region of Congo ; the Kalgoorlie Series, Government Kanowna Goldfield Conglomerate, Nullagine Series Glacials and Stuart Tillite of Australia ; the Kaldurga Conglomerate, of Mysore India, Chilpi Ghat Conglomerate and Bijawar Conglomerate of Central India the Haimanta Conglomerate of the Himalayas India and pre-Palaeozoic glacial deposits of China, U.S.A. and Siberia (see Ahmad, 1960, pp. 642-656). Palaeozoic glacial beds have been recognised from various parts of the world and include Central Brazillian Tillite ; Zeehan Tillite, Australia, Cambrian ; the Cape System Tillite South Africa, Devonian ; the Furnas Guandacol Tillite, South America, Devonian ; the San Juan Tillite and Type Series Tillite, Argentina, Carboniferous ; the Kutting Tillite, East Australia, Carboniferous ; the Dwyka Series of South Africa and Congo, Permo-Carboniferous and deposits of similar age recorded from various parts of Australia, India, Falkland Islands and Antarctica (see Ahmad, 1960 pp. 650-657). Mesozoic glaciation has been recorded from Bolivia (Mandiyuti Conglomerate), Congo, Narbada Valley India and Australia; Eocene glaciation from Cape Hamilton, Antarctica and Pleistocene glaciation from many parts of the world (see Ahmad, 1960, pp. 661-663).

Umbgrove, 1947, p. 93, suggested a distinct glacial periodicity of about 250 million years.

With regard to the arguments of Middlemiss 1896 as stated on page 20 recent revision of the stratigraphy of Hazara, by the author 1969-1970 establishes the following facts :

1. The unconformity is not restricted to the Tanakki horizon and other equally important ones are recorded :

   (*a*) Between Sirban and Tarnawai Formations (Post Lower Cambrian).

   (*b*) Between Tarnawai Formation and Thandiani Group (Toarcian);

   (*c*) Between Thandiani and Hothla Groups (Oxfordian) ;

   (*d*) Between Hothla and Galis Groups (Danian)

   (*e*) Between Galis and Rawalpindi Groups (Burdigalian) ;

   (*f*) Between Rawalpindi and Havelian Groups (Lower Middle Pleistocene).

2. The conglomerate and/or breciated rocks occur at other horizons :

   (*a*) The Micro-conglomerate at the base of Maira Formation ;

   (*b*) The Conglomerate as Fatehjang Zone at the base of Murree Formation ;

   (*c*) The Conglomerates of the Havelian Group.

3. The Tanakki Member is entirely composed of conglomerate derived from local rocks, Hazara Group & Tanol Formation, as against the Talchir Boulder Bed, which is mainly composed of crystalline rocks derived from peninsular India.

4. The red and purple sandstones, quartzites and dolomites of Hazara are always found to be younger than Tanakki Member, whereas a similar sequence in the Salt Range is always older than Talchir.

5. The Toarcian unconformity in Hazara has been found to be more pronounced South East South wards with the result that the Abbottabad Group and Tarnawai Formation including the basal Tanakki Member, are completely eliminated from areas in the south east thereby bringing the Hazara Group directly in contact with the Jurassic rocks of the Thandiani Group.

The above facts suggest that the Tanakki Member may not be homotaxial with the Talchir Boulder Bed of Salt Range. The present studies further reveal that the Tanaki Member consists of boulders and pebbles of undoubted glacial origin, as suggested originally by Wadia 1931. The possibility of slickensiding of Tanakki Boulders as suggested by Marks and Mohammad Ali, 1961, is correct as far as the faulted Khote di Qabar section is concerned. However this cannot be used as an argument against the glacial view as definite glacial striations have been recorded by the author and G. Fuchs in December 1969 from Thandiani section and peculiar boulder shapes from other sections to support a glacial origin of the Tanakki conglomerate. The present studies further reveal a very close lithologic similarity of the pre and post-Tanakki sequence of Hazara with the pre and post-Blaini sequence of Simla as suggested by Wadia 1931, a correlation which has now been universally accepted, whether or not they agree with the Blaini and Talchir correlation. If the above corerelation of the Himalayan and sub-Himalayan Palaeozoic rocks and the glacial nature of Tanakki is accepted, it is obvious that the Tanakki Member and Blaini Boulder Bed are not homotaxial

Fig. 1. Glacial striations on a Tanakki Boulder near Thandiani.

with the Talchir Boulder Bed of Salt Range and Orrisa and that the former two represent an older glacial phase possibly Pre Cambrian.

Most latest evidence to support the above view is the presence of fossils like Hyolithes and Chancelloria, Latif 1972 and Rushton 1972, of Cambrian age from upper parts of Sirban Formation/basal parts of Hazira Member which units are far younger in stratigraphic sequence than the Tanakki Member. Latif, 1973, has recorded the partial extension of Saline Series facies Cambrian of Salt Range into Hazara which lies stratigraphically below the Tanakki Conglonerate. Some globular organisms of Algonkian age have been reported from Blaini Beds (verbal communication with G. Fuchs) which goes further to establish the point of view given above. Dr. Rushton, 1973 who examined the fossil bearing samples from Hazira Shale from Hazara is also of similar view and states. "A Cambrian age for the Hazira Shale is therefore fully confirmed. If the Tannaki Boulder Bed at the base of the Abbottabad Group is of glacial origin, it becomes feasible to correlate it with the widespread late Pre-Cambrian glaciation".

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MINERALOGY AND PETROLOGY OF A SPINEL LHERZOLITE FROM BAR BANDAI, SWAT DISTRICT, PAKISTAN

BY

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Abstract : *Minor ultramafic bodies occur sporadically within the so-called Upper Swat Hornblendic Group (? Precambrian) of northern Pakistan. A spinel lherzolite outcropping near Bar Bandai, Swat District, Pakistan, has been investigated. It's field relations, textural features and petrography is described. Modal analyses of twelve samples and chemical analysis of one of them are included.*

Contemporaneous with the crystallization of silicate minerals, a spinel solid solution exsolved into two phases, a non-titaniferous magnetite and a chromehercynite. Ore microscopic features of the spinel phases and their alteration products are described.

INTRODUCTION

The so-called Upper Swat Hornblendic Group of probable Precambrian age (Martin et al., 1962; Davis, 1965; Jan and Kempe, 1973) outcrops over a large area in Swat District, Pakistan. It extends to Nanga Parbat and farther in the east, and crosses Afghanistan border in the west. It is composed mainly of diorites, norites and other model varieties, with their southern portion metamorphosed to amphibolites and gneisses. Throughout the complex, minor ultramafic bodies, mainly of peridotitic composition, are present. They have irregular form and variable size and are often partly to wholly serpentinized.

THE SPINEL LHERZOLITE

During the geological investigations of rocks exposed north of Mingora town in Swat District, the presence of spinel lherzolite, described in the present paper, was noticed. The rock outcrops near Bar Bandai village (34° 49′ N70° 24′ E) situated about six miles northeast of Mingora. A geological sketch map of this area on a scale of three inches to a mile (Fig. 1) shows an elongation of the ultramafic body subparallel to the E N E—W S W foliation of the surrounding rocks. The contact is irregular and no thermal aureole surrounds the lherzolite body. The immediate enclosing rock is a well foliated gneiss composed of abundant epidote and hornblende, and minor amounts of quartz, feldspar, chlorite, muscovite, sphene and magnetite. The lherzolite exhibits a holocrystalline, hypidiomorphic granular texture with superimposed mild tectonic fracturing. The fractures in the component grains of the rock carry serpentine with secondary magnetite present regularly along the central portions of the veinlets. In hand specimen and in polished surface, the rock gives a peculiar nodular appearance, produced by relative abundance of serpentine veinlets in olivine rich areas that surround big, and relatively fresh, pyroxene crystals.

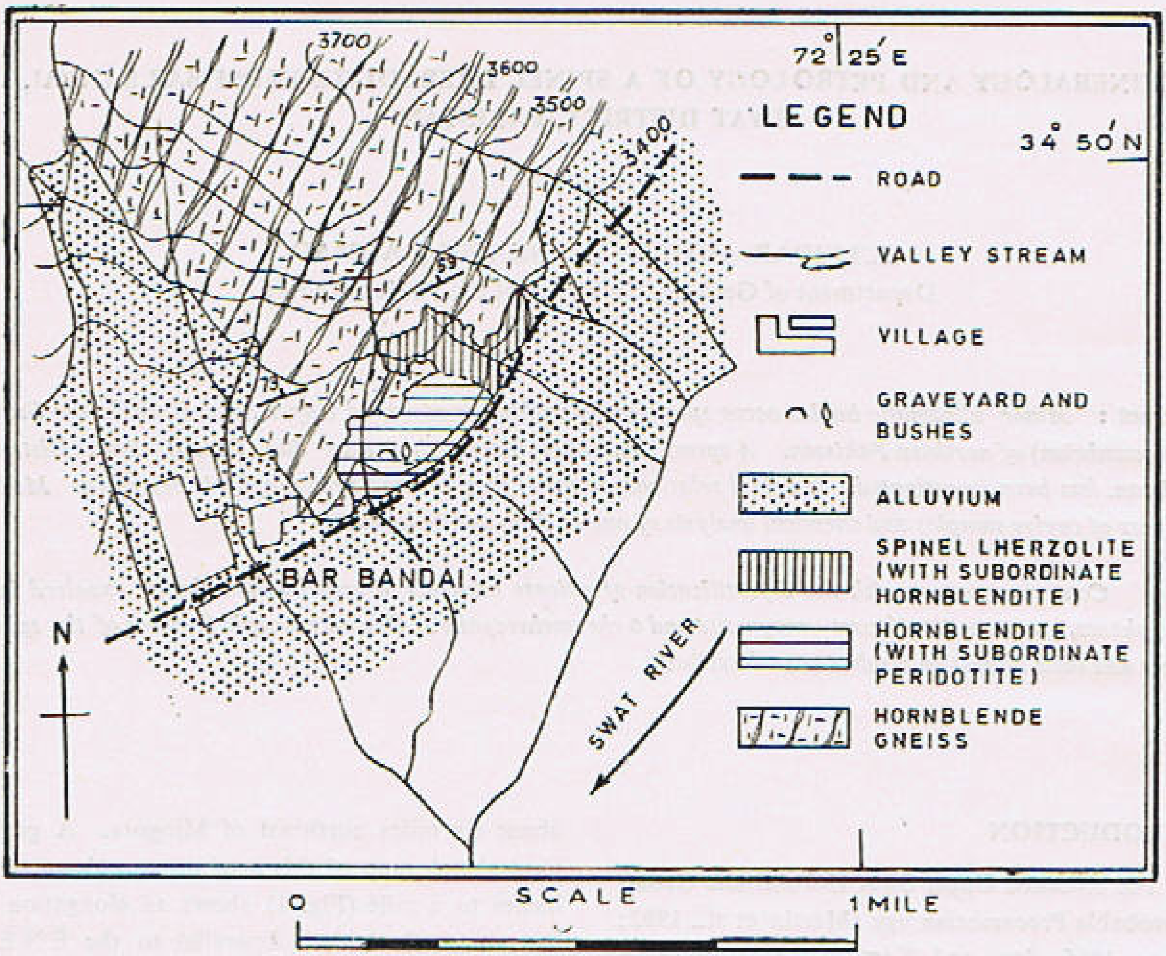


Fig. 1. Geological Sketch Map of Bar Bandai Area, Swat District, Pakistan.

CHEMISTRY

The chemical analysis and CIPW norm of a representative sample of the spinel lherzolite is presented in Table 1. It's comparison with the average peridotite analysis (Table 1) illustrates it's higher Fe_2O_3, Cr_2O_3 (both due to ore minerals) and CaO (due to clinopyroxene) percentages and lower SiO_2 and FeO percentages. This rock has lower SiO_2 and MgO contents and higher CaO content as compared to the chemical analyses of high temperature alpine type peridotites of the world (Green, 1967).

MINERALOGY

The modal analyses of twelve thin sections of the spinel lherzolite are given in Table 2. The primary mineral assemblage of the rock consists of olivine, both clino-and ortho-pyroxenes, and minor amounts of magnetite and chromehercynite.

Olivine forms 48.1 to 67.1 percent of the rock by volume, but in certain pyroxene-rich places, it may be only 35%. It is colourless in thin section with composition ranging from Fa_8 to Fa_{17}. Crystals are quite fresh and the secondary products do not exceed 20 percent of the mode. There is

TABLE 1

Chemical composition of the spinel lherzolite and average peridotite

Oxide	*% By Weight*	
	1	2
SiO_2	36.99	43.54
TiO_2	Traces	0.81
Al_2O_3	7.55	2.51
Fe_2O_3	0.41	—
Cr_2O_3	7.55	9.84
MgO	35.83	34.02
CaO	7.35	3.46
MnO	0.22	0.21
Na_2O	N.D.	0.56
K_2O	N.D.	0.25
H_2O^+	2.04	0.76
H_2O^-	0.20	—
P_2O_5	N.D.	0.05
Total	99.81	100.00

N.D. = Not determined

C.I.P.W. Norm

ol	59.76
di	23.47
an	4.83
cr	0.44
mt	10.90

1. Spinel lherzolite, Bar Bandai, Swat District (Sp. No. 12, Table 1).
2. Average of 23 peridotite analyses (Nockolds, 1954)

no evidence for any reaction rims or resorption shown by the olivine grains.

The clino-and ortho-pyroxenes are closely associated, and make up 17.6 to 35.7 percent of the average mode. In some specimens the pyroxenes become more abundant with dominant enstatite. Clinopyroxene is mostly a diopsidic augite with 2V ranging from 50° to 65°. Ortho-pyroxene in most cases is an enstatite ($Fs<12\%$), but sometimes a magnesium-rich bronzite is present. Pyroxenes are non-pleochroic, except bronzite which is faintly pleochroic. Following two types of exsolution textures are quite conspicuous in some pyroxene grains, especially the coarser ones, and impart them a schiller effect.

(*i*) Presence of linearly oriented inclusions of opaque ore minerals (magnetite and chromehercynite), which may be lacking in the marginal parts of the host pyroxene crystals. This is the only kind of zoning observed in pyroxenes.

(*ii*) Presence in diopsidic augite crystals of the (100) exsolution lamellae of ortho-pyroxenes.

The lamellae form thin, linear and continuous sheets, sometimes slightly curved. However, small flattened blebs of irregular ouline are formed if the exsolved phase is very small in quantity. The bleb-shaped exsolved phases, lack cleavages, even if cleavage is well developed in the host clinopyroxene. These two types of pyroxene exsolution lamellae never combine. When observed in the same pyroxene grain, they are confined to different, although sometimes adjacent, parts.

The olivine grains, and to a lesser degree the pyroxene grains, show effects of mild *serpentinization*. They produce, in most cases, a slipfibre *chrysotile*, forming a network of veinlets, leaving polygonal areas of fresh olivine grains. *Magnetite* produced by serpentinization is also associated with serpentine veinlets. The pyroxene grains were more resistant to serpentinizatin than olivine.

TABLE 2

Modal analyses of the spinel lherzolite

	1	2	3	4	5	6	7	8	9	10	11	12
Olivine	36.5	50.5	53.4	56.0	48.1	55.8	60.3	57.0	62.5	67.1	64.9	61.1
Orthopyroxene	9.6	11.6	11.5	12.1	12.1	11.3	13.6	13.6	12.4	12.3	12.7	10.8
Clinopyroxene	26.1	17.8	15.2	14.9	19.5	15.5	10.5	12.9	11.0	5.3	6.3	11.5
Primary opaque ore	7.2	6.2	5.2	5.0	5.3	5.3	4.9	5.1	4.6	2.9	4.1	3.9
Secondary magnetite	9.2	9.0	7.7	6.8	7.8	6.4	5.1	5.4	3.6	4.5	5.1	5.6
Serpentine	11.4	4.9	7.0	5.2	7.2	5.7	5.6	6.0*	5.9	7.9	6.9*	7.1

*including secondary carbonate minerals (less than 1 %)

They have smaller-sized and less frequent serpentine-magnetite veinlets. When the serpentine veinlets, crossing olivine grains reach a pyroxene grains, they end up or become thinner. In some pyroxene grains, *carbonate-magnetite veinlets* are found in addition to those of serpentine.

Opaque Mineals

The opaque spinel-group minerals (8.2 to 16.4 percent of mode) occur in following three fashions:

(*i*) Anhedral magnetite that forms the central portion of serpentine veinlets (Fig. 2,h). Relatively thinner veinlets contain magnetite as thin, central, sometimes discontinuous lines,. Thicker veinlets contain magnetite as aggregates of minute specks and grains, and as stringers, trails, and fracture fillings. Very rare instances of the presence of sulphide minerals and martitization effects were noted. The magnetite of the magnetite-carbonate veinlets crossing pyroxene grains is located where such veinlets meet opaque ore inclusions.

(*ii*) Minute, linearly oriented opaque ore inclusion arranged in parallel rows within pyroxene (bronzite and diopsidic augite) crystals (Fig. 2, a-d). The inclusion may

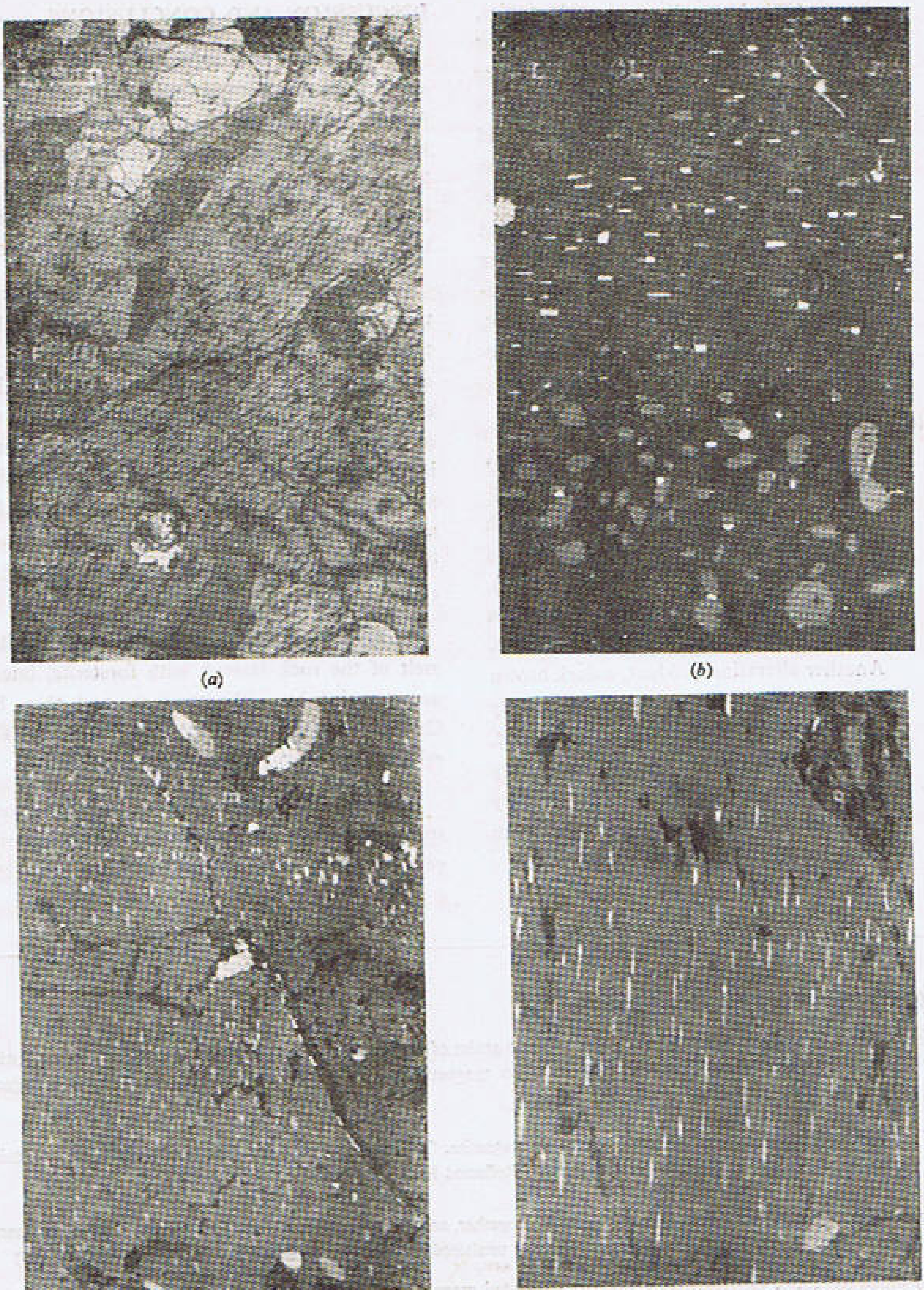
Fig. 2. Photomicrographs of the spinel lherzolite.

(*a*) A portion of big pyroxene crystal surrounded by and enclosing olivine grains. Pyroxene crystal shows oriented inclusions of exsolved opaque ore (black), and its thin serpentine veinlets become thicker entering olivine grains. Transmitted light, crossed nicols. (X 56).

(*b*) Unaltered opaque ore inclusions composed of magnetite (white) and chromehercynite (grey) within silicates (black) are displaying gradual variation in size and shape. Plane polarized reflected light. Immersed in oil. (X 215).

(c) Primary opaque ore inclusion composed of magnetite (white) and chromehercynite (light grey) lying inside bronzite (dark grey). Minute inclusions are substituted by much coarser grains on left side of the same pyroxene grain. Plane polarized reflected light. (X 165).

(*d*) Inclusions of opaque ore elongated parallel to orientation. Reflected light. (X 165).



(a) (b) (c) (d)

be elongate terminating at acute angles, rectangular or roughly square shaped or long needles or half-spindles. Under reflecting microscope, two separate phases of different reflectivities i.e., magnetite and chromehercynite, are found to compose these inclusions. The chromehercynite, is transluscent and brownish green in thin sections. Some pyroxene crystals are without such inclusions, but may contain instead, relatively coarser oval, runic, finger-shaped or irregularly shaped disseminated grains with rounded surfaces.

(*iii*) Idiomorphic to subhedral coarser grains of magnetite and chromehercynite usually with an outer thin shell of secondary magnetite (Fig. 2, e-g). Two or more such grains may, sometimes, join together to form dumb-bell shaped grains (Fig. 2, g). Secondary magnetite is found in between such joined grains, and around them. Another alteration product, a dark brown chromium-poor spinel, encircles partly the primary chromehercynite grains, sometimes enclosed by the secondary magnetite film. The amount of secondary spinel phases is more in areas of more advanced serpentinization of the rock.

DISCUSSION AND CONCLUSIONS

The alpine type origin of (Thayer, 1974) this spinel lherzolite body is indicated by many of it's features described in this paper, such as the irregular form, indistinct contact metamorphism, if any, it's tectonic fracturing and complicated structural relations of associated hornblendite and predominance of highly magnesian olivine over pyroxene.

The spinel lherzolites are characteristic rock types known from the lherzolite subtype of alpine-type peridotite-grabbro complexes in other areas of the world (Jackson and Thayer, 1972). However, the rock under discussion differs from those of lherzolite subtyp3 of Jackson et al., in possessing a higher maximum iron content of it's olivines and pyroxenes; in the plagioclase and garnet being absent; in containing enough magnetite, although ilmenite is not intergrown; and in lacking any clearcut association of a gabbroic rock.

The crystallization from the parent silicate melt of the rock started with forsterite, later on accompanied by orthopyroxene, and then by a Ca-rich clinopyroxene (diopsidic augite). These minerals show usual compositional variations.

Besides the silicate phases, a heterogeneous spinel phase was also existing, and its composition varied between a nearly pure magnetite and a chro-

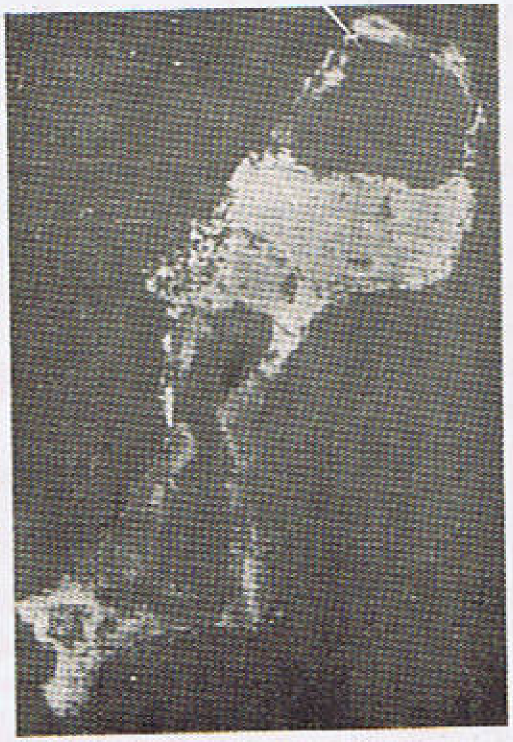
Fig. 2 (Cont) Photomicrographs of the spinel lherzolite.

(*e*) Inside a serpentine veinlet (black) are found two grains of chromehercynite (grey) and one of magnetite (white). All three grains show marginal alteration to magnetite which has a higher reflectivity than primary magnetite. Reflected light. Immersed in oil. (X 215).

(*f*) Secondary magnetite surrounding the primary magnetite. The former displaying martitization effects and containing a few specks of sulphide ore minerals (white). Reflected light. Immersed in oil. (X 215).

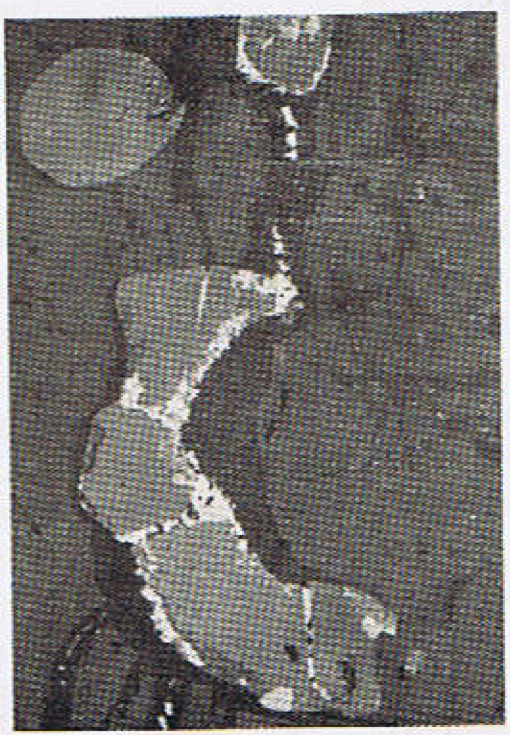
(*g*) Grains of chromehercynite (light grey) sticking together, and possessing thin film of alteration products along margins and cracks. In the lower left corner is relatively unaltered grain of chromehercynite. Reflected light. (X 165)

(*h*) Small serpentine veinlets (dark grey) with associated magnetite (white) in their central portions. Reflected light. (X 165).



(e)

(f)



(g)

(h)

mehercynite. This firstly appeared as minute spinel inclusions exsolved in bronzite and diopsidic augite. Many pyroxene crystals continued their growth after this unmixing ceased. The spinel phase later on appeared again as slightly coarser disseminated grains. The spinel solid solution forming minute inclusions as well as the disseminated grains exsolved into two compositions—a magnetite and a chromehercynite. These two components in such grains and inclusions complement each other in different ratios. The rest of the spinel phase exsolved in semi-solid state and formed euhedral to subhedral disseminated crystals of either magnetite or chromehercynite.

Later on, limited amounts of silica-rich aqueous solutions penetrated the rock along thin fractures. Apart from the usual process of serpentinization, these solutions also produced post-serpentine magnetite which appears in the central portions of serpentine veinlets. The borders of primary magnetite as well as chromehercynite were also enveloped by deposition of thin shells of magnetite, which is distinctly more reflecting than the primary magnetite. An alumina poor brown spinel appears to be an intermediary substance produced during the alteration of chromehercynite to magnetite.

The intergrowth of chromehercynite with a non-titaniferous magnetite described in this paper, is a unique feature, hitherto (Ramdhor, 1969) unknown.

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MAGNETIC SURVEY OF PACHINKO-LUFTO AREA, CHAGAI DISTRICT, BALUCHISTAN PROVINCE, PAKISTAN

BY

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Abstract : *Detailed geological and geophysical investigations have been carried out in Pachinko and Lufto areas to map the surface and subsurface distribution of the ore body. The results of these studies form the basis for selecting suitable sites for exploratory drill holes and finally for estimating the reserves of the ore. On the basis of the Magnetic Anomaly Map, seven sites for exploratory drilling have been recommended. In the hole No. 4, drilled on a magnetic closure, a number of iron ore lenses, totaling to about 100 feet in thickness, were proved within a depth of 150 feet. The details of the magnetic results have been discussed in this report. It is concluded that if all the recommended sites are drilled and the geophysical inferences are proved correct, the Magnetic Anomaly Map will prove a reliable base for the estimation of iron ore reserves in Pachinko-Lufto area.*

INTRODUCTION

The Geological Survey of Pakistan (GSP) and Pakistan Industrial Development Corporation (PIDC) initiated in October 1972 a joint programme of exploration of the iron ore deposits in Pachinko-Lufto area, 50 miles northwest of Nokkundi, Chagai District, Baluchistan, (Fig. 1). The first phase of investigations i.e. geological and geophysical studies, has been completed. Drilling of the test holes based on these studies is being carried out.

The preliminary geological studies were carried out by PIDC in early 1972 and a number of small magnetite/hematite bodies were mapped in Pachinko-Lufto area. These bodies are in the form of small lenses and pockets. The GSP has carried out detailed geological and geophysical studies of the prospect area. Magnetic technique of geophysical prospecting was employed and the distribution of the intensity of the vertical component of the magnetic field was measured. Taking into consideration the geological setting of the mineralized area the magnetic anomalies were interpreted and the recommendations for test drilling sites were made. The results of the test holes No. 4 and No. 5 (Fig. 4), drilled on the magnetic anomalies strongly suggest that the Magnetic Anomaly Map of the prospect area can be used as a reliable base for the estimation of the ore reserves.

GEOLOGY OF THE MINERALIZED AREA

The mineralized area is underlain by Sinjrani extrusive and Chagai intrusive rocks and unconsolidated surficial deposits. The Sinjrani extrusives include agglomerate, tuff, andesite, rhyolite and porphyrite and the Chagai intrusives predominantly consist of felsite rocks. Dykes of porphyritic andesite cut the extrusive rocks. Structurally the area constitutes a part of the northern Chagaiarc.

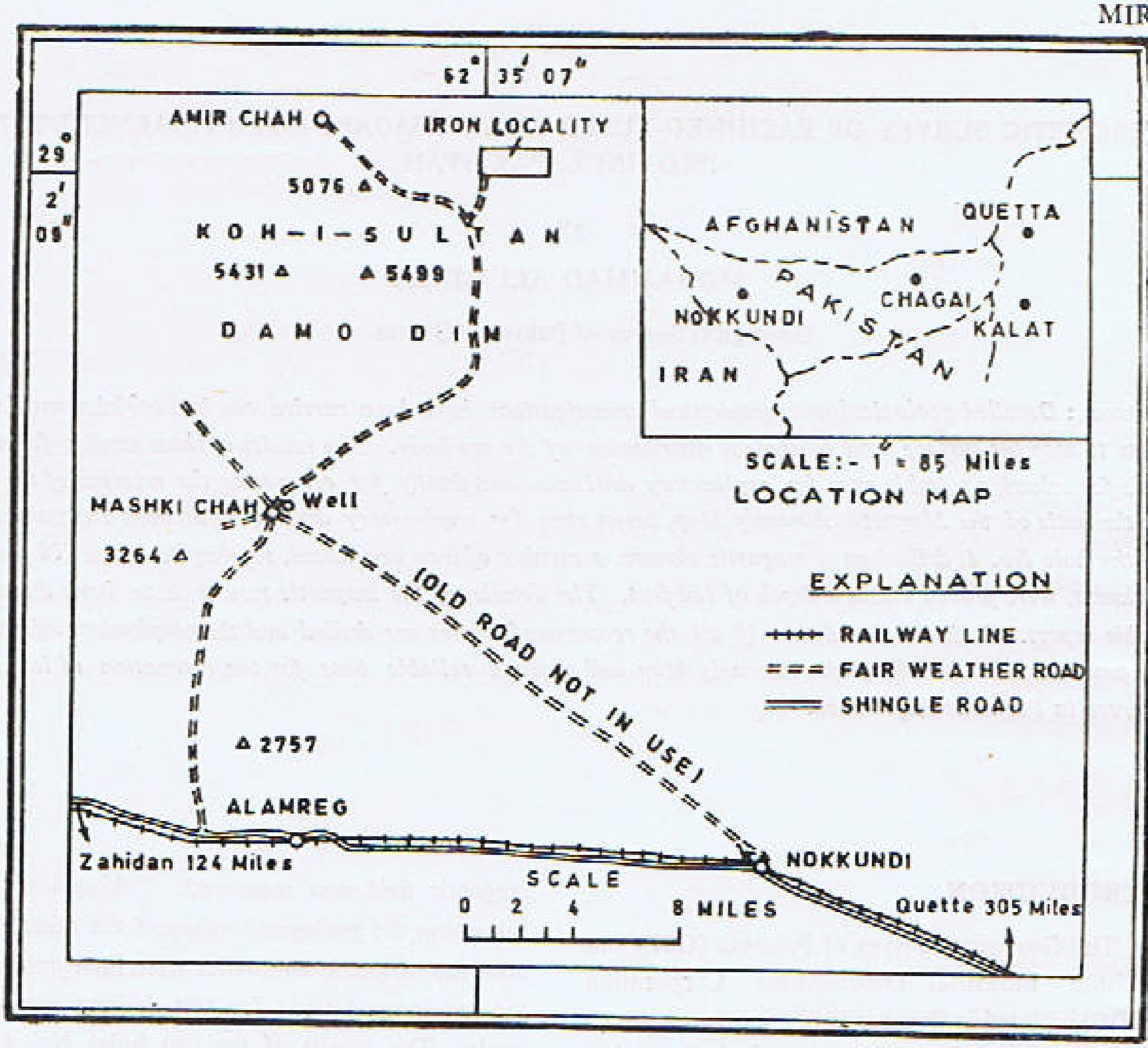
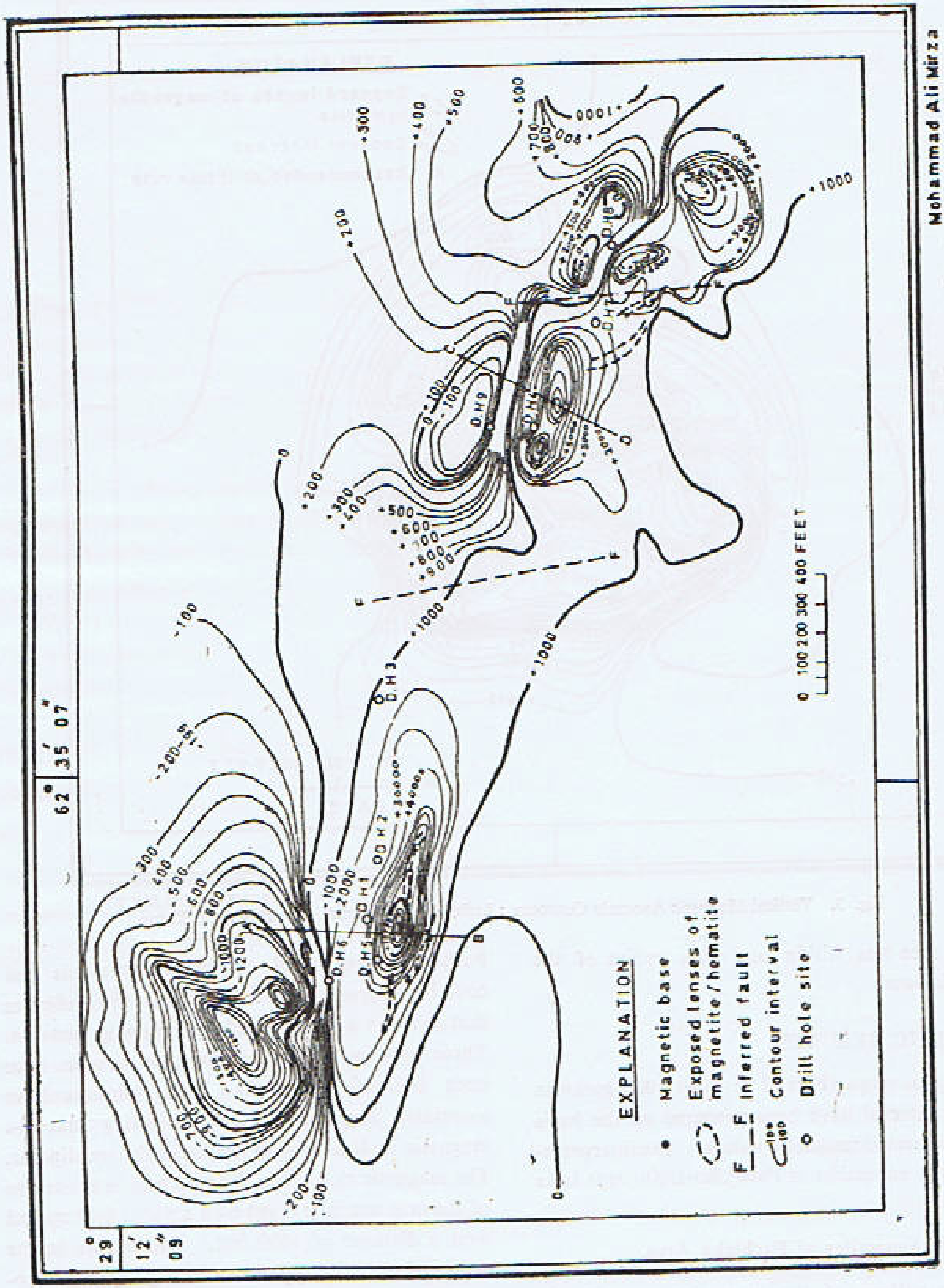


Fig. 1. Location Map of Pachinko-Lufto Iron Deposits, Chagai District, Baluchistan, Pakistan.

Iron bodies occur in irregular lenticular form of different dimensions, sporadically distributed within the Sinjrani volcanics. In Pachinko-Lufto area the iron bodies varying in thickness from 3 feet to 20 feet are exposed at several places (Fig. 4). Hematite is associated with magnetite in almost all the known deposits. The ore is of high grade, containing on the average 50 percent iron.

MAGNETIC MEASUREMENTS

Magnetic measurements were made in the field at an interval of 50-150 feet with the help of Askania Torsion Balance No. 62147 having a range of 140,000 gammas. In Pachinko area 2000 × 4000 square feet and in Lufto area 1000 × 1500 square feet were covered by these measurements. The magnetic measurements were reduced to an arbitrary base located outside the anomalous zone (Fig. 2). The observations were corrected for diurnal variation obtained from the observations at the base station made at a regular interval of ½ hr. during the working period. The diurnal variation in general ranged from 20 to 60 gammas. The latitude correction was not considered necessary



Mohammad Ali Mirza

Fig. 2. Vertical Magnetic Anomaly Contours ; Pachinko Area Nokkundi Baluchistan, Pakistan.

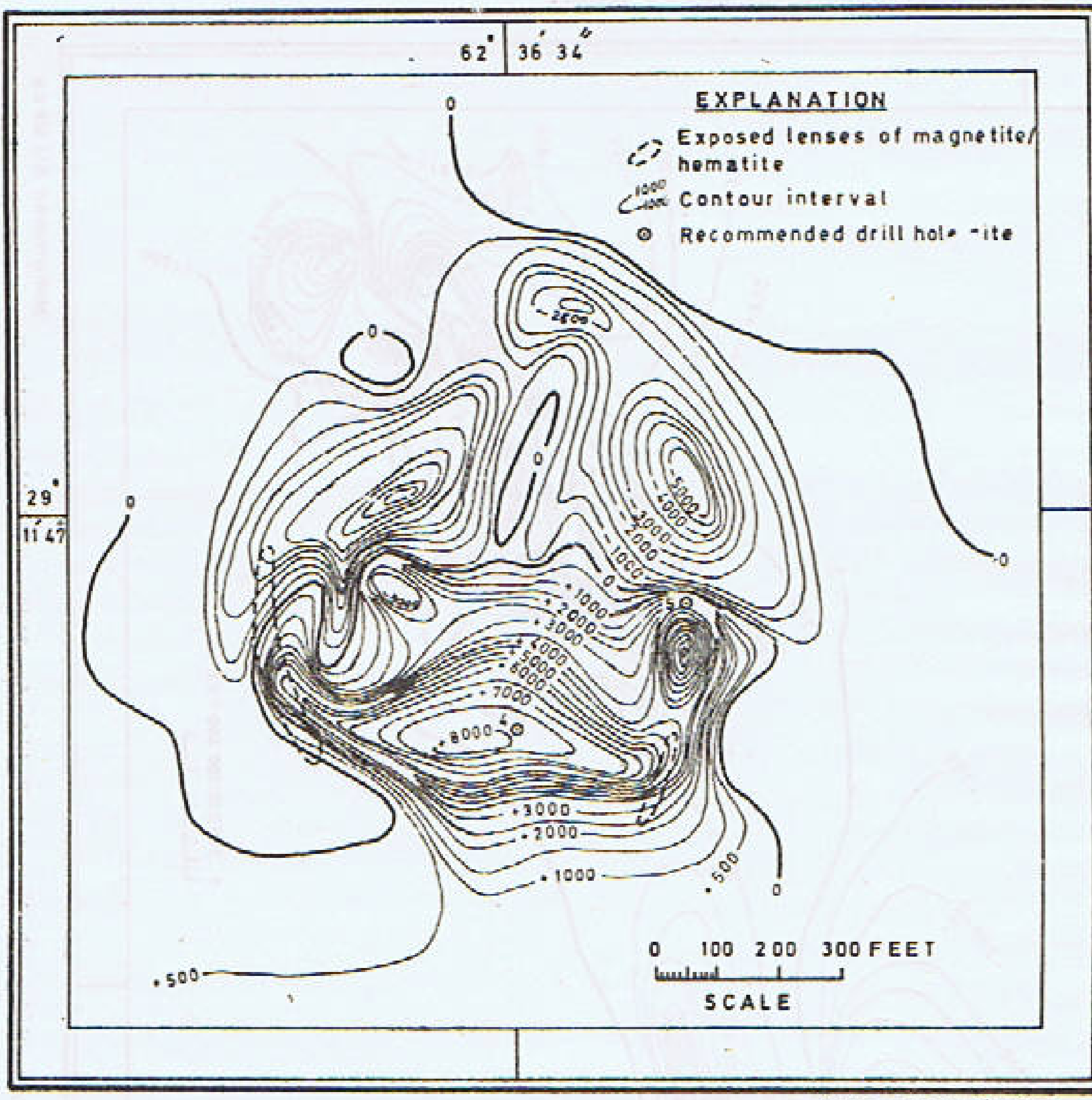


Fig. 3. Vertical Magnetic Anomaly Contours : Lufto Area, Nokundi, Baluchistan, Pakistan.

as the area was within one miles radius of the magnetic base.

MAGNETIC RESULTS

Isogam maps (Figs. 2 & 3) at 1000 gammas contour interval have been prepared on the basis of the corrected magnetic values. The interpretation of the anomalies in Pachinko-Lufto area is as under :

Magnetic Anomalies of Pachinko Area.

The pattern of the magnetic anomalies in Pachinko area, based on 465 observations and covering an area of 2000 × 4000 square feet, indicates that there is a mineralized belt running eastwest. Three prominent positive magnetic closures have been delineated (Fig. 2). These closures have associated negative closures indicating that the magnetic bodies causing the anomaly are dipolar. The magnetic closures in the west and in the centre of the map are intervened by a smooth field spread over a distance of 1000 feet. The closure in the centre of the map appears to be slightly shifted towards south with respect to the closure towards

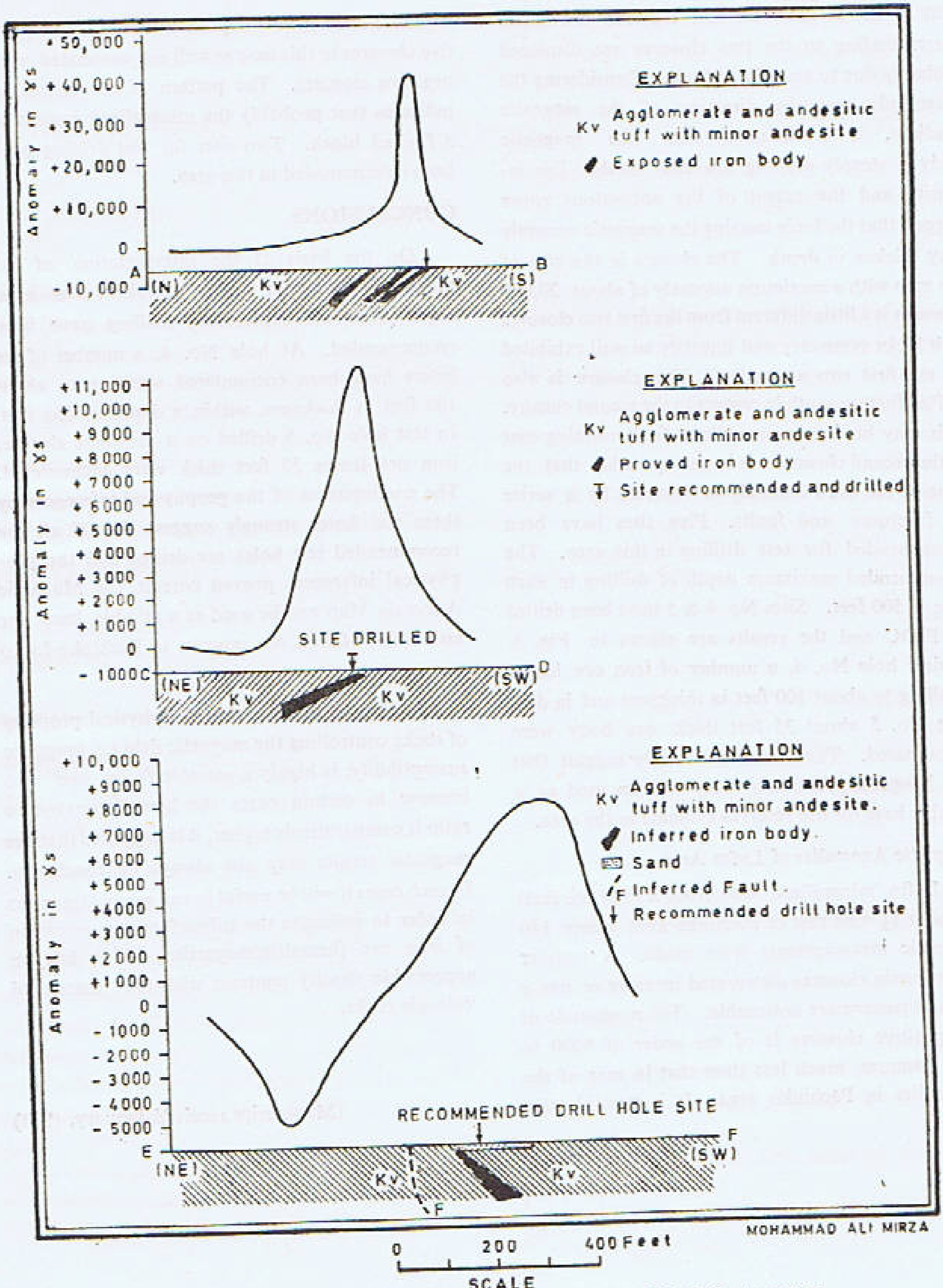


Fig. 4. Magnetic Anomaly Profiles and Geological Sections in Pachinko Lufto Area along AB, CD, and EF (See Fig 2 and 3)

west of it. It indicates that the iron ore lenses corresponding to the two closures are displaced probably due to an oblique fault. Considering the magnitude and the direction of the magnetic gradient, it is inferred that the magnetic body is steeply dipping towards north. The intensity and the extent of the anomalous zones suggest that the body causing the magnetic anomaly may thicken in depth. The closure in the east of the map with a maximum anomaly of about 20,000 gammas is a little different from the first two closures as it lacks symmetry and linearity so well exhibited by the first two anomalies. This closure is also shifted further south in respect to the second closure. This may be due to an oblique fault running east of the second closure. It is also possible that the zone of the third anomaly is traversed by a series of fractures and faults. Five sites have been recommended for test drilling in this area. The recommended maximum depth of drilling in each case is 500 feet. Sites No. 4 & 5 have been drilled by PIDC and the results are shown in Fig. 4. In drill hole No. 4, a number of iron ore lenses totalling to about 100 feet in thickness and in drill hole No. 5 about 35 feet thick ore body were encountered. These results strongly suggest that the Magnetic Anomaly Map can be used as a reliable base for ore reserves estimate in the area.

Magnetic Anomalies of Lufto Area

Lufto mineralized area (1000 × 1500 sq. feet) is about 1½ mile east of Pachinko area where 140 magnetic measurements were made. A number of magnetic closures distributed in more or less a circular pattern are noticeable. The magnitude of the positive closures is of the order of 6000 to 8000 gammas, much less than that in case of the anomalies in Pachinko area. It is possible that hematite ratio in this deposit is higher. The positive closures in this case as well are associated with negative closures. The pattern of the anomalies indicates that probably the mineralized zone is in a faulted block. Two sites for test drilling have been recommended in this area.

CONCLUSIONS

On the basis of the interpretation of the magnetic anomalies of Pachinko-Lufto area, seven sites for exploratory drilling have been recommended. At hole No. 4, a number of ore lenses have been encountered totalling to about 100 feet in thickness, within a depth of 150 feet. In test hole No. 5 drilled on a magnetic closure, iron ore lenses 35 feet thick were encountered. The confirmation of the geophysical inferences by these test holes strongly suggest that if all the recommended test holes are drilled and the geophysical inferences proved correct, the Magnetic Anomaly Map can be used as a reliable base for estimation of iron ore reserves in Pachinko-Lufto area.

In view of the fact that the physical property of rocks controlling the magnetic field i.e. magnetic susceptibility, is highly a variable factor and also because in certain cases the hematite/magnetite ratio is comparatively higher, it is suggested that the magnetic results may not always be conclusive. In such cases it will be useful to run gravity traverses in order to delineate the subsurface concentration of iron ore (hematite/magnetite) which has an appreciable density contrast with the associated volcanic rocks.

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GEOLOGY OF KHAGRAM AREA, DIR DISTRICT

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Abstract: *A map of ninty square miles of the area is presented. Bojites, diorites, tonalite, trondhjemite, norite, hypersthene gabbro, hypersthene diorite, pyroxenite, intermediate pegmatites and amphibolites occur in the area. Normal igenous differentiation of two different magma types is postulated to be responsible for two different types of related rocks i.e. basaltic magma of andesite rhyolite association, which resulted in the formation of bojite, diorite, tonalite and trondhjemite and the tholeiitic magma which gave rise to norite, hypersthene gabbro, hypersthene diorite and pyroxenite. The study suggests that the formation of the complex progressed by independent intrusions of earlier basaltic magma of andesitic, rhyolitic association to latter of tholeiitic nature with subsequent differentiation.*

INTRODUCTION

Location : The area is located in the middle of Dir Distt. of N.W.F.P. of Pakistan. The area lies between latitudes 35° to 34° 51′ 30″N and longitudes 72° to 72° 9′ 30″E. The main Dir road passes through the area. The river Panjkora passes through the N.W. extremity of the area. The maximum relief of the area is 6489′. The height of peaks ranges from 7000 to 9489 feet.

Previous Work : Hayden (1916) studied the geology of the area along the road side on his route to Chitral & Pamir. He described the area as :

"To the north of Rabat, along the river, the coarse diorites continue with basic pegmatites and great masses of amphibolite, which is often very coarse and which at first sight looks like a coarse diallage rock. The series is interrupted here and there by comparatively insignificant patches of hornblendic schist relics, no doubt of metamorphosed sedimentary series. At about three miles south of the levy post Warai, the basic series is pierced by occassional veins of eurite, which increases in number northwards and subsequently pass into a coarse biotite granite. The change in the nature of the rock is reflected in topography and the steep, dark rugged hills of basic series are replaced by rolling hummocky country with white sandy surface. This belt of granite is only about three miles wide and gives place at about a mile above Warai to schists and gneisses full of granite veins."

Bakr and Jackson (1964) while producing geological map of Pakistan, have placed the rocks of the area in granite gneisses and schists with metasedimentary rocks of possibly precambrian into which granodiorites, syenites and diorites of probably Early Tertiary age are intrusive. Davies (1965) considered the rocks of the area similar to those occuring between Khwaza Khela and Kalam (Swat) by observing the trend of the latter towards southwest into Dir.

AGE OF THE COMPLEX

Wadia (1932) included the Sulkhala series occuring in the North of Nanga Parbat in Precambrian age. He also suggested that volcanics overlying Sulkhala are of uppermost Cretaceous to lower Eocene. Gansser (1964) regarded norites, hypersthene diorite and local dunites slightly younger than the volcanics occuring near Chilas. Bakr and Jackson (1964) regared these intrusive granodiorites and diorites of early Tertiary in age. Rocks occuring in Dir are a continuation of those occuring in Chilas. In 1971 fossils were discovered by Aftab, Shafiq, Muzaffar and Shaukat near Chukiatan in calcareous schists. The fossils were identified as Nummulites and Assilina. This proved an Eocene age of the country rocks into which the igneous rocks have intruded. Therefore these country rocks are of Eocene age whereas the intrusives are of post Eocene age.

GENERAL GEOLOGY

Following is a generalised sequence of the main rock units of the area :—

The Norite Complex
The Trondhjemite Intrusion
The Diorite Complex
The Amphibolite

Each of the units has been described briefly in the following :

The Norite Complex

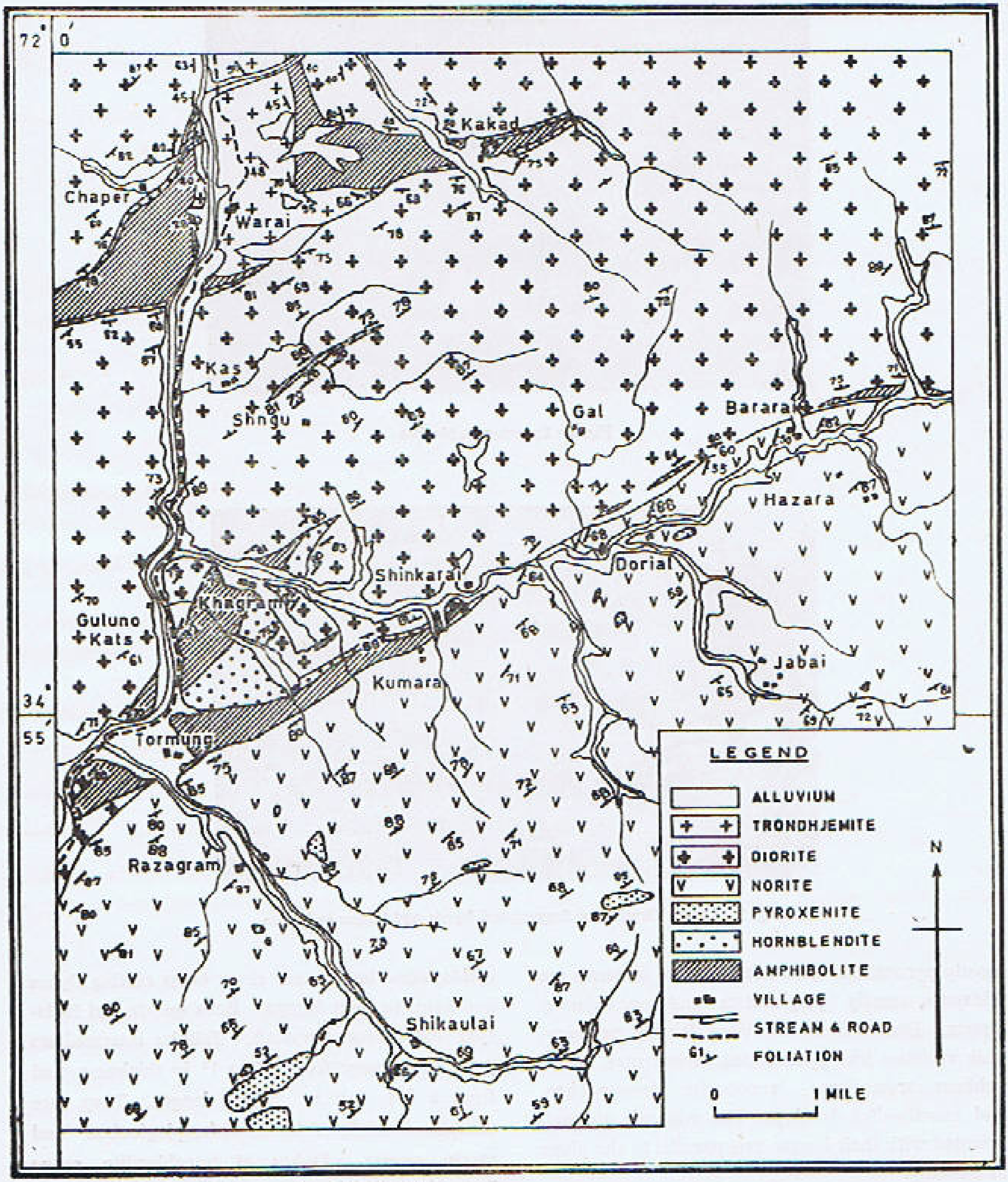
Norites and hypersthene gabbros occupy about 40 square miles of the area and are restricted to southeastern half of the area mapped. This basic intrusion is composed of melanorite, norite, hypersthene gabbro and hypersthene diorite. In field norite is the predominant rock type.

This intrusion is in contact with both amphibolite and diorite. Assimilation at contact with amphibolites can be easily seen. The contact with the diorites is sharp. The diorite is cut by a few apophyses of norite. At contact alteration to sericite and clay of the plagioclase of diorite is common whereas the plagioclases of norite are fresh. Xenoliths and screens of diorite and amphibolites are present in this basic intrusion.

In hand specimen pyroxene and plagioclase can be easily identified. Both joints and foliation are well developed in this intrusion. Melanocratic norites are brownish black with colour index close to 80%. Due to banding and layering in the intrusion the colour index in norite and gabbros varies considerably over short, distances.

Norite and hypersthene gabbro show rusty yellowish brown to light brown weathering colour, melanorite gives reddish rusty colours. Foliation is well developed in this intrusion. It trends northeast southwest. At contact with diorites and amphibolites, it dips inward with an average angle of 70°. In the southeast corner the dip is 60° northwest whereas in the centre of the body it is from 80°—90°.

Banding and Layering : Layering and seggregation banding is fairly common in the intrusion (Fig. 1 and 2). The bands vary in thickness from a fraction of an inch upto 6". Their length varies from a couple of feet upto 100 feet. These bands are parallel to the general foliation and roughly parallel to the floor. The contact of these bands are from more or less sharp to gradational. The bands do not show clear cross cutting relations. Most bands are straight and regular, however, occasionally disturbance is observed (Fig. 2). Some bands are rich in ferromagnesian minerals whereas the others are rich in light coloured minerals. The dark coloured minerals are



Geological Map of Khagram Area Dir District.

Fig. 1 Layering in Norites

Fig. 2 Layers Grading to Seggregated Bands and Lenses in Norite

mostly pyroxenes. The non-coloured minerals are feldspars, mostly plagioclases and occasionally quartz. Due to these variations, locally, petrographic varieties like pyroxenites, melanorites, melagabbros, troctolites, leuconorite, leucogabbro, and anorthosites develop. The minerals are well oriented with their longer axis parallel to the plane of banding.

Quartzofeldspathic veins and dykes, and hornblendites cut this basic intrusion. The quartzofeldspathic bodies are either cross cutting dykes and veins or joint fillings. Both quartz and feldsspar form large crystals. Tabular intermediate pegmatites range from 6″ to 1′ in thickness and from a few feet to 20′ in length. They are composed chiefly of hornblende, plagioclase and rarely quartz. Dykes of hornblendite range from 2′ to 20′ in thickness and from a few feet to about 300′ in length. They are composed of coarse hornblende crystals with minor plagioclase.

Pyroxenite: Pyroxenites occur as lensoid to spindle shaped and layer like bodies scattered throughout norites and hypersthene gabbros. (Fig. 3 and 4). Generally the longer dimension of pyroxenites are parallel to the foliation of the enclosing rock. The pyroxenites are well jointed rocks and show poor foliation. The grain size of the rock is variable. It alters readily on the surface giving rusty colours. The contact of the pyroxenites may be either sharp or gradational. The sharp contacts are observed between medium grained norites and big oval shaped bodies of pyroxenites. The gradational contacts are seen between coarse grained norites and hypersthene gabbros and the pyroxenite lenses and layers. Xenoliths of earlier formed pyroxenites occur in the pyroxenite from microscopic to a few inches in diameter (Fig. 5). Following three types of dykes occur in pyroxenites.

1. Quartzofeldspathic dykes. They occur along the joints as well as along and across the foliation. They are composed mainly of quartz and feldspar. At the contact of these dykes the pyroxene of the pyroxenites alters to hornblende from a fraction of an inch to 6 inches.

Fig. 3 Seggregated Lens of Pyroxenite in Norite

Fig. 4 Spindle Shaped Pyroxenite Standing out Prominently on Surface

2. One foot to 3 feet thick norite dykes.

3. Hornblendite dykes from fraction of an inch to 20′ thick.

Fig. 5. Pyroxenite Xenolith in Pyroxenite TS 13150.

The Trondhjemite Intrusion

A part of the trondhjemite body falls within the area. Here it covers about four square miles. Its contact with the amphibolite is very sharp. A small area, where it is in direct contact with quartz mica tonalite, the contact is marked by a granite porphyry. Apophyses (from norite), occurring in the northwest and northeastern extremities, are seen cutting trondhjemites through banded amphibolite. Trondhjemite shows chilling effects at the contact. At the surface the rock is badly weathered.

It is leucocratic almost white fairly homogeneous and very coarse grained rock. In hand specimen feldspar, quartz with minor amount of mica and hornblende can be easily identified.

The Diorite Complex

The diorite occurs as one main belt like body trending northeast southwest and two separate intrusions in the northern part of the area mapped. The two separate smaller intrusions are of meladiorite.

The diorites have been mapped as one unit. This unit is not uniform. It varies in composition from meladiorite, to diorite to quartz diorite to tonalite. But diorite is the predominant member.

Diorites are well foliated and well jointed rocks. Foliation in quartz diorite and tonalite is more pronounced than the normal diorites. Foliation trends northeast southwest.

Except a small area, where the diorite comes in contact with trondhjemite, the northern contact of the main diorite body is in contact with amphibolite. The contact is marked by a thin hornblendite strip which, away from the contact, grades into banded amphibolites. Southern contact of the diorites is with norite. The contact is very sharp. Amphibolite screens and xenoliths and inclusions are quite common in both meladiorite & diorite (Fig. 6). The screens are however lacking in tonalites and quartz diorites. Xenoliths of meladiorites have been found in diorites. Some dioritic relicts were also identified in quartz diorites and tonalites. The xenoliths are generally parallel to the foliation. The diorites are cut by granite porphyry, quartzofeldspathic veins, pegmatites and epidiorite veins.

Diorite and Meladiorites ; Meladiorites differ from the normal diorites in having greater abundance of dark coloured constituents and less foliated nature. The two independent intrusions in the northeast north and north west extremities of the area comprise of only meladiorites. In the main beltlike intrusion, the meladiorite is particularly observed near the Goplam Baba Ziarat and Guntal Khar. Diorites particularly occupy the central and northeastern part of main dioritic body. A detailed mapping of the various facies in the main beltlike intrusion is yet to be done. Meladiorite is massive looking and dark coloured

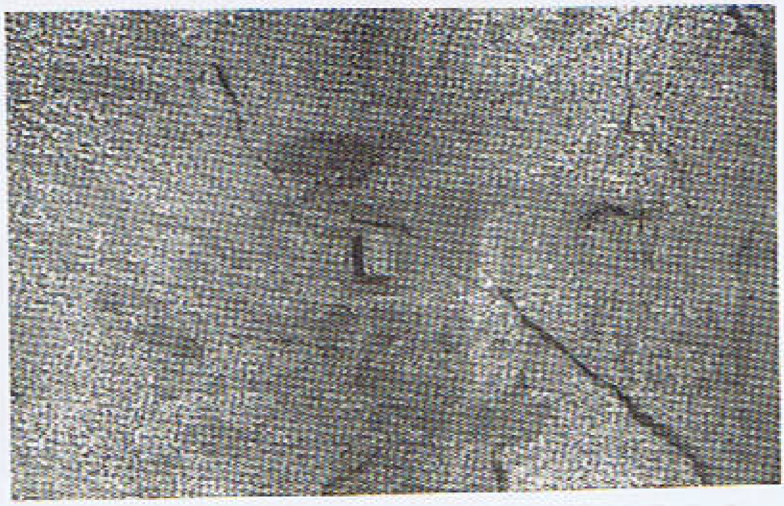


Fig. 6 Dark Amphibolite Inclusions in Diorite

rock, with black hornblende and white to grey plagioclase. The diorites are composed of white plagioclase and black hornblende. It has mottled black and white appearance.

Tonalite: Tonalite is grey to moderately dark rock. It resembles diorites but can be easily identified by the presence of quartz. Foliation is well developed. Their colour index ranges from 20% to 50%. Hornblende, quartz, plagioclase and biotite are the main minerals of the rock.

Bojite ; Bojite is exposed on the right bank of river Panjkora near Guluno Kats. Both to the north and south along the river it grades into meladiorite. It is a fairly coarse grained rock. It is well foliated and jointed. The quartzofeldspathic veins filling the joints are common.

Granite porphyry : Granite porphyries occur in diorites. They are from 5′ to 20′ thick. They are fine grained rocks with quartz and feldspar phenocrysts standing out prominently. Groundmass appears dense to the unaided eye. The feldspar phenocrysts are grey to white in colour while the groundmass is light grey to brownish in colour.

Epidosite veins : They occur as fine grained greenish yellow veins. Epidote and quartz can be identified in hand specimen. They occur as 2″ to 6″ thick veins. They are from a few inches to several yards in length.

Pegmatites: They occur as tabular dykes from 1′ to 20′ thick. They are chiefly composed of coarse feldspar, hornblende and quartz. Some pegmatite dykes are, however, composed of feldspar, quartz and muscovite.

Quartzofeldspathic veins: These veins have a more or less uniform texture. They generally have straight sides. Sometimes they do show pinch and swell structure. They range in thickness from a fraction of an inch to 20′ and from a few inches to hundreds of feet in length.

Xenoliths: The most common xenoliths are of amphibolites. They are composed chiefly of amphibole, feldspars and quartz.

Amphibolites

The amphibolites occur in the area as thin strips and screens. They can be divided into epidote mela-amphibolite and plagioclase mela-amphi-

Fig. 7 Similar Folding in Horizontal Direction in Bande Amphiblites

Fig. 8 Younger Vein not Effected by Folding in Banded Amphibolite

bolite. Most outcrops show moderate to strong banding some show fodling (Fig. 7 & 8). The darker (bands) are rich in amphibole whereas the light coloured bands are composed mainly of epidote or feldspar with quartz. The bands are generally ½" to 3" thick but thickness of upto 7" has been observed. Folding, warping and pegmatic structures are often seen (Fig. 8). The epidote mela-amphibolite is medium grained. Both epidote and hornblende can be easily identified in hand specimen. Epidote and hornblende form alternating layers. The bands are yellow and black in colour. The colour index is around 70%.

Plagioclase mela-amphibolites occur in between the amphibolite diorite contact and the centrally placed epidote amphibolites. The epidote mela-amphibolite grades into plagioclase mela-amphibolite close to the igneous contacts. The rock is well banded, the alternating bands consisting of plagioclase and amphibole. Its colour index is also around 70%.

Three types of veins can be distinguished in amphibolites.

1. *Intermediate pegmatites*: These are composed mainly of hornblende and quartz. They range from ½" to 10' in thickness and range upto 100' in length. Hornblende usually forms well developed crystals.

2. *Quartzofeldspathic veins*: They are composed chiefly of quartz and plagioclase. They are medium grained veins from fraction of an inch to about 9" in thickness and from a few inches to 12" in length.

3. *Granite porphyry dykes*. They range from 5' to 20' in thickness and upto 200' in length. They are composed chiefly of phenocrysts of quartz and feldspar. Their groundmass is fine grained and compact.

Assimilation Zone

Assimilation Zone: This zone marks the contact between norites, hypersthene gabbro and amphibolite. In field it can be clearly seen that it has formed as a result of the action of magma on the amphibolites. It is present along the entire contact between norite and amphibolite. This zone is about 40' to 50' thick.

PETROGRAPHY

The Norite Complex

The norite complex is composed of norite, mela norites, quartz norite, and quartz hypersthene gabbro. Melanorite generally shows ophitic and hypidiomorphic texture. Flow lining in norite and quartz norite is commonly present (Fig. 9). Modal analyses of norites are given in Table 1 along with that of gabbros.

Plagioclase is generally lath shaped. Its composition ranges from An_{50} to An_{60}. In melanorite plagioclase is either interstitial or is poikilitically enclosed in pyroxene. Hypersthene shows from

Fig. 9. Flow Texture in Norite T. S. 12453.

pale green to strong pink pleochroism. Brown rectangular plates in hypersthene form schiller structure. Partial to complete reaction rims of hornblende surround the pyroxene. Sometimes the hornblende rims are surrounded by biotite. Augite occurs from subhedral to anhedral crystals. It is pleochroic from colourless to pale green. Twinning on (001) is sometimes present. Extinction $C \wedge Z$ varies from 42°–48° and 2V=60°. Diallage with parting parallel to (100). is less abundant. Blebs of hypersthene may occur parallel to (100) in it. Rutile, quartz, haematite and ilmenite occur as accessories.

Gabbros: The gabbros may be further divided into hypersthene gabbro and quartz hypersthene gabbro It shows hypidiomorphic texture. The modal analyses of gabbros are given in Table 1 along with that of norites. Plagioclase occurs as large equidimensional to lath shaped crystals showing twinning on both albite and pericline law. Its composition ranges from An_{50} to An_{55}. It mainly alters to sericite and epidote. Augite and diallage both occur. The extinction angle $C \wedge Z$ in augite is 44°–48°, 2 V=60° (+). Parting and twinning in diallage is parallel to (100) plane. It occurs as large subhedral crystals. Occasionally exsolved hypersthene occurs parallel to partings. Hypersthene occurs as stumpy crystals. It is pleochroic from pale green to pink. Pyroxenes are often

TABLE 1

Modal Variation in Melanorite, Norites & Hypersthene Gabbros

T. S. No.		Plag.	Hyp.	Aug.	Hb.+Bt.	Qtz.	Ore
12481	..	73.9	9.4	8.2	1.0	5.6	1.6
12487	..	66.2	12.1	10.6	3.2	6.0	1.6
12488	..	67.1	20.8	10.4	0.4	0.2	0.9
12489	..	63.4	19.7	7.9	4.0	4.0	0.7
12494	..	64.1	10.3	2.3	16.1	4.9	2.0
12508	..	63.4	13.2	9.9	3.0	7.3	2.4
12514	..	71.8	16.2	8.4	2.2	0.9	0.1
12515	..	66.2	15.0	12.4	3.3	1.9	0.7
12516	..	63.3	18.0	10.7	0.3	6.0	1.5
13134	..	61.5	13.11	6.7	14.3	3.4	0.7
13139	..	54.5	18.9	19.3	2.8	2.9	1.3
13148	..	61.1	12.3	15.2	8.3	0.3	2.5
13239	..	68.5	10.0	8.3	4.4	7.4	2.1
13241	..	65.1	18.1	9.8	3.7	1.4	1.5
13246	..	63.5	18.5	10.8	6.4	1.4	4.9
13247	..	14.1	72.9	11.8	2.3	0.0	0.7

rimmed by green hornblende which sometimes is, in turn, rimmed by biotite. Sometimes quartz also occurs. It may contain rutile needles (Fig. 10). Ore and hornblende occur associated. Ilmenite and haematite occur intergrown (Fig. 11).

Quartz Hypersthene Diorite : It has a coarse grained hypidiomorphic texture. Sometime it shows ophitic to subophitic texture. Plagioclase, twinned on both albite and pericline law, occurs as prismatic crystals. Its anorthite contents range from An_{42} to An_{48}. It alters to sericite and epidote. Diallage, with strong (100) parting and twinning gives $C \wedge Z = 46°$, is the most prominant clinopyroxene. Some grains show schiller structure. Its grains are usually rimmed with hornblende. Bushveld type hypersthene rimmed by hornblende and iron ore intergrowths occur as anhedral and strongly pleochroic grains. Amphibolite is mostly secondary but primary crystals are also present. Light brown to dark brown pleochroic biotite occurs after hornblende.

Pyroxenites: The pyroxenites can be divided into two types i.e. augite hypersthenites and websterites.

Augite hypersthenites: It has a hypidiomorphic texture. It is composed essentially of hypersthene, augite, diallage and minor iron ore with less common plagioclase. Cumulates of early formed hypersthene, diallage and augite occur in intercumulates of augite and plagioclase. Five modal analyses of the augite hypersthenites are given in Table 2. Hypersthene occurs from euhedral to subhedral crystals. Two reaction rims, first of green hornblende and the second of brown biotite, may surround the hypersthene crystals.

Hypersthene of Bushveld type with thin rutile lamellae of exsolved clinopyroxene parallel to (100) are common (Fig. 12). The lamellae are augite with $C \wedge Z = 48°$ and 2 V about 60°. Hypersthene is pleochroic from colourless to pale pink. Development of schiller structure is quite common (Fig. 12). Augite inclusions may occur in hypersthene.

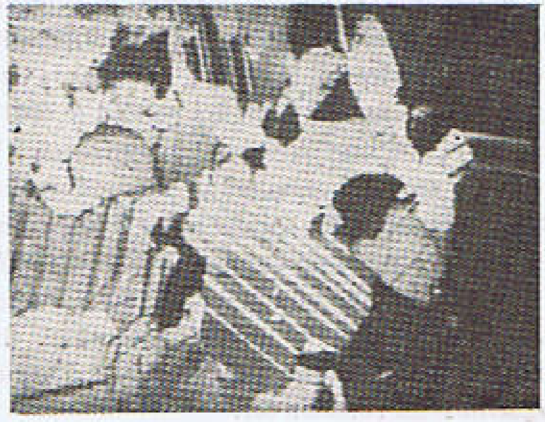


Fig. 10. Rutile Needles in Quartz of Norite

Fig. 11. Ilmenite in Hematite of Norite.

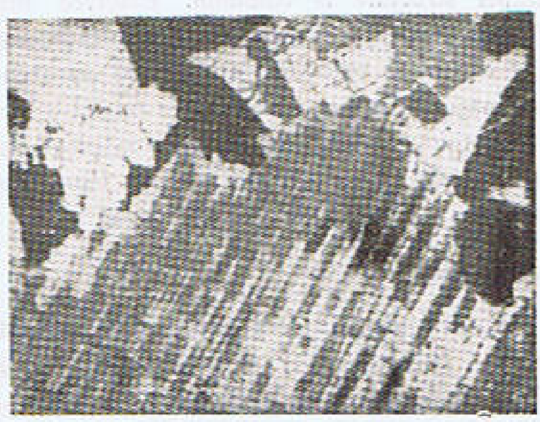


Fig. 12. Schiller Structure in Pyroxene of Norite, T.S. 13264.

Augite occurs as large subhedral to anhedral crystals. The extinction angle C∧Z is from 46° – 50° and 2 V is positive and about 60° Twinning is very rare but when present is always parallel to (001). Diallage is the next common clinopyroxene. It occurs as euhedral cumulate crystals. Twinning is fairly common and is parallel to the (100) parting of diallage. The extinction angle C∧Z is 42° – 46°. It is biaxial positive with 2 V about 60°. Plagioclase when present is usually interestitial. Its composition varies from An_{52} to An_{56}. Ilmanomagnetite is the common ore.

Websterite : The rock is hypidiomorphic granular with interlocking grains of augite, diallage and hypersthene. Late magmatic hornblende, which is green in colour, when present, encloses hypersthene poikilitically. Twelve modal analyses of websterite are given in Table 2.

Hypersthene occurs from anhedral to subhedral crystals. Bushveld type hypersthene with exsolution of augite in fine lamellae parallel to (100) usually occurs in stumpy crystals. It is pleochroic from colourless to pale pink. Schiller structure is strongly developed.

Diallage occurs as big euhedral crystals with oriented haematite needles parallel to its parting. Its extinction angle C∧Z is 46° to 48° and 2V is about 60°. Augite is subhedral to anhedral. Schiller structure is common. Exsolved blebs of hypersthene also occur in it. Hornblende generally occurs as reaction rims around pyroxenes. Late magmatic primary hornblende may also occur as interstitial crystals. Some interstitial plagioclase also occurs. Its composition is labradorite. Ilmanomagnetite is an accessory mineral.

Hornblendite

Hornblendite: It has hypidiomorphic granular texture. It is composed chiefly of hornblende with minor cummingtonite and plagioclase. Hornblende makes up about 85% of the rock. It is pleochroic from pale green to green to dark green. Its extinction angle C∧Z=15°–20°. Small amounts of cummingtonite also occurs. Hornblende alters commonly to chlorite and epidote. Plagioclase occurs interstitially. It is strongly altered to sericite and epidote.

The Diorite Complex

Bojite: It has hypidiomorphic granular texture. Hornblende sometimes encloses plagioclase crystals poikilitically.

Bojite is composed essentially of basic labradorite and green hornblende. Plagioclase makes up about 42% of the rock. Its composition ranges from An_{56} to An_{70}. It is equidimensional to lath shaped. At places the plagioclase shows normal zoning. Here the cores are more altered than the margins. Alteration to sericite and epidote is comparatively rare. Hornblende occurs from subhedral to anhedral crystals which often contain inclusions of quartz and iron ore. The original schiller structure of the pyroxenes is still preserved in many grains. It is pleochroic from yellowish green to green to dark green. Extinction angle C∧Z is from 15° to 19° and the optic axial angle is about 80°. Twinning parallel to (100) is quite common. A few grains of light green augite and colourless to pink and pleochroic hypersthene are also present. Quartz, ilmenite and titanomagnetite are the common accessories. They occur mostly as interstital grains. Modal variation in diorite intrusion is shown in Fig. 13 & 14.

Diorite and Meladiorite : Diorites and the meladiorites are both hypidiomorphic granular in texture. In the mela diorite hornblende may often enclose plagioclase poikilitically. Sometimes inclusions of quartz in hornblende give sieve like texture. Six modal analyses of diorites are given in Table 3.

Hornblende is the most abundant mineral of the diorites. It is from euhedral to subhedral mineral. It is pleochroic from yellowish green to green to dark green. Extinction C∧Z varies

TABLE 2

Modal Variation in Pyroxenite

T. S. No.		Plag.	Hyp.	Aug.	HB	Ore
			Augite Hypersthenites			
13151	..	x	65.1	6.4	28.4	x
13192	..	x	47.6	46.9	5.3	x
13193	..	x	78.7	17.9	2.0	x
13242	..	6.4	69.2	15.0	7.5	1.6
13249	..	1.0	58.9	26.7	12.9	0.2
			Websterites			
13133	..	x	46.9	53.3	x	x
13140	..	x	41.9	57.6	0.4	x
13149	..	x	38.1	53.4	8.4	x
13150	..	x	26.6	68.3	5.0	x
13194	..	x	40.9	56.8	2.2	x
13240 (*a*)	..	4.2	25.7	69.2	0.7	x
13240 (*b*)	..	3.9	30.5	65.2	0.3	x
13259	..	2.7	42.6	51.3	2.9	0.2
13260	..	6.6	36.9	55.5	0.9	x
13261	..	2.0	30.1	68.0	0.6	0.1
13262	..	6.2	39.3	54.0	0.2	0.2
13264	..	8.9	37.8	52.3	0.7	0.1

Mixed Zone

Quartz	..	50.1%
Garnet	..	8.3%
Plagioclae	..	8.7%
Ore	..	1.3%
Hypersthene	..	11.7%
Biotite	..	12.9%
Hornblende	..	5.8%
Epidote	..	1.2%

TABLE 3

Modal Variation in Diorite Intrusion

T. S. No.		Plag.	Hb.	Qtz.	Epid.	Sphen.	Bt.	Ore	Chl.
12472	..	41.7	29.6	19.8	8.5	Small	x	0.1	x
12486	..	42.7	54.9	0.2	1.4	0.4	x	0.1	x
12502	..	30.9	66.4	2.5	0.1	x	x	x	x
12503	..	42.3	56.8	0.1	x	0.1	x	0.5	x
12505	..	57.8	21.7	18.4	1.8	x	x	0.1	x
12506	..	37.3	48.9	11.6	0.2	1.5	x	0.5	x
12513	..	25.7	70.2	2.1	1.8	x	x	x	x
13135	..	24.8	70.6	4.4	x	0.2	x	x	x
13203	..	30.0	67.6	1.5	0.7	x	x	x	x
13257	..	43.3	12.5	24.1	0.7	x	17.4	x	1.7

Modal Variation in Trondhjemite

T. S. No.		Plag.	Qtz.	Hb.	Bt.	Chl.	Epid.	Ore
12498	..	56.1	26.9	6.7	x	5.5	3.9	0.9
12517	..	72.4	18.5	0.2	0.1	3.3	5.3	x
13207	..	53.8	26.9	15.3	x	0.4	1.8	1.4
13209	..	58.4	30.7	9.7	0.2	0.3	0.5	x
13182	..	51.0	31.7	13.3	x	0.9	2.8	x
13233	..	49.0	18.0	20.7	x	5.6	6.1	0.3
13234	..	50.9	44.4	1.1	x	0.6	1.4	1.2
13235	..	64.5	23.0	8.5	2.2	x	0.4	1.0
13236	..	62.2	31.3	3.2	0.5	0.6	0.8	1.0

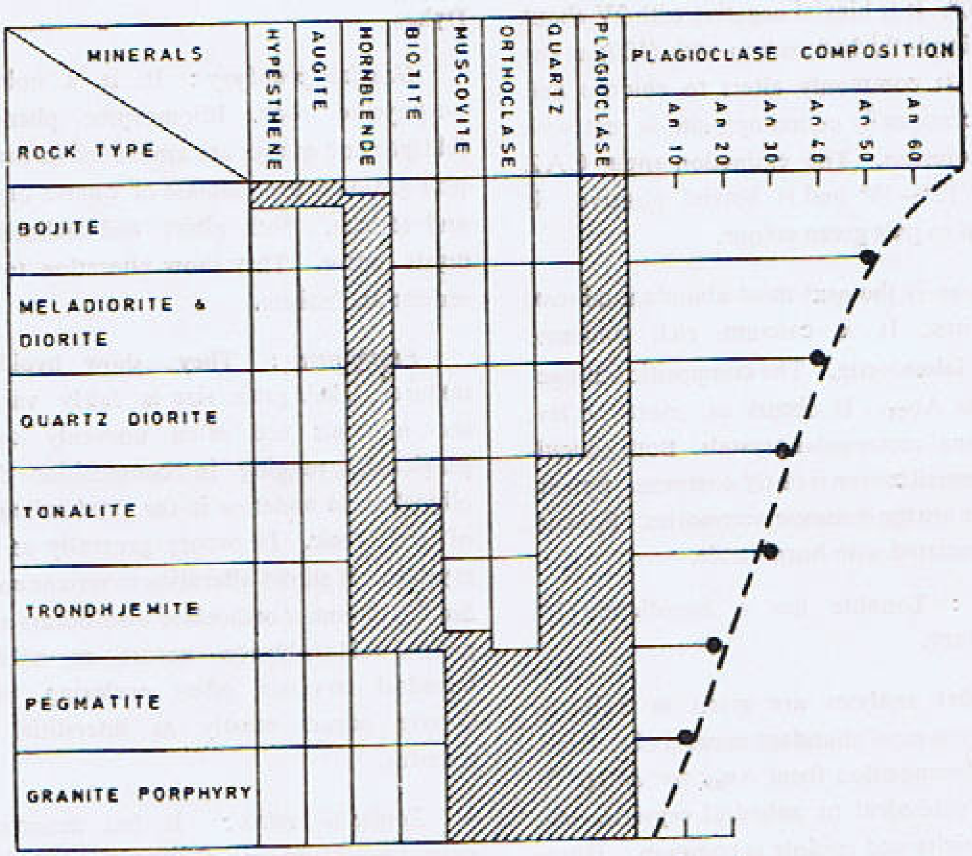


Fig. 13 Mineralogical Variation in Dioritic Intrusion (Trondhjemite is also plotted)

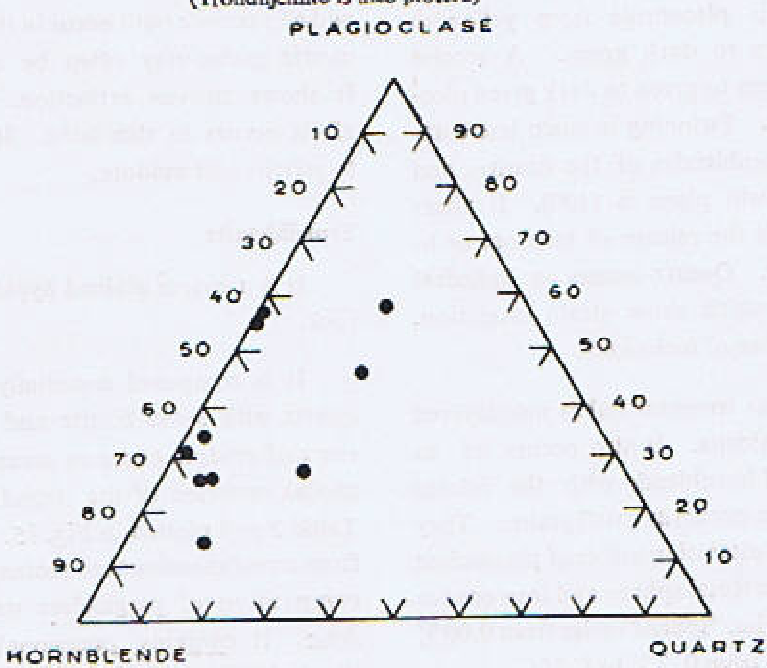


Fig. 14 Modal Analyses of 10 Samples of Diorites Recalculated to 100%

from 15°–20°. It is biaxial negative with 2V about 80°. Twinning is fairly common with (100) as the twin plane. It commonly alters to chlorite and epidote. Occasionally cummingtonite is met with in the meladiorites. The extinction angle C∧Z varies from 10°–18° and is biaxial positive. It shows neutral to pale green colour.

Plagioclase is the next most abundant mineral of the diorites. It is calcium rich andesine approaching labradorite. The composition ranges from An_{41} to An_{91}. It occurs as more or less equidimensional rectangular crystals. Both sericitization and sassuritization is fairly common. Sphene and magnetite are the common accessories. Sphene is usually associated with hornblende.

Tonalite : Tonalite has a hypidiomorphic granular texture.

The modal analyses are given in Table 3. Plagioclase is the most abundant mineral of tonalite. It ranges in composition from An_{30} to An_{44}. It occurs from subhedral to anhedral crystals. Alteration to sericite and epidote is common. Hornblende occurs as prismatic crystals often with irregular outline. It is pleochroic from yellowish green to olive green to dark green. A second variety with pale green to green to dark green pleochroism also occurs. Twinning is much less common than in the hornblendes of the diorites and meladiorites. The twin plane is (100). It alters either to biotite with the release of iron ore or to chlorite and epidote. Quartz occurs as anhedral seggregated grains which show strain extinction. Quartz is generally free of inclusions.

Biotite occurs as irregular flakes interlayered with muscovite or chlorite. It also occurs as an alteration product of hornblende with the release of iron ore. Epidote occurs as small grains. They are derived from the alteration either of plagioclase or hornblende. Interstitial sphene and iron ore are the common accessories. Sphene varies from 0.00% to 1.5% and epidote from 0.2% to 8.5%.

Dykes

Granite prophyry : It is a holocrystalline porphyritic rock. Idiomorphic phenocrysts of feldspar and quartz are embedded in the xenomorphic granular groundmass of quartz or orthoclase and sericite. Both albite and orthoclase phenocrysts occur. They show alteration to kaolinite, sericite and zoisite.

Pegmatites : They show hypidiomorphic texture. Their grain size is fairly variable and the minerals are often unevenly seggregated. Plagioclase ranging in composition from high oligoclase to andesine is the predominant mineral of the rock. It occurs generally as subhedral crystals. It shows alteration to sericite and epidote. Small amount of orthoclase also occurs as anhedral grains. Hornblende occurs as subhedral to anhedral crystals often enclosing plagioclase. Quartz occurs mostly as interstitial pools of anhedra.

Epidosite viens : It has xenomorphic to sievelike texture. It is composed exclusively of epidote and quartz with minor plagioclase. Zoisite and clinozoisite both occur in these veins. Anhedral quartz grains may often be enclosed in epidote. It shows uneven extinction. Minor amount of albite occurs as slim laths. It is strongly altered to sericite and epidote.

Trondhjemite

It is a coarse grained hypidiomorphic granular rock.

It is composed essentially of plagioclase and quartz with some biotite and hornblende. Chlorite and epidote occur as accessory minerals. The modal variation of the trondhjemite is shown in Table 3 and plotted in Fig. 15. Plagioclase occurs from equidimensional to rectangular crystals. The composition of plagioclase varies from An_{30} to An_{42}. It contains occasional quartz inclusions. Plagioclase shows alteration to sericite and epidote.

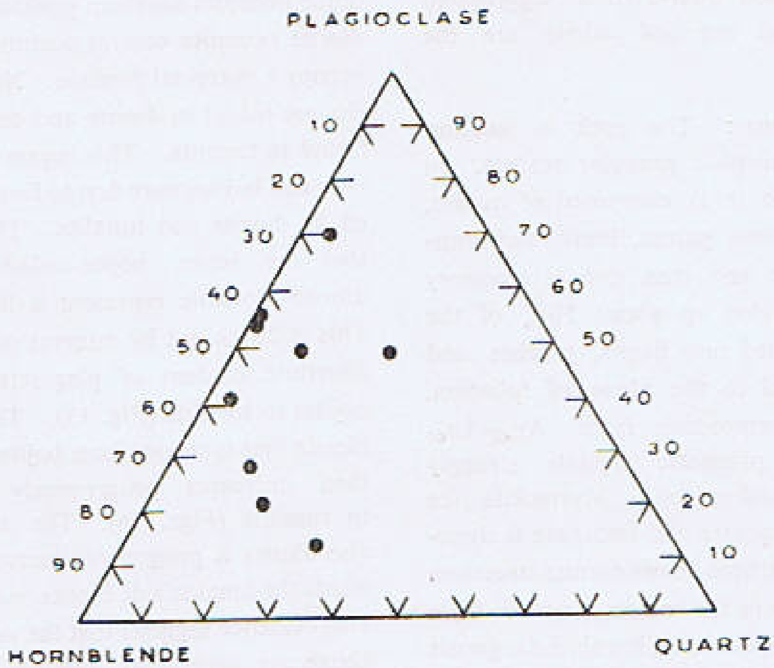


Fig. 15 Modal Analyses of 9 Samples of Trondhjemite Recalculated to 100%

Alteration to clay is rare. Sometimes the plagioclase crystals are entirely replaced by epidote and sericite or muscovite. Alkali feldspars are absent. Quartz occurs as seggregated anhedra interstitial to plagioclase. Quartz is free of inclusions and shows straight extinction.

Hornblende occurs as euhdral to subhedral crystals. Both simple and repeated twinning (on) (100) are observed. It is strongly pleochroic from pale yellow to dark green. Extinction angle C∧Z is from 15° to 20°. It alters to biotite, epidote chlorite and magnetite. Biotite occurs as spindle shaped to irregular flakes. It is strongly pleochroic from light brown to dark brown although rarely greenish brown biotite is also found. It commonly alters to chlorite. Leucoxene, iron ore and sphene are the common accessories.

Amphibolites

The amphibolites have been subdivided into two types, the epidote amphibolite and the plagioclase amphibolite. The petrography of each type is given below :—

Epidote Amphibolite : It has hypidioblastic granular texture. The hornblende crystals show preffered orientation and lie parallel to the schistosity plane. The rock is composed of hornblende and epidote with or without some plagioclase. Hornblende shows rough crystal boundries. Extinction angle C∧Z is 18° with 2 V nearly 55°. Inclusions of epidote occur in hornblende. Both zoisite and clinozoisite occur. Plagioclase has a composition close to An_{45}. Calcite and sphene may occur as accessories, but the latter is rare.

Plagioclase Amphibolite : It shows hypidioblastic texture. Hornblende occurs as subhedral to anhedral crystals with abundant inclusions of quartz and iron ore. Sometimes cummingtonite is also encountered. Plagioclase occurs as subhedral grains. It shows both albite and pericline twinning. Its composition is about

An_{45}. Plagioclase and quartz form seggregated bands. Sphene, iron ore and calcite are the accessories.

Assimilation Zone : The rock is medium grained with xenomorphic granular texture. In order of abundance it is composed of quartz, plagioclase, hypersthene, garnet, biotite and hornblende with epidote and iron ore as accessory minerals. Quartz makes up about 50% of the rock. It is seggregated into bands, patches and layers mostly parallel to the plane of foliation. Plagioclase with composition from An_{48}-An_{60} occurs as subhedral prismatic crystals strongly altered to epidote and sericite. Myrmekite like intergrowth between quartz and feldspare is sometimes present. Hypersthene shows corona structure. Sequence of minerals in the corona structure, from centre outwards, is hypersthene, hornblende, garnet and plagioclase. At other places hypersthene is rimmed by hornblende with inclusions of plagioclase.

Biotite and hornblende both occur either as reaction rims or as independent crystals. Pink and slightly altered garnet is developing at the expense of biotite. Magnetite or ilmenomagnetite is often rimmed with hornblende and sometimes biotite. Epidote occurs as an alteration product of plagioclase and sometimes hornblende.

PETROGENESIS

There are two main intrusive rock series in the area namely diorites and its differentiates and norites and its differentiates. There is ample evidence to suggest that the diorite body is older than norite and trondhjemite intrusions. Dykes and apophyses of norite in trondhjemite and diorite suggest that norite is younger than both the trondhjemite and diorite.

The Diorite Complex

The diorite intusive consists of main diorite and a number of related facies like bojite, meladiorite, quartz diorite and tonalite. In the diorite intrusion, bojite occupies southern position, diorite and meladiorite occupies central position whereas tonalites occupy a marginal position. Xenoliths of meladiorite are found in diorite and diorite xenoliths were found in tonalite. This suggests that the meladiorites and bojites were first to form and were followed by diorite and tonalite. This further suggests that the series bojite-meladiorite-diorite-quartz diorite—tonalite represent a differentiation series. This is borne out by mineralogical evidence. The anorthite content of plagioclase decreases from bojites to tonalite (Fig. 13). The content of hornblende first increases from bojite to meladiorite and then decreases progressively through diorites to tonalite (Figs. 16). The amount of quartz also shows a progressive increase (Fig. 17). Towards the tonalite side biotite, makes its appearance. This evidence suggests that the various facies named above are genetically related and represent a differentition series.

Plagioclase and pyroxene were the earliest phases to precipitate. They were followed by hornblende and then biotite in the tonalites. Epidote and chlorite are late deuteric minerals. High anorthite content with some decrease towards tonalite along with predominant hornblende in the earlier phases and increasing quartz in the later phases, indicate high alumina, silica and lime contents of the original magma. Paucity of alkali feldspar indicates very low potash contents. There is considerable petrographic evidence to suggest that pyroxene was present in bojites and perhaps in meladiorites most of which was later transformed to hornblende. All the above evidences suggest that the diorite intrusion along with its differentiate was of basalt—andesite—rhyolite association. This magma underwent crystallisation differentation. There was a progressive decrease in the anorthite content of plagioclase from bojites to tonalites. Pyroxene was the first mineral to form. It was soon followed by hornblende. Earlier pyroxene of the now bojites, was converted to hornblende. The quantity of hornblende decreases from meladiorites to tonalites.

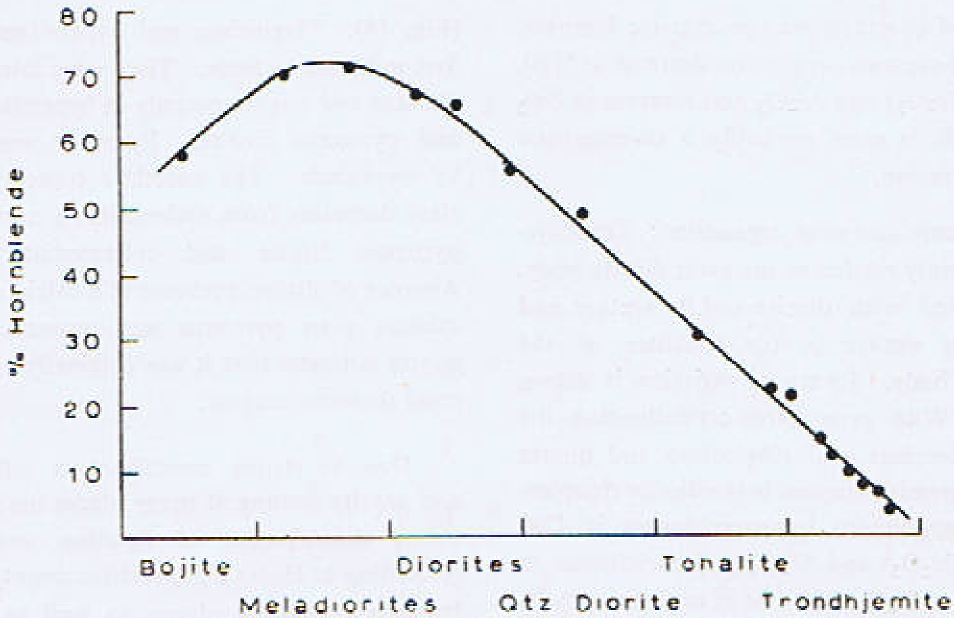


Fig. 16. Modal Variation of Hornblende in Diorite Intrusion.
(Trondhjemite is also plotted)

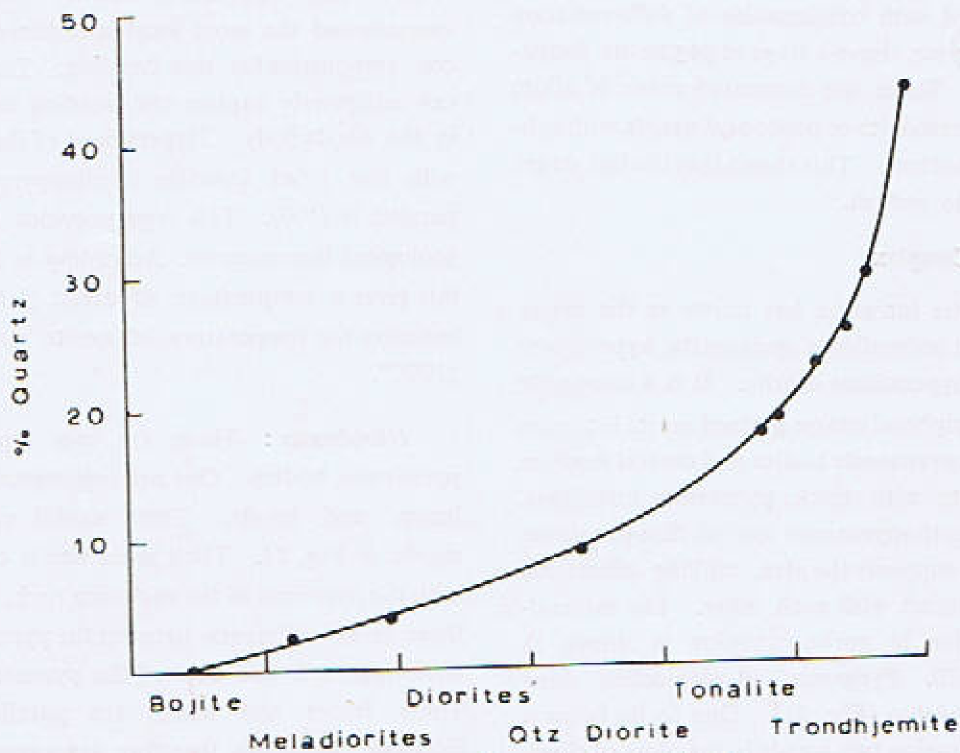


Fig. 17. Modal Variation of Quartz in Diorite Intrusion.
(Trondhjemite is also plotted)

The amount of quartz shows a progressive increase. This sequence suggests progressive decrease in Mg0, Ca0, (Fe0+Fe_2O_3) and Al_2O_3 and increase in $Si0_2$ and Na_2O. It is most probably a co-magmatic composite intrusion.

Trondhjemite and acid pegmatites : Trondhjemite is genetically related to the main diorite body. It is associated with diorite and its texture and mineralogy is similar to the tonalites of the main dioritic body. Its modal variation is shown in Fig. 14. With progressive crystallisation the hornblende decrease and plagioclase and quartz register a progressive increase in the diorite complex. This entails continuous improverishment in Ca0 Mg0, (Fe0+Fe_2O_3) and Al_2O_3 and enrichment in Na_2O, SiO_2, and K_2O. This line of evolution resulted in the formation of the progressive series i.e. bojitemeladiorite—diorite—-quartz diorite—tonalite. With further decrease in Mg0, Ca0, and (Fe0+Fe_2O_3) and increase in $Si0_2$, Na_2O and K_2O tonalites give rise to trondhjemite. The formation of trondhjemites and with continuation of differentiation on the lines given above a stage of pegmatite formation ensues. These are composed either of albite quartz and muscovite or albite and quartz with subordinate orthoclase. This shows that the last stages were richest in potash.

The Norite Complex

The norite intrusion has norite as the major member with subordinate melanorite, hypersthene gabbro and hypersthene diorite. It is a composite body with peripheral coarse grained norite intrusion lacking thick pyroxenite bodies and central medium grained norite with thick pyroxenite intrusions. The plot of orthopyroxenes against clinopyroxenes (Fig. 18) also supports the idea. chilling effects are lacking at contact with each other. The mineralogical variation in norite intrusion is shown in Fig. 19 and 20. Pyroxene and plagioclase show inverse relationship (Fig. 21). Due to its being a composite intrusion two trends in the plots of clinopyroxene against orthopyroxene can be seen (Fig. 18). Plagioclase and hypersthene were the first minerals to form. They were later joined by diallage and augite specially in hypersthene gabbro and pyroxene diorite. Pyroxene was followed by amphibole. The anorthite content of plagioclase decreases from melanorite to norite, gabbro, pyroxene diorite and intermediate pegmatite. Absence of olivine, presence of a calcium rich and a calcium poor pyroxene and presence of minor quartz indicates that it was originally an oversaturated tholeiitic magma.

Due to strong crystallisation differentiation and gravity settling at many places the rock shows strong development of banding and layering. According to Hess (1938) relative density difference between crystalline phases as well as crystalline phases and magma and short epoches of mild but irregular turbulances is a cause of banding. Turner and Verhoogen (1960) regard slow and continuous emplacement of a magma sheet fed by several sources and subsequent activity of convection currents and the more local intermittent turbulences responsible for this banding. These reasons can adequately explain the banding and layering in the norite body. Hypersthene of Bushveld type with fine ruled lamellae of clinopyroxene occur parallel to (100). This type provides a valuable geological thermometer. According to Hess (1938) this gives a temperature of about 1100 c°. This indicates the temperature of norite magma above 1100C°.

Ultrabasics : There are two types of the pyroxenite bodies. One are seggregated pyroxene lenses and bands. Their modal variation is shown in Fig. 24. Their grain size is comparable with the pyroxene of the enclosing rock. Moreover there is no difference between the pyroxene of the enclosing rock and that of the pyroxenite lenses. These lenses and bands are parallel to the foliation. These are, therefore, seggregated pyroxenite bodies.

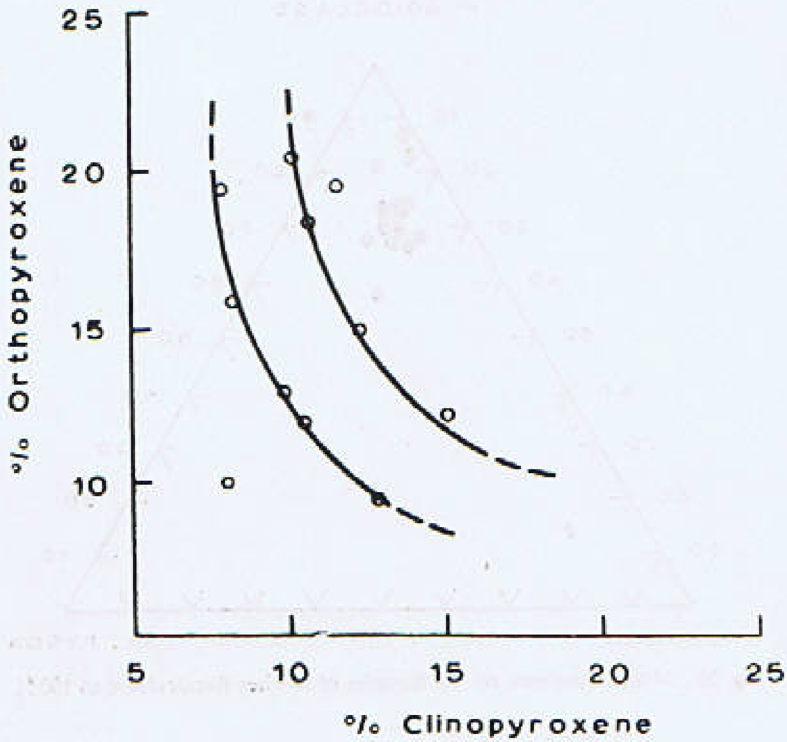


Fig. 18 Modal Variation of Orthopyroxene in Relation to Clinopyroxene in Norites and Gabbros

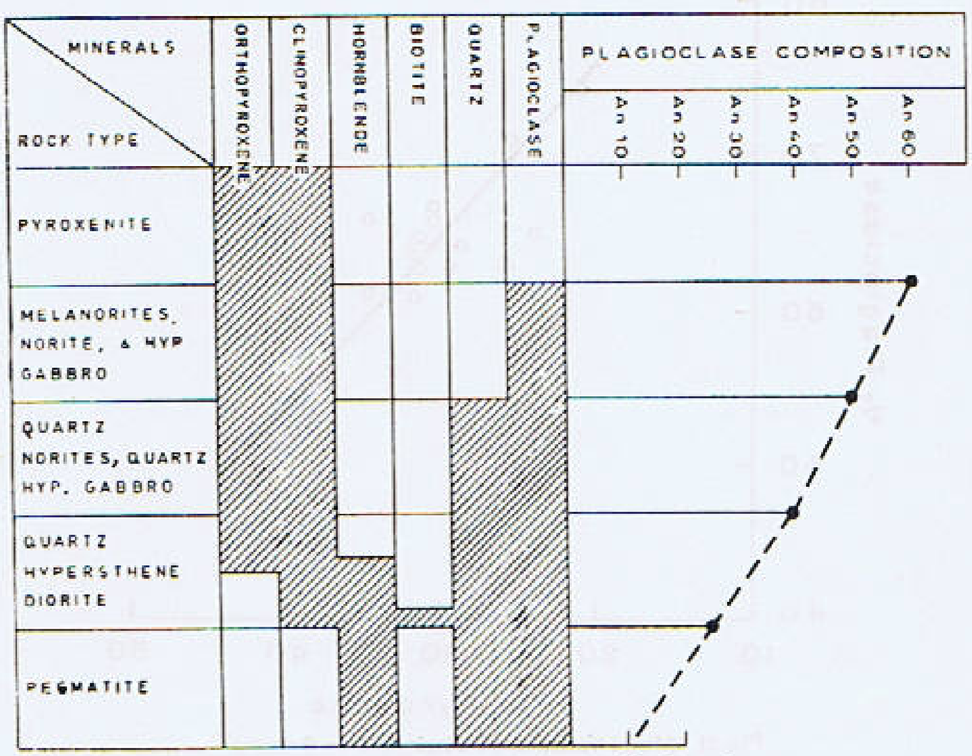


Fig. 19 Mineralogical Variation in Noritic Intrusion

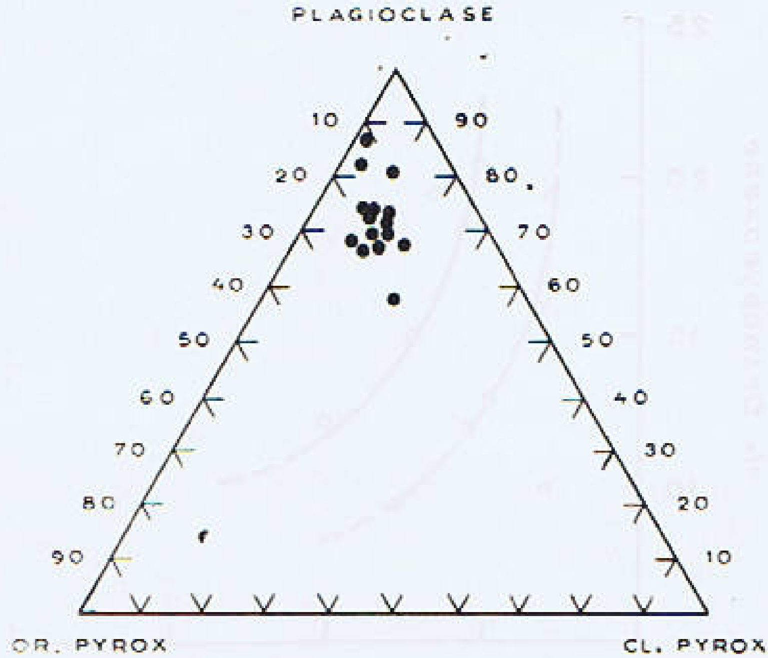


Fig. 20 Modal Analyses of 16 Samples of Norites Recalculated to 100%

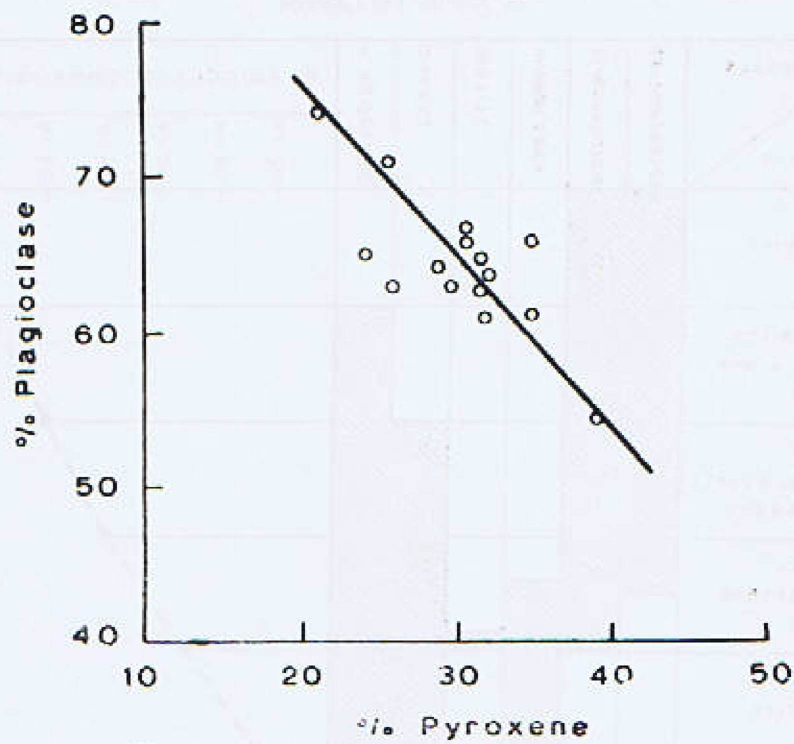


Fig. 21 Modal Variation of Plagioclase in Relation to Pyroxene in Norites and Gabbros

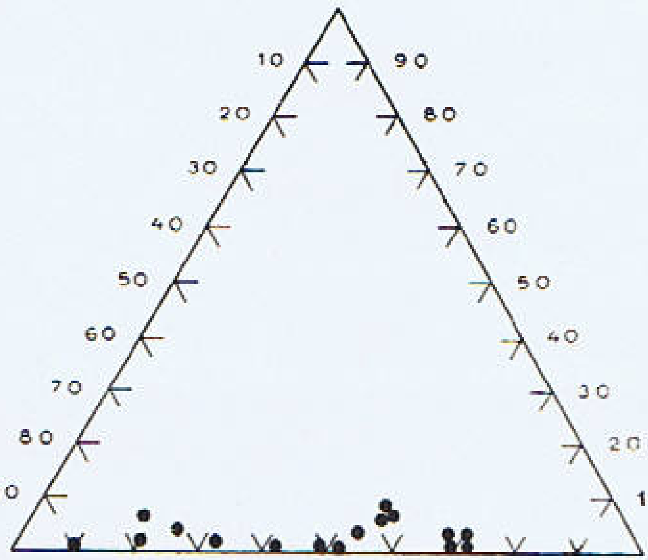


Fig. 22. Modal Analyses of 16 Samples of Pyroxenites Recalculated to 100%

However the big oval shaped pyroxenite bodies are different. They have sharp contact with the enclosing rock and are associated with medium grained norite. Their grain size is very coarse. This suggests that they have not formed in situ. They are later intrusives which have formed from material derived from some deeper seat. In the case of some pyroxenites the surrounding rock's foliation curves around this. This indicates that they are most probably screens picked up from some deeper pyroxenite body formed due to differentiation at deeper levels.

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METASOMATISM OF META-DOLERITE AT CONTACT WITH THE MELDON APLITE IN THE GRANULITE QUARRIES, DEVONSHIRE, ENGLAND

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Abstract : *Metamorphic and metasomatic effects are described in a meta-dolerite dyke at contact with a sodium and lithium rich aplite dyke, commonly known as the Meldon aplite dyke. The mineral assemblage hornblende—plagioclase has been replaced by garnet-pyroxene-axinite-pyrrhotite, amphibole-axinite-pyrrhotite and axinite-calcite-chlorite-muscovite-quartz assemblages. During this transformation an overall addition of calcium, mangenese, boron, ferrous iron and carbon and an overall depletion in silicon, aluminium, titanium, sodium, ferric-iron, magnesium, phosphorous and sulphur has taken place.*

INTRODUCTION

The Meldon aplite, near Okehampton, is a sodium and lithium-rich aplite dyke about 60 to 80 feet in thickness, which occurs three quarters of a mile northwest of the main Dartmoor granite (Worth, 1920). In the Meldon aplite quarries (commonly known as the granulite quarries) south of the main Railway Quarries, it forms contact skarns with a meta-dolerite dyke and calcareous shales to the south, with calc-flintas (meta-sedimentary rocks with alternating calcareous and siliceous bands) to the northeast and with the calcareous shales to the northwest. Albite, quartz, lepidolite and orthoclase are the essential minerals and elbaite, topaz, fluorite, apatite and petalite are the accessory minerals of the aplite. The skarn formation in calcareous shales and calc-flintas is very poor and may even be absent at places. The maximum development, both in extent and in variety of mineral assemblage, is taking place in the metadolerite dyke. This paper deals with these skarns only. The skarn formation starts at contact and along joint faces and works its way outwards. The skarns range from a few inches to about 6 feet in maximum thickness.

PETROGRAPHY

Metadolerite

It is a compact, medium-grained buff to brownish black rock. Heavily altered, sericitised and kaolinised plagioclase occurs as subhedral to euhedral laths. Plagioclase makes up from 50% to 70% of the whole rock. Petrographic methods indicate a composition varying from An_{45} to An_{38}. The second most important mineral is a light green and poorly pleochroic amphibole. It occurs as short columnar crystals often intergrown with and occasionally enclosed by plagioclase. It shows oblique extinction with c $\wedge$ γ or Z from 15°–26°. It makes up from 30% to 40% of the rock. Sphene, pyrrhotite and magnetite are important accessory minerals. Sphene occurs as individual crystals as well as aggregates. It makes up from 3% to 4% of the whole rock. Pyrrhotite varies from 1% to 3%. Its concentration is more close to joints than away from them. Specks and finely divided anhedra of magnetite make up X 2% to 3% of the rock. Occasionally a few grains of calcite, quartz, epidote and possibly axinite may also occur. Just outside the skarn, dolerite assumes a light-pink colour upto a few inches due to excessive concentration of sphene. Here the concentration of sphene may be as high as 10%.

The Skarns

The metamorphosed and metasomatised metadolerite is termed as "skarn" here. Depending upon their mineralogical composition and their degree of metamorphism three broad subdivisions are made. The minerals combination in each of the classes indicates all the important minerals that may occur in that class. The proportions in which the various minerals may occur is highly variable. The classes are as follows :

(1) Garnet-Pyroxene-Pyrrhotite-Axinite-Skarn

(2) Amphibole-Axinite-Pyrrhotite-Skarn

(3) Axinite-Calcite-Muscovite-Chlorite-Quartz-Skarn.

These classes have been arranged in order of their decreasing temperatures of formation. They form very irregular lithologic units varying widely in their thickness from place to place. Not all the classes may be present in a given cross-section. The classes are very heterogeneous both in their quantitative mineral compositions as well as their textures.

(1) Garnet-Pyroxene-Pyrrhotite-Axinite-Skarn

The garnet-pyroxene-pyrrhotite-axinite-skarn is very irregular both in its thickness as well as its lateral continuity. At many places along the contact it is absent altogether. It varies in colour from buff to tan. This skarn is coarse-grained with very uneven segregation of its component minerals. Locally due to the abundant development of pyrrhotite, they assume a tarnished bronze colour. The following mineral assemblages, which are transitional, generally occur.

(1) Hedenbergite—garnet—pyrrhotite.

(2) Diopside—garnet — pyrrhotite — (axinite-sphene)

(3) Diopside—axinite — pyrrhotite — (garnet-sphene)

(4) Diopside-axinite—(pyrrhotite-amphibole)

The minerals enclosed within brackets are ubiquitous in their relevent assemblages, but generally occur in minor amounts. The first assemblage is rare and occurs very close to the contact. The third assemblage is derived from the second by replacement of garnet and to a lesser extent of pyroxene by axinite. The last assemblage is transitional to amphibole-axinite-pyrrhotite skarn.

Hedenbergite generally occurs as aggregations of subhedral to anhedral crystals, light green in colour and non-pleochroic. Andradite and grossularite both occur. Grossularite is, however, by far the commoner of the two. Close to the contact garnet occurs as aggregates of small crystals, but away from the contact it occurs (grossularite) as big and somewhat anisotropic porphyroblasts. Axinite occurs in very variable amounts. In some cases it may make up as much as one third of the rock whereas in others it may assume the status of an accessory. Axinite occurs either as typical wedge shaped crystals or as stringer like and xenomorphic forms, replacing, working into and even enclosing garnet and to a lesser extent pyroxene as well. In cases of extreme replacement of garnet only irregular bits of garnet are left enclosed in axinite porphyroblasts. The axinite varies in colour from almost brownish black to medium brown. Pyrrhotite replaces all other minerals. It varies from less than 1% to almost 30% in some cases. Its extreme concentrations are rare and confined very close to the contact. It may alter to limonite, haematite and even to thin films of malachite. sphene, calcite, quartz and chlorite may occur at places.

(2) Amphibole - Axinite - Pyrrhotite - Skarn

It develops on a much larger scale than the garnet - pyroxene - pyrrhotite - axinite-skarn. The amphibole-axinite-pyrrhotite-skarn shows a marked tendency towards the segregation of their two chief constituents, namely the axinite and the amphibole. They segregate into patches, streaks and irregular bands. These segregations range from a few millimetres to an observed maximum of 8 cms. Sometimes this segregation is so strong that the individual aggregates may consist of more than 80% of one of the two main minerals. The amphibole rich aggregates may contain appreciable group amounts of pyrrhotite. The amphibole belongs to the hornblende series. It is medium to dark green in colour and strongly pleochroic with X yellow green γ green and Z dark green. The extinction c $\wedge$ γ or Z ranges from 15° to 27°. The axinite occurring in this skarn is lighter in colour more euhedral, less poikilitic, more often twinned and zoned than the axinite occuring in the garnet-pyroxene-pyrrhotite-axinite-skarn. Aggregates of quartz and calcite may occur in certain parts, close to the contact with the aplite. Brown to greenish brown sphene occurs as an accessory. Epidote groups minerals are rare.

(3) Axinite-Calcite-Muscovite-Chlorite-Quartz-Skarn

These skarns represent the lowest temperature metamorphic- metasomatic reconstitution. They, on the inside, merge into the amphibole-axinite-pyrrhotite skarn and on the outside they split into veins which eventually merge into the metadolerite. These skarns are parti-coloured; white, light green and pink colours appear due to the irregular and poor local segregated development of calcite, mica, chlorite and axinite. A very wide range of variation in their mineral contents is the most striking feature of these rocks. Some rocks are almost monomineralic consisting of axinite, whereas in others axinite may well be exceeded by some combination of calcite, muscovite, chlorite and quartz in varying proportions. The contents of calcite, muscovite, chlorite and quartz show large variations. One or more of these minerals may assume the status of an accessory mineral.

Axinite occurs as subhedral to euhedral poikilitic crystals of pink to light brown colour. The inclusions consist of subhedral to euhedral quartz and sphericules of chlorite and mica. Both chlorite and mica occur as sphericular aggregates. These sphericules show best development in the calcite patches. They are suppressed against axinite and quartz. The sphericules of mica and chlorite are either closely associated or intergrown with each other. The chlorite occurs in various shades of green to yellow green. It shows strong to moderate pleochroism from light green to green. Some varieties show normal first order colours whereas the other show anomalous pale and blue interference colours. Calcite occurs as patches, veins as well as coarse plates.

CHEMICAL CHANGES DURING METASOMATISM

The rocks were analysed by standard wet chemical techniques. Boron was determined by the titrimetric method of Kramer (1955). Twelve chemical analyses, one of the metadolerite, one of the sphene rich front in meta-dolerite, six of the axinite-calcite - muscovite - chlorite - quartz skarns, three of the amphibole-axinite-pyrrhotite-skarns and one of the garnet-pyroxene-axinite-pyrrhotite skarn are presented in Table 1. The metadolerite sample MN 25 has been selected to represent approximately the composition of the parent rock which has been converted to skarns on metamorphism and metasomatism. The chemical gains and losses during this transformation relative to MN 25 have been calculated following the method used by Barth (1952). The method consists of comparing the cations of the standard cell of the reconstituted rock compositions to the original rock composition. The cations of the standard cell are the cations associated with 160 oxygens. All the cationic gains and losses during reconstitution have been calculated with respect to the parent rock represented by the sample MN 25. The numbers of cations in the unit cell are listed in Table 2 and the cationic gains and losses are given in Table 3. The cationic gains and losses in the various classes are given below.

Sphene—rich front in metadolerite

The sphene-rich front occurring just outside the main metamorphic aureole shows a large enrichment in Ca and lesser enrichment in Ti, H, B and Mn^{2+}. It shows depletion in Si, Al, Fe^{2+}, Fe^{3+}, Na, S and P.

(3) Axinite-Calcite-Muscovite-Chlorite-Quartz-Skarn

All the six samples of this skarn show an enrichment in Mn^{2+}, H, B and a depletion in Ti, Fe^{3+}, Na, P and S. Four out of the six samples in each case show gains and two samples show losses in K and Fe^{2+}. This skarn appears to show an overall enrichment in K and Fe^{2+}. They also show an overall loss in Si, Al, Mg and an overall enrichment in Ca. Summing up this unit has been enriched in Mn^{2+}, H, B, C and Ca and depleted in Ti, Fe^{3+}, Na, Si, Al, Mg, P and S. The contents of K and Fe^{2+} have most likely increased.

Key to Table 1

MN 25.	Buff coloured metadolerite from the top of the southern edge of the southern granulite quarry.
MN 29.	Pinkish gray sphene-rich dolerite just outside the main metamorphic-metasomatic aureole.
M 80.	Axinite - calcite - muscovite - chlorite-quartz skarn. This sample represents quartz-rich skarn which is poor in chlorite.
MN 312.	Axinite - calcite - muscovite - chlorite-quartz-skarn. This sample represents extreme concentration of axinite.
MN 398.	Axinite - calcite - muscovite - chlorite-quartz-skarn. This rock is composed chiefly of axinite and chlorite.
M 9.	Axinite - calcite - muscovite - chlorite-quartz-skarn. This rock is composed chiefly of axinite and muscovite with some chlorite.
M 83 & M 9 B.	Axinite - calcite - muscovite - chlorite-quartz-skarn. The rocks are composed chiefly of axinite and calcite with lesser amounts of muscovite and some chlorite.
MN 313 & MN 315.	Amphibole - axinite - pyrrhotite-skarn. These samples are from amphibole rich bands which consist of more than 90% of amphibole. MN 313 contains some free quartz. MN 315 contain more than 5% pyrrhotite.
MN 397.	Amphibole-axinite-pyrrhotite-skarn.
G-H-S	Garnet-pyroxene-axinite skarn. The garnet is grossularite and the pyroxene is diopsidic augite (?).

TABLE I

Chemical analyses of metadolerites and skarns

Samp. No.	MN25	MN29	M80	MN312	MN398	M9	M83	M9B	MN313	MN315	MN397	G-H-S
SiO_2	47.91	43.20	64.98	42.48	41.69	40.49	36.58	32.70	54.13	49.88	43.16	42.52
TiO_2	1.99	3.79	0.06	0.06	0.44	0.00	1.70	1.84	0.37	0.69	0.15	0.37
Al_2O_3	18.48	16.89	8.79	17.43	17.02	19.06	13.40	15.52	14.50	4.82	8.72	14.18
Fe_2O_3	3.87	1.90	1.06	0.87	0.93	1.91	0.69	1.98	1.15	2.69	1.31	2.61
FeO	5.79	3.11	8.59	8.04	5.68	6.46	5.12	6.66	6.01	18.24	9.85	8.78
MgO	4.73	5.19	0.90	1.72	6.99	2.82	3.98	3.02	7.73	11.50	13.62	7.78
CaO	10.35	20.82	7.10	19.20	17.92	19.57	24.04	19.94	9.22	9.02	18.51	20.80
Na_2O	2.91	1.60	0.15	0.08	0.10	0.19	0.21	0.19	1.54	0.13	0.19	0.15
K_2O	0.51	0.45	0.85	0.40	0.09	1.94	0.88	1.94	0.60	0.05	0.13	0.04
MnO	0.62	0.85	1.66	3.93	3.33	2.20	2.14	2.13	0.12	0.33	1.93	2.10
H_2O^+	0.96	1.21	1.08	1.14	1.25	1.87	2.03	1.87	2.68	0.91	0.81	0.33
H_2O^-	0.13	0.13	0.18	0.09	0.16	0.16	0.20	0.16	0.21	0.06	0.07	0.08
B_2O_3	0.10	0.28	3.12	4.57	3.92	3.08	3.01	2.99	0.06	0.08	1.13	0.33
S	1.08	0.21	0.38	0.21	0.50	0.12	0.23	0.16	0.30	2.90	0.43	0.31
P_2O_5	0.64	0.03	0.08	0.03	0.26	0.07	0.08	0.07	0.00	0.02	0.09	0.04
CO_2	0.25	0.31	1.66	0.26	0.33	0.42	5.89	9.02	0.28	0.09	0.41	.015
$S \equiv O$	100.32 −0.54	99.97 −0.11	100.64 −0.19	100.51 −0.11	100.61 −0.25	100.36 −0.06	100.18 −0.13	100.19 −0.08	99.30 −0.15	101.41 −1.45	100.50 −0.21	100.57 —0.17
Total	99.78	99.86	100.45	100.40	100.36	100.30	100.05	100.11	99.15	99.96	100.29	100.40

Analyst : M. Nawaz Chaudhry.

TABLE 2

Number of cations associated with 160 oxygens

Sample No.	MN25	MN29	M80	MN312	MN398	M9	M83	M9B	MN313	MN315	MN397	G-H-S
Si	45.09	41.80	57.9	40.66	39.42	38.93	34.43	30.49	49.41	48.73	42.77	42.57
Ti	1.41	2.76	0.04	0.05	0.31	0.00	1.20	1.29	0.25	0.50	0.11	0.28
Al	20.50	19.27	9.10	19.66	18.97	21.60	14.86	17.06	16.03	5.55	10.18	16.74
Fe^{3+}	2.74	1.38	0.70	0.62	0.66	1.39	0.49	1.39	0.79	1.97	0.98	1.96
Fe^{2+}	4.56	2.52	6.31	6.44	4.49	5.19	4.03	5.20	4.59	14.91	8.17	7.35
Mg	6.63	7.48	1.18	2.46	9.85	4.04	5.58	4.20	10.52	16.74	20.12	11.61
CaO	10.44	21.59	16.68	19.70	18.15	20.16	24.25	19.93	9.02	9.44	19.66	22.32
Na	5.31	3.00	0.25	0.15	0.18	0.36	0.38	0.35	2.72	0.25	0.37	0.29
K	0.61	0.56	0.95	0.48	0.11	2.38	1.05	2.31	0.70	0.06	0.17	0.05
Mn^{2+}	0.49	0.70	1.24	3.19	2.66	1.79	1.71	1.69	0.09	0.28	1.62	1.78
H	6.03	7.81	6.33	7.28	7.89	11.99	12.75	11.64	16.32	5.93	5.36	2.20
B	0.16	0.47	4.73	7.55	6.40	5.11	4.89	4.80	0.10	0.13	1.93	0.57
S	1.91	0.38	0.63	0.37	0.88	0.21	0.41	0.28	0.52	5.31	0.80	0.58
P	0.51	0.02	0.06	0.02	0.20	0.06	0.07	0.06	0.00	0.01	0.07	0.04
C	0.32	0.41	1.99	0.34	0.43	0.55	7.57	11.49	0.35	0.12	0.55	0.20
Total	106.71	110.15	97.28	108.97	110.61	113.76	113.67	112.18	111.41	109.93	112.86	108.54

TABLE 3

Catonic gains and losses with respect to MN 25

Sample No.	MN29	M80	MN312	MN398	M9	M83	M9B	MN313	MN315	MN397	G-H-S
Si	−3.29	+12.00	−4.43	−5.67	−6.16	−10.66	−14.59	+4.32	+3.64	−2.32	−2.52
Ti	+1.35	−1.37	−1.36	−1.10	−1.41	−0.20	−0.12	−1.16	−0.90	−1.30	−1.13
Al	−1.23	−11.39	−0.84	−1.53	+1.10	−5.63	−3.44	−4.47	−14.94	−10.31	−3.76
Fe^{3+}	−1.35	−2.04	−2.12	−2.08	−1.35	−2.25	−1.35	−1.95	−0.76	−1.76	−0.78
Fe^{2+}	−2.04	+1.76	+1.88	−0.06	+0.64	−0.53	+0.64	+0.03	+10.35	+3.61	+2.79
Mg	+0.85	−5.46	−4.18	+3.22	−2.60	−1.05	−2.44	+3.88	+10.11	+13.48	+4.98
Ca	+11.15	−3.76	+9.25	+7.71	+9.72	+13.81	+9.49	−1.42	−1.00	+9.22	+11.98
Na	−2.31	−5.05	−5.16	−5.12	−4.95	−4.92	−4.96	−2.58	−5.06	−4.94	−5.02
K	+0.05	+0.34	−0.13	−0.50	+1.77	+0.44	+1.70	+0.09	−0.55	−0.44	−0.56
Mn^{2+}	+0.21	+0.74	+2.69	+2.17	+1.30	+1.22	+1.20	−0.40	−0.22	+1.13	+1.29
H	+1.79	+0.30	+1.25	+1.86	+5.97	+6.72	+5.61	+10.30	−0.10	−0.67	−3.83
B	+0.31	+4.57	+7.39	+6.24	+4.95	+4.73	+4.64	−0.06	−0.03	+1.77	+0.41
S	−1.53	−1.28	−1.53	−1.02	−1.69	−1.50	−1.63	−1.39	+3.40	−1.11	−1.32
P	−0.49	−0.45	−0.49	−0.30	−0.45	−0.44	−0.45	−0.51	−0.50	−0.44	−0.47
C	+0.08	+1.67	+0.02	+0.10	+0.23	+7.25	+11.17	+0.03	−0.21	+0.23	−0.12
Total	+3.55	−9.42	+2.24	+3.92	+7.07	+6.99	+5.47	+4.71	+3.23	+6.15	+1.84

(2) Amphibole-Axinite-Pyrrhotite-Skarn.

All the three samples show a gain in Fe^{2+} and Mg and a loss in Ti, Al, Fe^{3+} and Na. The gains and losses of other cations can be seen from Table 3.

(1) Garnet-pyroxene-pyrrhotite-axinite-skarn.

Only one analysis of the garnet-pyroxene-pyrrhotite - axinite - skarn is presented. It shows a depletion in Si, Ti, Al, Fe^{3+}, Na, K, H, P and C and enrichment in Fe^{2+}, Mg, Ca, Mn^{2+} and B.

If all the metamorphosed-metasomatised classes are grouped together the following gains and losses may be recognised. There is an overall gain in B, Fe^{2+}, Ca, Mn^{2+}, C and H and a loss in Si, Ti, Al, Fe^{+3}, S, P and Na. K seems to have moved out of the garnet - pyroxene - pyrrhotite - axinite skarn and amphibole-axinite-pyrrhotite-skarn and concentrated in the axinite-calcite-muscovite-chlorite-quartz-skarn. Mg seems to have been added to garnet - pyroxene - pyrrhotite - axinite - skarn and the amphibole - axinite - pyrrhotite - skarn. But it has been removed to a fair extent from most of the axinite-calcite-muscovite-chlorite-quartz-skarn.

DISCUSSION

There is sufficient evidence to show that the metamorphic-metasomatic reconstitution took place in two stages. In the first stage iron, Mg and Ca were added which gave rise to garnet, pyroxene and amphibole minerals. This was followed by addition of B, Mn^{2+}, C, H and outward movement of K (from the garnet - pyroxene - pyrrhotite - axinite skarn and amphibole - axinite - pyrrhotite skarn). These cations were introduced with falling temperatures and gave rise to minerals like axinite, calcite, muscovite and chlorite; which replaced the earlier mineral assemblages. Sulphur moved out and is fixed in pyrrhotite along the joints, cracks and within the metadolerite itself. A depletion in Fe^{3+} appears to be due to its reduction to Fe^{2+}. If we take this fact into account, net addition of iron to the skarns may probably be small. Titanium, which is expelled during skarn formation concentrates in two forms, firstly as sphene-rich fronts just outside the metamorphic-metasomatic aureole and secondly as small aggregates within the skarn. Expelled Si and Al combine with K and Mg to form muscovite and chlorite aggregates, veins and patches in the axinite-calcite-muscovite-chlorite-quartz-skarn. The balance of Na, Al and Si give rise to local feldspar-rich areas within the metadolerite.

The source of the introduced cations i.e. B, Mn^{2+}, Ca, H, C and iron is the Meldon aplite. Geochemical studies (paper under preparation) show that towards the closing stages of crystallisation significant amounts of B, Mn^{2+}, H, iron and also Ca were available. The evidence of their availibility is shown by fairly large scale tourmalinisation and lepidolitisation (rich in Mn^{2+}, H and iron). The metasomatic fluorite and apatite point to the availability of Ca.

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GEOLOGY OF TIMURGARA-LAL QILA AREA DIR DISTRICT N.W.F.P.

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Abstract : *One hundred and twenty square miles of the Timurgara-Lal Qila area, a part of Hindu Kush Range, and situated in the middle of Dir Distt. N.W.F.P. was mapped on 4"=1 mile scale. A map on the reduced scale is presented. The oldest rock of the area is an amphibolite. This has been intruded by a diorite intrusion followed by a noritic intrusion. The amphibolites have formed as a result of the regional metamorphism of basic igneous rocks. The diorite body is composed of diorite, quartz diorite and tonalite. It has formed by the crystallisation of a dioritic magma of pyroxene andesitic composition. The latter basaltic magma of strong tholeiitic affinities formed the norite intrusion. Differential crystallisation of this magma gave rise to peridotites, pyroxenites, norite and gabbro. Petrogenesis of the area is discussed at length and sixty modal analyses of the various types have been presented.*

INTRODUCTION

Location and Accessibility ; The Timurgara-Lal Qila area is located to the north of Peshawar in N.W.F.P., Pakistan. The area lies between longitudes 71° 55′ to 71° 51′ and latitudes 34° 48′ to 34° 57′. 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 traversing the area is the Balambat Lal-Qila road. This road is unmetalled.

Previous Work : The first geologist to write someting on the area was H.H. Hayden (1916). He regarded the intrusive rocks as a cause of metamorphism of the schist series. His work was of a very preliminary nature. Davies (1965) considered the rocks of the adjoining areas as similar to the gabbro, norite and diorite of Khwazakhela and Kalam. Bakr and Jackson (1964) placed the diorites and norites of the area as intrusives in the metasediments. Detailed mapping and study was started in Dir in 1970 under the supervision of one of the authors. (M. Nawaz Chaudhry). As a result of which ortho-amphibolites, para-amphibolites, norites, noritic gabbro, gabbroic norite, quartz norite, bejite, meladiorite, diorite, quartz diorite, tonalite, trondhjemite, granites, peridotite, scyelite, pyroxenites, websterite, garnet-pyroxene-quartz rock, hornblendite, quartzofeldspathic dykes and veins, acid pegmatites, acid porphyries, intermediate pegmatites, calcareous quartzites, pelitic schists and phyllites and quartzites with volcanics were distinguished and studied.

GENERAL GEOLOGY

Following are the major rock units of the area arranged according to their relative ages.

The Norite Complex
The Diorite Complex
The Amphibolite

Each of these units has been described in the following :

The Norite Complex

It is a composite intrusion composed of gabbroic norite, noritic gabbro and hornblende norite. All these facies are leucocratic. Gabbroic norite is speckled white and olive green massive and well jointed rock. Noritic gabbro is coarser than gabbroic norites and is also speckled white and black rock with olive tints. The hornblende norite resembles noritic gabbro in field but is coarser textured. Detailed mapping of the various facies has yet to be done. The weathering colours of these rocks are light brown to yellowish brown.

The norite intrusion is cut by pyroxenites and hornblendites.

Pyroxenite : It is an oval shaped body in the norite. It has sharp contact with the surrounding rock. It has shining black colour and its weathering colour is yellowish brown.

Hornblendites: They occur as small intrusions in norite intrusion. Their contacts are sharp with the host rock. Their colour is black and weathering colours are jet black.

The Diorite Complex

The diorite complex is composed of the following :—

Diorite, Quartz Diorite and Tonalite : The diorite intrusion covers about 40% of the area investigated. The main minerals of the rock i.e. plagioclase, hornblende and quartz can be readily identified in hand specimen. It shows from medium to coarse-grained texture. This intrusion is also composite. More than three intrusive phases are involved in its formation. The bulk of the intrusion is diorite whereas quartz diorite and tonalite occur as marginal facies. The diorite intrusion is cut by pegmatites and porphyries.

Diorite and quartz diorite are massive and well jointed rocks. They are black and white looking rocks. They weather to dirty dark brown colours.

Tonalites are white to cream coloured rocks showing weak foliation. They weather from gray to rusty gray colours.

Scyelite dyke : A roughly pipelike dyke of scyelite (Judd, 1885) is found in the diorite intrusion. It is massive looking and black in colour. It resembles hornblendite in appearance. It is composed chiefly of hornblende, olivine and pyroxene.

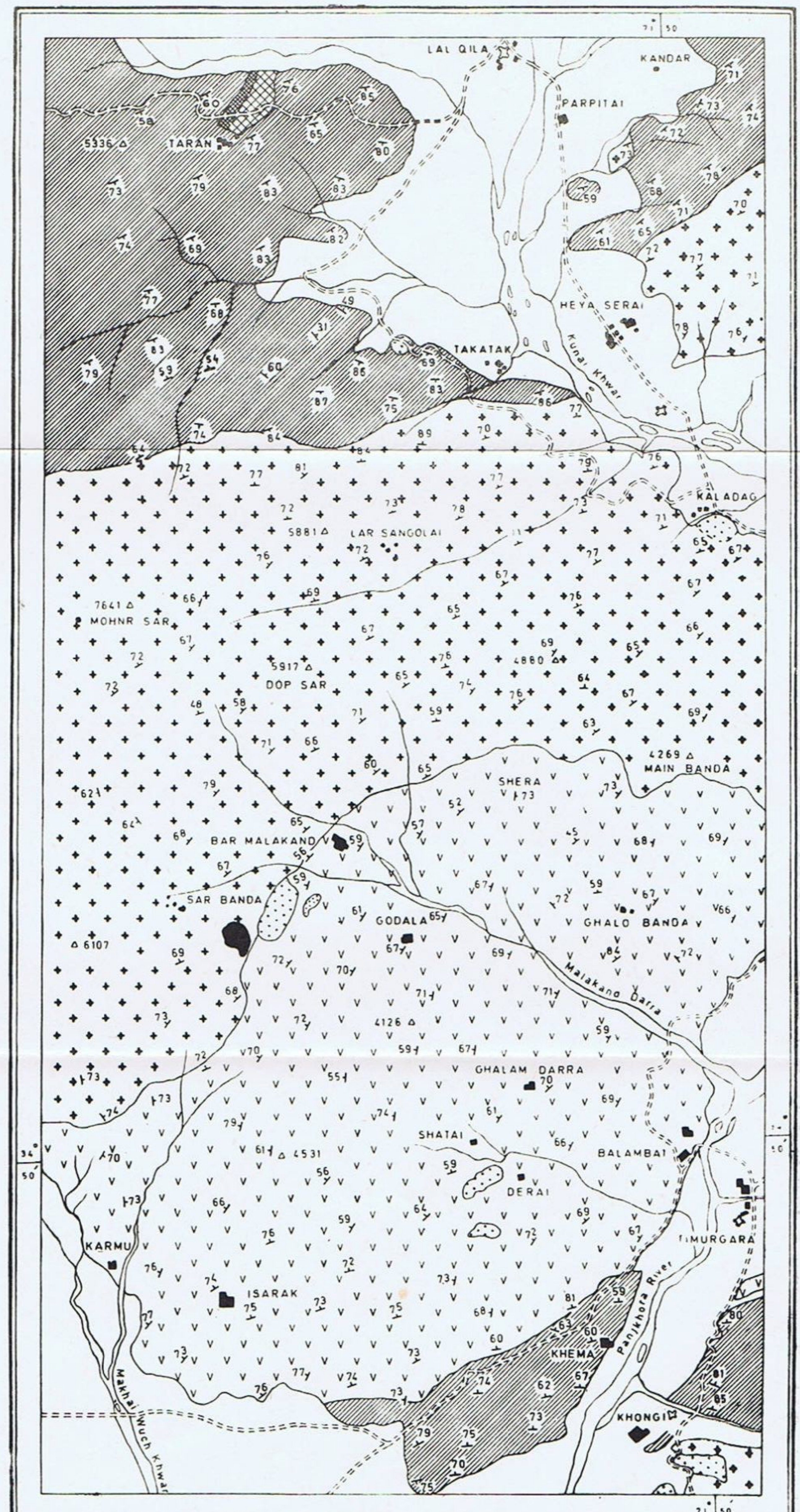
Hornblendites : Hornblendite patches, often pegmatitic are developed in diorite intrusion near the contact with norite. A few hornblendite dykes also occur. These are black rocks showing dark brown weathering colours.

Quartz Porphyries: They commonly occur in the diorite intrusion. Clear phenocrysts of quartz are embedded in white to cream very fine grained groundmass of feldspar, mainly plagioclase. They are fresh white to light gray rocks.

Pegmatites : White coloured pegmatites and pegmatitic patches are fairly common in the diorite intrusion. They are composed mainly of feldspars, quartz and hornblende or quartz, feldspar and mica. They range in thickness from about 5 feet to about 150 feet in length.

Epidosite Veins : Occasionally a few veins of epidosite are also encountered in the diorite

54/155



Geological Map of Timurgara—Lal Qila Area.

intrusion. The veins are fine grained pale green and massive. They are composed chiefly of epidote and quartz with minor chlorite, sericite and calcite.

Xenoliths : Garnet amphibolite xenoliths occur in diorite intrusion specially near the contact with amphibolite. Oval shaped xenoliths composed mainly of amphibole with minor plagioclase are also found in diorite. Such xenoliths have also been found in the diorites in the Khagram area of Dir.

THE AMPHIBOLITE

Well banded, layered (Fig. 1) and foliated amphibolites form the country rock of the area. Epidote amphibolite, plagioclase amphibolite and garnet amphibolite can be easily distinguished in field. The amphibolites are cut by quartzofeldspathic veins and quartz veins, feldspar and amphibole pegmatites. These are banded, foliated and jointed rocks. In field on the basis of their texture and structure the amphibolites can be divided into four types namely banded amphibolites, layered amphibolites, gneissic amphibolites and foliated amphibolites. They show intergradations. They weather from dark brown to jet black colours. Extreme metamorphic differentiation has lead to the formation of quartzofeldspathic layers on the one hand and hornblendite layers on the other. The amphibolite is also cut by a garnet-pyroxene-quartz dyke. Deformation of layers, folding and ptygmatic folding is often observed.

Quartzofeldspathic veins and dykes: They are white coloured rocks composed chiefly of quartz and feldspar. They range in size from ½″ to about 1′ in thickness and from about 4 feet upto 100 feet in length. At places some of these veins show strong folding.

Pegmatites : They range from 6″ to about 6′ in thickness and from about 10′ to 150′ in length. The individual crystals may be as big as 6″. They are composed mainly of feldspar, amphibole and quartz.

Hornblendites : Black hornblendite patches, dykes and layers are found in amphibolite. While the dykes are intrusive the patches and layers grade into the amphibolites. These bodies range from 1½″ to 20′ in thickness and from about six feet to about about 250′ in length.

Fig. 1 Layered Amphibolites.

Pyroxene quartz garnet dyke : It is a discordant body. It is more or less massive. It is white, green and brown rock. Its weathering colour is reddish brown. Pyroxene, quartz and garnet can be easily identified in hand specimen. It contains clear quartz crystals often intergrown with translucent garnet.

CONTACT RELATIONS

The amphibolite is cut by both norite intrusion and the diorite intrusion. The contact between the amphibolite and the norite intruion is rather sharp. At the contact the amphibolite has been toughened and garnet appears in them. Also hornblendite patches develop in amphibolite within the aureole of norite intrusion. Xenoliths of amphibolite occur in the norite intrusion at the contact. At places apophyses of norite also cut amphibolite. The contact between the diorite intrusion and the amphibolite is also relatively sharp. At contact the amphibolite becomes massive but distinctly coarse grained with the ubiquitous development of garnet. The quantity of quartz also increases at the contact. Xenoliths of amphibolite are often present in diorite at the contact.

The contact between the norite intrusion and the diorite intrusion is variable. The contact is rather gradational with the dioritic facies whereas it is sharp with the quartz diorite and tonalite facies of the diorite intrusion. Apophyses of norite cut the dioritic facies of the intrusion. At contact the diorite intrusion is locally enriched in coarse hornblende.

PETROGRAPHY

The Norite Complex

The norite intrusion is composed of noritic gabbro, gabbroic norite and hornblende norite. Their petrography is described in the following :

Gabbroic Norites and Noritic Gabbro : Their petrography is being described together since they have similar mineralogy. Both have hypidiomorphic texture. At places poikilitic texture is also encountered. The gabbroic norite is finer textured compared with the noritic gabbro.

They are composed chiefly of hypersthene, diopsidic augite and labradorite. Quartz, biotite, sphene, apatite and magnetite are the accessory minerals. For modal analyses see Table 1 and 2.

Hypersthene occurs as subhedral to anhedral crystals. It is pleochroic from neutral green to pink. Its 2V is about 78°. Schiller structure is often observed in hypersthene (Fig. 2). Exsolution lamellae of augite in hypersthene can often be recognised. At places hypersthene is found enclosed in diopsidic augite. Magnetite inclusions in hypersthene are common. It shows alteration to hornblende. (Fig 3) and uralite.

Diopsidic augite generally occurs as short prismatic subhedral crystals. Its extinction angle $C \wedge Z$ varies from 40° to 48° and 2V varies from 58° to 60°. It is colourless to light green and is non pleochroic. Diopsidic augite also occurs as exsolution lamellae in hypersthene.

Plagioclase shows from euhedral to subhedral crystaal. Its shows albite, pericline and carlsbad twinning. Its composition is An_{52}-60. It alters to epidote, sericite and clay. Hornblende occurs either as primary subhedral crystals or as alteration rings around pyroxene. It is light green in colour and pleochroic from yellowish green to bluish green. Its extinction angle $C \wedge Z$ is from 25° to 29°. At places biotite develops either as independent crystals or as an alteration product of hornblende. It is a normal biotite, brown in colour and strongly pleochroic from straw yellow to dark brown. Quartz often occurs associated with it. Quartz occurs as fresh interstitial grains. It is an important accessory to minor mineral. At places it contains rutile.

Small grains of epidote and clinozoisite, occur

TABLE 1

Modal Analyses of Gabbroic—Norites

Minerals/T. S. No.		14782	14750	14749	14807
Orthopyroxene	..	39.48	10.64	21.89	21.93
Clinopyroxene	..	10.29	10.12	14.19	16.35
Plagioclase	..	47.09	63.34	38.85	51.09
Hornblende	..	1.77	8.32	5.29	4.70
Quartz	..	0.86	3.62	4.03	1.85
Ore	..	0.53	1.83	3.63	4.08
Biotite	..	00.00	1.88	00.00	00.00
Sassurite & Sericite	..	00.00	00.00	11.08	00.00
Accessories	..	00.00	0.24	1.02	00.00
	..	100.02	99.99	99.98	100.00

TABLE 2

Modal Analyses of Noritic—Gabbros

Minerals/T. S. No.		14848	14825	14781	14763	14823	14824
Orthopyroxene	..	24.37	15.85	8.87	10.83	10.28	5.27
Clinopyroxene	..	24.84	16.60	21.43	12.26	19.01	11.57
Plagioclase	..	41.65	54.50	57.08	60.02	40.60	66.72
Hornblende	..	2.42	2.26	1.49	4.15	1.44	1.10
Biotite	..	0.89	1.10	0.00	0.00	4.61	2.57
Sassurite & Sericite	..	0.00	0.00	2.22	1.03	14.83	0.00
Quartz	..	3.44	6.42	2.76	2.78	4.63	9.94
Ore	..	2.37	3.24	5.64	8.11	4.89	2.83
Accessories	..	0.00	0.00	0.54	0.78	0.00	0.00
	..	99.98	99.97	100.03	99.96	99.85	100.00

Fig. 2 Schiller Structure in Hypersthene in Norites.

Fig. 3 Hypersthene and Diopsidic Augite Rimmed by Hornblende in Norite

due to sassuratisation. Apatite is rather rare. Magnetite, rutile and haematite all occur as anhedral to subhedral accessory minerals. In addition to occurring independently magnetite also occurs as inclusions in pyroxene and hornblende. Haematite may sometimes form a schiller pattern in hypersthene. Rutile needles generally occur as inclusions in quartz and biotite.

Hornblende Norite : It is coarser textured than the noritic gabbros and gabbroic norites. Its texture is similar to the varieties described above. Both hypersthene and diopsidic augite occur but they are much poor in exsolution lamellae than the pyroxenes described earlier. Hornblende occurs as short prismatic crystals. An interesting feature of this hornblende is its schiller structure which looks like that of pyroxene. Their modal analysis are given in Table 3. Its $C \wedge Z$ is from 26° to 28°. It contains both quartz and pyroxene inclusions. The composition of plagio-

TABLE 3

Modal Analysis of Hornblende Norite

Minerals/T. S. No.	14852	14850	14753
Plagioclase	52.33	52.46	46.79
Hornblende	18.30	12.56	28.52
Quartz	11.94	10.56	12.63
Orthopyroxene	9.67	12.92	0.00
Clinopyroxene	0.00	0.00	6.31
Biotite	3.53	7.46	2.37
Iron Ore	4.21	4.07	3.35
	99.98	100.03	99.97

TABLE 4

Modal Analysis of Pyroxenite

Minerals/T. S. No.	14815
Diallage ..	10.12
Diopsidic augite ..	86.53
Chlorite ..	1.84
Sphene ..	0.36
Iron Ore ..	1.17
	100.02

clase is from An_{56} to An_{64}. The content of quartz is abnormally high, it assumes the status of essential mineral. Primary biotite and secondary biotite after hornblende both occur.

Pyroxenite: These rocks have medium to coarse-grained hypoidiomorphic texture. One modal analysis of this unit is presented in Table 4.

Diopsidic augite and diallage are the main constituents while chlorite, sphene and iron ore are the accessories.

The amount of diopsidic augite is 86.53%. It is colourless to light green and is nonpleochroic. The grains are anhedral. It alters to pale chlorite. Inclusions of iron ore are present. The amount of diallage is 10.12%.

It is colourless in thin section. It occurs as prisms. The amount of chlorite is 1.84%. It develops along the boundries and fracture planes of pyroxene. It is pleochroic from pale green to brown green. The amount of sphene is 0.36%.

The grains are subhedral. It is yellowish brown in thin section. The amount of iron ore is 1.17%. Magnetite and Haematite are present. The grains are poiklitically enclosed by pyroxene.

Hornblendites: These rocks have medium to coarse-grained granular texture. Four modal analysis of this unit are presented in Table 5. They

TABLE 5

Modal Analysis of Hornblendite

Minerals/T.S.No.	14841	14803	14689	14767
Hornblende	93.36	85.63	93.37	98.72
Haematite	1.38	0.39	0.00	0.00
Magnetite	4.01	0.00	4.13	0.52
Quartz	0.13	7.64	0.00	0.00
Epidote	1.16	5.55	0.45	0.38
Sphene	0.00	0.78	2.05	0.38
	100.04	99.99	100.00	100.00

14841 — Hornblendite in Norite

14807 — From contact between Norite and Amphibolite

14689 — Hornblendite in Amphibolite.

14767 ,,

occur both in norites and diorites hornblende is the main constituent while quartz, epidote, sphene and iron ore are the accessories.

The amount of hornblende varies from 85.63% to 98.72%. The grains are euhedral to subhedral. It is pleochroic from pale yellowish green to light green. The amount of epidote varies from 0.38% to 5.55%. It is colourless in thin section and occurs along the cleavage and fracture planes of hornblende. The amount of quartz varies from 0.00% to 7.64%. It is colourless in thin section. Inclusions of quartz are present in hornblende.

The amount of sphene varies from 0.00% to 2.05%. It is light brown in thin section. The grains are subhedral.

The amount of iron ore varies from 0.00% to 5.39%. Magnetite and haematite are both present as accessories.

Diorite, Complex

Diorite, Quartz Diorite and Tonalite: The intrusion is composed mainly of diorites with marginal facies of quartz diorite and tonalite. To avoid repitition their petrography and minerals will be described together but giving distinctive characters of each type. The modal analyses of the complex are given in Table 6, 7, 8 and 9.

Diorite shows a very wide variation in texture. Hypidiomorphic texture is however predominant. But poikilitic, sieve (Fig. 4) and porphyritic textures are also seen specially in the coarser textured diorites. Xenomorphic and ophitic looking textures are rare but present neverthless. Quartz diorite and tonalite show hypidiomorphic and poikilitic texture. Porphyritic or rather porphyroblastic texture is seen in quartz diorite at contact with norite. Tonalites show poor foliation whereas the diorites lack it.

TABLE 6

Modal Analysis of Diorite

Minerals/T. S. No.	14808	14717	14810	14851	14642*	14638*	14849*	14821*
Plagioclase	37.81	39.68	57.49	38.44	37.95	35.41	35.09	38.26
Hornblende	53.08	47.99	31.84	48.96	40.63	45.09	42.31	37.38
Quartz	0.94	2.64	5.01	4.15	7.08	6.74	12.54	12.34
Epidote	3.44	0.94	0.45	3.58	3.10	2.05	2.06	6.53
Biotite	0.77	2.99	1.44	0.00	8.64	0.00	0.84	0.97
Chlorite	0.00	3.88	2.57	0.00	0.00	0.00	0.00	0.00
Sphene	0.00	0.00	0.00	3.91	0.37	0.89	0.00	0.57
Iron Ore	3.94	1.54	1.22	0.95	0.75	8.74	1.43	1.20
Apatite	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Mica & Sericite	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00
Orthoclase	0.00	0.00	0.00	0.00	1.51	0.00	5.71	2.75
	99.97	100.00	100.02	99.99	100.03	100.03	99.98	100.00

*Quartz Diorite

TABLE 7

Modal Analysis of Diorite

Minerals/T.S.No.	14853	14695	14755
Plagioclase	32.07	13.57	45.60
Hornblende	21.23	34.47	8.24
Quartz	14.05	7.49	4.32
Epidote	7.72	44.13	3.23
Biotite	1.88	0.00	4.93
Garnet	14.03	0.00	0.00
Chlorite	8.15	0.00	30.32
Iron Ore	0.89	0.36	0.88
Sphene	0.00	0.00	2.08
Apatite	0.00	0.00	0.23
	100.02	100.02	99.83

14835 — Garnet Diorite
14695 — Epidote Diorite
14755 — Chlorite Diorite

TABLE 8

Modal Analysis of Tonalite

Minerals/T.S.No.	14835	14652	14644	14715
Plagioclase	48.31	33.54	42.22	30.45
Hornblende	11.04	33.29	24.00	48.42
Quartz	24.83	22.28	23.92	17.31
Chlorite	5.52	0.00	0.00	0.00
Epidote	2.28	1.23	1.05	0.00
Biotite	2.78	7.82	2.21	0.00
Sphene	0.00	0.00	0.28	1.98
Iron Ore	2.11	1.81	1.53	0.10
Orthoclase	1.05	0.00	2.83	0.00
Apatite	0.00	0.04	0.00	0.00
Mica & Sericite	0.00	0.00	2.00	1.73
	100.03	100.01	100.04	99.99

TABLE 9

Modal Analysis of Minor Bodies in Diorite

Minerals/T.S.No.	14661	14839	14840	14836
Plagioclase	20.59	31.51	32.23	19.89
Chlorite	7.72	8.60	0.00	0.00
Quartz	17.93	10.56	26.87	35.14
Calcite	0.13	3.28	0.00	1.80
Epidote	45.76	43.89	0.34	8.38
Orthoclase	5.86	2.03	5.61	6.58
Garnet	0.00	0.00	16.08	27.92
Iron Ore	1.99	0.13	1.96	0.25
Biotite	0.00	0.00	16.51	0.00
Apatite	0.00	0.00	0.41	0.00
	99.98	100.00	100.01	99.96

14661 — Epidosite vein in Diorite.
14839 — " "
14840 — Screen in Diorite
14836 — Xenolith in Diorite.

TABLE 9-A

Modal Analysis of Porphyritic Dyke

Minerals/T. S. No.	14834
Plagioclase	15.23
Chlorite	13.99
Orthoclase	22.13
Quartz	13.05
Calcite	0.53
Epidote	1.35
Sericite & Mica	2.73
Ground Mass	30.76
Iron Ore	0.24
	100.01

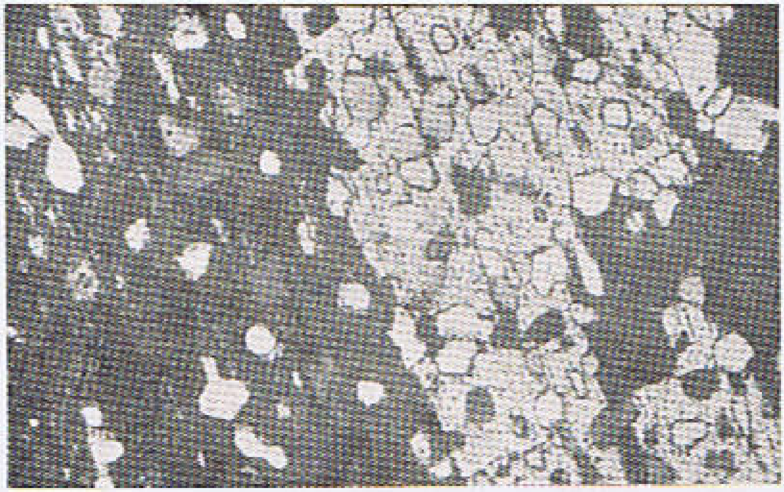


Fig. 4 Inclusion of Quartz in Hornblende giving Sieve Structure in Diorite.

The diorites are composed mainly of andesine and hornblende. Sphene, biotite, magnetite, apatite and quartz are the accessory minerals. Rarely remanents of pyroxene are found in hornblende (Fig. 5). Quartz is less than 5%. Rarely epidote, chlorite or garnet may concentrate at places giving rise to local varieties which may be called epidote diorite, garnet diorite and chlorite diorite. The quartz diorite differs from diorite in having quartz from 5% to 15% and ubiquitous accessory orthoclase. In tonalites quartz is more than 15%. The colour index is much lower than that of diorite and quartz diorite. The amount of orthoclase is more than in quartz diorite.

Hornblende is green and pleochroic from pale green to dark green. Extinction angle $C \wedge Z$ varies from 22°—28°. It occurs generally as subhedral prismatic crystals. At places it shows schillar structure (Fig. 6). Inclusions of quartz, epidote and apatite often occur. At places it shows alteration to biotite and chlorite. Plagioclase occurs from euhedral to subhedral crystals. In diorite its composition varies from An_{34} to An_{44}, in quartz diorites from An_{43}—An_{44} and in tonalites from An_{32} to An_{35}. Plagioclase often shows alteration to kaolin, sericite, zoisite, clinozoisite and calcite.

Quartz occurs either in little pools or as an interstitial mineral. It is anhedral and often shows wavy extinction. It also occurs as inclusions in hornblende and biotite. In diorites it is invariably interstitial and less than 5%. In quartz diorites it varies from 5% to 15% and besides occurring as interstitial mineral also forms a few patches and pools. In tonalites it is more than 15%. Here it occurs either as bigger anhedra or as short bands, layers and patches giving the rock a rather foliated texture.

Greenish brown to medium brown biotite occurs in all the facies of the diorite intrusion. In diorites it occurs sporadically. Here it is often formed from hornblende although seemingly primary crystals also occur. Its amount increases in quartz diorites and it becomes a ubiquitous minor to accessory mineral in tonalites. It is pleochroic in brown and brownish green tones. It occurs from subhedral to anhedral grains. It commonly alters to chlorite. In some cases magnetite inclusions in biotite are seen. Chlorite occurs as a secondary mineral after both hornblende and biotite. Epidote, both zoisite and clinozoisite occur in granular forms. It is an alteration product of plagioclase and hornblende. Anhedral orthoclase is comparatively rare in diorite but it increases from

Fig. 5 Remnants of Hypersthete in Hornblende Crystals in Diorite

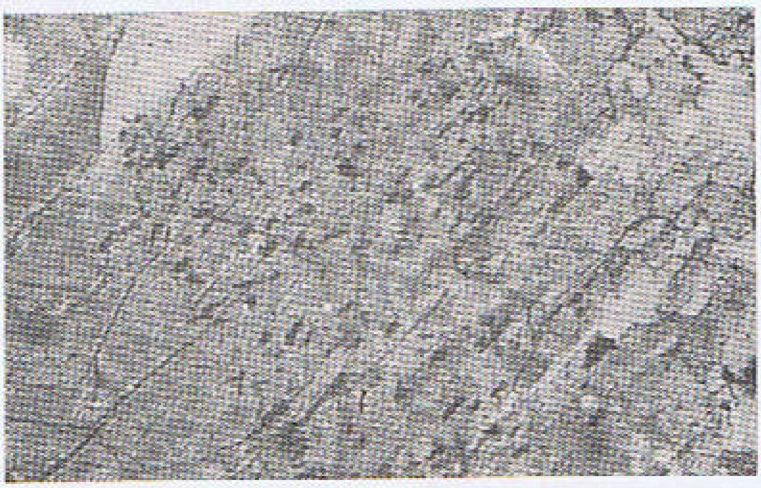


Fig. 6 Schiller Structure in Hornblende (after Pyroxene) in Diorites.

quartz diorite to tonalite. It is an interstitial mineral in diorite and quartz diorite. Sphene, calcite, apatite, magnetite and haematite are the accessory minerals. Occasionally ilmenite may form lamellar intergrowths in haematite.

Scyelite : These rocks have medium to coarse-grained hypidiomorphic and granular texture. Two modal analysis of this unit are presented in Table 10. Olivine, pyroxene and hornblende are the main constituents while serpentine, iddingsite and iron ore are the accessories.

The amount of olivine varies from 9.69% to 10.61%. The grains are anhedral. It commonly alters to serpentine and iddingsite. Iron ore inclusions are common. The amount of hypersthene varies from 9.55% to 13.10%. It is pink coloured. The grains are prismatic.

The amount of diopside varies from 36.55% to 40.46%. It is colourless showing pale yellow interference colours. It alters to hornblende. The amount of hornblende varies from 28.73% to 30.84%. It is light green in colour and pleochroic

TABLE 10

Modal Analysis of Scyelite

Minerals/T. S. No.	14722	14669
Olivine	10.61	9.69
Hypersethene	13.10	9.55
Diopside	36.55	40.46
Hornblende	28.73	30.84
Serpentine	0.86	0.72
Iddingsite	3.90	3.76
Iron Ore	6.25	4.98
	99.99	100.00

from green to neutral green.

The amount of serpentine varies from 0.72% to 0.86%. It develops along cleavage and fracture planes. It is the alteration product of olivine.

The amount of iddingsite varies from 3.76% to 3.90%. It is yellowish brown in colour. It is alteration product of olivine.

The amount of iron ore (magnetite) varies from 4.98% to 6.25%. The grains are subhedral to anhedral.

Amphibolites

On the basis of their mineralogy, mineral composition and texture the Amphibolites have been divided into five main pertrographic varieties. Their modal variation is given in Tables 11, 12 and 13.

Mela Amphibolite : It is composed essentially of amphibole, plagioclase and quartz. It is distinguished because of its high colour index. Amphibole is generally more than 50%. The composition of plagioclase is from An_{41-44}. It is distributed sporadically throughout the area. Mela amphibolites are formed due to the seggregation of melanocratic minerals in amphibolites.

Leuco Amphibolite : They are composed essentially of amphibole, plagioclase, quartz and orthoclase. Colour index is low and amphibole is generally less than 30%. The composition of plagioclase is from An_{40-45}. The melanocratic minerals predominate. This variety is formed due to the seggregation of leucocratic minerals.

Hornblende Plagioclase Amphibolite : This is the most widespread and predominant variety. Quartz is from 2% to about 7% and amphibole is from 45% to 55%. The composition of plagioclase is from An_{38-34}.

Garnet-Amphibolite : This type is restricted within the thermal aurales of norite intrusion and diorite intrusion in amphibolites. This variety is formed due to the local upgrading of the amphibolites. It is composed essentially of amphibole, plagioclase and quartz with garnet. Garnet ranges upto 3.53% whereas quartz is around 15% to 20%.

Epidote Amphibolite : Epidote amphibolite mostly occurs fartherest from the igneous intrusions. In this area the grade appears to be decreasing towards north due Kumbat. It is composed of epidote and amphibole with quartz and some plagioclase.

In the following a generalized petrographic description is presented.

These rocks have fine to medium grained, hypidiomorphic and granular texture. Allotrimorphic and idiomorphic textures are sometimes also seen. Amphibole, plagioclase, quartz, and orthoclase are the main constituents while garnet, epidote, chlorite, sphene, apatite, calcite and biotite are the accessories.

TABLE 11

Modal Analysis of Leuco & Mela Amphibolite

Minerals/T. S. No.	14685	14766	14688	14738	14743	14754
Amphibole ..	80.61	73.89	64.41	27.44	33.22	11.79
Plagioclase ..	10.62	22.92	17.95	56.01	50.52	59.28
Quartz ..	4.73	1.95	11.96	8.64	8.48	18.54
Sphene ..	1.54	0.84	0.16	0.00	0.48	0.00
Epidote ..	0.00	0.00	5.59	0.85	0.41	0.72
Calcite ..	0.00	0.00	0.16	0.11	0.00	0.00
Apatite ..	0.00	0.17	0.00	0.00	0.13	0.16
Chlorite ..	0.00	0.00	0.00	0.00	0.00	3.55
Orthoclase ..	0.00	0.00	0.00	1.69	2.91	4.36
Sericite ..	0.00	0.00	0.00	4.88	0.00	0.80
Biotite ..	0.00	0.00	0.00	0.00	2.36	0.00
Iron Ore ..	2.51	0.21	0.00	0.37	1.53	0.76
..	100.01	99.98	100.00	99.98	100.04	99.96

14685, 14766, 14688 — Mela Amphibolite.
14738, 14743, 14754 — Leuco Amphibolite.

TABLE 12

Modal Analysis of Epidote Amphibolite

Minerals/T. S. No.	14719	14707	14712	14687
Epidote ..	53.75	42.14	32.57	33.09
Amphibole ..	32.52	29.53	44.17	47.26
Plagioclase ..	9.27	19.25	21.08	16.52
Quartz ..	4.46	8.82	1.98	0.82
Iron Ore ..	0.00	0.29	0.18	0.98
Chlorite ..	0.00	0.00	0.00	1.29
..	100.00	100.03	99.98	99.96

TABLE 13

Modal Analysis of Amphibolite

Minerals/T. S. No.		14838	14811	14776	14780	14820
Hornblende	..	57.89	57.47	54.08	15.31	28.56
Plagioclase	..	41.35	37.88	37.35	47.00	33.01
Quartz	..	0.00	2.86	2.63	20.27	6.85
Garnet	..	0.00	0.00	0.00	3.63	0.00
Chlorite	..	0.00	0.00	0.00	0.00	20.18
Epidote	..	0.00	1.46	1.02	11.56	7.98
Sphene	..	0.63	0.33	2.52	0.80	0.00
Orthoclase	..	0.00	0.00	1.14	0.00	0.00
Calcite	..	0.00	0.00	0.00	0.83	0.00
Iron Ore	..	0.12	0.00	1.26	0.55	3.45
	..	99.99	100.00	100.00	99.95	100.03

14838, 14811, 14776 — (Hornblende-Plagioclase) Mela Amphibolite.
14780 — Garnet Amphibolite.
14820 — Chlorite Amphibolite.

The amount of amphibole varies from 54.08% to 80.61% in mela and 15.31 to 33.22% in leuco amphibolite, both cummingtonite and hornblende are present. Hornblende is pale yellowish green in colour and pleochroic from pale yellowish green to bluish green. Quartz is poikilitically enclosed in hornblende. It commonly alters to chlorite. Cummingtonite is light green in colour. It occurs in the form of prisms.

The amount of plagioclase varies from 10.62-22.92% in mela and from 50.52 to 59.29% in leuco amphibolites. The grains are euhedral to subhedral. Inclusions of quartz, epidote and orthoclase are common. It commonly alters to kaolin.

The amount of epidote varies from 0.00% to 5.59%. Both zoisite and clinozoisite were found. Clinozoisite shows normal second order interference colours whereas zoisite shows anamalous colours. The grains are anhedral. Quartz and pistacite inclusions are common in zoisite.

The amount of chlorite varies from 0.00 to 3.55%. It is light green in plane polarized light and shows 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 biotite varies from 0.00% to 3.26%. The grains are subhedral to anhedral. It forms platy pseudohexagonal crystals. The grains are brown to yellowish brown in colour. Some times it alters to chlorite.

The amount of garnet varies from 0.00% to

3.63%. It occurs in six sided idiomorphic crystals. In clusions of quartz and epidote are common.

The amount of quartz varies from 0.00% to 18.54%. The grains are anhedral.

The amount of orthoclase varies from 0.00% to 2.91%. The grains are subhedral to anhedral. It gives cloudy appearance due to incipient alteration to clay. The amount of sphene varies from 0.00% to 1.54%. The grains are euhedral. It is shining brown in colour. The amount of calcite varies from 0.00% to 0.11%. It is colourless in thin section. It shows well developed rhombic cleavage. Other accessories are apatite magnetite, rutile and limonite.

Pyroxene-Quartz-Garnet dike: These rocks have fine to coarse grained granular and hypidiomorphic texture. Two modal analysis of this unit are presented in Table 14. Pyroxene, quartz, garnet and sassurite and sericite are the main constituents while epidote, plagioclase, orthoclase and calcite are the accessories.

The amount of pyroxene varies from 0.69% to 14.85%. It is light green in colour. The grains are prismatic.

The amount of quartz varies from 26.21% to 27.36%. It is colourless in thin section. The grains are anhedral.

The amount of garnet varies from 18.38% to 29.85%. It is colourless to pale reddish in thin section. It becomes dark in crossed nicols.

The amount of sassurite varies from 21.06% to 23.79%. It is the alteration product of pyroxene. Sassurite shows dirty brown colour in thin section. It becomes dark in crossed nicols.

The amount of epidote varies from 1.29% to 14.13%. It is colourless in thin section. It is present as replacement mineral after pyroxene.

The amount of plagioclase varies from 1.62% to 2.94%. It commonly alters to sassurite and

TABLE 14

Modal Analysis of the Dyke

Minerals/T.S.No.	14735	14737
Pyroxene ..	9.69	14.85
Quartz ..	26.21	27.36
Garnet ..	18.38	29.85
Epidote ..	14.13	1.29
Plagioclase ..	2.94	1.62
Sassurite & Sericite	23.79	21.06
Orthoclase ..	3.68	3.97
Calcite .	1.18	0.00
..	100.00	99.99

sericite, polysynthetic albite and carlsbad twinning is present. Composition of plagioclase is An_{40-44}.

The amount of orthoclase varies from 3.68% to 3.97%. It is colourless in thin section.

The amount of calcite varies from 0.00 to 1.18%. It is colourless in thin section and occurs as subhedral grains.

PETROGENESIS

The Norite Complex

The foregoing description of the geology and petrography of the norite intrusion shows that this intrusion is younger than both diorite intrusion and amphibolites. The petrographic study shows that olivine is lacking in the norite intrusion. There are two pyroxenes a calcium rich pyroxene i.e. diopsidic augite and an orthopyroxene. Besides, quartz is a ubiquitous accessory mineral of the norite intrusion. Exsolution lamellae and schiller structure are common in hypersthene. All these facts clearly show that the magma from which noritic gabbro and gabbroic norites were formed was oversaturated tholeiitic magma. Textural relations and field evidence presented in the forgoing suggests that the hornblende norite is a later facies. It formed from the noritic gabbros and gabbroic norites due to the enrichment in volatiles, silica and alumina. Textural relations clearly show that the amphibole formed later than pyroxene. In addition conversion of pyroxene into hornblende can also be seen. Field study, textural evidence and plot of orthopyroxene against clinopyroxene (Fig. 7) suggest that there are from two to three intrusive phases involved in the formation of the norite intrusion. So it is a composite intrusion. Its modal variation is shown in Figs. 8 & 9.

Textural study shows that hypersthene was the first mineral to crystallise this was followed by diopsidic augite and plagioclase. As a result earlier gabbroic norites were followed by noritic gabbros. This was followed by crystallisation of hornblende, biotite and quartz due to the concentration of volatiles, silica and alumina. This gave rise to the hornblende norite and hornblende gabbro. This followed by a residual melt greatly enriched in silica and alkalies. This formed quartzo feldspathic veins. The last stage is marked by absolute enrichment in silica resulting in the formation of quartz veins.

Absolute enrichment in iron due to progressive differential crystallisation of saturated basaltic magma for the major part of the crystallisation period, has been described by Wager and Deer (1939) and Walker and Poldervaart (1949). They have also noted that towards the end the residuum is enriched in alkalies and silica. But in this case similar absolute enrichment in iron is not taking place. It shows progressive enrichment in alkalies, silica, water, fluorine and alumin.

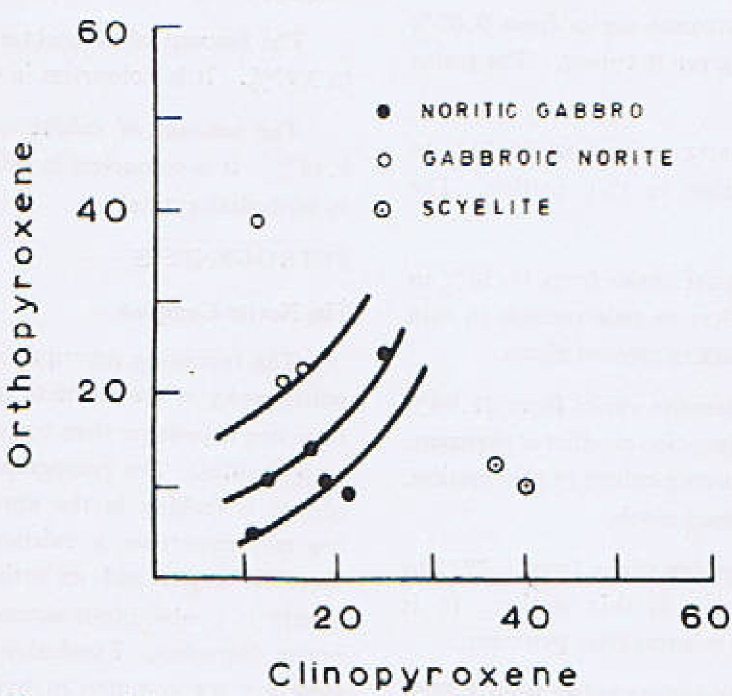


Fig. 7 Variation Diagram between Orthopyroxene and Clinopyroxene suggesting Multiple Intrusion.

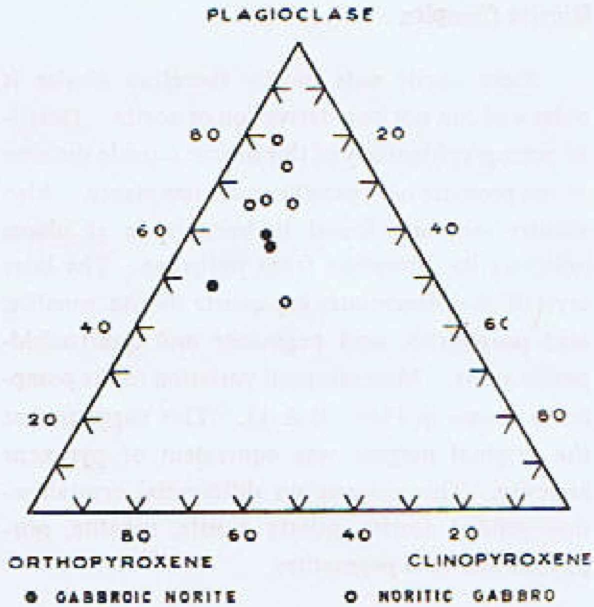


Fig. 8 The Diagram shows that Norite Gabbro is forming from a Basaltic Magma but the Intrusion period is different. Noritic-Gabbro is a later phase.

Uralitisation takes place due to the action of water at the close of crystallisation. According the Bowen and Tuttle (1949) during the initial stages of emplacement some magmatic water is present which with falling temperature caused uralitisation.

Scyelite : Magmatic gravitational differentiation of the basaltic magma is the cause of crystallization. It is postulated that a magnesian rich olivine is crystallizing shortly followed by ortho and clino pyroxene. Due to rapid change in temperature and action of volatiles in magmatic chamber, the magma is locally enriched in alumina and silica.

Now the temperature and composition is favourable for th: crystallization of Hornblende. These crystalline phases were then accumulated in

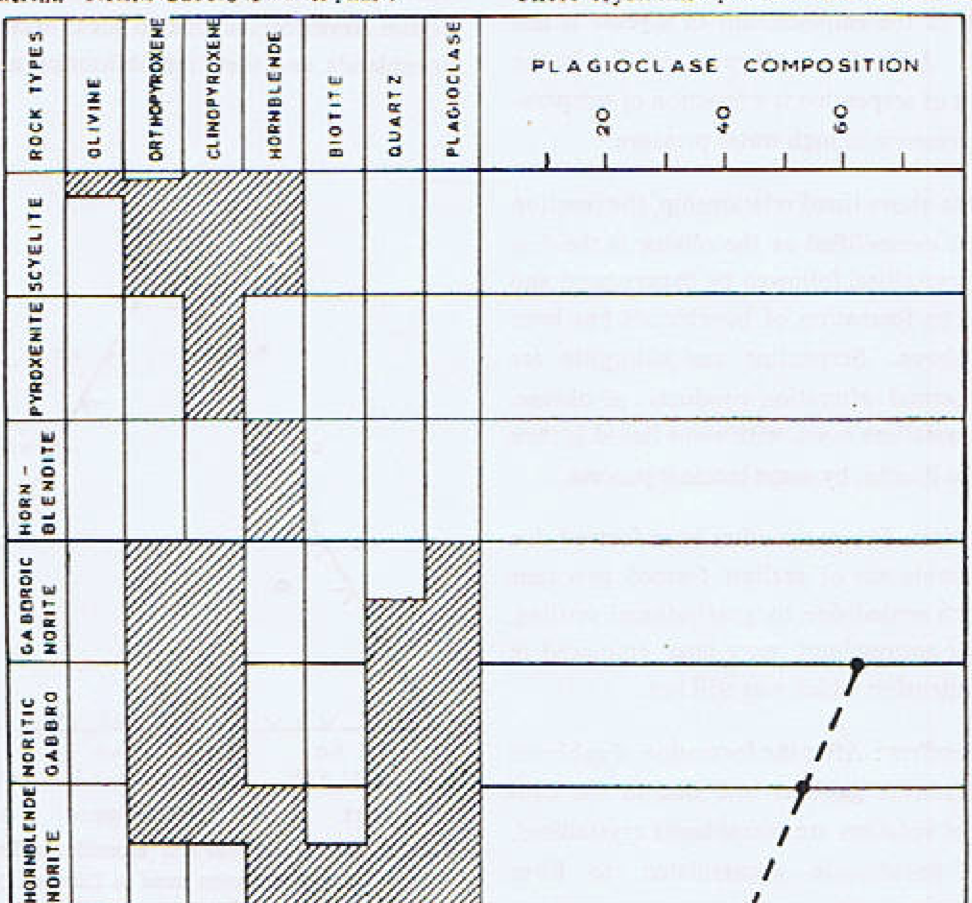


Fig. 9 Mineralogical Variation in Noritic Intrusion.

the magmatic chamber, due to gravitational settling. This crystalline melt is intruded in diorite at later stages.

Bowen (1928) has suggested that peridotite dikes have been intruded not as magma but as solid crystalline masses that have been moved in by dynamic processes. Hess (1944) on the other hand has suggested that peridotite magma has been intruded, the liquid condition being a result of high water content. It has also been suggested that mechanical intrusion of peridotite may be facilitated by the lubrication of crystal mass by colloidal hydrous magnesian silicates or serpentine. Small amounts of serpentine occuring along fracture plains and grain boundries of olivine and pyroxene in scyelite indicates the presence of above mentioned liquids at 500°C. Thus the temperature of the emplacement of scyelite is less than 500°C. According to Bowen and Tuttle, the development of serpentine is a function of temperature in the presence of high water pressure.

From the above listed relationship, the reaction series is well examplified as the olivine is the first mineral to crystallize, followed by hypersthene and diopside. The formation of hornblende has been explained above. Serpentine and iddingsite are the hydrothermal alteration products of olivine. This solid crystalline mass, with some liquid is then intruded into diorite, by some tectonic process.

Pyroxenites: The pyroxenites have formed due to the accumulation of earliest formed pyroxene crystals which settled due to gravitational settling. These earlier accumulates were later emplaced in the norite intrusion which was still hot.

Hornblendites : After the formation of gabbroic norites and noritic gabbros and due to the concentration of volatites etc. hornblende crystallised. At places hornblende accumulated to form hornblendites in norite.

Diorite Complex

Since norite cuts diorite therefore diorite is older and can not be a derivation of norite. Detailed petrographic study of this diorite outside the area shows presence of hypersthene at a few places. Also schiller structure found in hornblende at places indicates its formation from pyroxene. The later crystalline differentiates are quartz diorite, tonalite, acid porphyries, acid pegmatite and quartzofeldpathic veins. Mineralogical variation in the complex is shown in Figs. 10 & 11. This suggests that the original magma was equivalent of pyroxene andesite. This magma on differential crystallisation yeilded diorite, quartz diorite, tonalite, porphyries and acid pegmatites.

Hornblendites in diorite intrusion are formed due to two process. The intrusive hornblendite bodies have formed due to local accumulation of hornblende and their remobilisation and emplace-

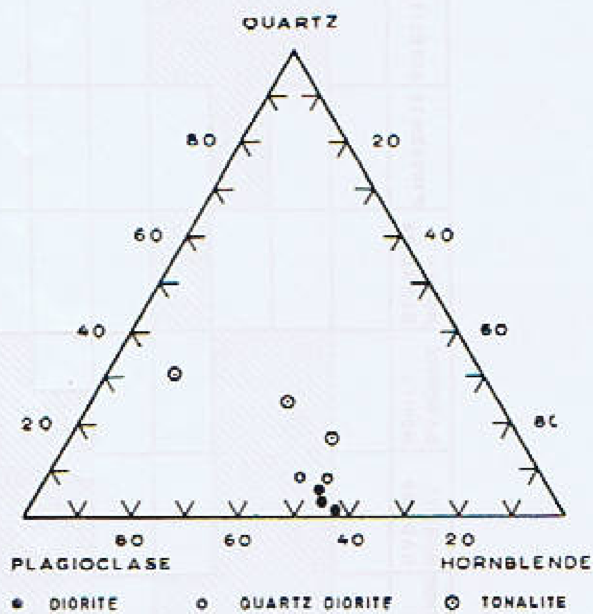


Fig. 10 Quartz, Feldspar and Hornblende Diagram shows the differentiation trend in Diorite, Quartz Diorite and Tonalite.

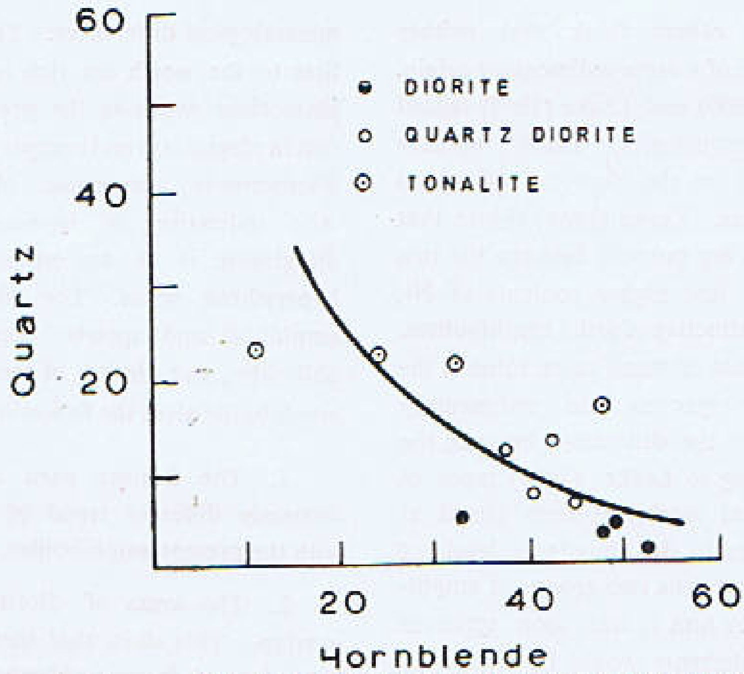


Fig. 11 Diagram shows Inverse Relation between Quartz and Hornblende in Diorite, Quartz Diorite and Tonalite.

ment as intrusive bodies in diorite. The irregular and patch like hornblendites formed at contact with norite are due to recrystallisation and local segregation of hornblende due to the effect of flow of heat and volatiles etc. from the norite. With progressive crystallisation the amount of silica volatiles and alkalies increased whereas the amount of calcium, magnesium and iron decreased. This caused progressive enrichment in quartz, sodic plagioclase, orthoclase and micas which successively formed quartz diorite, tonalite, porphyries and acid pegmatites.

There is no evidence to suggest that the diorite has formed due to hybridisation. According to Deer (1950) due to hybridisation in Glentilt diorite the grains size of hornblende decreases while that of the plagioclase increases. Other authors have also noted that the grain size of coarse grained rocks decreases during hybridisation. Such evidence is altogether lacking in the present case.

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 metamorphism 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 metasedimentary 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 rocks or by the 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 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 evidence should not be under rated. In the case of the amphibolites of this area the field, mineralogical, textural and structural criteria will be considered to decide the origin of these rocks.

Study of the present amphibolites shows that they have more or less uniform texture. They have not been found to grade into less metamorphosed sediments. Their mineralogical variation is shown in Figs. 12 & 13. Their comparison with the Bibiore para amphibolite shows distinct mineralogical differences. The Bibiore amphibolites to the north are rich in quartz and poor in plagioclase where-as the present amphibolites are rich in plagioclase and comparatively poor in quartz. Furthermore occurrence of cummingtonite is also indicative of igneous parentage. Cummingtonite is a corresponding equivalent of hypersthene series. The plot on plagioclase, amphibole and quartz diagram of these amphibolites, and diorites of the area and the Bibiore amphibolite gives the following result.

1. The Bibiore para amphibolites have a distinctly different trend of variation compared with the present amphibolites.

2. The areas of diorite and amphibolites overlap. This show that these amphibolites have been derived from compositions somewhat more basic than diorites i.e. mela diorite a leuco gabbro or leuconorite.

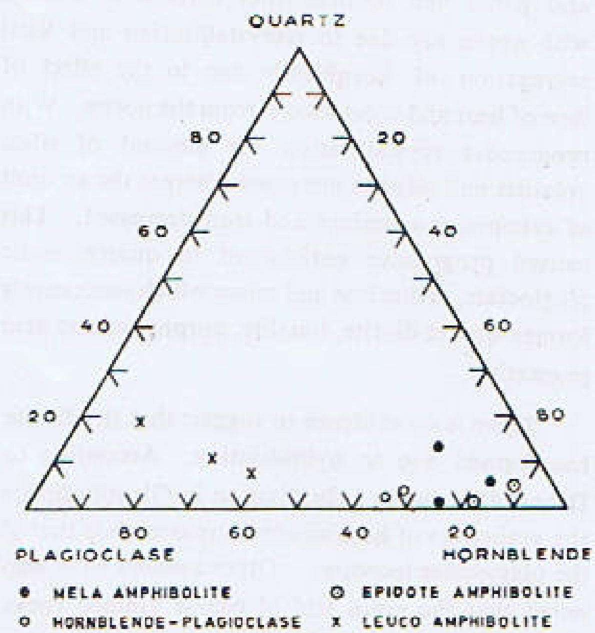


Fig. 12 Quartz, Feldspar and Hornblende Diagram Shows the Metamorphic differentiation in Amphibolite.

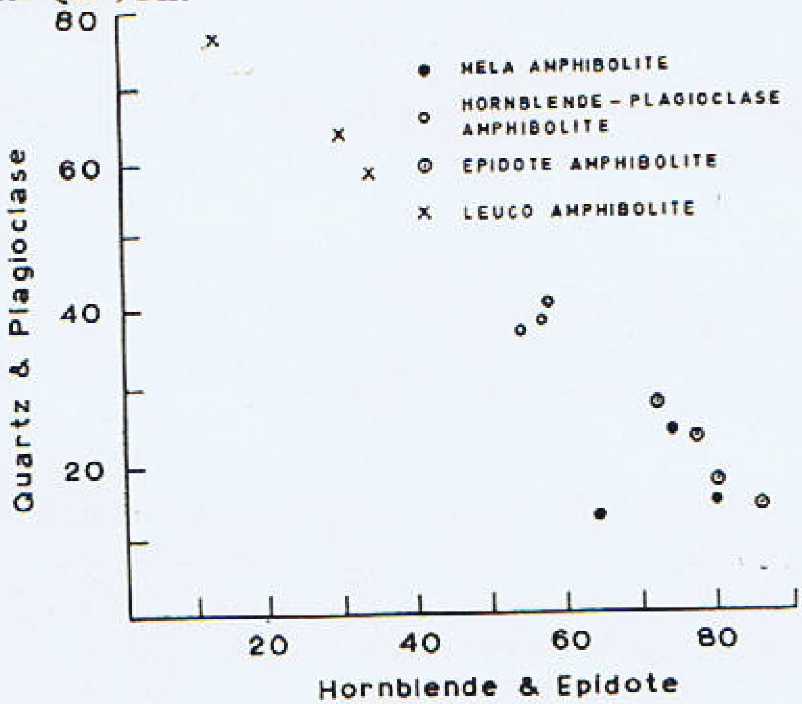


Fig. 13 Diagram shows Segregation of Leuco and Mela Amphibolite Bands.

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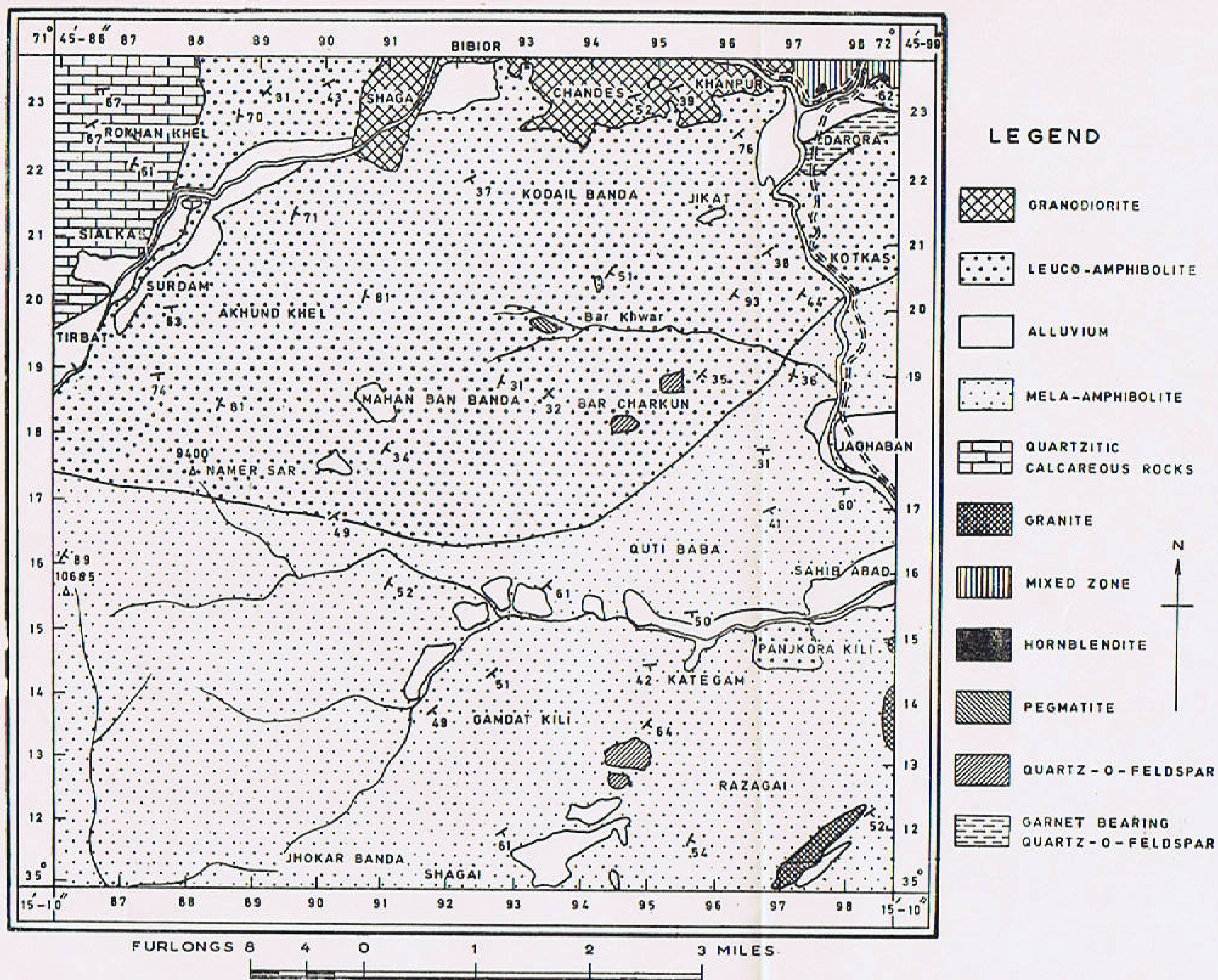

Geological Map of Sahibabad - Bibior area (Dir District).

GRAVITATIVE STRUCTURES OF THE KATTHA MASRAL REGION OF THE CENTRAL SALT RANGE, PAKISTAN

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Abstract : *Area north of Kattha Masral lies in the central part of the Salt Range, and occurs on the northern slopes of the Indian shield. A nearly 1275 ft. thick rock sequence of shelf deposits ranging from Cambrian or Eocambrian to late Lower Eocene with two major stratigraphic breaks and consisting of limestones, sandstones, shales and marls, rests on a highly plastic, thick Salt Range Formation composed of salt marls, gypsum, anhydrite, rock salt and occasional dolomites and oil shales of Cambrian or Eocambrian age. Initially the area had a cover of partially developed post-tectonic molassic Rawalpindi and Siwalik groups of the Potwar fore-deep. Structurally the area is characterised by the valley-coinciding sharp crested narrow anticlines with random attitude, separated by wide, flat-based synclines with sharply up-turning limbs occupying the intervening ridges, superimposed on generally northward dipping homocline. This "inverted topography", it is concluded, is the result of gravitative flow process (atectonic diapirism) due to the differential loading (or unloading) caused by the excavation of valleys. No significant involvement of the regional compressive lateral stress, despite the elongation of structures, is envisaged in the development of these features. The structures started developing after the uplift of the Salt Range in the early Pleistocene. Both time and stress available are enough to develop structures of this magnitude through superficial non-tectonic (gravitative) diapirism.*

INTRODUCTION

During the investigation of bauxite and laterite in 1969, Mohammad Ashraf prepared a geological map of the Kattha Masral area, about 16 miles north of Khushab, Sargodha District (Fig. 1). The region lies in the central part of the Salt Range with a roughly east-west trend having a general dip towards north. The map covered approximately 90 square miles of this deeply dissected cuesta of moderate relief; altitude ranging from 740 ft. above sea level in the south-west to 3,388 ft. in the north-west.

Though the entire sequence of sedimentary rocks exposed in the project area ranging from an evaporite series (rock salt, salt marls, gypsum, anhydrite and occasional dolomites) of the Salt Range Formation (Cambrian or Eocambrian) to Margala Hill Limestone (Sakeser Limestone) or Chorgali Formation (Bhadrar beds) of the uppermost Lowest Eocene age represents shelf deposittion, further north it is capped by the post-tectonic thick (10,000+ft.) molassic infilling of the fore-deep, such as in Dhok Tahlian region, north east of the area (Gee, 1944). Because of the para-conformable contact between the plateform sediments and the younger molasse it appears highly probable that most of the Siwalik sequence with at least Kamlial stage of the Rawalpindi Group capped the Eocene and older sequence. This leads us to conclude that a thickness of 10,000—12,000 ft. of sandstones, shales, limestones, dolomites and conglomerates rested above the hitherto un-estimated highly plastic and rock salt bearing Salt Range Formation. A generalised litho-log (Fig. 2) depicts the major breaks in sedimentation. The first stratigraphic gap occurs between the Jutana Dolomite or Kussak Formation of Cambrian age and the Permian Tobra Formation. The second gap is between Chhidru Formation or Wargal Formation of Permian Zaluch Group and the Hangu Formation belonging to the Palaeocene age, precluding all representatives of the Mesozoic era. The intervening unconformity is marked by a laterite/bauxite formation (Ashraf et al., 1972 a; 1972 b).

STRUCTURE

Major structural features include a number of broad flatbased synclines separated by somewhat narrow, sharp crested anticlines. As in inverted topography, the synclines occupy spurs, transverse or oblique to the main east-west structural trend of the homocline. The anticlines occur along the deeply eroded gorges and canyons, locally known as wahans. Even the side streams seem to follow the anticlinal trends. Axial lines of various anticlines and synclines (Fig. 1) show no particular parallelism. Rather in certain cases the angular divergence becomes as large as 80° or so.

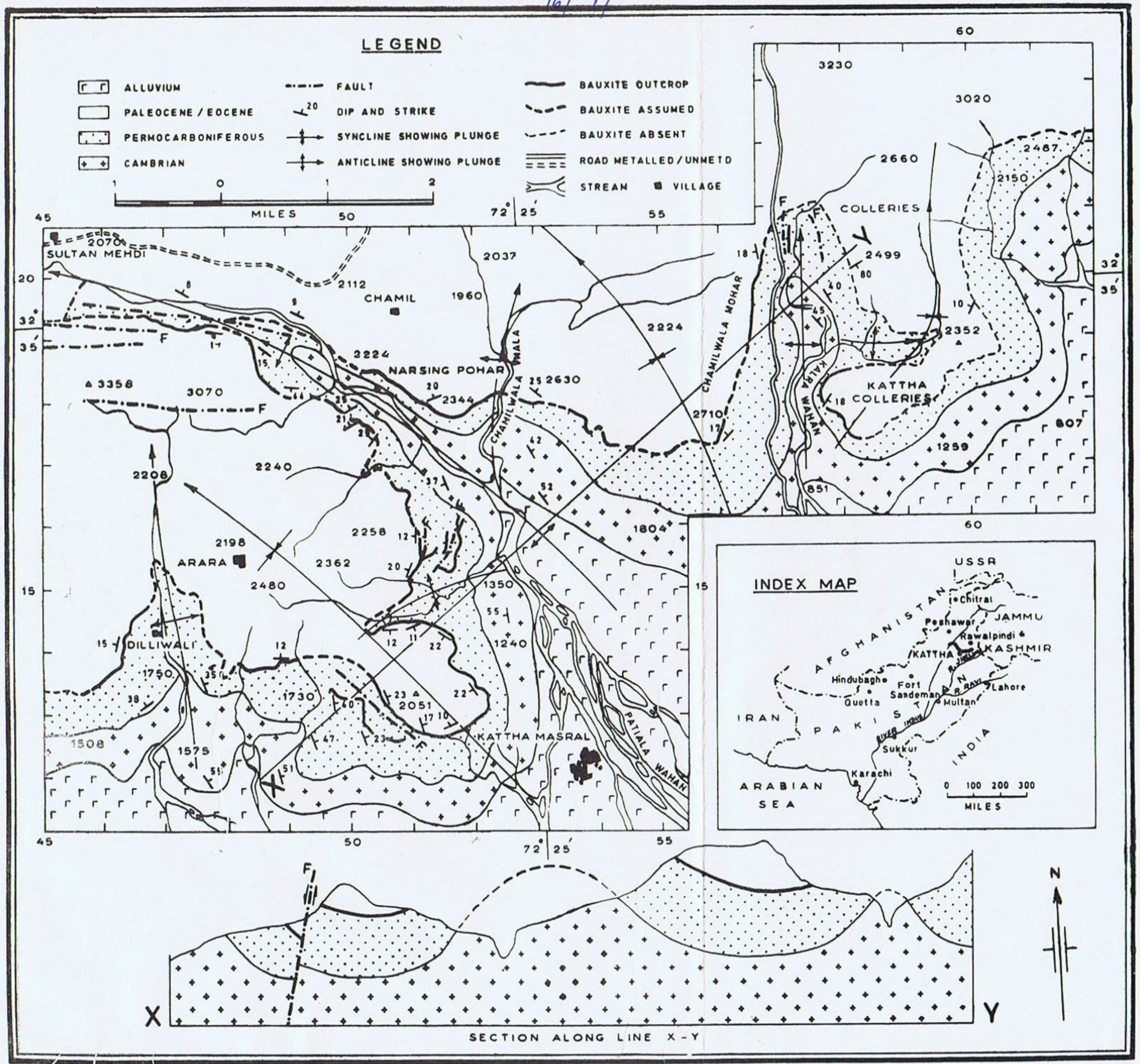
As far as faulting is concerned, small scale normal faults are numerous, particularly along the steep slopes of the deep ravines, more or less in the manner of step faulting. One major reverse fault is developed in Patiala Wahan near Narsing Pohar. A simplified section along X-Y shows the structural characteristics of the region. It also explains the steeper dips of the older formation as compared to the younger Eocene/Palaeocene beds.

NATURE AND ORIGIN OF THE STRUCTURES

The structural features with the structural trends transverse or oblique to the regional strike, lack of parallelism in fold axes, shape and locations of the anticlines and synclines as well as the associated faults led the senior author to conclude that the structural features were essentially the result of gravitative flow process (atectonic diapirism) involving the sub-surface flow of highly incompetent evaporite sequence of the Salt Range Formation (an enormous pile of red saline gypsiferous marls, gypsum, anhydrite, salt lenses and occasional dolomites and oil shales) due to differential loading caused by the excavation of canyons and ravines by erosional processes. The mechanism could be termed as superficial non-tectonic (gravitative) diapirism.

Fold diapirs are structural features in which a mobile core material is injected through less mobile layers (Spancer-1969). Commonly presence of a low density or highly ductile material such as rock salt, gypsum or clays etc, below the normal sediments create unstable condition. Local thining of the overlying sediments or removal of load by erosion disturbs the gravitative equilibrium, initiating the flow of plastic layer developing the diapiric structure, even in the absence of any lateral tectonic compressive force. "Halokinesis", a term introduced by Trusheim (1960) for purely gravitative salt tectonics, may be applied for the formation of such structures.

Diastrophism, however, causing the local uparching of the low density and plastic layer may triger the movement (Nettleton, 1934) creating doubts in the purity of non-tectonic nature of the process. Diastrophism, involving lateral compressive stresses in the presence of a thick ductile layer (or soap layer of Lutaud) may lead to the development of diapiric structures (Coats, 1964). In such environments lateral earthmovements generally result in detachment of the overlying non-ductile series from its basement, thus deforming



MODIFIED AFTER MOHAMMAD ASHRAF, 1969.

Fig. 1. Geological Map of Kattha Area, Salt Range.

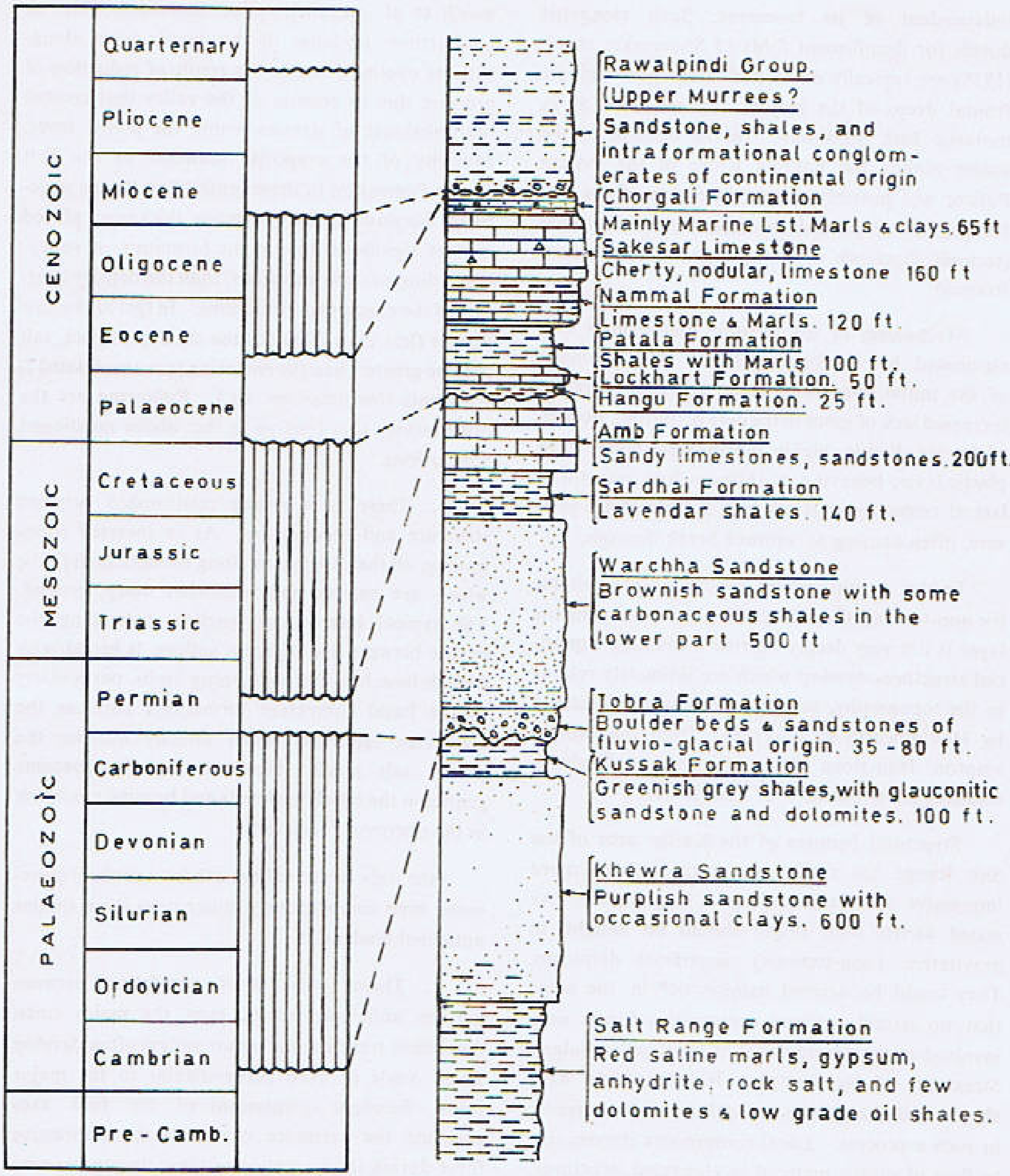


Fig. 2 Generalized Stratigraphic Column of Kattha Area of the Salt Range, based on rough estimates of the thicknesses of various Formations

independent of its basement. Such elongated domes (or decollement folds of Shoemaker et al. (1958) are typically developed in the post tectonic frontal deeps of the major orogenes, such as in molassic Jura Mountain. In the opinion of the senior author the Bakrala Ridge of the eastern Potwar and possibly eastern extension of the Salt Range, has originated through a similar process (tectonic diapirism involving regional compressive stresses).

Mechanism of the tectonic diapirism is ably elucidated by de Sitter (1964). The geometry of the initial concentric folds gradually develops increased lack of space in the core of the fold, occupied by the ductile, highly incompetent layer. The plastic layer, behaving as a viscous fluid, transforms lateral compressive stress into a hydrostatic pressure, often causing an upward break through.

In the regions, where conditions are suitable for non-tectonic diapirism, if the low density ductile layer is not very deeply burried interesting superficial structures develop which are intimately related to the topography, such as valley bulges described by Hollingworth et al. (1944) from the Northampton Iron-stone fields of northern England, resulting from the flow of Liassic clay.

Structural features of the Kattha area of the Salt Range are similar structure, perhaps more impressive and developed on a bigger scale. As stated earlier their origin should be sought in gravitative (non-tectonic) superficial diapirism. They could be termed halokinetic* in the sense that no lateral regional compressive forces were involved in the development of these valley bulges. Structures of Northampton Ironstone field have shown that the presence of salt is no prerequisite in such a process. Local compressive stresses due to flow of plastic material in elongated structures, however, may cause intricate folding in the core area of these so-called salt anticlines. (Hollingworth et al., op. cit.). The non-diastrophic or non-tectonic up-bulge of the ductile layer alongwith its overburden was the result of reduction of pressure due to erosion of the valley that created the imbalance of stresses within the plastic layer. Mobility of the evaporite sequence of the Salt Range Formation in these central Salt Range structures, because of its enormous thickness, played a more significant role in the formation of valley-coinciding narrow anticlines, than the density contrast of the concerned formations. In fact at shallow depths (less than 2000 ft.) the density of rock salt may be greater than the enclosing (unconsolidated ?) sediments (Nettleton op. cit.). Following are the observations that lead us to the above mentioned conclusions.

1. There is a strong relationship between structure and topography. As in inverted topography, all the valleys run along the anticlinal folds, which are narrow and somewhat sharp crested. The typical intervening syncline, coinciding the devide between the adjacent valleys, is broad with flattish base but sharply turning limbs, particularly in the basal competent formations such as the Cambrian sequence which directly overlies the plastic salt marls. However the dips become gentler in the overlying layers and become minimum in the upermost formations.

Not only larger valleys exhibit anticlinal structures, even comparatively minor ones show similar anticlinal tendencies.

2. There is no strict parallelism between various anticlinal trends, even the major ones. Anticlinal trends in the minor valleys often develop at an angle or even perpendicular to the major folds. Random orientations of the fold axes preclude the existance of a lateral compressive force during the formation of these structures, even though the folds are not circular in outline. The curvature of fold axes, such as in the case of Kattha

*Halokinesis — all process connected casually with the autonmous isostatic movement of the salt—Trusheim (1960).

Colleric syncline, follow topographic continuity.

3. Diapiric tendencies involving piercement of the overlying normal sediments, are manifested by the presence of thrusts at the base of the competent sequence. They are best seen in the Patiala Wahan, west of Narsing Pohar. This is in conformity with the view expressed by Trusheim (1960) that under a continuous supply of mother salt the swelling of the salt pillow increases. The diapiric stage commences, characterized as the stage of predominantly vertical salt migration. The salt paste during the upward thrust, sometimes intrudes along inclined shearing planes (high angle reverse faults—see Trusheim's fig. 14 on page 1530). However the upper layers of the overlying stratigraphic sequence (Eocene/Palaeocene succession) representing the outer arc of the developing arch, tensional rupturing is expected owing to streching due to ever-swelling plastic core. Such normal (gravity) faults are fairly common. Their association with diapirs is convincingly demonstrated by the experimental work with scale models of Curries (1956 fig. 5, 6 & 7) and the classic sections of the Reitbrook Salt Dome (Behermann, 1949) and the Heidelberg structures, Jespar county, Miss. U.S.A. (Hughes, 1960). This suggests a syngenetic development of normal faults along the slopes of the central Salt Range ravines rather than through "slumping" or land sliding.

STRESS CONSIDERATIONS

In Grand Saline Salt Dome, Texas, U.S.A., Balk (1949) considered that a shearing stress of 30 kg/cm^2 was needed to initiate deformation in rock salt, requiring a differential stress of over 60 kg/cm^2 in salt tectonics. Such a differential stress, according to Balk, may develop at a depth of 15000 ft. provided the bulk densities of the adjoining columns differ by 0.13—0.14.

Jones (1959) is, however, of the opinion that the differential stress needed to cause flowage in the salt may be approximately 30 kg/cm^2, developing at a depth of 7000 ft. in the Paradox basin of Utah and Colorado, U.S.A.

Overburden of 1000 meters and a thickness of 300 meters of salt, were considered to be necessary by Trusheim (1960) to initiate the process of flow in the German Zechstein basins.

In shallow diapirism ductility rather than density contrast between the plastic layer and the overlying sediments play a more significant role. The differential stress develops due to the sharp difference in bulk densities of the columns in the valleys and the adjoining ridges. In other words, the motive force in such cases results from the unloading of the plastic layer (not necessarily rock salt) through erosion of valleys. Stratigraphic column in the Northamptonshire area of central England (Edmund and Oakley, 1947) indicates that on an average 200 ft. Upper Lias Clay, consisting of blue shaly or sandy clay with thin bands of limestone flowed, upbulging the valley floors, under a load of about 150 ft. of sandstones, silts, limestones, ironstone and clays. In the Kattha Masral region of the Salt Range, where Sakesar Limestone caps the prominent escarpments, the Palaeozoic and lower Cenozoic sediments are more than 1200 ft. thick. The thickness of the molassic Miocene/Pliocene cover with, perhaps, Kamlial Formation overlying disconformably, was in the neighbourhood of 9,000 ft. as is the case in the adjacent Nurpur-Vasnal area (Gee, 1944). Valley bulges, however, seem to have developed after the Pleistocene uplift of the Salt Range. Though the event appears to be so recent, a million years or so may still have lapsed since the uplift. Rate of movement of salt of 0.0002 mm a day, estimated by Balk (op. cit.) is sufficient to raise the saline complex by 811 ft. This suggests that both stress and duration available are enough for the formation of central Salt Range superficial diapirs.

The authors intend to follow this preliminary report by a more thorough investigations in near future. It is hoped a more detailed picture may emerge providing us with better understanding of the Salt Range structural features.

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GEOLOGY AND PETROLOGY OF ACID MINOR BODIES FROM MANSEHRA AND BATGRAM AREA, HAZARA DISTRICT, PAKISTAN

BY

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Abstract : *The acid minor bodies are emplaced in the granitic and the associated metamorphic rocks. The bodies identified are* (1) *albitites,* (2) *albite-aplites/pegmatites* (3) *albite-(microcline)-aplites/pegmatites* (4) *albite-microcline-aplites/pegmatites* (5) *microcline-albite-aplites/pegmatites and* (6) *complex aplites/pegmatites and* (7) *quartz veins. Field, mineralogical and chemical evidences show that the acid minor bodies are genetically related with the granites.*

INTRODUCTION

The acid minor bodies on which this detailed study has been carried out are mainly albitites, aplites, pegmatites, albitized bodies and quartz veins emplaced in the granites and the associated metamorphic rocks of the Mansehra and Batgram area. Following major problems were undertaken in the present project :

(*i*) Classification of the acid minor bodies.

(*ii*) Detailed petrographical and chemical studies of different types.

(*iii*) Relationship between granites and the acid minor bodies, mode of their emplacement and origin.

The area studied is covered by the topographic sheets—43 F/2, 43 F/3 and a part of 43 F/1,43 F/6, 43 F/7 and 43 B/14 of the Survey of Pakistan.

GEOLOGY OF THE AREA

General geology of the area has been known for quite a long time but first systematic studies were started by Shams (1961) and completed by him in 1967. The area is composed of metamorphics and plutonic complex (Fig. 1). The metamorphic rocks occupy about one half of the Mansehra-Batgram area. Theses rocks are metamorphosed equivalents of the oldest clastic sediments which were laid down in the Himalayan geosyncline(Tethys sea). The various lithologic facies of sediments recognized by Shams (1969) are (i) psephitic facies, (*ii*) the psammatic facies (*iii*) the pelitic-psammatic banded facies and (*iv*) the calcareous facies.

The regional metamorphism was of the Barrovian type of the following grades (*a*) chlorite grade, (*b*) biotite grade, (c) garnet grade (*d*) staurolite grade, and (*e*) kyanite grade.

The granitic rocks are of varying types and of different ages of formation. They are Susalgali granite gneiss, Mansehra granite, andalusite granite, Suthangali granite, Hakle tourmaline granite and Chail Sar microgranite. The latter two types are younger and are more sodic.

GEOLOGY OF ACID MINOR BODIES

The acid minor bodies are those rocks which were formed from the alkalic and volatile rich liquids. They have been classified and identified

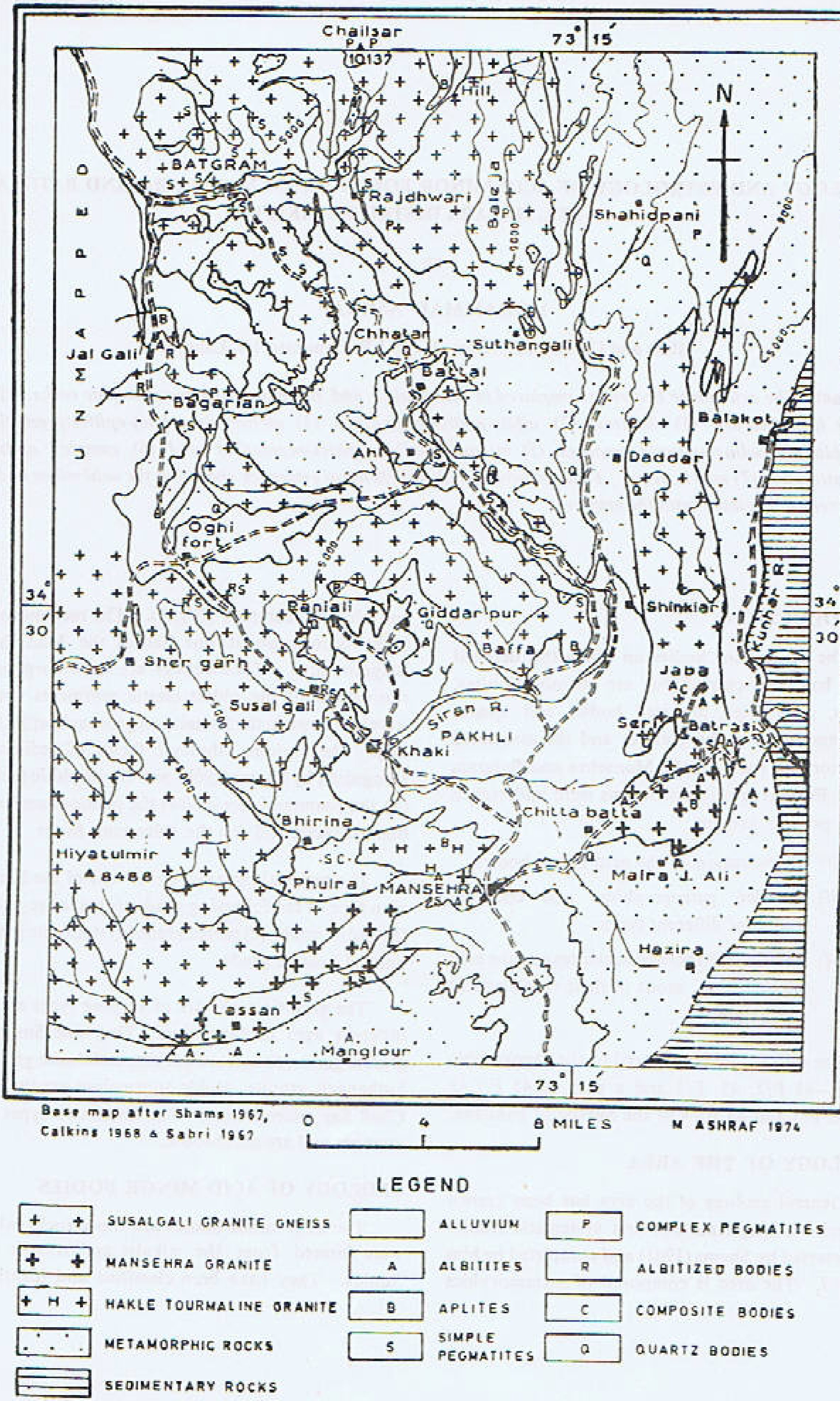

Fig. 1. Geological Map of Mansehra and Batgram Area, Hazara District showing Location and Distribution of the Acid Minor Bodies.

on the basis of mineral composition, form, size, relationship with the enclosing rocks, external and internal structures.

Type of Acid Minor Bodies : In the area following rock types have been identified on the basis of megascopic studies in the field, supplemented by the microscopy. The rocks which are less than 1 to 2 mm are termed as fine-grained rocks (albitites and aplites), 2 to 3 mm as medium-grained bodies (albitites and aplites) and more than 3 to 4 mm as coarse-grained bodies (pegmatitic-albitites and pegmatites). Following are the rock types recognized :

(*i*) Albitites (fine, medium-grained and pegmatitic).

(*ii*) Aplites (simple unzoned and complex zoned).

(*iii*) Simple pegmatites (both zoned and unzoned).

(*iv*) Complex pegmatites (zoned, unzoned, symmetrical and asymmetrical).

(*v*) Albitized or replacement bodies.

(*vi*) Composite bodies (albitite-aplite-pegmatite).

(*vii*) Quartz veins (quartz, quartz-ilmenite, quartz-kyanite).

Distribution and Localization : The acid minor bodies are distributed in the area in such a way that they have direct bearing on the place where they have got crystallized. Three zones have been recognized where slight modification has been made in Heinrich (1953) zones. The zones found by the author are (*i*) interior-lateral zone (1750 to 5500 feet above sea level, with albitites, albite-aplites/pegmatites as the characteristic rocks of the zone); (*ii*) interior-marginal zone (5000 to 9000 feet above sea level, with albite-microcline-aplite/pegmatites, and some complex pegmatites); and (*iii*) marginal-exterior zone (over 9000 feet above sea level, with mostly complex pegmatites).

Size, Shape, Form, External Structure and Relationship with the Enclosing Rocks : The acid minor bodies vary in thickness from less than a cm to over 20 metres as lensoid, lenticular, branching, pinch and swell, patch, pod, ptygmatic, and tabular bodies. These bodies have regular and sharp boundries and sometimes irregular to diffused contacts. The acid minor bodies and related rocks were reviewed in the light of classification suggested by Ginsburg (1928), Jahns (1955), and Edelman (1968).

Internal structure : The internal struc- ture of the acid minor bodies varies from one type to another. Zonation is perfectly developed in the pegmatites where mineralogical variations from one zone to another are pronounced and contrasting. The zones are wall+border zone, outer and inner intermediate zones and the core. Textural zonation has been found in the albitites (pegmatitic and medium-grained albitites).

PETROGRAPHY

The petrographic features of the albitites, aplites and pegmatites were studied in details under the microscope. The minerals identified in different rock types are albite, chessboard albite, microcline, quartz, muscovite, sericite, biotite, apatite, sphene, chlorite, tourmaline, beryl, columbite and samarskite.

The occurrence of important minerals and their distribution in some of the rock types is given in the Table 1.

GEOCHEMISTRY

Major Elements : Seventy eight specimens of different acid minor bodies were chemically analysed. Some of them are given in Table 2. The CIPW composition of the analysed samples was calculated in the manner described by Johannsen (1939). The chief normative minerals of the acid minor bodies were plotted in the ternary diagram (Fig. 2, albite, orthoclase and quartz)

TABLE 1

Modal Composition

	Pegmat-itic-Albitite	Albite-Aplite/Pegma-tite	Albite-(Micro-cline)-Aplite/(Pegma-tite)	Albite-Micro-cline-Aplite/(Pegma-tite)	Micro-cline-Albite-Aplite/(Pegma-tite)	Complex pegmatite Outer Inter-mediate Zone	Inner Inter-mediate Zone	Core
Albite ..	54.70	55.63	34.82	40.52	23.97	64.68	21.19	5.20
Chessboard Albite	27.62	5.39	0.00	0.00	0.00	0.00	0.00	0.00
Microcline ..	0.00	0.00	2.53	18.52	36.52	1.29	76.39	0.00
Quartz ..	6.95	26.07	38.03	25.31	27.77	21.15	0.15	93.25
Muscovite ..	0.93	10.53	18.87	12.72	6.92	6.85	2.11	1.55
Sericite ..	3.51	1.32	3.63	0.32	2.25	0.00	0.00	0.00
Biotite ..	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00
Apatite ..	1.59	0.69	0.27	1.02	0.02	0.59	0.00	0.00
Sphene ..	2.25	0.37	0.00	0.22	0.00	1.47	0.00	0.00
Chlorite ..	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tourmaline ..	0.00	0.00	1.71	1.32	1.63	0.00	0.00	0.00
Ore (magnetite etc).	0.00	0.00	0.14	0.03	0.17	0.00	0.15	0.00
Beryl ..	0.00	0.00	0.00	0.00	0.00	3.96	0.00	0.00

along with granites of Shams (1967). It is clear from this diagram that there does not exist a significant gap between the different rock types.

$$\text{Simpson (1954) formula} = \frac{(Na_2O + K_2O) \times 100}{(Na_2O + K_2O + CaO)}$$

has been modified in term of $\frac{(Na_2O + CaO) \times 100}{(Na_2O + CaO + K_2O)}$ because his formula is not applicable for the study of extreme alkalic rocks of the present case.

Geochemical correlation coefficient(r) and student(t) of 47 unzoned acid minor bodies were calculated by writing Fortran IV programme which were run on an IBM 360 model 44 computor. It is found that SiO_2 shows significant correlation with Na_2O (—ve), K_2O (+ve) and Al_2O_3 (—ve). Al_2O_3 shows significant correlation with Na_2O (+ve), FeO —ve), TiO_2 (+ve) and K_2O (—ve). TiO_2 also signifies correlation with SiO_2 (—ve), K_2O (—ve), Na_2O (+ve) and P_2O_5 (+ve). The correlation of Na_2O with K_2O is negative and very strong.

TABLE 2

Chemical Analysis

	Pegmat-itic-Albitite	Albite-Aplite/(Pegma-tite/	Albite (Micro-cline) Aplite/(Pegma-tite)	Albite-Micro-cline-Aplite-(Pegma-tite)	Micro-cline-Albite-Aplite/(Pegma-tite)	Complex pegmatite Outer Inter-mediate Zone	Inner Inter-mediate Zone	Core
SiO_2 ..	66.49	73.90	74.35	72.29	71.13	68.90	63.06	96.96
Al_2O_3 ..	19.33	16.80	15.90	15.10	17.08	18.80	20.37	2.53
TiO_2 ..	1.45	0.13	0.00	0.16	0.01	1.23	0.00	0.00
Fe_2O_3 ..	0.19	0.25	0.46	1.17	0.14	0.02	0.11	0.00
FeO ..	0.18	0.08	0.39	0.25	0.07	0.12	0.04	0.07
MnO ..	0.07	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MgO ..	0.30	0.10	0.15	0.30	0.35	0.35	0.00	0.00
CaO ..	1.54	1.61	0.98	0.84	0.77	0.49	0.00	0.00
Na_2O ..	8.62	4.95	4.20	3.79	2.44	6.53	3.37	0.41
K_2O ..	0.70	1.45	3.03	5.08	7.86	3.37	13.05	0.08
P_2O_5 ..	0.90	0.19	0.02	0.16	0.15	0.00	0.16	0.00
H_2O^+ ..	0.38	0.11	0.23	0.75	0.15	0.62	0.21	0.04
H_2O^- ..	0.00	0.06	0.05	0.04	0.03	0.09	0.05	0.04
Total : ..	100.15	99.73	99.76	100.56	100.18	100.52	100.42	100.13

Trace Elements : Some of the representative acid minor bodies were analysed by emission spectroscopy. The distribution of the trace elements found shows the crystallization trend in these rocks. The results are given in Table 3. It is evident from this table that Ga, Ba and Cu show almost similar distribution pattern throughout the process of evolution of acid minor rocks. The most contrasting distribution pattern is shown by Zr, Sr, Li and Pb.

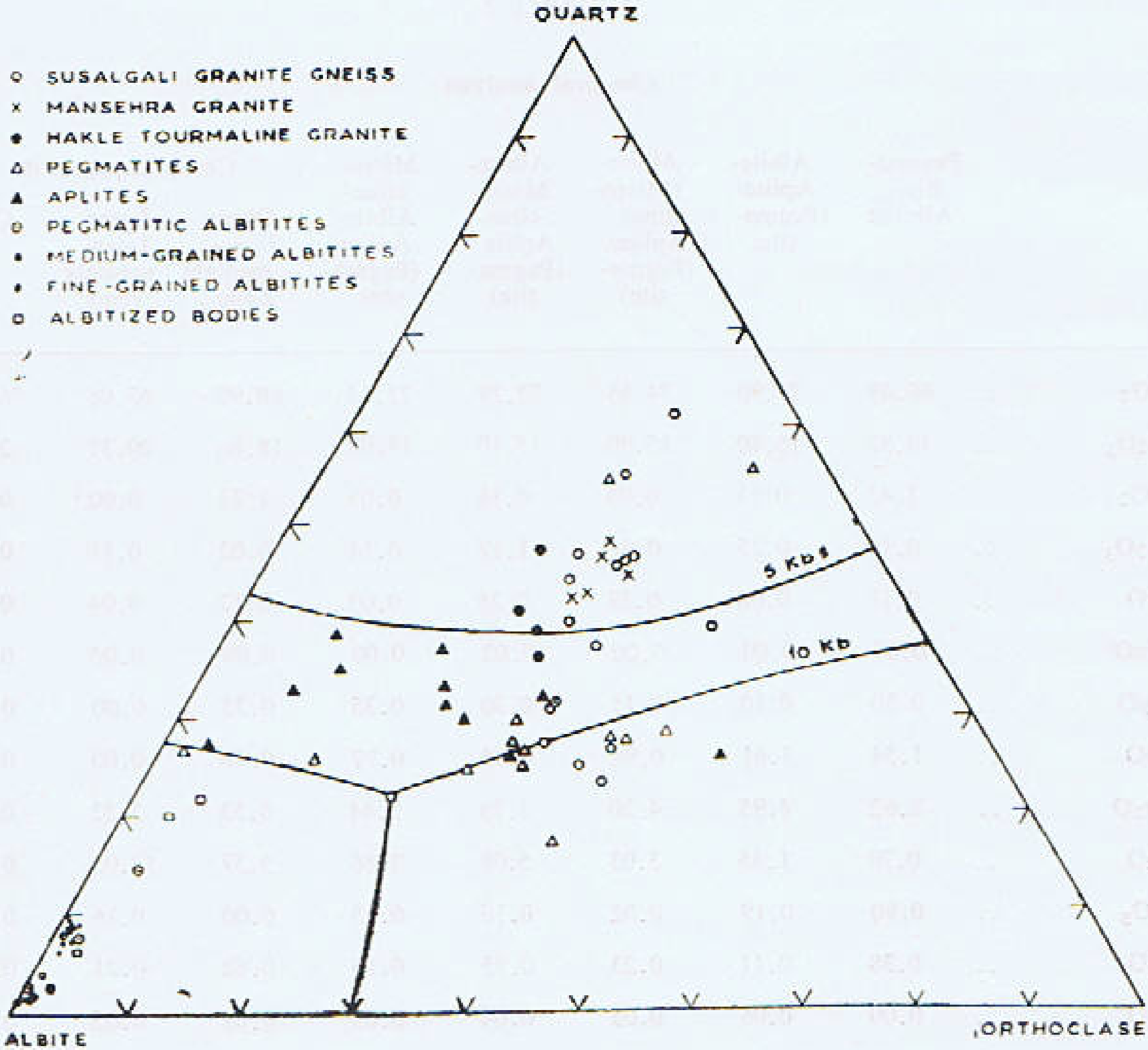

Fig. 2. Normative Albite, Orthoclase and Quartz Diagram of the Analysed Acid Minor Bodies (and Granites after Shams, 1967) recalculated to 100% (Luth et al., 1964).

TABLE 3

Trace Elements in ppm

	Albitite	Albite-aplite	Complex pegmatite (microcline zone)
Cr	14	—	30
Zr	300	5	—
Ga	10	5	5
Ba	10	10	10
Sr	80	5	5
Li	1	1	40
Cu	4	10	10
Pb	—	15	15
Rb	—	240	3000

PETROGENSIS

The acid minor bodies have been evolved from the granitic rocks of the area after the magmatic granitization process has more or less been completed. From the origin of granites (Shams, 1967), field, mineralogical, and chemical evidences for the acid minor bodies; conclusions of some fundamental importance were drawn :

(*i*) That the acid minor bodies have a strong genetic relationship with the granitic complex of the area.

(*ii*) Their regional zonal distribution is related in time and space to the granitic and the associated rocks.

(*iii*) Magmatic to rest magmatic liquids were available for the development and crystallization of the acid minor bodies in a close system.

(*iv*) Sodium metasomatism of the granitic rocks occurred during the formation of albitites or shortly afterwards.

The acid minor bodies as is evident, have a strong genetic relationship with the granites, is true in the light of recent experimental work of Luth et al. (1964). They studied the phase equilibrium relations in the granitic system at 4 to 10 Kbs where at more than 10 Kbs the isobaric quarternary minimum shifts progressively with the increasing $P(H_2O)$ towards albite apex.

The water vapour pressure must have increased in the granitic system gradually from minimum with the formation of Susalgali granitic gneiss, and the Mansehra granite at $P(H_2O)$ 500 bars (Shams and Rehman, 1966) but as the vapour pressure increased further, the soda rich members started coming into being as was also found by Hall; 1972, 1973 in the case of Caledonian and Variscan granites. These members are tourmaline granite, granite porphyry and microgranite, formed possibly at $P(H_2O)$ 5 Kbs. But with subsequent increase in $P(H_2O)$ more than 10 Kbs albitites solutions were resulted which were deposited in the fissures in the interior-lateral zone. Having risen to the maximum, the vapour pressure began to decrease with further decrease in temperature, which is very gradual within the enormous size of the granitic batholith. As the solutions moved from the interior-lateral zone to the outer zones, rather to higher structural levels the composition of the solutions changed from albitites, albite-aplites/pegmatites to albite-microcline, microcline-albite-aplites/pegmatites and complex pegmatites; with the decrease in $P(H_2O)$ gradually and progressively.

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THE ORTHO AMPHIBOLITES AND THE PARA-AMPHIBOLITES OF DIR DISTT., N.W.F.P.

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Abstract : *Extensive field and laboratory studies have been carried out on the amphibolites of Dir District. As a result the Dir amphibolites have been divided into southern Dir amphibolite belt and northern Dir amphibolite belt. As a result of field and laboratory studies and on the basis of textural, mineralogical and field characteristics, the northern Dir amphibolites have been called para amphibolites, while southern Dir amphibolites have been called ortho-amphibolites.*

INTRODUCTION

Location and Accessibility : Dir District is located in the N.W.F.P. of Pakistan and is a part of the Malakand Division. The main access to the area is by Dergai-Mingora road, from which at Chak-darra the road leads into the Dir District over the Swat river bridge. The area is traversed by a number of unmetalled roads.

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. Hayden described the area as :

"To the north of Rabat along the river the coarse diorite continues with basic pegmatites and great mass of amphibolite, which is often very coarse and which at first sight looks like a coarse diallage rock. The series is interrupted here and there by comparatively insignificant patches of hornblendic schist, relics no doubt of the metamor-, phosed sedimentary series. At about three miles south of Levy Post Warai, the basic series is pierced by occasional veins of eurite, which increase in number northwards and subsequently pass into a coarse biotite granite. The change in the nature of the rock is reflected in topography, and the steep, dark rugged hills of basic series are replaced by rolling hummocky country with white sandy surface. This belt of granite is only about 3 miles wide and gives place at about a mile above Warai to schists and gneisses full of granite veins".

Similar rocks of the adjoining Swat District have been briefly described by Davies (1965) and by Jan and Tahirkheli (1969). According to these workers the rocks are composed of hornblende bearing schists and gneisses, norites, diorites, peridotites, syenites, granite and pegmatites.

Bakr and Jackson (1964), while producing Geological map of Pakistan, have placed the rocks of the area in granite gneisses and schists with metasedimentary rocks of possibly Precambrian, into which granodiorite, syenites and diorites of probably Early Tertiary age are intrusive.

Some geological work has also been done on Shah Dheri amphibolites Swat District, which are similar to the amphibolites of southern Dir. The work was carried out in connection with the China Clay deposits at Shah Dheri by Shah et al. (1961), Faruqi and Ahmad (1967); Moosvi et al. (1966) and Faruqi et al. (1970a, 1970b)'. Ashraf (1969) gave a short account of the geology of magnetite-bearing rocks north of Shah Dheri and Jan et al. (1969) described briefly a corrundum bearing rock located 1¼ miles South-West of Shah Dheri.

Short accounts of the geology of corrundum bearing amphibolites in southern Dir at Timurgara has been given by Qasim et al. (1969) and Qasim et al. (1971). Geology of ShahDheri has also been given by Rehman et al. (1970).

Detailed investigations were started in Dir District in 1969 by the Punjab University and by the Peshawar University. The work has been carried out under the supervision of M. Nawaz Chaudhry for the Punjab University and by Safdar, Jan and Ehsan of the Peshawar University.

REGIONAL GEOLOGY

To the south of Dir lies the Malakand area. It falls in the southern part of the Attock-Hazara area. 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 few limestone 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) beleives 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 beyond river Swat for about 20 miles into Dir. Here they are quartzites, quartzitic schists and marbles. Towards the extreme north these rocks are composed of quartzitic schists and graphitic schist. Then starts the southern Dir amphibolite belt, which is intruded by the diorite complex and the norite complex. Near Warai, Warai granite is encountered, about 2 or 3 miles further north the northern Dir amphibolites start, which near Bibiore is intruded by Bibiore granodiorite. Two or three miles north of Bibiore, the amphibolites grade into the calcareous meta sediments. This meta sedimentary series is composed of marbles, calcareous quartzites, calcareous schist and quartzites. It continues for a few miles from Dir towards Lowari Top, where it is replaced by Lowari granites and granodiorites.

Megascopic Features : The northern Dir amphibolites are well banded, and layered. These have a gradational contact with calcareous rocks. Abundent quartz, quartz-o-feldspathic and epidote veins cut these rocks. These are dark coloured rocks. Mica is present in these amphibolites. Pegmatite veins bearing quartz, feldspar and muscovite are also present.

The southern Dir amphibolites have a higher colour index. These are comparatively less banded. These are cut by quartz-o-felds pathic and intermediate pegmatites containing quartz, feldspar and amphibole.

PETROGRAPHY

The Northern Dir Amphibolite Belt

Mela Amphibolites : These rocks have medium to coarse grained xenoblastic texture. They have very variable textures. Myrmekite like texture is also common.

Hornblende and epidote are the main constituents while chlorite, sphene, quartz, plagioclase and iron ore are the minor to accessory minerals.

The amount of hornblende varies from 40.00% to 60.00% in dark bands and from 1.96% to 12.09% in light bands. Quartz grains are embedded in it.

The amount of epidote varies from 6.77% to 21.24% in dark bands and from 24.65% to 50.31% in light bands. Both zoisite and clinozoisite are present. Magnetite and haematite inclusions are present.

The amount of chlorite varies from 3.52% to 32.22% in light bands and from 10.62% to 23.63% in dark bands. It is an alteration' product of hornblende.

Leuco Amphibolite : These rocks have medium to coarse grained porphyroblastic texture.

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

The amount of hornblende varies from 21.00% to 40.00%. Quartz grains are embedded in it. Hornblende commonly alters to chlorite.

The amount of quartz varies from 20.60% to 56.70%. Inclusions of epidote are present in quartz.

The amount of plagioclase varies from 0.49% to 14.62%. It commonly alters to kaolin. Inclusions of epidote, orthoclase and quartz are present.

The amount of chlorite varies from 0.48% to 30.00%. It develops along the cleavage and boundries of hornblende.

The amount of epidote varies from 0.20% to 14.62%. Both zoisite and clinozoisite are present. Inclusions of quartz are present.

The amount of garnet varies from 0.00% to 1.60%. Epidote and quartz inclusions are present.

The amount of orthoclase varies from 0.36% to 1.98%. The amount of sphene varies from 0.00% to 2.73%. Out of twenty four modal analyses, fifteen do not contain sphene, six contain less than 1% and three contain more than 1% sphene. Most of those amphibolites, which contain sphene occur near the granitic intrusions. It may be said that sphene is generally wanting.

The amount of muscovite varies from 0.00% to 16.09% and the average content of muscovite is 3.49%. It occurs both as primary as well as secondary mineral.

There are certain biotite bearing varieties, which cover fairly large area and the amount of it varies from 0.00% to 28.60%. The average amount of biotite is 11.80%.

Kaolin is a ubiquitous mineral of these amphibolites. Its amount varies from 0.00% to 33.77%. The average amount of kaolin is 13.59%.

Therefore it is clear that the northern amphibolite belt is much richer in potash bearing minerals like mica, and kaolin compared with the southern amphibolite belt. It is also much richer in quartz compared with the southern amphibolite belt.

The amount of calcite varies from 0.00% to 13.34%. Calcite grains are embedded in quartz.

The amount of iron ore varies from 0.81% to 19.73%. Magnetite, heamatite and limonite are present.

The Southern Dir Amphibolite Belt

Ampoibolites : These rocks have fine to medium grained, hypidiomorphic and granular texture. Allotrimorphic and idiomorphic textures are also present.

Amphibole, plagioclase, quartz and orthoclase are the main constituents while garnet, epidote, chlorite, sphene, apatite, calcite and biotite are the accessories.

The amount of amphibole varies from 54.08% to 80.61% in mela and 15.31 to 33.22% in leuco amphibolite. Cummingtonite and hornblende are present, Inclusions of quartz are also present.

The amount of plagioclase varies from 10.62 to 22.92% in mela and 50.52% to 59.28% in leuco amphibolite. Quartz, epidote and orthoclase inclusions are common.

The amount of epidote varies from 0.00% to 5.59%. Both zoisite and clinozoisite are present. Pistacite and quartz inclusions are common.

The amount of chlorite varies from 0.00% to 3.55%. It is an alteration product of hornblende. It develops along cleavage and boundries of hornblende. The amount of biotite varies from 0.00% to 3.26%. It sometimes alters to chlorite.

The amount of garnet varies from 0.00% to 3.63%. Quartz and epidote inclusions are common.

The amount of quartz varies from 0.00% to 18.54%.

The amount of orthoclase varies from 0.00% to 2.99%.

The amount of sphene varies from 0.00% to 1.54%.

The amount of calcite varies from 0.00% to 0.11%.

Magnetite, limonite, rutile and apatite are frequently scattered throughout the rock.

Comparsion Between Northern and Southern Amphibolites.

1. The southern Dir Amphibolites are much more uniform in texture than the northern Dir Amphibolites.

2. The northern Dir Amphibolites are lacking in cummingtonite, whereas the southern Dir amphibolites often contain cummingtonite.

3. Sphene is much more abundant and common mineral in the southern Dir amphibolites than in the northern Dir amphibolites.

4. Quartz and potasium bearing minerals like orthoclase, muscovite, biotite and clays are much more abundent in the northern Dir amphibolites than in the Southern Dir amphibolites.

5. The northern Dir amphibolites are mostly well banded, whereas banding in southern Dir amphibolites is less common.

6. The quantity of plagioclase and plagioclase epidote is much higher in the southern Dir amphibolites than in the northern Dir amphibolites.

7. The southern Dir amphibolites south of Bandgai Levy Post come in sharp contact with metasediments. They have not been seen to grade into the less metamorphosed metasediments. On the contrary at many places it is difficult to distinguish between Diorites and Amphibolites. However the northern Dir amphibolites grade into less metamorphosed quartzitic marls.

Trends of Mineralogical Variation :

In diagram No. 1 the northern Dir amphibolites, southern Dir amphibolites, diorites, mela diorites, quartz diorites, tonalites and trondhjemites of the area have been plotted on a triangular diagram in terms of amphibole+quartz+(epidote+plagioclase) =100. It can be clearly seen from the diagram that southern and northern Dir amphibolites show quite distinct trends in mineralogical variation. The northern Dir amphibolites vary along the quartz and amphibole join, whereas southern Dir amphibolites vary more or less along the amphibole+ (palagioclase+epidote) join. The variation trend of the southern Dir amphibolite is parallel to and overlaps with the variation trend of Mela diorite, diorite, tonalite, quartz diorite and trondhjemite. The northern Dir amphibolites vary neither parallel nor do they really overlap with igneous suite of the area.

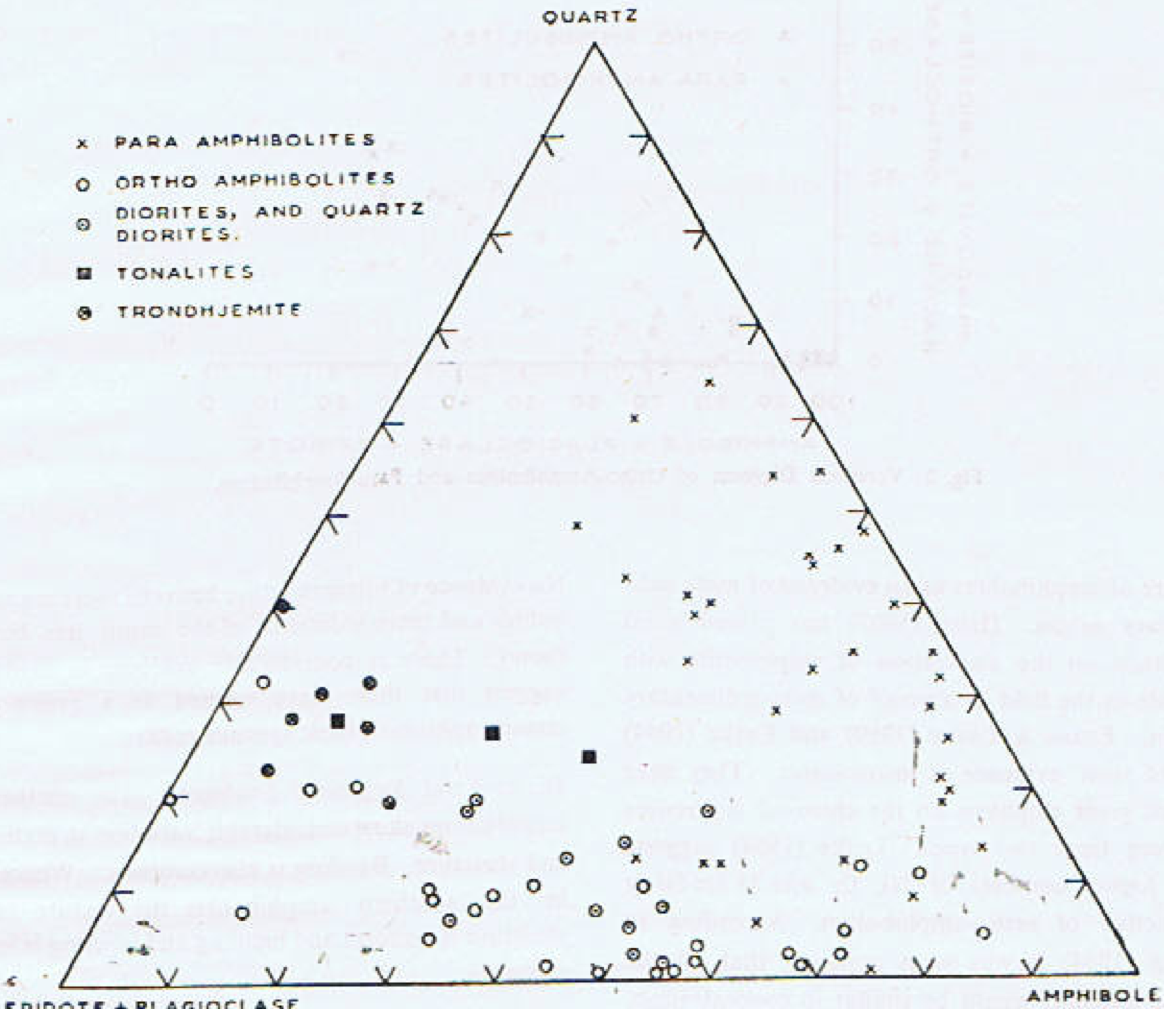

Fig. 1 Variation diagram of Ortho-Amphibolites and Para-Amphibolites in terms of Quartz+Epidote+plagioclase Amphibole=100%. Plotted on the diagram are also Diorites, Tonalites and Trondhjemite.

In Fig. 2 (amphibole+epidote+plagioclase) are plotted against (muscovite+biotite+orthoclase). The two show quite distinct trends of variation, showing that they have distinct mineralogical variation trends.

PETROGENESIS

Amphibolites can form by the metamorphism of both basic igneous and intermediate rocks as well as pelitic calcareous sediments. Amphibolites formed from the metamorphism of igneous rocks are called ortho-amphibolites and the amphibolites formed from the metamorphism of sedimentary rocks are called para amphibolites. Various authors have proposed various field, textural and structural criteria to distinguish between the two types. Wilcox and Poldervaart (1958) and Walker et al. (1960) have laid great emphasis on the banded

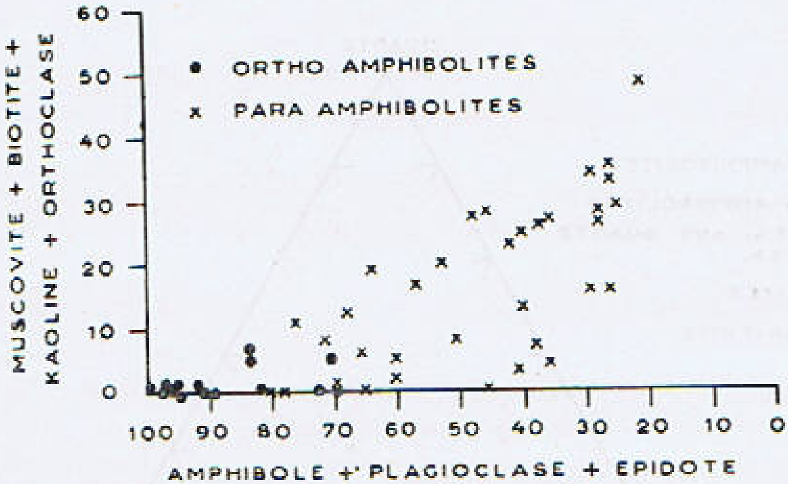

Fig. 2 Variation Diagram of Ortho-Amphibolites and Para-Amphibolites.

nature of amphibolites as an evidence of meta sedimentary origin. Heier (1962) has placed great emphasis on the association of amphibolite with marble in the field as a proof of meta-sedimentary origin. Evans & Leake (1960) and Leake (1964) regard such evidence as inconclusive. They have placed great emphasis on the chemical differences between these two types. Leake (1964) suggests that higher contents of Ni, Cr and Ti are fairly distinctive of ortho-amphibolites. According to Leake (1964) 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. Angel and Angel (1951) and Walker et al. (1960) have also focused attention on the trace elements.

Field Evidence : Amphibolites are in gradational contact with the calcareous schists in the northern amphibolites. There is considerable evidence in field to suggest that these amphibolites have formed as a result of progressive regional metamorphism of calcareous rocks.

The southern amphibolites are in sharp contact with diorites and norites. Their southern most contact is with pelitic schists, which is very sharp. No evidence of intergradation between these amphibolites and meta-sediments of the south has been found. There is considerable evidence in field to suggest that these have formed as a result of metamorphism of basic igneous rocks.

Textural and Structural Evidence : The northern amphibolites show considerable variation in texture and sturcture. Banding is also common. Whereas in the southern amphibolites the texture and structure is uniform and banding and layering is less common.

Mineralogical Evidence : The northern amphibolites are composed mainly of amphibole and quartz with lesser amounts of epidote, chlorite and mica. Plagioclase is very minor in these rocks. Titaniferous magnetite and sphene are rare. Cummingtonite is completely absent. Potash bearing minerals like mica, clay and orthoclase are more common than plagioclase. All these factors suggest that these amphibolites have formed from the metamorphism of calcareous rocks. Whereas the southern amphibolites have ubiquitous sphene, titaniferous ore, considerable amount of plagioclase and less amount of quartz. These clearly suggest that these amphibolites have formed from the metamorphism of igneous rocks. The presence of cummingtonite also suggests igneous origin of the southern amphibolites.

It is clearly seen from diagram No. 1 plotted on a triangular graph in terms of amphibole+quartz+(epidote+plagioclase)=100 that northern and southern Dir amphibolites show quite distinct trends in mineralogical variation. The northern Dir amphibolites vary along the quartz and amphibole join whereas the southern Dir amphibolite, vary more or less along amphibole + (plagioclase + epidote). The variation trend of the southern Dir amphibolite is parallel and overlaps with the variation trend of mela diorites, diorites, tonalites, quartz diorite and trondhjemite. The northern Dir amphibolites vary neither parallel nor do they really overlap with the igneous suite of the area. In diagram No. 2 amphibole + plagioclase + epidote are plotted against muscovite+biotite + orthoclase. The two show quite distinct trends of variation.

All these factors clearly suggest that northern Dir amphibolites have formed as a result of metamorphism of calcareous sediments, whereas the southern Dir amphibolites have formed as a result of metamorphism of basic igneous rocks.

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NOTICES, ABSTRACTS AND REVIEWS

THE GEOCHEMISTRY AND PETROGENESIS OF ALBITITES FROM MANSEHRA AND BATGRAM AREA, HAZARA DISTRICT. PAKISTAN

The albitites are present in the granitic rocks and the associated metamorphic rocks of the Mansehra and Batgram area. Three distinct types have been identified namely (i) pegmatitic-albitites (ii) medium-grained albitites and (*iii*) fine-grained-albitites. The former two are associated with the granites and the latter one is present in the metamorphics. The albitites occur as streaks, stringers, and 1 to 10 metres wide and five to more than seventy metres in length. The bodies occur as purely one type to composite type either with medium-grained-albitites or with albite-aplites and albite-(microcline)-aplites. The shape of these bodies is tabular and lensoid too, showing usually sharp contact relationship with the granites and gradational with the metamorphics. Mineralogically these rocks are usually formed of wholly albite with subordinate guartz, muscovite, rutile, sphene, chlorite and apatite. Sometimes zircon, tourmaline, and magnetite are also present. Chemically these rocks contain $SiO_2 = 66$ to 67%, $Al_2O_3 = 19$ to 21%, $Na_2O = 9$ to 11%, $K_2O = 0.2$ to 0.7%. The significant negative correlation is found between SiO_2 and Al_2O_3 and between Na_2O and K_2O. The trace elements found in them are Cr, Ba, Zr, Y, Ga, Sr, Li, and Cu. Their origin has been evaluated in the light of recent experimental work in the granitic system at 5 to 10 Kbs and it has been suggested that at a water vapour pressure more than 10Kbs the granitic system shifts towards albite and thereby forming albititic solutions and their deposition and crystallization took place in the fissures of the host rocks with gradual cooling of the system.

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PHOSPHORITE DEPOSITS OF GARHI HABIBULLAH KHAN, HAZARA DISTRICT

INTRODUCTION

Posphorite has been found in the Garhi Habibullah Khan area north-west of Dalola Village. The posphorite was discovered during a pleasure trip in the Galis area. The rocks of phosphate were already known near Kakul, Lagarban, and Baghlagali. Their occurrences have been reported earlier by Latif (1970), Bhatti et al. (1972) and Mahmood (1973). So far this deposit near Dalola is concerned was not known fully before.

The phosphorite outcrop can be approached from Sihali-da-Katha and Naroke-da Katha. This outcrop was studied from the point where Bhatti left it in the Survey of Pakistan toposheet No. 43 F/7. In the present reconnaissance survey particular emphasis was given to the Galdanian Formation of Calkins (1968) because of its very promising and prospective appearences as regards the phosphorite. There are chances of occurrences of phosphorite in Abbottabad Formation in this area too but due to lack of time it was not studied in any detail.

GEOLOGY

Geologically the area consists of Kakul Formation formed of quartzite, dolomite, sandstone and siltstone etc., Abbottabad Formation is grey, hard medium to thick bedded dolomites with chopboard appearence having occasional interbeds of shales fine-grained sandstone and limestone; quartzite sandstone and uppermost dolomite contains lentils of phosphate rock. The overlying Formation are those of Galdanian and Daulatmar Limestone.

Galdanian Formation: The name has been given by Calkins (1968) to the thin but highly distinctive and persistent sequence of red and brown shale, quartzoze sandstone, calcareous band and phosphate lentils, hematitic and manganese bearing beds that crop out in the Galdanian, Chure Gali, Kakul, Dalola areas. The Galdanian Formation provides key to the stratigraphy and complex structure in theses areas. The Galdanian Formation in the Dalola area occupies a northeast-southwest trend starting near Baghla Gali and terminating near grid ref. 4(5 384 of 43 F/7 just south of Sihali-da-Katha.

Phosphorite: in the present area phosphorite is dark brown, reddish, carbonaceous, light grey and dark grey pelletal. It is medium to thin bedded with intercalations of grey to reddish shales and sandstones, and rarely calcareous and carbonaceous bands. The thickness of the phosphorite bed vary from 30 to 50 feet and is traced for more than two miles. The samples collected from the Garhi Habibullah Khan area were checked qualitatively for phosphate and it was found out that dark brown, reddish, carbonaceous and grey pelletal material contains phosphorite.

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NATURAL RESOURCES

Shortages or Shortcomings

INTRODUCTION

Nature has bestowed man with best of materials for his existance and survival on this globe. Ever since the known history of man, he has made use of these materials to his advantage and need. Early stoneage man used stone to make tools. He carved wood with these stonetools to make bows and arrows as well as used bark of the trees for his clothing. In contrast to the early man, modern man has delved into a sophisticated technology for the diverse utilisation of the resources in his environment. Thus natural resources could be defined as the materials which man can profitably utilize.

Today, the man has reached a stage when he is made to think of the future utilization of these natural resources. In the modern age of technology and communication, the interaction of many factors have to be considered for the future development of natural resources of this globe. A recent manifestation of these interactions is the effect of Middle East oil "embargo" resulting in worldwide economic "crisis". Thus, in modern age, demand and supply of these natural resources is a global affair.

The demand for these resources is dependant on the size of population as well as the standard of living. "Explosive" population growth in some countries with a strong lag in the discovery and production of new resources, has generated a contrasting situation with those nations with controlled population growth and abundant resources. This has led to some sort of forecasting about population growth for furture socio - economic planning. Standard of living can be best expressed as the *per-capita* consumption of these resources. Thus industrialised nations are utilizing these resources to much greater extent than the developing nations—which in turn are trying to imitate the industrialised nations to "improve" their standard of living. This disparity between rich and poor nations has resulted in a race to achieve better standards of living. Some clues about the standards of living can be obtained by comparing the GNP (gross national product) of the nations.

AGRICULTURE

Food is man's first and foremost need and it is often reported that a great majority of world's population is either underfed or ill-fed. Major proportion of man's food is derived from land through agriculture. Land surface of the earth is huge but only a small portion is either arable or under cultivation. Further restrictions are placed on their production in certain countries by their "quota systems" in order to maintain an economic balance rather than the meet the needs of hungry and under-fed millions on purely humanitarian grounds. These affluent countries even dump their surpluses underground to achieve the economic balance. Yet the agricultural production has been affected in other ways—such as excessive use of fertilizers to boost production—causing serious problems to the environments, and distrurbing the natural balance. Although climatic variations play a grest role in the productivity of land, yet "Green Revolutions" were devised by many developing countries to achieve self sufficiency in food production. This was based on improving productivity thorough the use of fertilizers. Fertilizers industry was shaken recently by the "oil crisis" thus shattering the "Green Revolution" of these countries.

WATER

Man's other source of food is the hydrosphere—oceans, rivers, lakes etc. Although it is mainly confined to fisheries, other sources the use of which man has not yet fully realised are there in the hydrosphere to be tapped. On the fishery itself, there are political battles as well as physical skirmishes taking place throughout the world. Many countries have extended their rights to oceans for beyond the internationally recognised limits. Others have developeds ephisticated techniques to pick-up huge "catches" from open oceans and bigger game. International bodies, such as United Nations has been forced to consider seriously the problem of rights of nation on open seas, and their resources.

Water is another renewable resource which make up man's lifeline. With increased population, greater care and planning is required for the utilization of water resources. Already "careless" use has resulted in pollution problems of immen_e dimensions in some industrialised nations. Although nature plays its part in the form of climatic variations and changing environments yet man is largely responsible for the "misuse" of water resources. Availability as well as the quality of water resources is a major part of the future planning of these resources.

MINERALS

Mine al resources including fossil fuels are the other major commodity on which present day man relies heavily. These mineral resources are the backbone of technology and industrialisation. To a great extent it will be ture to say that a nation's might and strength can be expressed in term; of its mineral resources. A recent example of this is the "oil embargo" by the O.P.E.C. creating an "oil crisis". This has led to the re-thinking about the sensible utilization of petroleum throughout the world. Similar concern has been expressed about the future of other mineral resources. This possible future shortage of metal supplies has been ascribed partly to the fact that these resources are "non-renewable" and partly to depletion of known reserves. At the present rate of consumption the "lifetimes" of different metal reserves is as follows: Mercury—15 years; Tin—20 years; Silver—20 years; Lead and Zinc—25 years; Copper—35 years; Petroleum—35 years; Natural gas—40 years. These figures are further reduced when a future growth demand is taken into account. All this has prompted strong groups within the society who favour conservation of these resources to certain extent. These conservationists view the situation from two different angles. Firstly they consider the present rate of exploitation is rather too excessive without much regard to the availability of these resources to the future generations. Secondly, conseravtionists are concerned about the environment. Mass exploitation of resources without due care of the natural environments has produced changes in natural setup thus causing an extensive pollution problems which in many cases reach unmanagable proportions.

Answer to the first problem of conservationists lies in the fact that man until recent times has exploited only the mineral resources on land. Sufficient quantities of different mineral resources are believed to occur under ocean waters to supply earth's industrial needs for many centuries. Exploration and exploitation of these under water resou ces will be limited by economic, political or technological factors.

Present day technology is already making progress in two di ections. On the one hand sophisticated tools are being designed to exploited under-water mineral resources (such as dredging of manganese nodules in recent years) and on the other hand scarcity of certain mineral resources is beign overcome by re-cycling and re-use. Stress is also being laid in recent years to avoid wastage of mineral resources.

Second point of conservationists is being countered by different nations in the form of establishing governmental bodies—such as Environmental Protection Authority in Western Australia. These bodies look into different mining projects submitted to the government and suggest remedies for environmental protection. Rehabilitation of mined areas is a major form of remedy.

More recently, it has been revealed in the United States, that some major oil companies were hoarding their stocks to strike huge profits during the "oil crisis". This makes the situation even more critical. A more balanced and logical approach is required for future exploration and exploitation of natural resources on this globe. Future resources management will have to seek local, national and international cooperation in order to achieve this goal. This will mean overcoming the physical, socio-cultural and technological barriers which may exist at present due either to human shortcomings or any other reasons.

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PRELIMINARY TECTONIC STUDY OF THE KALA CHITTA RANGE, PUNJAB, PAKISTAN.

During the students field training programme, 1971-73, involving lithostratigraphic mapping of the eastern part of the Kala Chitta Range in the north-western part of the Punjab, the author made the following observations.

The rock sequence ranges from Triassic Kingriali Formation to late Pleistocene infilling of the Campbellpur basin. Apart from a number of minor disconformities, two major stratigraphic gaps occur in the depositional sequences. The first gap occurs between the Lower Cretaceous Lumshiwal Formation and argillo-calcareous Tertiary succession. The absence of Kawagarh Formation, from the eastern part, and a patchy appearance of pisolitic Surg Laterite Formation directly overlying the Lumshiwal sequence, may mean a prolonged period of non-deposition and leaching under warm humid climate with very low relief, and with a phase of denudation prior to the post-Danian marine transgression. Marine conditions prevailed till late Lower Eocene. No residual deposit marks the second long hiatus in the stratigraphic record. The sudden upsurge of clastics in the early Miocene, perhaps, marks the major uplift of the Himalays.

The continental molassic infilling of the fore-deep continued with increasing rate and grain-size, when early Pleistocene earth movements thrusted the mio-geosynclinal infilling over the platform-cum-fore-deep sediments. The emergence of Kala Chitta Ranges as a results of Marginal Uplift, created a post-tectonic intra-deep or interior basin (Campbellpur basin) behind the ridge, with almost undisturbed clastic infilling.

While in the western part of the Kala Chitta Range the oldest rock formation belongs to the Mianwali Formation in the eastern part, despite repeated thrusting, the oldest formation that has come up is not older than the Kingriali Formation. Perhaps this Triassic succession is undergoing an attenuation towards southeast and the Kingriali Formation is directly resting over a 'Soap Layer', which could, perhaps, be the Salt Range Formation.

Presence of the 'Soap Layer' is also indicated by the structure of the ridge which suggests the possibility of the role of, at least, local decollement in its development.

The range represents a para-autochthonous pile of thrust sheets, a few of which could justifiably be termed as nappes. The typical cross-section is not in conformity with the popular isoclinal or fan-fold concept of the Kala Chitta Range (Pasco, 1920, Pinfold, 1954, Sokolov and Shah, 1966). In fact the folded thrust sheets have undergone overturning in the northern part. The thrusting has suffered a concomitant phase of cross-folding with steep or nearly vertical axes. Thrusting appears to have played the major role in the formation of cross-folds as only a few seem to cross the transverse cross-folded zone. It is likely that the cross-folding resulted from differential right-lateral transverse movement of the basement blocks effecting the overlying sedimentary vaneer, a mechanism suggested by Wegmann (1961) for folding and faulting in the Jura Mountains. Role of 'Soap Layer' in the development of local decollement and disharmonic folding forms an important aspect of the mechanism. The overlying sedimentary veneer has experienced a greater southward shove in the west, undergoing greater differential movements along the thrust planes. This progressive increase of thrust movement towards west imparts a rotational character to some of these thrust movements.

The detailed structural studies are now being extended to the adjoining Kohat region in the west and the southern Hazara in the east by the author along with his co-workers.

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