M.Phil

PETROLOGY AND GEOCHEMISTRY OF THE SOUTHERN AMPHIBOLITE BELT ROCKS FROM MAHAK AND SURROUNDING AREA, SWAT, NORTH PAKISTAN.

THESIS PRESENTED FOR THE DEGREE OF MASTER OF PHILOSPHY AT THE UNIVERSITY OF PESHAWAR.

BY

IDREES HUSSAIN BANGASH

NATIONAL CENTRE OF EXCELLENCE IN GEOLOGY
UNIVERSITY OF PESHAWAR
PAKISTAN.

March, 1991.

CONTENTS

LIST OF FIGURES

FIGURES PAGE

LIST OF TABLES

TABLES PAGE

LIST OF PLATES

ACKNOWLEDGEMENTS

The author wishes to express his profound gratitude to Dr. S. Hamidullah, the thesis advisor, for his valuable suggestions, useful discussions of the thesis problems, and critical review of the manuscript. He is also thanked for helping in geochemical work and providing literature from his personal library. Prof.Dr.M.Qasim Jan is gratefully achnowledge for suggesting thesis area.Mr.Wasim Ahmad is thanked for providing company in the field.

The author is obliged to Dr. B.L.Weaver of Oklahoma University,U.S.A. and Dr. M. Nawaz Chaudary of Punjab University for taking keen interst in the thesis and critically reading the final draft. Sincere thanks are extended to Mr. Irshad Mohammad for carrying out X-R-F analysis. Dr.M. Rafiq is thanked for helping in the prepara-tion of photomicrographs. I am much indepted to Mr. Luqman Ali Bangash M.B.E. and Mr. Sabir Hussain for typing the final manuscript.Mr. Qazi Sufyan and Mr.Rasool Mohammad are thanked also for helping in typing the final manuscript.

ABSTRACT

The Mahak and surrounding area is located in the southern amphibolite belt of North Pakistan. A detailed petrography and geochemistry of the Mahak area is presented. Rocks of the area are distinguished into amphibolites, hornblendites, hornblende-pegmatites, diorites, metagabbros, metapyroxenites, and quartzo- felspathic veins and dykes.

Amphibolites are the most abundant rocks of the area, and are distinguished into epidote-amphibolites, plagioclase-amphibolites,and epidote-plagioclase amphibolites. These are generally medium to coarse-grained, and consist of hornblende, plagioclase, epidote, clinopyroxene, orthopyroxene, sphene, quartz, ore, rutile, and chlorite. Hornblendites are usually monomineralic, but have a variable grain size. They are mainly composed of hornblende, cloudy plagioclase, epidote, chlorite, quartz, rutile and ore. Hornblende-pegmatites are coarse grained, containing hornblende and plagioclase as dominant minerals, epidote, quartz, sphene, rutile and opaque minerals as accessories. Diorites are medium to coarse grained homogeneous rocks. Metagabbros are homogeneous rocks, containing honrblende, clinopyroxene, plagioclase and epidote. Metapyroxenites are medium to coarse grained, inequigranular in texture, composed of clinopyroxene and hornblende as dominant constituents and chlorite, sphene, epidote, and opaque minerals as accessories.

The major and trace element geochemistry of the amphibolites suggest their derivation from a basic igneous parent of tholeiitic character developed in an island arc type environment. Hornblendites are derived from the amphibolites mainly by metasomatic replacement.

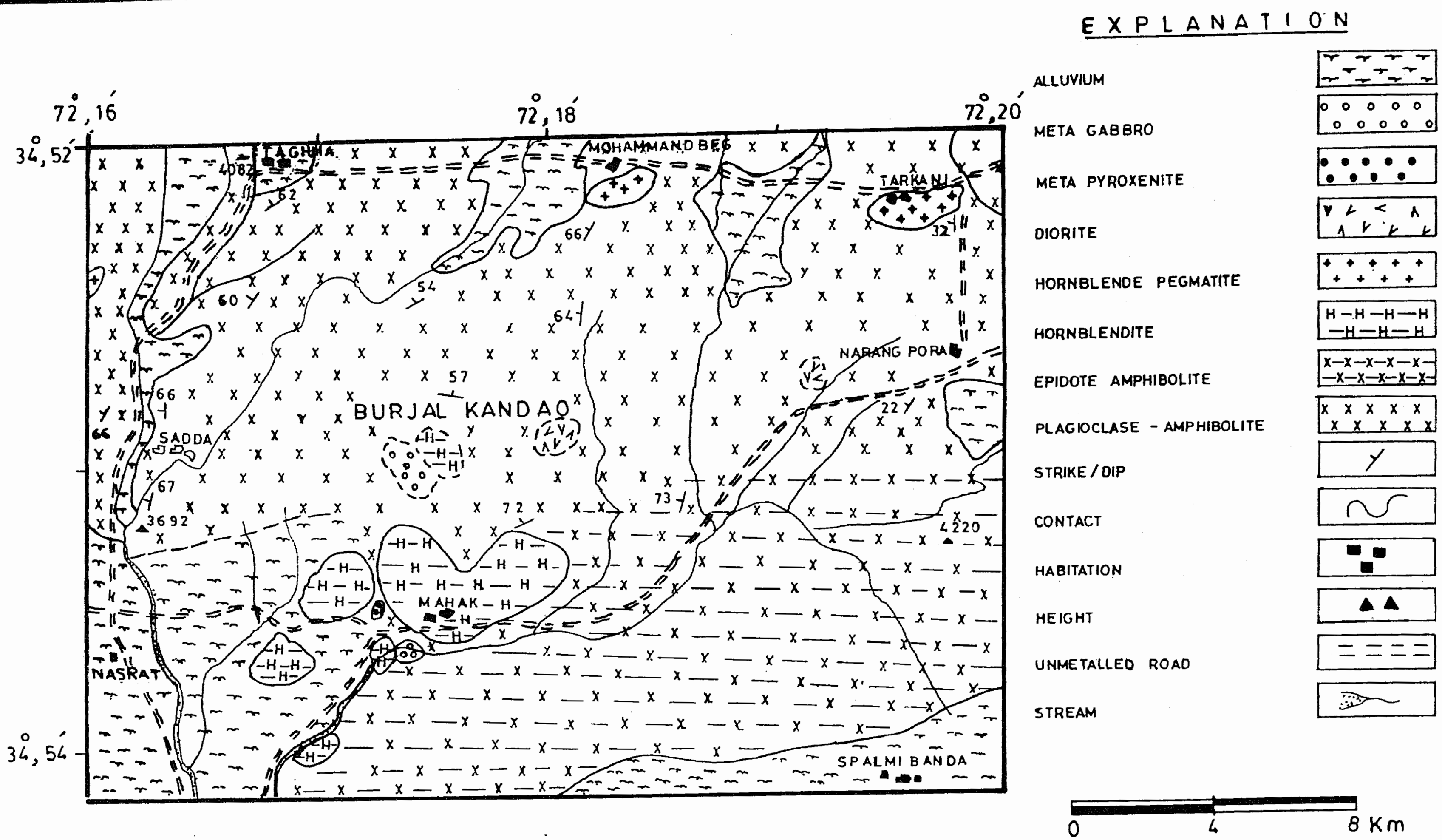


Fig. 1 GEOLOGICAL MAP OF MAHAK AND SURROUNDING AREA, KOHISTAN ARC, SWAT NORTH PAKISTAN

CHAPTER 1

INTRODUCTION

The first geological map of Pakistan was published by the Geological Survey of Pakistan in 1964. This map contains about 36,000 Km^2 of geologically unmapped area located in the northern part of the country (Tahirkheli, 1979). The Kohistan Island arc (KIA) is delineated by the Main Karakoram Thrust (MKT) in the north and Main Mantle Thrust (MMT) in the south, initially differentiated by Desio (1964) as a tectonic zone of the Karakoram, is located in the northern part of Pakistan. It is a 400 Km long segment with a maximum width of 170 Km, along the Yasin-Pattan profile (Fig. 2). It is generally truncated on its eastern and western extensions after crossing into Ladakh and Afghanistan, respectively. This sequence of rocks covers an area of about 36,000 Km^2 and is considered to represent the crust and mantle of a fossil arc, obducted over the Indian plate during the Himalayn orogeny (Tahirkheli and Jan, 1979).

The general rock sequence from north south as established in Kohistan is (a) Chalt ophiolitic Melange, (b) Yasin group, (c) Rakaposhi volcanic complex, (d) Ghizar molasse, (e) Ladakh intrusives, (f) Dir group, (g) Kalam group, (h) Deshai diorites,(i)the Chilas Complex,

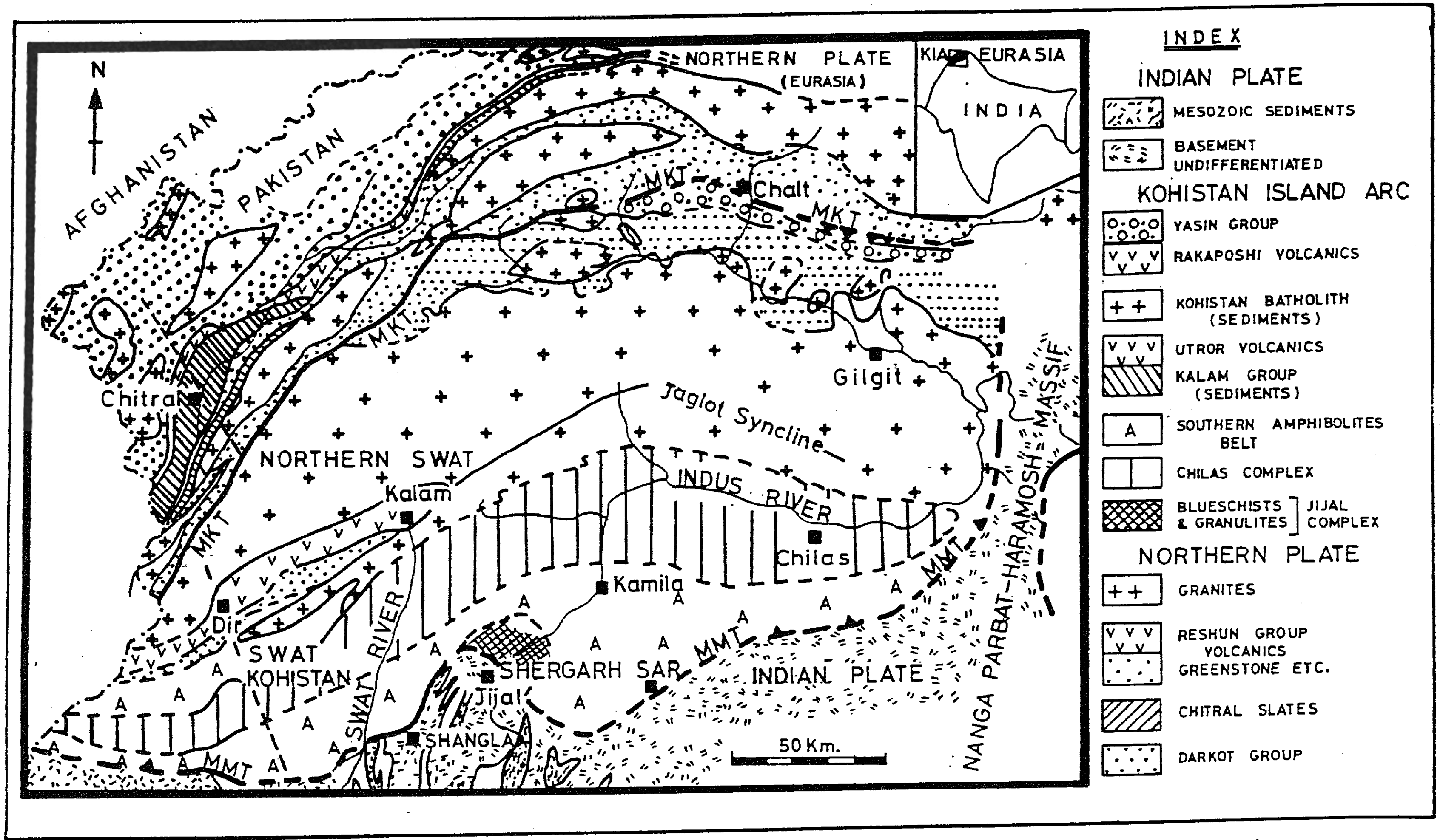


Fig.2. Geological map of the Kohistan island arc, modified after Coward et al.(1982).

(j) The southern amphibolite belt, (k) Garnet granulites, (l) the Jijal complex and (m) the Melange zone rocks (blue schist) along the MMT (Jan, 1979; Coward et al, 1982). These various rock sequences of the KIA have generally an E-W extention and occur in the northern parts of Swat, Hazara, Dir, Gilgit and Chilas as well as the southern parts of Hunza and Chitral. These rock sequences are principally Cretaceous to Eocene in age, are dominantly plutonic and volcanic,and range in composition from ultrabasic to acidic (Jan, 1979). Several workers have studied the southern amphibolite belt (SAB). The preliminary account was given by Martin et al. (1962). Davies (1965) suggested that the SAB rocks are possibly of metamorphic origin rather than plutonic igneous ones. The SAB is a 5 - 15 Km thick sequence which extends from Nanga Parbat in east through Babusar, Indus valley, Swat, Dir,Bajaur to Afghanistan in the west. In Dir, where the Chilas Complex terminates, the amphibolites become thicker and extend westward across the border into Afghanistan (Shams, 1975; Ahmad and Chaudhry, 1976).

The SAB rocks have been described by Jan (1979) as medium to coarse grained, dark grey to black and foliated. On the basis of texture and structure three varieties of amphibolites are differentiated: (a) massive and homogenous amphibolites, (b) banded and sheared amphibolites, and (c) bedded amphibolite. All of these varieties are considered to be the products of prograde metamorphism of basic to intermediate plutonic and volcanic rocks with associated oceanic sediments and tuffs. The massive amphibolite has been described as rich in hornblende and derived from gabbros and diorites of both tholeiitic and calc-alkaline character. The banded variety shows alternate layers due to variations in the proportions of amphibole and plagioclase + quartz and derived from igneous material, mainly tuffs and some flows. Shearing and folding of these two varieties of amphibolites are observed, mainly at Dir along the Panjkora river about twelve km downstream of Timurgarha, and upstream of Pattan along the Karakoram Highway (Fig. 2). The bedded variety is not as common as the other two. This now appears as micaceous schist,hornblende schist, and light colored fine to medium textured amphibolites. Some of these amphibolites contain 3-4 cm large garnet porphyroblasts (Jan, 1979).

Detailed petrographic and geochemical accounts of the SAB rocks are scarce. The only such studies are those of the Allai Kohistan amphibolites, Hazara district, performed by Shah (1986) , where amphibolites occur as the predominent rock type. On the basis of mineralogy, Shah (1986) differentiated two varieties of amphibolite epidote-amphibolites and garnet epidote-amphibolites. Shah (1986) considered the amphibolites to have been derived from a basic igneous parent of tholaiitic character developed in an Island arc type environmnt.

The present study was performed to construct a detailed geological map and carry out petrographic and geochemical investigation of the SAB rocks from the Mahak and surrounding areas, with the aim of understanding the petrogenetic history of these rocks locally, and by comparision with the previous work on similar rocks,and the petrogenetic history of the SAB rocks in general.

The area under investigation lies in the vicinity of Mahak and Taghma villages and covers an area of about 25 km^2 (topsheet NO: 43 B/4; latitudes 34°. 52'E to 34° .54'E, longitudes 72°. 16'N to 72°. 20'N). About 200 samples were obtained from the major exposures in the area. More than 100 representive samples were selected for petrographic and geochemical studies.

The investigated area mainly comprises amphibolites, hornblendites, diorites, hornblende-pegmatites, metagabbro and metapyroxenite. The amphibolites and hornblendites are locally cut by quartzo felspathic veins and dykes. The amphibolites are generally homogeneous and foliated, while banded types are also present locally. The hornblendites and hornblende-pegmatites are predominantly massive.

CHAPTER 2

REGIONAL GEOLOGICAL AND TECTONIC SETTING

2.1 REGIONAL GEOLOGICAL SETTING:

The Kohistan region constitutes an area of more than 36,000 Km^2 on the northwestern tip of the Himalayan syntaxis. It has an east-west extension and incorporates the northern parts of Swat and Hazara, Dir, Gilgit and Chilas, and the southern parts of Hunza and Chitral. It forms a chain of mighty and topographically very high, rugged, and geologically complex mountains.

As described previously (Chapter 1), the KIA is a tectonically distinct zone of magmatic, metamorphic, metasedimentary and some recent sedimentary rocks, considered to represent a sequence from mantle (south) to crustal (north) rocks. Martin et al. (1962) assigned the Kohistan rocks to be of Pre Cambrian age and thrust faulted over the Palaeozoic Lower Swat-Buner Schistose group of the upper Himalayas . The northern and southern limits of the Kohistan region are formed by two branches of the Indus Suture Zone, which marks the collisional line of India and Eurasia in Pakistan (Desio, 1964). The northern bounbary, the Hini-Chalt-Yasin-Drosh fault, is called the Northern

Megashear or Main Karakoram Thrust (MKT). It separates the Kohistan region from the Asiatic mass. The southern boundary delineates the Kohistan region from the Indian plate. It passes through the Mohmand, Bajaur, Dir, Swat and Bisham areas, and has been named the southern Megashear or Main Mantle Thrust (MMT) (Tahirkheli, 1979). Both the MKT & MMT have an association of melange rocks, including ultramafics. The MMT also carries a wedge of garnet-granulites (Jan and Howie,1982).

The Karakoram area , just north of the MKT, is comprised of metamorphosed pelitic sediments, showing an increase in grade of metamorphism northward from chlorite through biotite, garnet and staurolite to sillimanite zones of the Barrovian type (Winkler, 1967). The other rock units of the area include biotite-garnet-gneisses, calc-silicate rocks, amphibolites, graphitic schists,marbles and thinly bedded grits. The unit grades further north into the Karakoram batholith (Tahirkheli, 1979).

The Indian plate, in the near vicinity of the MMT, is composed of metasediments intruded by various plutons.The metasedimentary sequence comprises pelitic rocks, quartzites and calcareous rocks. The grade of metamorphism increases from south to north towards the MMT; from almost unmetamorphosed rocks south of Abottabad to sillimanite-kyanite-amphibolite facies rocks to the north of

Abbottabad (Calkins et al., 1975). Further north granites and granodiorites occur as the major acid igneous bodies, but small to large sills and dykes of gabbro, dolerite and diorite also occur (Tahirkheli, 1979). On the east, the Kohistan region is flanked by the acid igneous pluton of the Ladakh Island arc (Klootwijk et al, 1979), and both arcs are now generally considered as a single arc, the Kohistan-Ladakh Island arc (KLIA), the Nanga Parbat Harmosh Massif (NHM). On the west the KIA is terminated by the Chaman transform fault. The major lithologic subdivisions of the Ladakh Island arc have been recognised from north to south by Sharma and Kumar (1978) as (a) Tegargranite and metamorphic Paleozoic host rocks, (b) Shyok volcanics and volcano-sediments, (c) Ladakh granite and gabbroic intrusives, (d) Indus mollase, (e) Indus flysch and volcanics, (f) Ophiolite melange and deep sea sediments, (g) Indus volcanics and associated sediments, (h) Northern crystallines, (i) Tethyan sediments and (j) Southern crystallines. Klootwijk et al.(1979) proposed that the Ladakh Island arc collided with the Indo-Pak plate in the late Paleocene-Early Eocene.

As described earlier (Chapter 1), the lithologic aspects of the Kohistan region have been codified in terms of a 30-40 km thick pile of metamorphosed plutonic, volcanic and sedimentary rocks by Bard et al (1980). These authors described the Kohistan sequence in detail, and divided the sequence into eight main units from north to south as follows:

2.1A The upper detrital sequence :

The upper detrital sequence contains shales, wackes, calcareous beds and volcanics, having about 150 m thickness,forming the northern part of the Kohistan arc and lying along the MKT.It lies conformably over the Uthror volcanics, and contains coarsepolygenic conglomerates and pebbles of the Uthror volcanics.Cretaceous fossils are reported from this sequence .

2.1B The Calc-alkaline unit:

The calc-alkaline unit is composed of schistose meta-andesitic agglomarates or lavas, meta dacites and rhyodacites. It is a 6-8 km thick unit, which is intruded by syn- to post-kinematic tonalitic, granodioritic and dioritic plutons (Majid et al., 1980).

2.1C The Volcano-Sedimentary Unit (Kalam group):

The volcano-sedimentary unit is 8-10 km thick, mainly composed of green or black shales, metagreywacks, basaltic metatuffs, and fine grained metacherts. It has a conformable contact with the underlying amphibolites. The black - grey chert is present within greywacks which also contain some marble. Metamorphism has transformed these rocks into quartzite, mica-schist and calc-silicate gneisses and skarns (Bard,1983).

2.1D The Northern Amphibolite belt:

The Northern Amphibolite belt rocks are predominantly composed of amphibolites with some metagabbros and metabasalts. These amphibolites are homogeneous to banded and stripped, and overlie the Chilas Complex. This unit grades into southern amphibolites to the NE of Timurgara, where the rocks of the Chilas complex seem to be pinched out. The belt is intruded by various types of diorites.

2.1E The Chilas Complex:

The Chilas complex extends over 250 km, from the Panjkora valley of Dir in the west to the Nanga Parbat massif in the east, with a maximum thickness of more than 15 km. The complex is mainly composed of basic rocks with subordinate ultramafic bodies and lenses (see Jan, 1979, Hamidullah & Jan, 1986). The plutonic rocks of the complex have a calc- alkaline chemistry, with an island arc affinity, which is in line with the idea that the Chilas complex forms the lower crust of the Kohistan Island arc .

2.1F The Southern Amphibolite belt (SAB) rocks:

The SAB rocks are described in detail in Chapter 1. These are mainly composed of massive or banded amphibolites, having 1-10 cm thick alternating bands of various felsic rocks and fine - grained amphibolites. The grade of metamorphism generally increases from this belt towards the centre of the Kohistan sequence in the north.

The lower part of the belt (southern edge of the SAB) contains ultramafic bodies, which are mainly composed of diopside-pyroxenites with lesser peridotites.

2.1G Jijal-Complex:

The garnet granulites of the Jijal-complex cover an area of 150 Km^2 in the NW Himalaya. The complex consists of high-P granulites with a 4 Km thick slab of ultramafic rocks on their south along the MMT. The most abundant paragenesis consist of garnet, plagioclase, clinopyroxene, quartz and rutile. The granulites are derived from a series of Early Cretaceous gabbros, troctolites, anorthositic rocks, pyroxenites and quartz diorites that may represent the lower Tethyan crust or magmatic cumulates at the bottom of the Kohistan arc. The ultramafic rocks consists of diopsidite, dunite, harzburgite, websterite and podiform chromatite representing a diapir or tectonic slab of the upper mantle

The Jijal complex has been considered to have undergone two phases of deformation and progressive metamorphism. An early metamorphism produced two pyroxene granulites at ~ 750 C, 6-8 Kb (Jan, unpublished data). This was followed by garnet - granulite facies metamorphism (800-900 C, 12-14 Kb; Jan and Howie, 1982; Bard, 1983). During uplift, the rocks were retrogressed, with overprints of amphibolite- and greenschist facies. Some hornblande, epidote, kyanite, and paragonite were produced during uplift Glaucophanic amphibole has been also found in a secondary vein in pyrigarnitite (M.A. Khan, pers.com.).

2.1H The Shangla Blueschist:

The Shangla blueschist melange is composed of large dismembered masses of metavolcanics and phyllites with smaller lensoid masses of serpentinite, metagabbro, metadolerite, metagraywacke, metachert and marble; some rocks contain piemontite (Jan and Symes, 1977). Kazmer et al. (1983) have reported fossils of Jurassic to Middle Cretaceous age from a limestone block.

The petrography of these rocks has been described by Shams (1975), Jan,(1979). Among the typical minerals suggesting high-P and low-T metamorphism, jadeitic pyroxene has been reported from Shangla (Guiraud et al., in prep.) and aragonite from Mingora , phengite is common but lawsonite has not been found. Blue amphibole occurs in blueschists, metagraywackes, and rarely in metacherts and pure calcite rocks. Jan et al. (1981) suggested that the blueschists were metamorphosed at about 7 Kb and 380 C, with a possible higher-T overprinting as indicated by the garnet-bearing veins.

2.2 TECTONIC SETTING:

The tectonic setting of the Kohistan region has been interpreted by various workers, Tahirkheli, 1979, Jan and Kempe,1973; Klootwijik et al, 1979; Hamidullah & Jan, 1986). These workers have suggested that the igneous rocks of the Kohistan sequence are generally calcalkaline in character, typical of orogenic belts and island arcs. Tahirkheli et al (1979) suggested that the entire Kohistan rock sequence represents a complex remnant of the crust and mantle of a fossil island arc. Jan (1980) established that the Kohistan sequence is as an obducted island arc sandwiched between the Eurasian and Indo-Pak continents.

According to Powell (1979), convergence of India and Eurasia persisted, though at a reduced rate, even after the initial collision of India and Eurasia about 55 Ma ago. It caused under-thrusting of 600 to 700 Km of the Indo-Pak slab beneath Eurasia (Molnar and Tapponnier, 1979) resulting in the vertical uplift of the Himalyas and associated regions. The thrusting is believed to have migrated progressively from the Indus Suture Zone towards the south, roughly parallel to the Main boundary thrust (MBT), from Eocene to Recent. This thrust and suture 'progradation' (Sillitoe, 1979) gave rise to under-thrusting of continental crust, first at the Indus suture zone and MMT, and later along the MBT, both sites being on the leading edge of the Indian plate.

The tectonic history of Northern Pakistan begins from the time of Gondwanaland. This huge continent comprised such recent continents as South America, Australia, Africa, Antarctica, the subcontinent of Indo-Pak, and Eurasia. The break up of Gondwanaland started about 160-200 Ma ago. The process of breakup resulted in north-ward drifting of the Indo-Pak sub-continent, the progressive closure of the Tethys ocean, and subduction of oceanic crust under the Eurasian plate. The KIA was produced in front of the Indian plate due to its subduction.

Keeping in view the recently determined radiometric ages and some of the structural complexities of the Indo-Eurasian suture zone,pointed out by different authors (Coward et al, 1982; Andrews- Speed and Brookfield, 1982), Jan and Asif (1983) presented a tectonic model of Northern Pakistan (Fig. 3) as follows:

(a) Early-Mid Cretaceous: N-facing subduction of the neo-Tethyan oceanic crust to produce volcanic and plutonic rocks (the Drass, Chalt-Shyoke,and Kohistan amphibolites), resulting in the formation of the Kohistan-Ladakh Island arc.

(b) Middle-Late Cretaceous: Intrusion of the Chilas, Jijal, and Kargil mafic complexes, and development of the blueschists.

(c) Paleocene-Early Eocene: Collision of the Island arc with India (Powell, 1979); obduction of ophiolites and

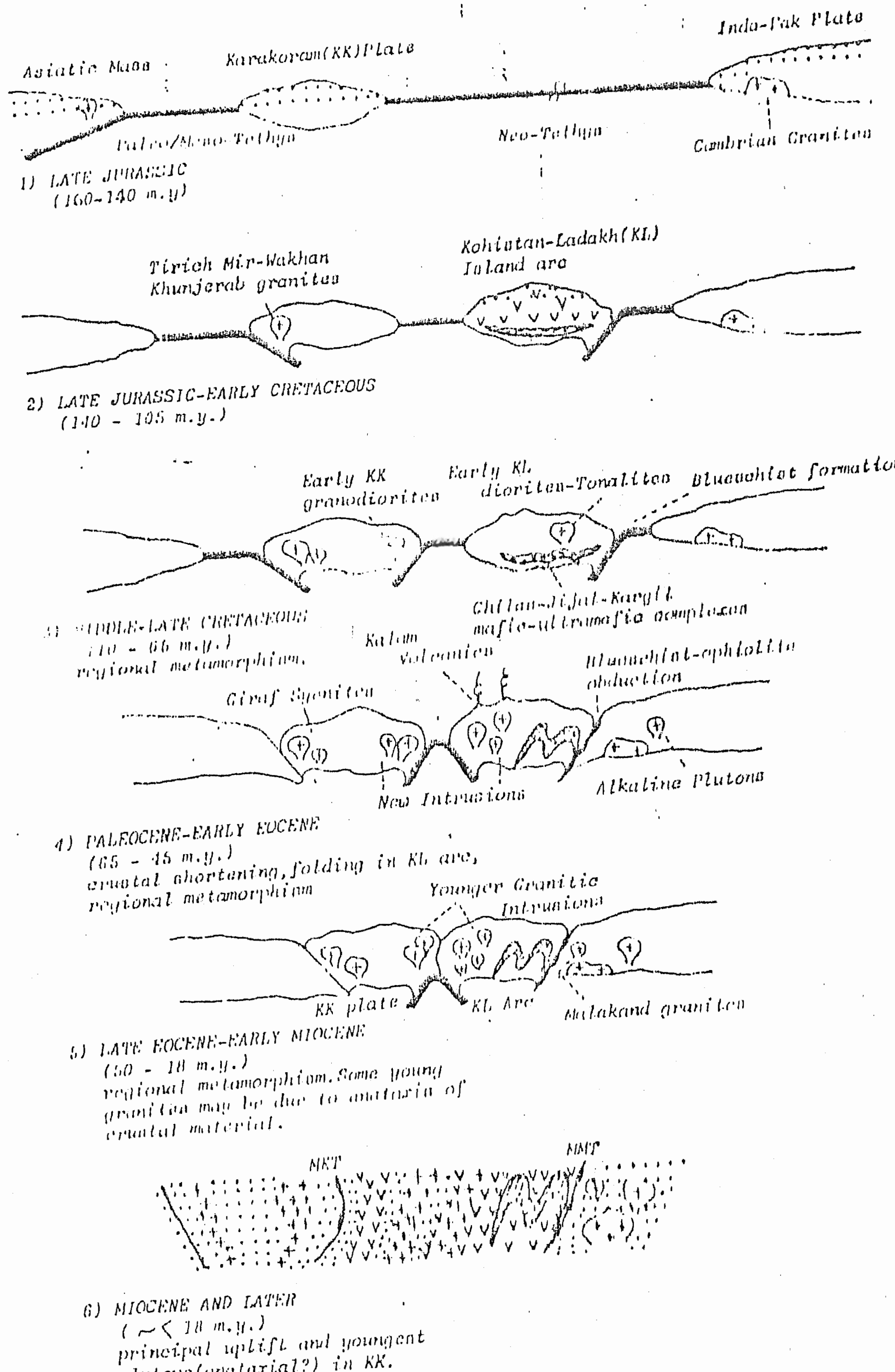


Fig. 3. Tentative model for the tectonic and magmatic evolution of North Pakistan (based on models of Jan and Asif, 1981; Andrews-Speed and Brookfield, 1982; Le Fort *et al.*, in press; Windley *et al.*, in press).

blueschists; simultaneous north and south facing subduction of the oceanic crust intervening between a Gondwanic microcontinent and the Island arc to produce the earlier phases in the Karakorum and Kohistan-Ladakh granitic belt; regional metamorphism.

(d) Late Eocene - Early Miocene: Eruption of the Eocene Kalam volcanites; younger intrusions in the two granitic belts.

(e) Miocene and Later: Principal uplift and youngest plutons in the Karakoram.

CHAPTER 3

LOCAL GEOLOGY

On the basis of field features and petrographic observations, the following rock types can be distinguished at Mahak and the surrounding areas, just north of the MMT.

3.1 Amphibolites,

  3.1a Epidote-amphibolites

  3.1b Plagioclase-amphibolites

3.2 Hornblendites

3.3 Hornblende-Pegmatites

3.4 Diorites

3.5 Metagabbros

3.6 Metapyroxenites

3.7 Quartzo felspathic veins and dykes.

3.1 Amphibolites

The amphibolites are the most voluminous rocks developed in the area. These are mostly homogeneous, well-foliated and, at places, banded (Plate 3.1-2). The general trend of the foliation is E-W and NE-SW, with moderate northward dips, similar to those of the Indus valley amphibolites. The homogeneous amphibolites are generally medium-to coarse-grained. In some of the rocks fine and coarse material is irregularly intermixed. Banded

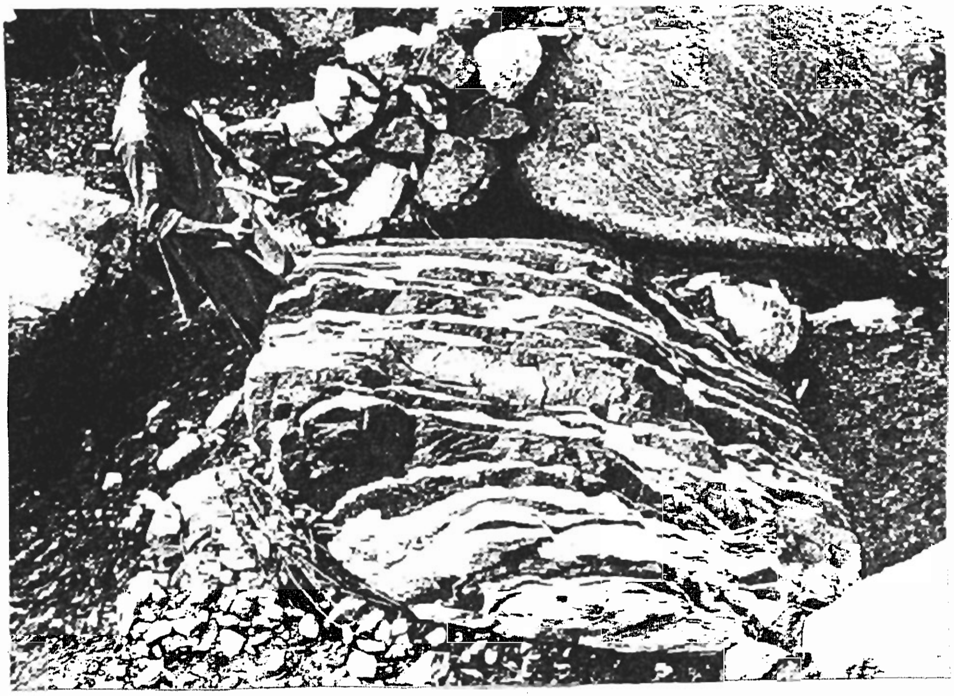


Plate 3.1. A block fo banded amphibolite from Mahak area, having alternate bands of felsic and mafic minerals.

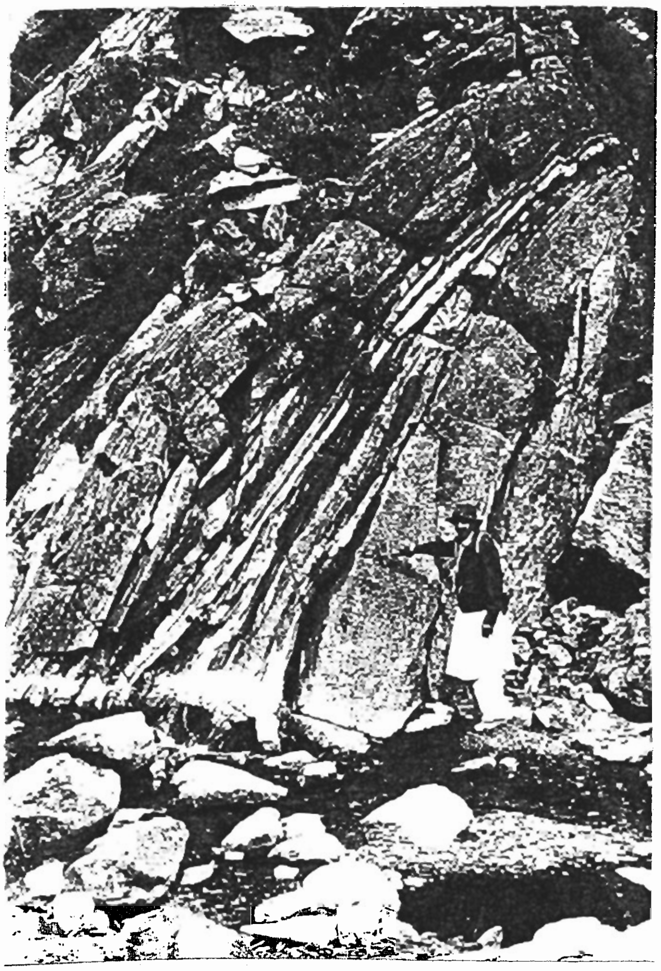


Plate 3.2 Amphibolite showing fracturing and banding from main stream, near Naranjpura village.

amphibolites are also present in the area, but are of local extent. Banding is generally due to preffered orientation of hornblende and plagioclase + quartz (Plate 3.1). These bands range from thin streaks to bands many centimeters in thickness. The contacts of the amphibolites with associated rocks are mostly graditional. In the contact zones the amphibolites intermixed with hornblendites.

Shah (1986) distinguished two types of amphibolites in the Shergarh Sar area of Allai Kohistan: (a) epidote-amphibolites (b) garnet-amphibolites. At Mahak those amphibolites which are dominantly composed of epidote and amphibole are named epidote-amphibolites, while those which are dominantly composed of plagioclase and amphibole are named plagioclase-amphibolites.No distinct outcrop of garnet-amphibolite is present in the investigated area, although patches of garnet within the plagioclase amphibolites are noticed at certain localities (Plate 3.3).

The epidote-amphibolites are mostly exposed at the east, south- east and southern parts of Mahak village. These are medium- to coarse-grained rocks recognisible in the field by their dark green epidote, with white plagioclase and prismatic black amphibole. These amphibolites are generally fractured and sheared (Plate 3.4). Quartzo felspathic (Plate 3.5) and hornblendite dykes and veins are common in these rocks. The hornblendite dykes are fine grained, homo-

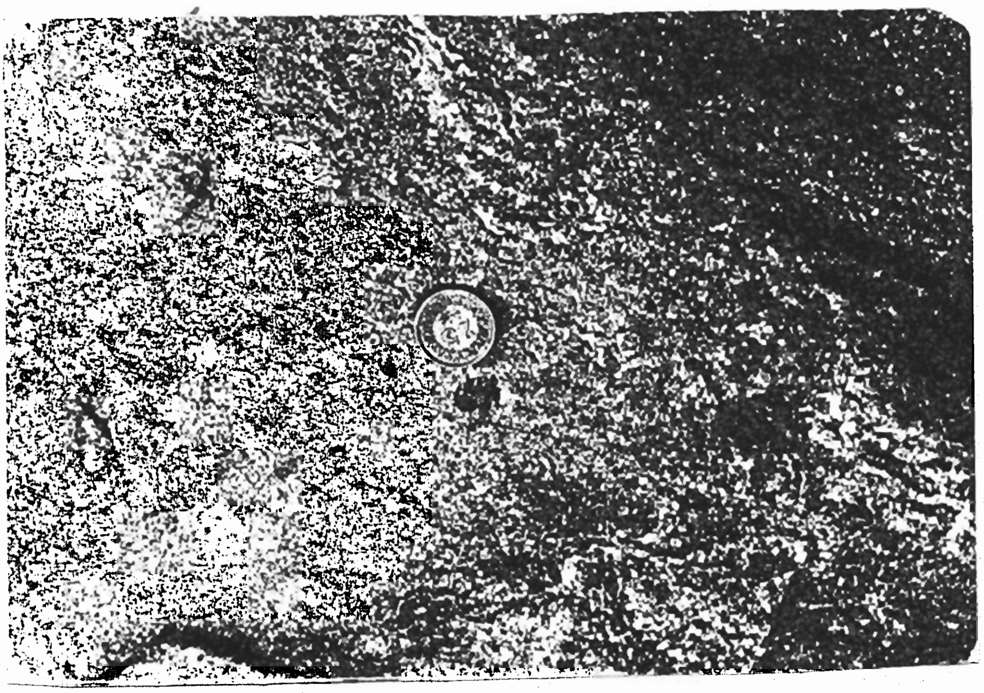


Plate 3.3 Plagiocalse amphibolite containing small patches of garnet.

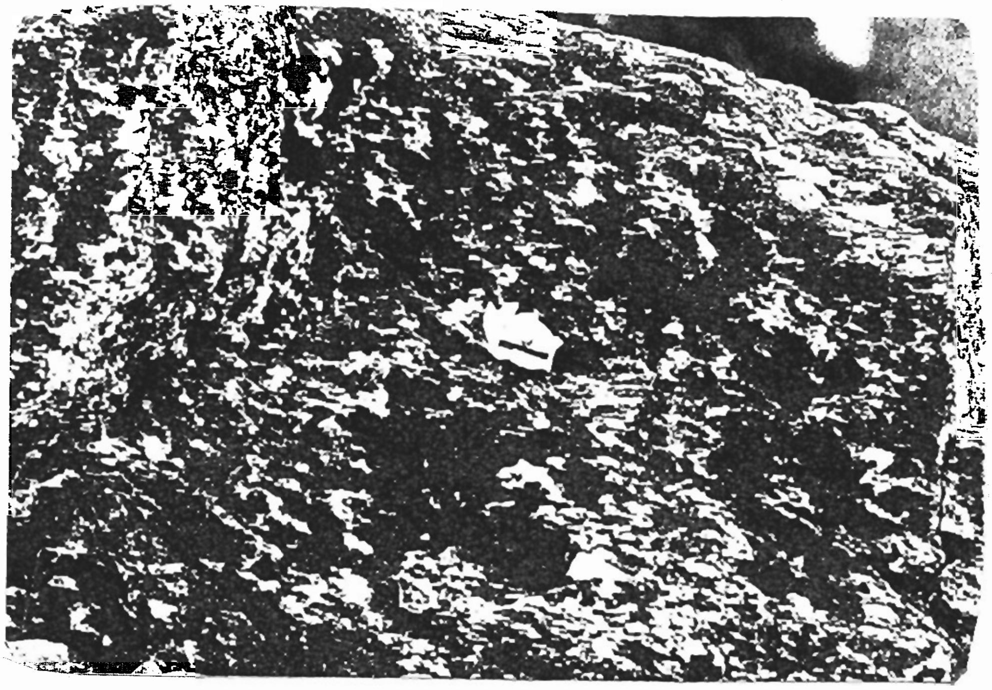


Plate 3.4 Epidote-amphibolite showing fracturing and shearing.

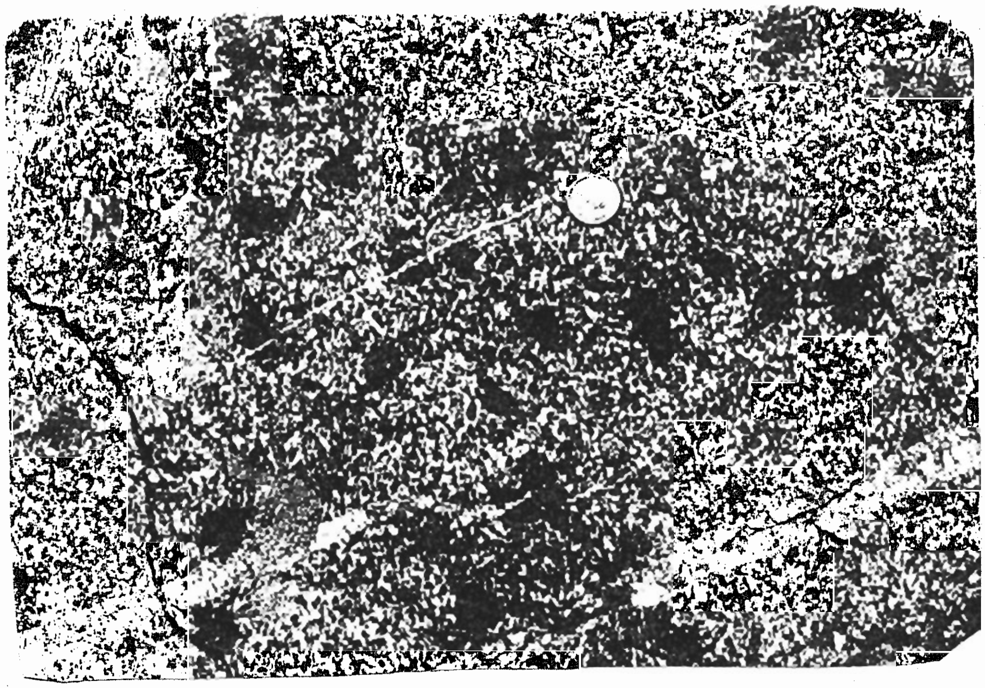


Plate 3.5 Epidote-amphibolite showing fracturing and small quartzo felspathic veins.

geneous and reach a thickness of 25 cm at certain localities. In the main stream, south-eastwards of Mahak village, a two meter long hornblendite dyke occurs within epidote-amphibolite.

The plagioclase-amphibolites are exposed to the north, north- east and north-west of Mahak village. These rocks are recognisible in the field by white plagioclase and black prismatic amphibole.The relative proportions of plagioclase and amphibole, as well as their grain sizes (fine to coarse), are highly variable in these rocks. These plagioclase-amphibolites are highly weathered, fractured (Plate 3.6), and jointed and have also been cross cut by quartzo felspathic dykes and veins (Plate 3.7).

At Burjal Kandao and Naranj Pora, the plagioclase-amphibolites are intruded by diorites and metagabbros whereas at Taghma, Mohammad Beg, Tarkani and Chauthar villages, these rocks are intruded by coarse pegmatites, containing large crystals of hornblende and feldspar. The contacts of the plagioclase- amphibolites with the pegmatites, diorites and metagabbro are graditional.

3.2 Hornblendites

Hornblendites are the second most important rocks of the investigated area. A large hornblendite body (3x1.5 km) occurs at Mahak village, whereas four other small oval shaped bodies generally trending NW-SE occur to the SW

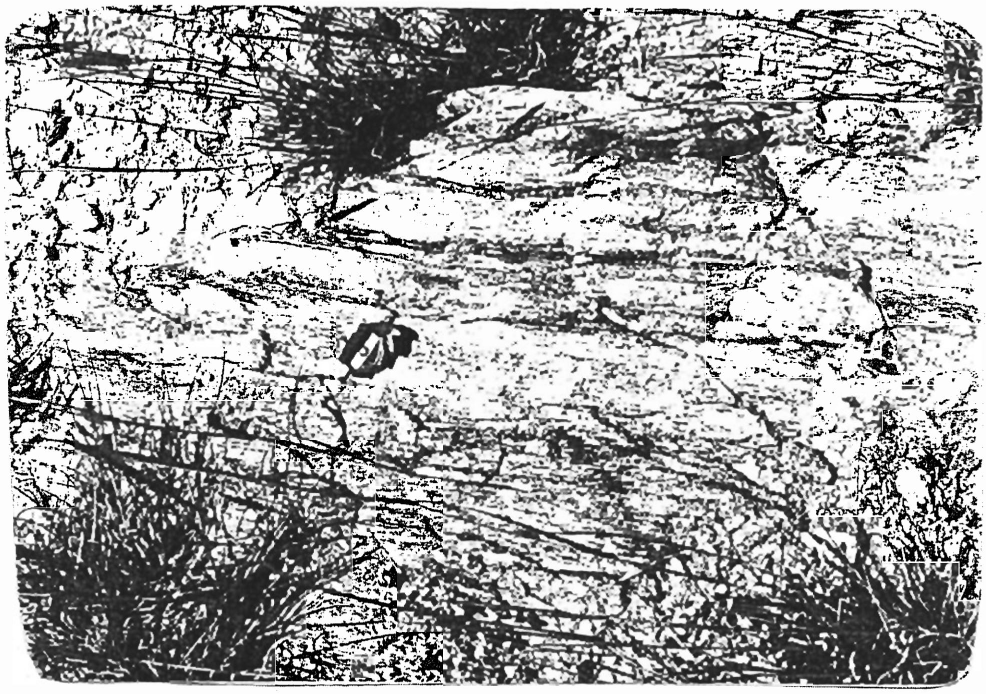


Plate 3.6 Plagioclase-amphibolite showing fracturing and shearing.

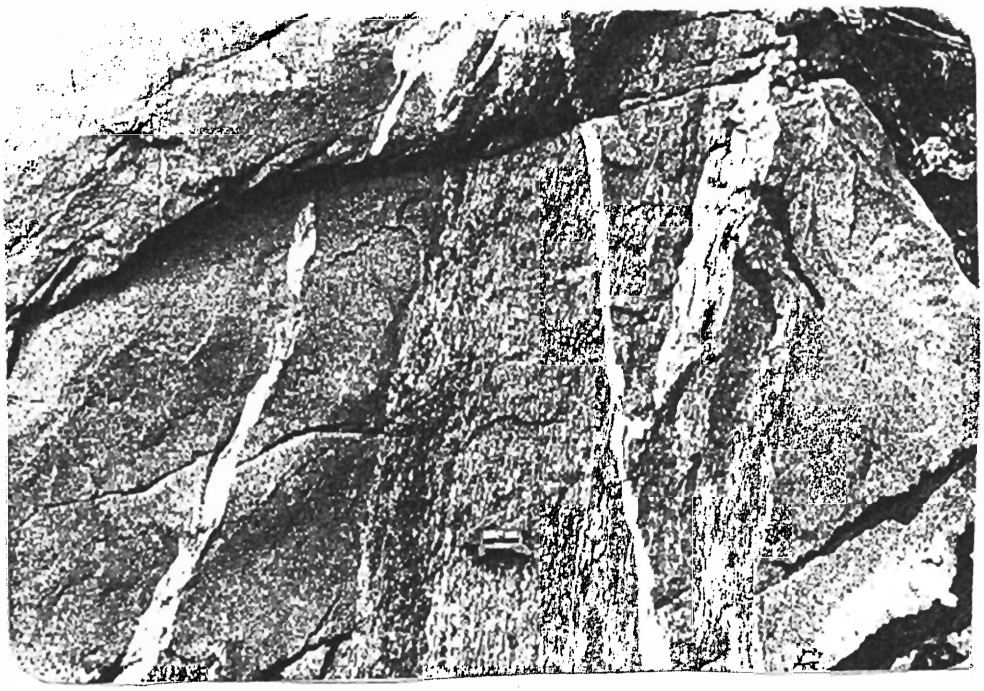


Plate 3.7 Quartzo felspathic veins irregularly cross cutting amphibolite at Mahak.

of Mahak village. These bodies have an average dimension of 1x0.5 km.

The hornblendites are predominantly coarse-grained, containing hornblende crystals from 1-8 cm in length. Medium to fine-grained varieties as well as pegmatitic varieties containing up to 20 cm long crystals of hornblende are also present locally. A single outcrop showing a gradation through fine, medium to coarse-grained hornblendite is present (Plate 3.8). In the main stream, just east of Mahak village, crystals reaching up to 10 cm in length are noted in hornblendite. These crystals are locally oriented in a NE - SW direction, but generally no preffered crystal orientation is observed in hornblendites. All the varieties of hornblendites are fractured and jointed, and quartzo- felspathic and epidote veins are developed along the fractures. The hornblendite is deviod of any layering or banding, and is generally massive in nature. It contains relics/xenoliths of amphibolites. The hornblendites are also cut by numerous quartzo- felspathic dykes and veins. All of these dykes and veins have sharp contacts with the hornblendites. In the large stream west of Naranj Pora, hornblendites seemingly replace amphibolites (Plate 3.9-10). Generally the contacts of the hornblendites with the amphibolites are graditional.

Plate 3.8 Hornblendite showing a gradation from fine, through medium to coarse grained.

No. 44-c

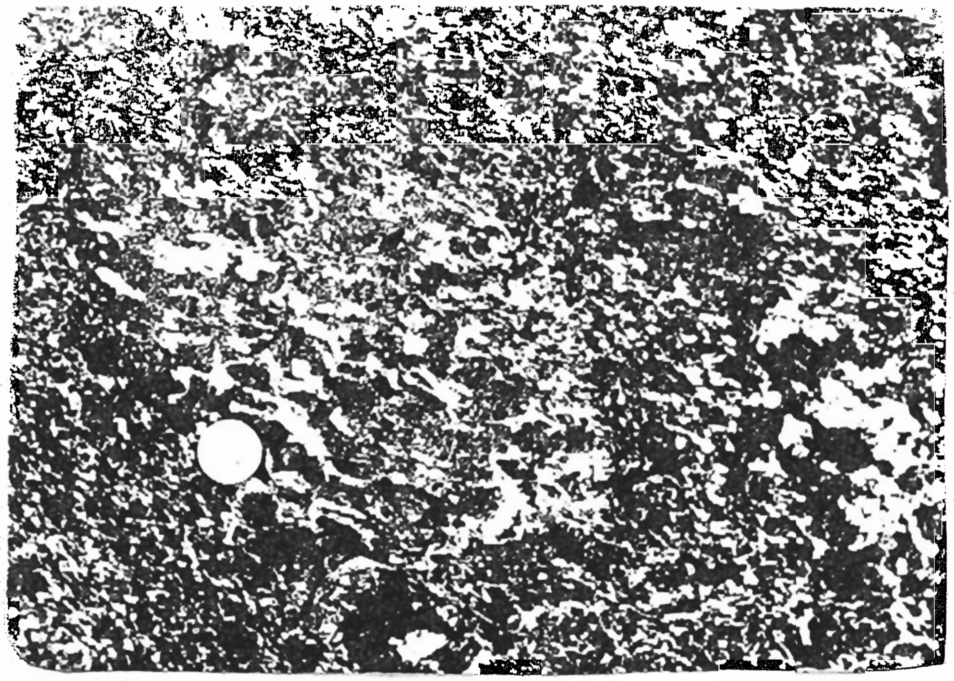


Plate 3.9 Amphibolite transforming into hornblende. The quarzo felspathic material seems to have mobilized during this phenomenon.

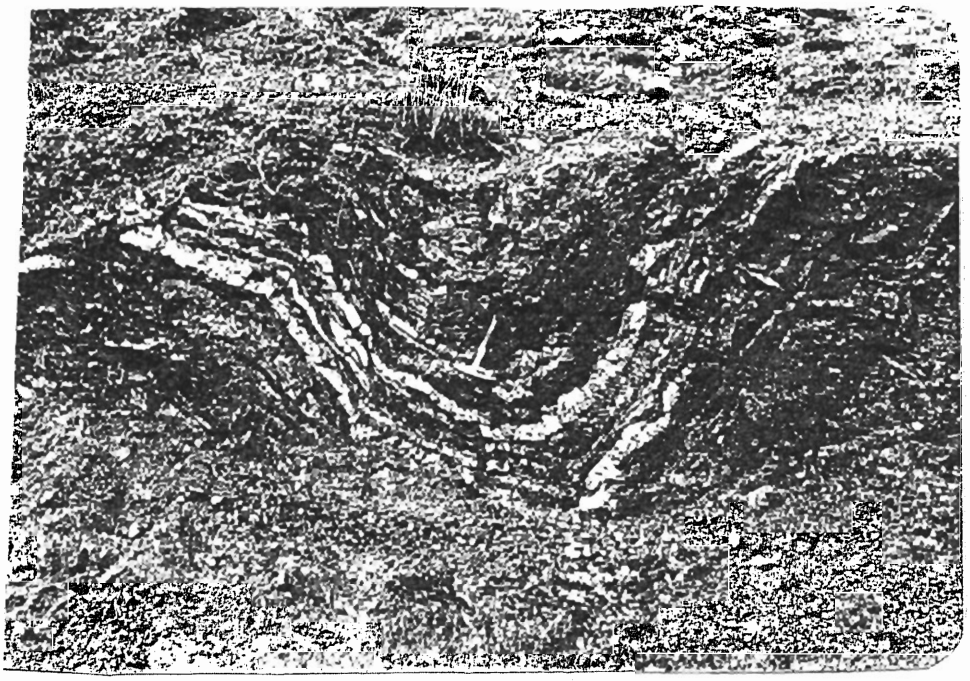


Plate 3.10 Synclinal fold south of Naranjpura. Amphibolite transforming into hornblendite.

3.3 Hornblende-Pegmatites

The hornblende-pegmatites occur as separate bodies trending NE to SW within amphibolites at Taghma, Mohammad Beg, Tarkani and Chauter villages. These bodies are of variable sizes, with length ranging from 1000 m to 1 km and widths ranging from 100m to 500m. In the field the hornblende pegmatites can be recognised by large prismatic crystals of hornblende, plagioclase, quartz, and dark green epidote. The hornblende crystals range in size from 1 cm to 10 cm. The hornblende pegmatites are intruded by quartzo- felspathic dykes and veins of variable sizes. The contacts of the hornblende pegmatites with the enclosing amphibolites are graditional.

3.4 Diorites

Two dioritic intrusions occur within amphibolites at Burjal Kandao and Naranj Pora village (Fig. 1). The cores of these dioritic bodies are fresh and equigranular, while at the margins gneissosity and weathering are reflected. Plagioclase and other ferromagnesiam minerals can be identified in hand specimens of these diorites. The diorites have sharp contacts with the amphibolites.

3.5 Metagabbros

Two outcrops of metagabbro are exposed within amphibolites at Burjal Kandao, just north of Mahak village (Fig. 1). It is hard to distinguish between metagabbro and amphibolite in the field, but generally metagabbro is hard, compact and fresh as compared to amphibolite in its vicinity. Weathering is however noticed in the metagabbros too. The metagabbros contain quartzofelspathic veins and dykes, and small patches of hornblende near contacts with amphibolites. The contacts of metagabbro with amphibolites and hornblendites are sheared and are not very sharp.

3.6 Meta-pyroxenite

Only one small exposure of meta pyroxenite is found, being just east of Mahak village (Fig. 1). It is a fine to medium grained, hard and compact rock having a sharp contact with the hornblendites and a moderately sheared and deformed contact with the amphibolites.

3.7 Quartzo-felspathic veins and dykes.

Quartzo-felspathic veins and dykes intruding amphibolites and other rocks are fairly common in the investigated area. These dykes and veins are hard and compact in hand specimen, fine- to medium-grained in texture, and whitish in colour. In the field white plagioclase, black amphibole and dark green epidote can be easily distinguished. These veins and dykes also show deformation, and at certain places folding, faulting, and complex networks can be observed. The thickness and length of these dykes and veins varies from place to place (thickness 1-2 m; length 10-50 m).

Augen structures are also generally noticed in these veins and dykes indicating that deformation prevailed after their emplacement.

Quartzo-felspathic dykes and veins containing large crystals of amphibole and epidote cross- cut the epidote - amphibolites,especially in the main stream south of Mahak village. These dykes and veins have sharp contacts with the hornblendites and amphibolites.

CHAPTER 4

PETROGRAPHY

On the basis of petrography, the amphibolite belt rocks of Mahak and the surrounding areas represent the following varieties:

4.1 Amphibolites

Amphibolites are the most abundant rocks of the area. On the basis of mineralogy and texture the following types of amphibolites have been locally distinguished.

(A) Epidote-amphibolites

(B) Plagioclase-amphibolites

(C) Epidote-plagioclase-amphibolites

(A) Epidote-amphibolites.

Megascopic Features: The epidote-amphibolites are dark green to light green, medium- to coarse-grained, compact rocks, with a well developed fabric. The dominant constituent minerals are hornblende, epidote, and plagioclase, which are easily recognisable in hand specimen. The hornblende grains are black in color, usually less than 6 mm in size, and have a well-defined fabric.Epidote occurs as elongated medium- to coarse grained crystals (1mm to 5mm long),easily recognisable in hand specimen.

Microscopic Features:

In thin section, the epidote-amphibolites reflect hypidioblastic to xenoblastic and inequigranular to subequigranular textures. They are uniform in composition, and contain abundant epidote, hornblende, and substantial amounts of cloudy plagioclase, quartz, sphene, chlorite, rutile and opaque minerals. Epidote occurs both as elongated subhedral and cleaved crystals, and as small anhedral granular aggregates with highly birefringent interference colours. The elongated subhedral epidote and hornblende occur in close association, and are intergrown with each other (Plate 4.1). On the basis of interference colors, zoning has been noticed in the elongated subhedral epidote (Plate 4.2), having cores displaying an anamoulous bluish interference color, and margins showing greenish or reddish interference colors. (Plate 4.2)

Occasionally, hornblende has been noticed in the cores of elongated crystals of epidote (Plate 4.3). The occurrence of epidote as cores to hornblende crystals is also common.Plagioclase occurs as relics in the cores of elongated crystals of epidote. In some epidote-amphibolites, plagioclase has been completely replaced by epidote.

Hornblende occurs as subhedral to anhedral grains varying from <1 to 1.2 x 2.8 mm in size. The small grains

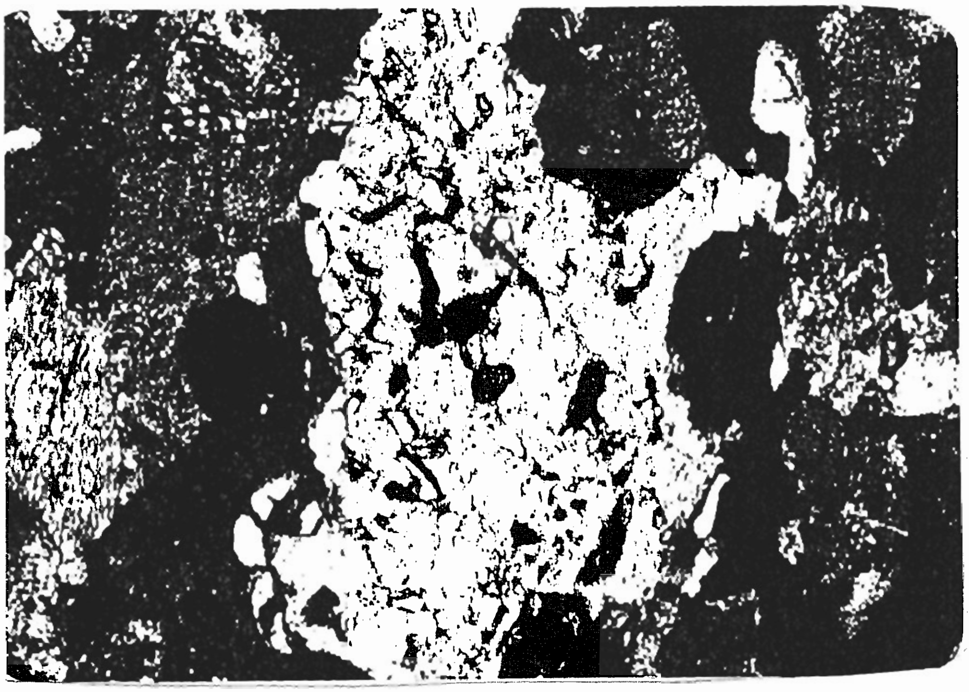


Plate 4.1 Photomicrograph showing elongated Subhedral epidote in association with hornblende (Nicols crossed).

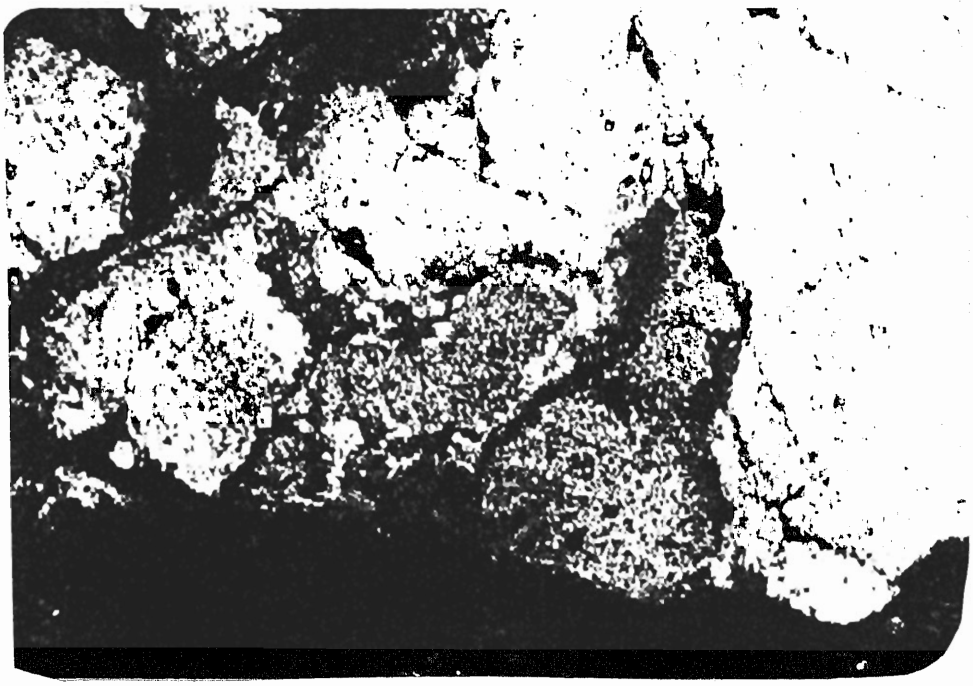


Plate. 4.2 Photomicrograph showing zoning of epidote in epidot-amphibolite (Nicols crossed).

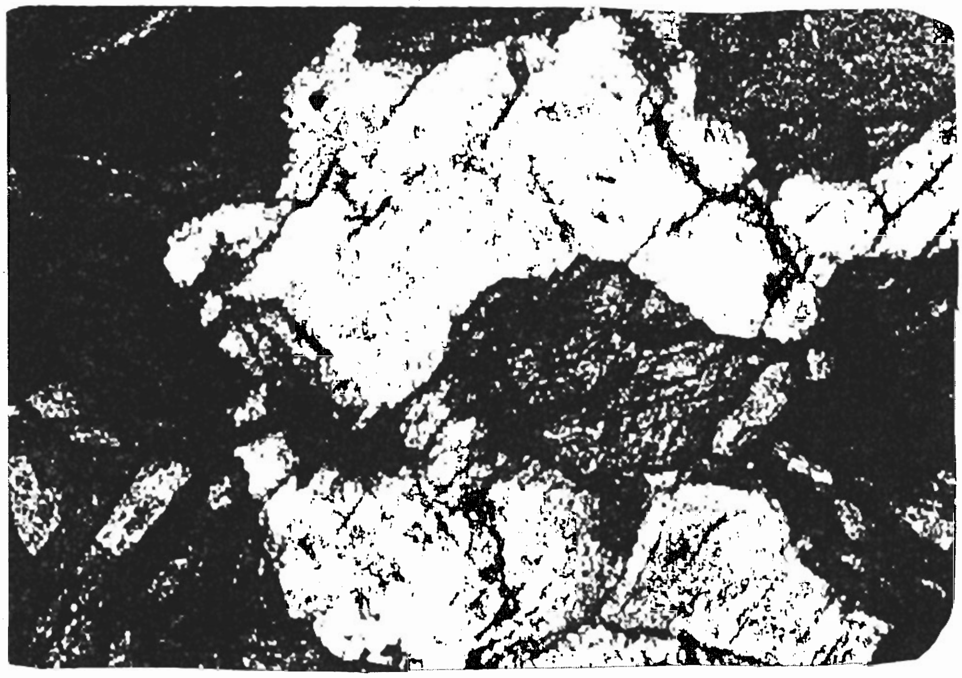


Plate 4.3 Photomicrograph showing epidote surrounding hornblende (cross nicols)

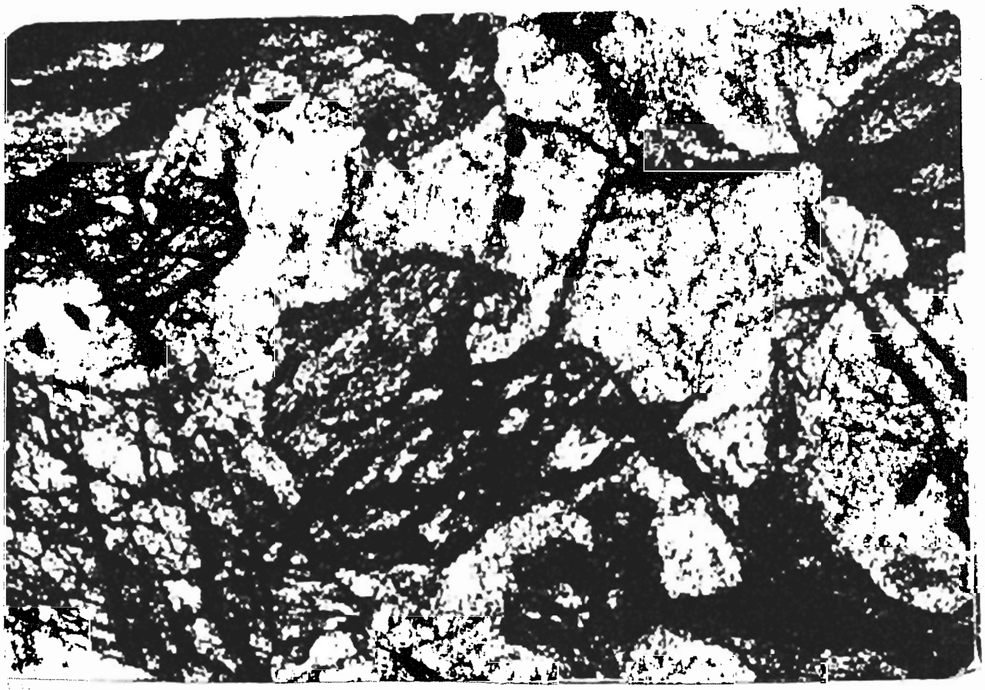


Plate 4.4 Same as plate 4.3

are generally fresh but the large one occasionally show sign of fibrolitization and utralitization at their boundaries.Hornblende shows evidences of growth prior to, as well as along with, epidote. It is homogenously pleochroic from light green to brownish green. In some of the rocks hornblende displays only a faint pleochroism from light green to green, probably due to a high Mg/Fe ratio (Jan, 1977).

The development of hornblende and epidote at the expense of clinopyroxene and plagioclase , the common association and intergrowing relationship of epidote and hornblende with each other,all indicate that epidote-amphibolite facies condition prevailed for a considerable time.If the relic clinopyroxene and plagioclase are considered as the original assamblage , then the parent for epidote-amphibolite was presumably of gabbroic to dioritic composition (Shah, 1986).

Occasionally the hornbelende grains also display zoning with bluish cores and greenish blue margins (Plate 4.5).In some rocks, hornblende surrounds or is surrounded by epidote (Plate 4.4) . Blebs and small inclusion of hornblende within large hornbelende crystals are also commonly observed (Plate 4.6) Plagioclase occurs in substantial amounts in most of these rocks. It is generally cloudy ,but in a few rocks, well developed,fresh and twinned plagioclase is also found . The composition of plagioclase, as determined by the methed of maximum symmetrical extinction angle fall in the albite range.

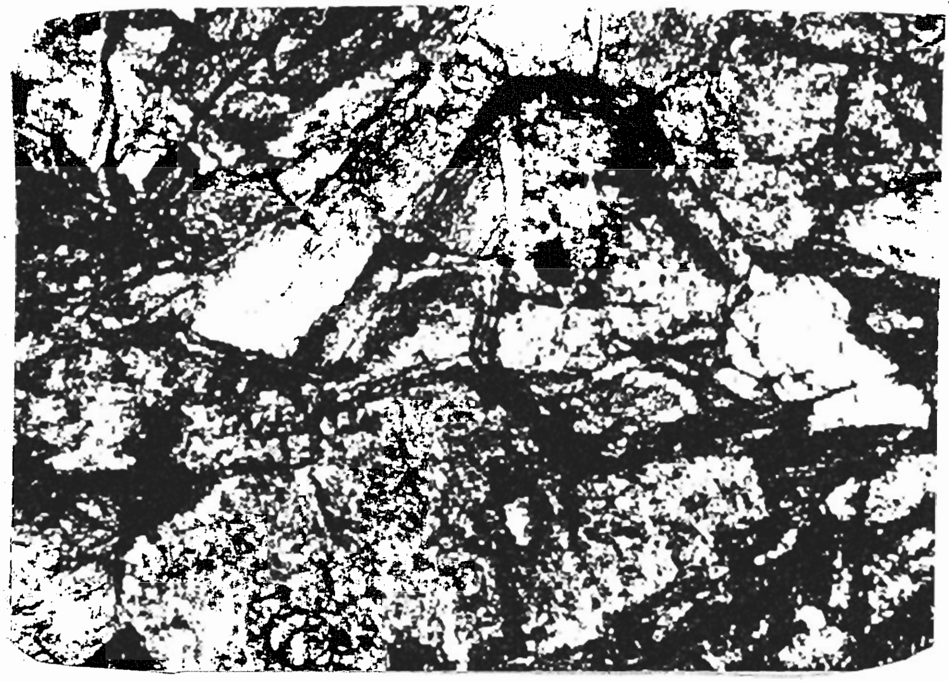


Plate 4.5 Photomicrograph showing zoning of hornblende in epidote- amphibolite (Nicols crossed)

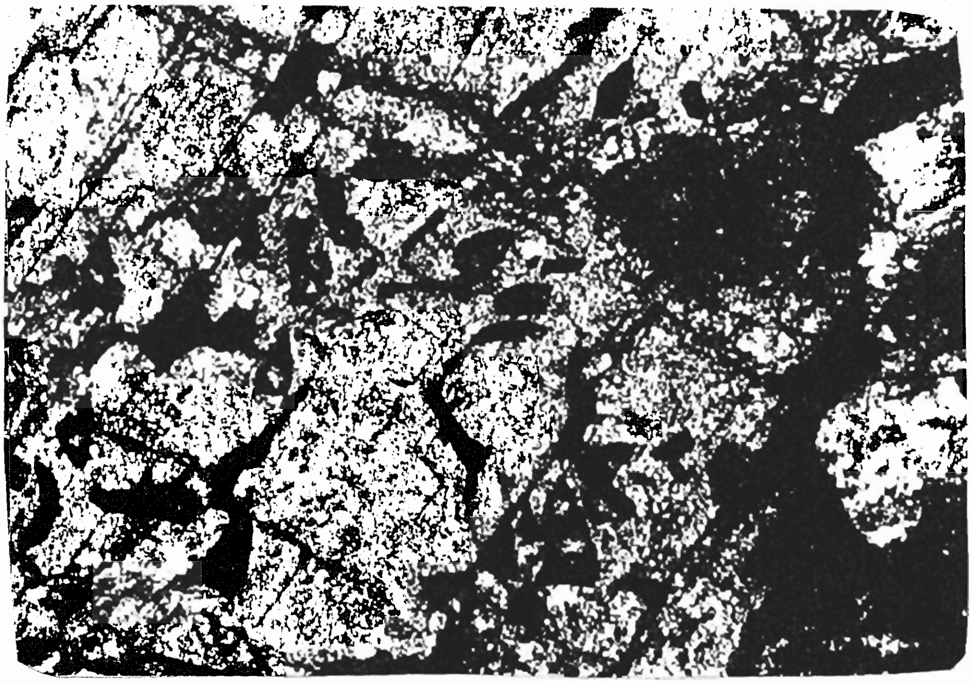


Plate 4.6 Photomicrograph showing the irregular inclusions of hornblende within large hornblende crystal (Nicols crossed).

Sphene is a common accessory mineral of all amphibolites. It is generally devoloped along the fractures, cleavages and grain boundaries of hornblende. Bluish tabular chlorite occurs in association with hornblende.

Opaque minerals generally occur in the cores and at grain boundaries of the hornblende crystals. It is most probable that these may be representing primary magnetite or its metamorphic equivalents, as epidote-amphibolites are cosiderably rich in normative magnetite (see Shah, 1986). The rutile noticed in most of the epidote - amphibolites seems to be the metamorphic product, most probably devloped at the expense of Tio^2 released by magnetite. The interpretation is supported by the close association of rutile with the opaque minerals. The evolutionary pattern established on the basis of the study of mineral assamblages in the epidote- amphibolite shows localised retrogressive metamorphic conditions. This interpretation is supported by the zoning reflected both in the pleochroic and interference colors of hornblende and epidote (see Miyasiro, 1973, P.254).

Table 1

Model Composition of Epidote-Amphibolites.

Sample No.	Percent of Component Mineral									
	Pg.	Hb.	Epi.	Cpx.	Opx.	Sph.	Qtz.	Ore	Rutile	Chl.
M2	15	30	40	7	3	5	–	–	–	T
M5	10	50	30	5	T	2	–	1	–	2
M6	15	35	40	–	–	5	–	2	T	3
M8	20	25	45	T	–	3	–	2	T	5
M9	20	32	40	–	–	3	–	T	T	5
M10	15	35	35	5	5	3	–	2	T	–
M12	17	40	30	3	2	5	–	3	1	–
M22	25	20	32	T	T	8	5	3	2	5
M29	10	35	40	5	3	–	–	3	2	2
M30	15	32	43	T	T	6	–	2	T	2

Table 1 Continued.

Model Composition of Epidote-Amphibolites.

Sample No.	Percent of Component Mineral									
	Pg.	Hb.	Epi.	Cpx.	Opx.	Sph.	Qtz.	Ore	Rutile	Chl.
M32	15	43	30	T	–	5	T	3	2	2
M33	20	45	28	T	–	3	T	2	T	2
M36	18	22	35	T	T	10	2	5	3	5
M37	10	50	25	T	–	8	T	3	2	2
M42	10	35	30	5	T	5	T	5	4	6
M47	10	40	35	T	T	4	3	2	1	5
M50	15	35	38	–	–	5	2	2	T	3
M55	15	40	30	–	–	8	2	2	T	3
M57	15	40	30	T	–	7	–	3	2	3
M66	15	42	30	–	–	5	–	2	–	5

Table 1 Condtinued.

Model Composition of Epidote-Amphibolites.

Sample No.	Percent of Component Mineral									
	Pg.	Hb.	Epi.	Cpx.	Opx.	Sph.	Qtz.	Ore	Rutile	Chl.
M74	15	40	30	–	–	5	–	3	2	5
M82	15	50	20	–	–	5	–	5	3	2
M94	15	45	25	T	–	5	–	3	2	5
M104	10	30	45	–	–	5	–	5	3	2
N1	10	50	15	5	5	5	–	3	2	5
N3	15	45	20	5	3	3	–	3	2	4
N14	15	30	40	2	–	5	–	3	2	5
A1	10	50	28	T	–	5	2	3	2	–
A3	20	25	35	2	–	8	T	3	2	5

(B) Plagioclase-amphibolites.

Megascopic Features:-

The plagioclase-amphibolites are generally medium to course grained,fresh, hard,massive and compact rocks, containing white plagioclase and dark hornblende. Locally on weathered surfaces,the rocks are grey or yellowish grey. Plagioclase and hornbelende can be easily distinguished in hand specimen.

Microscopic Features:-

In thin section, the plagioclase-amphibolites are medium to coarse grained, porphyroblastic to xenoblastic rockswith an inequigranular texture. They contain plagioclase (~30-50%) and hornblende (>30%) as the dominant constituents. Epidote, chlorite, sphene, quartz, rutile, and opaque minerals occur as accessories.

Plagioclase, the most dominant mineral, is generally cloudy (Plate 4.7), but fresh plagioclase with occasionally weakly devoloped zoning is also present (Plate 4.8). The composition of fresh and unzoned plagioclase, as determined by the methed ofmaximum symmetrical extinction angle, is in the oligoclase-andesine range. Hornblende is homogenous pleochroic from green to brownish green, and has a porphyroblastic texture . On the basis of microscopic characters, it seems to be generally similar to the hornblende of the epidote-amphibolites.

Hornblende contains inclusions and blebs of cloudy

Plate 4.7 Photomicrograph showing cloudy plagioclase in plagioclase - amphibolite.

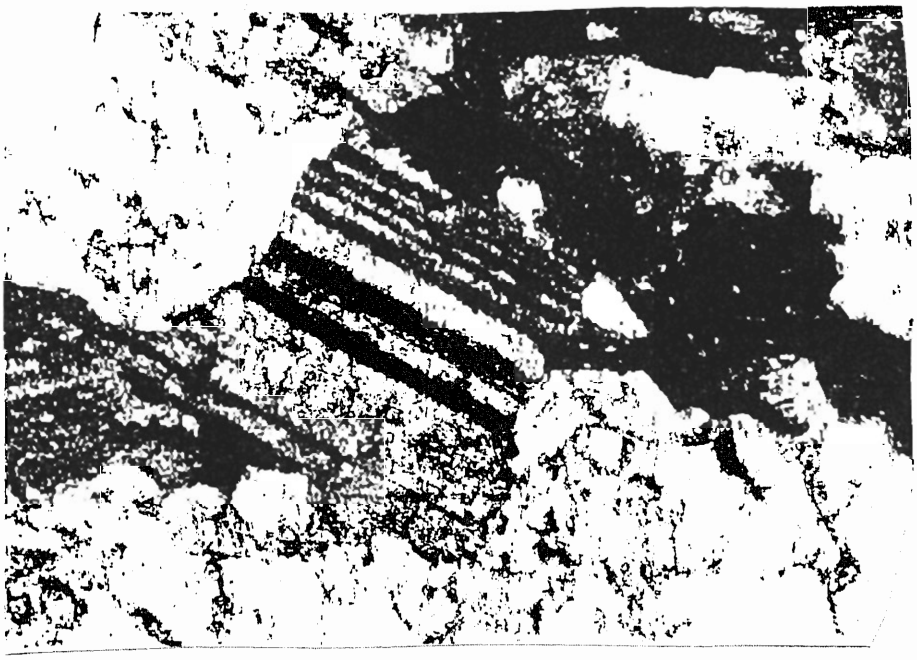


Plate 4.8 Photomicrograph showing twinned plagioclase in plagioclase amphibolite (Nicols crossed).

plagioclase,quartz, and opaque minerals as well as hornblende of an earlier generation. In a few rocks, these inclusions have a vermicular texture.

Epidote, occurs as subhedral crystals in granular and columnar aggregates. It contains small inclusions of cloudy plagioclase, sphene and hornblende ,and occassionally is very tiny. The grains of epidote occur in the interstices of plagioclase, and inclusions of epidote in hornblende are also noticed. In certain cases interstisial epidote occurs as rims or margins to the cloudy plagioclase grains. This epidote appears to be developed at the expense of cloudy plagioclase,and in certain cases at the expense of both plagioclase and hornblende.

Chlorite occuring as anhedral flakes is generally associated with hornblende, and occasionally with epidote. Quartz occurs as small inclusions in hornblende and plagioclase, or as microveins cross- cutting the rock. Its proportion varies from trace to 3 percent.

Rutile and ore minerals (magnetite/illmenite) occur in variable amounts as small inclusions in hornblende, and along fractures, cleavages and grain boundaries in hornblende. Independent grains of these accessories are also not uncommon.

Table 2

Model Composition of Plagiopclase-Amphibolites

Sample No.	Percent of Component Mineral									
	Pg.	Hb.	Epi.	Cpx.	Opx.	Sph.	Qtz.	Ore	Rutile	Chl.
M3	50	10	25	T	–	5	–	3	2	5
M16	45	25	17	–	–	5	T	3	2	3
M46	50	30	5	T	–	4	2	5	1	3
M53	50	30	10	T	–	2	–	3	2	3
M55	25	30	20	–	–	10	5	3	2	5
M65	20	55	5	5	3	6	T	2	2	2
M70	25	47	15	2	1	5	3	2	–	–
M84	25	40	17	3	–	5	–	3	2	5
M93	25	43	20	–	–	5	–	2	–	5
M96	30	35	20	T	–	8	–	2	–	5
M97	35	35	20	T	–	5	–	2	–	3

(C) Epidote-plagioclase-amphibolite.

Megascopic Features:

In hand specimen, the epidote-plagioclase-amphibolites are medium grained, hard and compact rocks with variable proportion of plagioclase and epidote. The three major components of the rock (hornblende, plagioclase, and epidote) can be easily recognised in hand specimen.

Microscopic Features:

In thin section,the epidote-plagioclase-amphibolites are medium to coarse-grained, hypidioblastic, inequigranular to subequigranular in texture. In addition to hornblende (~50- 60%),epidote, and plagioclase (both ~15-30%), sphene, chlorite,quartz, rutile and opaque minerals occurs as acessories.

Hornblende, the most abundent mineral of these rocks, is pleochroic from light green to dark green. It has intergrown with epidote and plagioclase, and contains inclusions of sphene, chlorite, quartz and opaque minerals.

Epidote is colourless and has high relief. The grains are mostly subhedral and cleaved, and occur in the form of granular aggregates. In a few rocks, discontinous microveins of epidote cross- cutting the rock are noticed.

Plagioclase is generally cloudy, probably due to kaolinization or saussuritization. In certain cases fresh and well developed twinned plagioclase of albite composition occurs. It is noticed as irregular inclusions in epidote and hornblende,but inclusions of hornblende, rutile and sphene are also present in plagioclase.

Sphene occurs as small inclusions with a vermicular structure in epidote, whereas chlorite generally occurs in the form of small flakes within hornblende.

Quartz is variable in amount, and occurs as tiny blebs and inclusions in hornblende and epidote.

Rutile and opaque minerals (~<0.1-2%) generally occur in association along cleavages, fractures, and grain boundries of hornblende and epidote.

Table 3

Modal Composition of Epidote-Plagioclase-Amphibolites.

Sample No.	Percent of Component Mineral									
	Pg.	Hb.	Epi.	Cpx.	Opx.	Sph.	Qtz.	Ore	Rutile	Chl.
M20	25	20	35	T	–	7	3	3	2	5
M34	20	50	25	T	–	2	T	T	–	3
M35	12	60	18	–	–	T	2	3	2	5
M38	15	50	20	–	–	5	2	2	1	5
M39	20	40	30	–	–	3	–	3	2	2
M45	15	55	20	T	–	3	5	2	–	–
M72	20	50	20	T	–	2	T	2	1	5
M78	15	55	20	T	T	3	–	3	2	2

4.2 Hornblendites

Megascopic Features:

The hornblendites are dark, medium- to coarse-grained, compact and massive rocks, which are moderately weathered, fractured and jointed. The cleavage surfaces and faces of prismatic hornblende crystals are smooth and shiny when fresh, but dull and rusty when weathered. Hornblendites are generally monomineralic with hornblende > 95%. However, plagioclase-hornblendite and epidote- hornblendite are also present. Plagioclase-hornblendites display a dark and white combination of colours, while epidote-hornblendites are greenish-black in color.

(A) Monomineralic Hornblendites.

The monomineralic hornblendites contain hornblende > 95% together with plagioclase, epidote, chlorite, sphene, quartz, rutile and opaque minerals, all varying between 1-5%.

Under the microscope, monomineralic hornblendites are generally medium to coarse-grained, with euhedral, subheadral and anhedral grains and thus reflect a hypautomorphic-granular texture.

The hornblende grains are strongly pleochroic from light to brownish green or dark green. Hornblende appears to be of two generations: (a) brownish green and (b) dark green varieties. The brownish green variety display zoning as well as twinning. The dark green variety of hornblende is

Table 4

Model Composition of Monomineralic Hornblendites.

Sample No.	Percent of Component Mineral							
	Pg.	Hb.	Epi.	Sph.	Qtz	Ore	Rutile	Chl.
M13	3	95	2	-	T	T	T	-
M21	2	95	3	T	-	T	T	T
M23	T	98	2	T	-	T	T	T
M24	T	95	T	2	-	2	1	T
M27	1	94	T	2	-	1	-	2
M28	3	95	2	T	-	T	T	T
M40	T	98	T	1	-	1	T	T
M43	-	92	3	1	-	1	1	2
N12	-	92	-	2	-	3	2	1

commonly found to penetrate the brownish green variety, suggesting that dark green hornblende is devoloped later than the brownish green hornblende. Inclusion of dark green variety in brownish green variety is also quite common.

Plagioclase is mostly cloudy, but fresh plagioclase with albite twining can also be absorved. It is generally interstitial to hornblende.

Epidote occurs as granular aggregates in the interstices of hornblende crystals. Chlorite, sphene, quartz, rutile and opaque minerals have developed along the interstices, cleavages and fractures of hornblende.

(B) Plagioclase-hornblendites.

The plagioclase-hornblendites are similar to the monomineralic hornblendites except for the high proportion of plagioclase (~15-30%), fine- grained texture, and the absence of pleochrism and multiple twinning in hornblende.Plagioclase is very cloudy, and shows alteration to epidote.

(C) Epidote - hornblendites.

On the basis of petrography, the epidoite-hornblendites also closely corrospond to the monomineralic hornblendites except for the high proportion of epidote and relatively fine-grained texture.

Plagioclase is also present in the interstices of hornblende and has altered to epidote, which occurs as granular aggregate. Microveins of epidote also cross cut the hornblende crystals.

Table 5

Model Composition of Epidote-Hornblendites

Sample No.	Percent of Component Mineral							
	Pg.	Hb.	Epi.	Sph.	Qtz	Ore	Rutile	Chl.
M7	3	75	10	5	–	2	2	3
M11	1	80	9	5	T	T	T	5
M14	1	90	5	T	T	2	2	T
M18	2	85	8	T	–	2	T	3
M76	–	88	5	2	–	2	2	1
M77	T	85	5	2	–	3	2	3
M90	–	85	10	T	–	2	1	2

Table 6

Model Composition of Plagioclase-Hornblendites

Sample No.	Percent of Component Mineral							
	Pg.	Hb.	Epi.	Sph.	Qtz	Ore	Rutile	Chl.
M4	8	88	–	2	–	1	1	–
M15	5	90	T	2	T	2	1	T
M16	5	92	3	T	–	T	T	T
M19	8	90	1	–	–	2	–	–
M73	5	90	2	2	–	T	T	1
M87	7	87	2	1	–	1	T	2

4.3 Hornblende-pegmatite

Megascopic Feature:

In hand specimen, the hornblende-pegmatites are hard and compact rocks. The large crystals of hornblende (1-10 cm x 1-5 cm across) and plagioclase (1-4cm x 1-2cm across) can be clearly recognised.

Microscopic Features:

The hornblende-pegmatites are coarse grained, poikiloblastic, inequigranular rock containing hornblende (~85%) and plagioclase (< 15%) as the dominant constituents. Epidote, quartz, sphene, muscovite, rutile and opaque minerals occur as accessories.

Hornblende occurs as long, prismatic crystals, strongly pleochroic from yellowish green to dark bluish-green, and contains quartz, muscovite, rutile and opaque minerals along fractures, cleavages and grain boundaries.

Plagioclase is generally cloudy, contains small inclusions of epidote and hornblende, and shows alteration to kaoline and epidote. Fresh plagioclase (oligoclase-andesine) is also present.

Epidote is generally colourless and occurs in association with plagioclase. Their textural relationship shows that epidote represents alteration of the plagioclase. Quartz occurs as small inclusions in hornblende and plagioclase.

Sphene occurs as pale yellow to brownish euhedral grains, mostly within hornblende crystals.

Chlorite, rutile and opaque minerals generally occur along cleavages and grain boundaries of hornblende.

4.4 Diorites.

Megascopic Features:

The diorites are generally medium-to coarse-grained and homogeneous rocks. The dioritic intrusions, however, also reflect geneissosity along the fine grained margins. In hand specimen, black prismatic hornblende and patches of plagioclase can be easily recognised. On weathered surfaces, the diorites show dark spots of hornblende and reddish iron oxide.

Microscopic Features:

The diorites are medium- to coarse-grained rocks with an inequigranular xenomorphic texture. They contains plagioclase, hornblende and epidote as the dominant constituents, with minor proportions of opaque minerals, sphene, rutile and quartz.

Plagioclase (~35-55%) occurs as both cloudy and fresh, subhedral to anhedral grains. Albite twinning is shown by fresh subhedral grains, whereas partial alteration to epidote and kaoline is noticed along the boundaries and fractures of the altered plagioclase. In certain cases, this alteration effects up to 30% of the total plagioclase.

Hornblende (~30%), is pleochroic from light green to dark green, occurs as subhedral to anhedral grains, and twining is occasionally observed . Iron oxide occurs along the fractures in hornblende crystals. In association with opaque minerals, hornblende and epidote display a sieve texture.

Epidote (~25%) is colourles and shows anomalous inatrference colors. It is associated with plagioclase and hornblende crystals. Microveins of epidote cross- cutting the rock are also present.

Quartz (< 8%) occurs as minute anhedral grains at the interstices of hornblende and plagioclase phenocrysts.

Sphene (< 5%) occurs as small inclusions within epidote and plagioclase grains.

Chlorite, rutile and opaque minerals occurs as minute grains in trace amounts within epidote, plagioclase and hornblende grains, as well as within the ground mass.

Table 7

Modal Compositions of Diorites.								
Sample No.	Percent of Component Mineral.							
	Plag.	Hb.	Epi.	Sph.	Qtz.	Ore.	Rutile	Chl.
M52	55	20	15	5	5	Trace	Trace	Trace
M56	50	15	25	5	5	"	"	"
M58	45	30	20	2	3	"	"	"
M100	40	25	25	5	5	"	"	"

4.5 Metagabbros.

Megascopic Features:

The metagabbros are medium-to coarse-grained, homogeneous rocks with weakly developed gneissosity at the centre of intrusion and strongly developed foliation at margins and along the contacts with amphibolites and hornblendites. In hand specimen, fresh rocks are hard, massive and compact.

Microscopic Features:

Under the microscope, the metababbros are medium-to coarse-grained, hypidioblastic to xenoblastic and subequigranular,containing hornblende (~ 30-60%),clinopyroxene (~ 15-30%), plagioclase (~ 5 - 10 %) and epidote. Foliation and gneissosity are strongly developed in some cases at the margins of the intrusion, where the hornblende crystals shows a preferred orientarion.

Hornblende is pleochroic from light green to brownish green, and commonly contains clinopyroxene relics. Some of the hornblende grains are fractured, and contain inclusions of opaque minerals (megnetite).

Clinopyroxene is colourless, and non- pleochroic. It is commonly replaced by hornblende.

Orthopyroxene also occurs and ranges from ~ 5-15% in abundance, is pleochroic from pink to green, and is surrounded by secondary hornblende.

Most of the plagioclase grains are cloudy and show alteration to epidote and kaoline, both of which form a matrix around the plagioclase crystals. Fresh plagioclase is however, also present, and on the basis of albite twin laminations, has a composition in the oligoclase-andesine range.

Sphene, chlorite, quartz, rutile and opaque minerals occur as trace amounts in the groundmass, fractures, cleavages and at grain boundaries of hornblende.

4.6 Meta-pyroxenites.

Megascopic Features:

The meta-pyroxenites are hard, compact and massive, medium- to coarse-grained rocks having a light greenish- grey to dark-grey colour in hand specimen.

Microscopic Features:

Under the microscope, the meta- pyroxenites are medium- to coarse-grained, hypidioblastic and inequigranular in texture. They are composed predominantly of clinopyroxene with subordinate amounts of hornblende. The accessory minerals are chlorite, sphene, epidote, and opaque minerals.

Clinopyroxene (~ 30-80%) is colorless, mostly subhedral in form, and occurs in close association with hornblende with the later partially replacing the former.

Hornblende (< 20%) is pleochroic from light green to brownish green, geneally developed along fractures and cleavages of clinopyroxene.

Sphene (up to 5%) occurs generally in clinopyroxene and rarely in hornblende in the form of small aggregates. Chlorite, epidote and opaque minerals occurs as traces within hornblende and clinopyroxene crystals.

CHAPTER 5

GEOCHEMISTRY

ANALYTICAL TECHNIQUES

Eighteen samples of amphibolites and fifteen samples of hornblendites from Mahak and surrounding area have been analysed for major and trace elements. Powdered whole-rock samples of the least altered samples were analysed by Pye-Unicam Sp 191 Atomic Absorption, X-Ray flourescence Spectrometer VF-310 Shimadzu and UV/ Visible spectrophotometer. A measured amount of each sample,usually about 0.5 gm, was digested with hydrofluoric acid (HF) and taken into solution. Sixteen of samples, analysed by wet chemical method, were duplicated by X-Ray flouresence spectrometer, VF-310 Shimadzu using STM1, G-2, DNC1. BRC-1 as internal standards. Consistency within the oxide values calculated through x-ray fluoresence and wet chemical methods verifies the experimental certainty of the concentration abundances.

Total iron was determined as Fe2O3 in XRF analyses. The weight percent FeO has been determined in each sample by the ammonium- meta - vanadate (AMV) method (Wilson, 1955, 1960).Ignition loss was determined by heating the rock powder to 1000 C for two hours. CIPW norms along with Niggli's and other useful values have been calculated using a computer programme set by Dr. S. Hamidullah, the Assistant Professor of the NCE in Geology , University of Peshawar.

5.1 Amphibolites

Eighteen selected samples of the different varieties of amphibolites were analysed by X-Ray Fluorescence Spectrometer VF-310 Shimadzu for major elements and the data are presented in Table 8.

The majority of the amphibolite analyses plot within the field nd the trend shown for Karroo dolerite on an niggli al-alk. vs. c and niggli c vs mg plots (Fig. 5.1,a-b) of Evans and Leake (1960) and Leake (1964). These characters generally indicate an igneous parantage for the amphibolites of Mahak and the surrounding area.

On an SiO_2 vs alkali plot (Fig.5.2), the majority of the amphibolites plot in the tholeiitic field, whereas certain amphiboilites (Table 8, analyses 1, 5 and 17) plot in the fields for the high alumina and mildly alkaline series. On an AFM diagram (Fig.5.3), the data follow the general trend of the tholeiitic series. Such characters indicate the origin of the Mahak amphibolites from a magma of tholeiitic affinities.

The occurrence of certain analyses 1, 5 and 17 of amphibolites in the fields for high alumina basalt and mildly alkaline series are due to the high percent of their Na_2O and K_2O content.

Continuous variations indicating crystallization differentiation from a common parent magma are shown by the majority of plots of amphibolites on oxide vs. S.I.

Table-8. The major elements along with C.I.P.W.Norms and Niggli's values for amphibolites and hornblendites from Mahak area, Swat.

Sample No.1-12. Epidote-amphibolites.
Sample No.13-15. Plagioclase-amphibolites.
Sample No.16-18. Epidote-plagioclase-amphibolites.
Sample No.19-33. Hornblendites.

MAJOR ELEMENTS

	1	2	3	4	5	6	7
	M22	M42	M51	M84	M104	N1	N3
SiO2	48.05	44.01	50.04	45.71	50.15	48.88	47.34
TiO2	1.40	1.25	0.99	0.93	0.29	0.35	0.15
Al2O3	11.46	12.75	12.66	15.70	11.48	11.76	14.75
Fe2O3	3.25	5.71	4.12	4.53	3.90	2.31	2.67
FeO	8.2	7.86	6.63	6.97	7.17	5.64	5.11
MnO	0.20	0.15	0.15	0.07	0.03	0.08	0.06
MgO	6.82	10.63	8.52	9.70	8.69	14.69	12.68
CaO	11.5	12.64	12.4	11.66	10.20	12.39	14.16
Na2O	5.04	3.21	1.95	2.02	5.93	1.26	1.32
K2O	0.00	0.00	0.93	0.40	0.07	0.33	0.13
P2O5	0.00	0.05	0.09	0.00	0.39	0.00	0.00
H2O+	3.5	1.9	1.2	1.8	1.95	1.6	1.3
H2O-	0.25	0.37	0.27	0.39	0.51	0.47	0.14
TOTAL	99.67	100.53	99.95	99.88	100.76	99.76	99.81
C	26.0	27.0	30.0	26.0	32.0	26.0	30.0
S.I	30.0	38.78	38.46	41.06	33.73	60.62	57.87
al-alk	6.42	9.54	10.58	13.28	8.38	10.17	13.30
mg	0.49	0.59	0.60	0.61	0.59	0.77	0.75

C.I.P.W. NORMS

	1	2	3	4	5	6	7
Q	0.00	0.00	0.0	0.00	0.00	0.00	0.00
Or	0.00	0.00	5.5	2.36	0.41	1.95	0.77
Ab	24.45	8.68	16.5	17.09	27.26	10.92	11.17
An	8.65	20.38	23.05	32.59	4.5	25.32	33.94
Ne	9.86	10.01	0.00	0.00	12.41	0.00	0.00
Di	39.52	34.15	30.74	20.48	35.59	28.79	29.04
Hy	0.00	0.00	14.42	0.05	0.00	15.56	3.94
Ol	6.54	18.27	2.42	17.61	13.86	11.79	16.74
Mt	4.2	3.99	3.61	3.52	2.6	2.63	2.39
Il	2.66	2.37	1.88	1.77	0.55	0.66	0.28
Ap	0.00	0.12	0.21	0.00	0.90	0.00	0.00

MAJOR ELEMENTS

	8 N5	9 N6	10 T5	11 A2	12 A3	13 M38	14 M65	15 M110
SiO2	46.37	47.81	47.1	50.8	51.8	47.47	45.52	40.21
TiO2	0.22	0.95	0.30	0.65	1.0	0.81	0.38	0.96
Al2O3	14.54	17.25	18.61	15.6	15.88	12.36	14.18	16.58
Fe2O3	6.51	3.50	3.35	3.67	3.76	5.38	2.3	4.12
FeO	8.81	4.7	5.9	9.3	9.12	8.9	5.1	8.54
MnO	0.11	0.2	0.09	0.20	0.16	0.13	0.08	0.17
MgO	7.84	7.88	9.58	4.48	5.05	10.94	15.64	10.13
CaO	12.27	12.0	12.14	9.77	8.28	12.19	13.83	12.98
Na2O	2.01	2.15	1.12	1.57	1.60	1.72	1.51	1.12
K2O	0.00	0.38	0.21	0.76	0.86	0.00	0.06	0.00
P2O5	0.00	0.15	0.00	0.00	0.00	0.02	0	0.37
H2O+	1.80	1.70	1.40	2.60	2.73	0.60	2.15	4.80
H2O-	0.21	0.55	0.27	0.18	0.10	0.18	0.12	0.15
TOTAL	100.69	99.22	100.07	99.58	100.34	100.70	100.87	100.09

NIGGLI'S VALUES

C	28.0	29.0	28.0	27.0	29.0	31.0	28.0	30.0
al-alk	13.09	14.73	17.28	13.27	13.42	10.64	12.61	15.52
mg	0.49	0.64	0.65	0.50	0.46	0.47	0.80	0.48
S.I	31.14	42.34	47.51	22.64	24.76	40.60	63.55	42.36

C.I.P.W. NORMS

Q	0.00	0.00	0.00	6.63	8.53	0.00	0.00	0.00
Or	0.00	2.25	1.24	4.49	5.08	0.00	0.35	0.00
Ab	17.09	18.19	9.48	13.29	13.54	14.55	7.04	5.75
An	30.61	36.3	45.13	33.28	33.61	26.01	31.74	40.11
Ne	0.00	0.00	0.00	0.00	0.00	0.00	3.11	2.02
Di	25.16	17.87	12.21	12.76	6.22	28.05	29.27	17.80
Hy	2.39	12.35	20.37	21.86	24.88	10.21	0.00	0.00
Ol	20.04	4.2	6.63	0.00	0.00	15.85	23.6	2.05
Mt	2.49	3.55	2.61	3.12	3.62	3.35	2.73	3.57
Il	0.42	1.80	0.57	1.23	1.90	1.54	0.72	1.82
Ap	0.00	0.35	0.00	0.00	0.00	0.05	0.00	0.86

Table-8 Continued.

MAJOR ELEMENTS

	16	17	18	19	20	21	22	23	24
	M3	M20	M45	M4	M13	M27	M40	M43	M77
SiO2	52.50	51.05	46.52	48.50	50.01	43.13	44.76	42.08	43.68
TiO2	1.20	1.40	2.09	0.51	0.78	2.16	1.58	1.31	0.58
Al2O3	16.25	16.46	10.13	8.83	9.64	10.3	9.33	13.66	9.15
Fe2O3	4.2	3.25	5.41	5.9	6.22	5.49	6.2	5.1	6.21
FeO	8.72	8.20	9.53	8.31	6.71	8.0	8.32	7.95	6.39
MnO	0.15	0.20	0.21	0.13	0:11	0.13	0.13	0.14	0.16
MgO	4.62	1.82	7.46	13.10	12.46	12.44	11.27	11.44	17.26
CaO	5.48	11.50	10.48	12.44	11.19	12.29	13.90	12.47	13.31
Na2O	3.74	5.04	3.10	0.84	2.81	3.58	2.15	3.13	0.87
K2O	0.00	0.00	0.62	0.05	0.20	0.25	0.75	0.62	0.45
P2O5	0.00	0.00	0.23	0.00	0.00	0.00	0.07	0.00	0.00
H2O+	2.80	0.90	3.10	1.90	1.60	2.40	2.10	2.30	2.0
H2O-	0.18	0.22	0.51	0.17	0.21	0.14	0.16	0.14	0.20
TOTAL	99.84	100.04	99.39	100.68	101.94	100.27	100.72	100.34	100.26
S.I.	21.99	10.13	28.54	46.45	41.85	41.85	39.28	40.50	55.35
NIGGLI'S VALUES									
C	28.0	30.0	29.0	26.0	26.0	28.0	27.0	26.0	28.0
al-alk	12.51	11.42	6.41	7.94	6.47	5.5	8.43	9.91	7.83
mg	0.46	0.57	0.48	0.63	0.60	0.64	0.54	0.62	0.72
C.I.P.W. NORMS									
Q	5.49	0	0	0	0	0	0	0	0
Or	0	0	3.66	0.30	1.18	1.48	4.43	1.52	2.66
Ab	31.65	35.91	25.39	7.11	23.78	5.27	4.64	0	0.44
An	27.19	22.29	11.90	20.18	13.10	11.30	13.59	21.39	19.73
Lc	0	0	0	0	0	0	0	1.68	0
Ne	0	3.65	0.45	0	0	13.54	7.34	14.35	3.75
Di	0	29.64	31.67	33.80	34.36	39.89	44.59	32.76	37.20
Hy	26.06	0	0	25.92	2.19	0	0	0	0
Ol	0	0.53	12.81	7.04	20.34	16.65	15.93	19.40	29.74
Mt	3.91	4.2	5.21	2.91	3.31	5.31	4.47	4.07	3.02
Il	2.28	2.66	3.97	0.97	1.48	4.10	3.0	2.49	1.10
Ap	0	0	0	0	0	0	0.16	0	0

TABLE 8 CONTINUED.

MAJOR ELEMENTS

	25 M64	26 M85	27 M106	28 N2	29 N10	30 N12	31 N14	32 T2	33 M17
SiO2	41.81	45.35	45.43	44.20	50.71	48.41	54.11	45.66	49.81
TiO2	0.99	1.14	1.17	0.15	0.42	0.51	0.73	1.42	0.54
Al2O3	11.18	8.30	14.58	14.72	10.20	5.24	10.55	9.27	10.62
Fe2O3	5.90	6.32	5.21	3.29	6.73	6.60	5.93	7.21	3.62
FeO	7.33	8.13	8.54	5.60	8.75	7.12	5.97	8.35	7.91
MnO	0.14	0.15	0.09	0.09	0.14	0.20	0.11	0.15	0.15
MgO	14.79	12.22	6.87	14.03	6.28	15.67	6.37	9.43	8.70
CaO	15.28	14.06	13.50	13.31	10.86	12.32	10.37	13.82	12.52
Na2O	0.98	2.26	2.0	1.49	2.16	1.15	2.82	1.93	2.51
K2O	0.37	0.00	0.78	0.34	0.51	0.54	0.61	0.20	0.70
P2O5	0.00	0.00	0.08	0.00	0.16	0.60	0.16	0.31	0.52
H2O+	1.60	1.72	1.70	2.60	1.0	1.60	1.40	2.40	2.51
H2O-	0.17	0.16	0.69	0.17	0.15	0.30	0.14	0.17	0.15
TOTAL	100.54	99.81	100.66	99.99	98.07	100.28	99.27	100.34	100.28
S.I.	50.35	42.23	29.33	54.68	25.70	51.93	29.35	30.16	37.11

NIGGLI'S VALUES .

C	29.0	29.0	31.0	27.0	28.0	29.0	28.0	30.0	28.0
al-alk	9.83	6.04	11.04	12.89	8.53	3.53	8.12	7.15	7.41
mg	0.67	0.50	0.48	0.65	0.43	0.69	0.59	0.55	0.75

C.I.P.W. NORMS

Q	0	0	0	0	1.81	0	5.43	0	0
Or	0	0	4.61	2.01	3.01	3.31	3.60	1.18	4.14
Ab	0	8.71	11.37	4.42	18.28	9.73	23.86	14.71	21.24
An	25.02	12.50	28.50	32.47	16.63	7.48	14.27	16.04	15.64
Lc	1.71	0	0	0	0	0	0	0	0
Ne	4.49	5.64	3.01	4.44	0	0	0	0.88	0
Di	30.19	46.52	31.33	26.89	30.30	40.20	29.79	41.42	35.19
Hy	0	0	0	0	22.44	15.72	15.40	0	7.31
Ol	27.40	18.20	12.92	24.15	0	16.21	0	15.47	8.68
Mt	3.61	3.83	3.87	2.39	2.78	2.91	3.23	4.23	2.99
Il	1.88	2.17	2.22	0.28	0.80	0.97	1.39	2.70	1.06
Ap	0	0	0.19	0	0.37	1.39	0.37	0.72	1.20

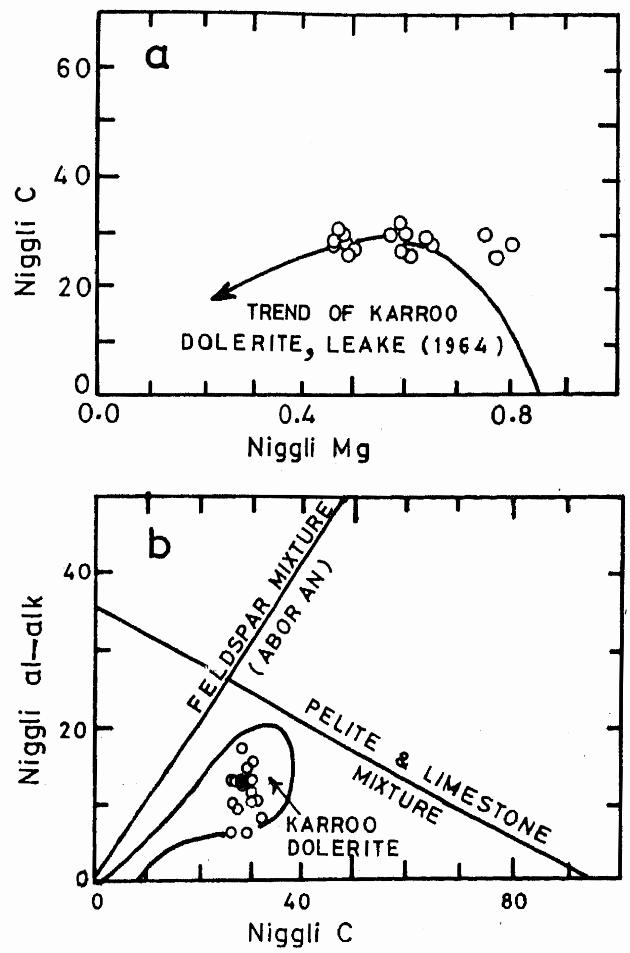


Fig. 5.1(a-b). Plot of niggli al-alk vs. c and plot of niggli c vs. mg for the amphibolites from Mahak area. Various fields after Evans & Leake (1960).

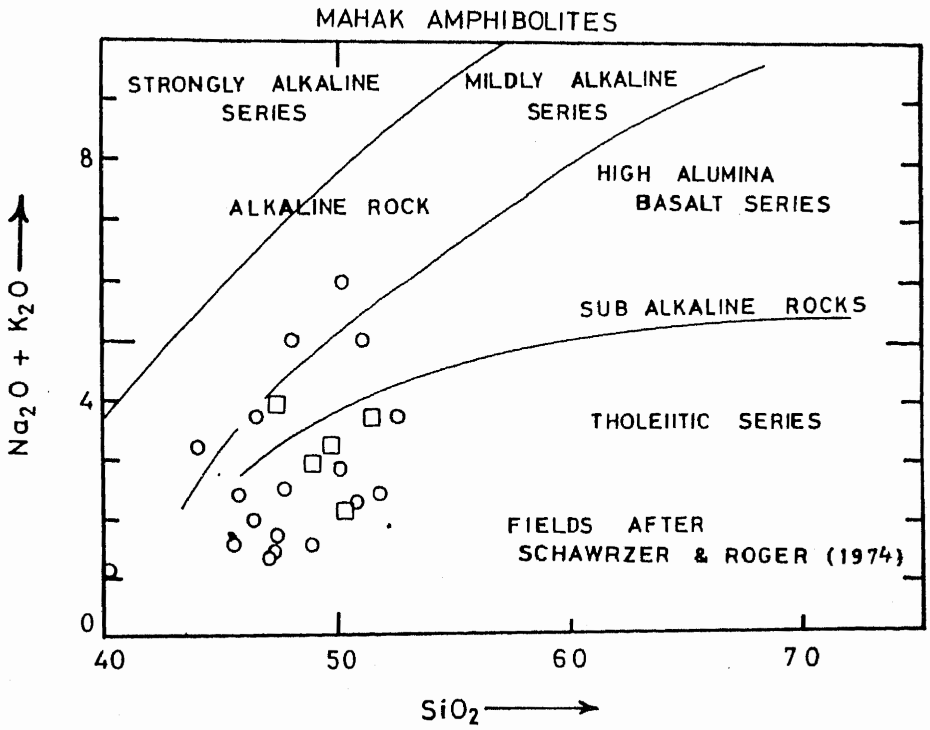


Fig. 5.2 Alkali vs. silica plot for amphibolites from the Mahak area. The division lines are after Schwarzer and Roger (1974).

Symbols ○ = Mahak amphibolites

□ = Greenland amphibolites

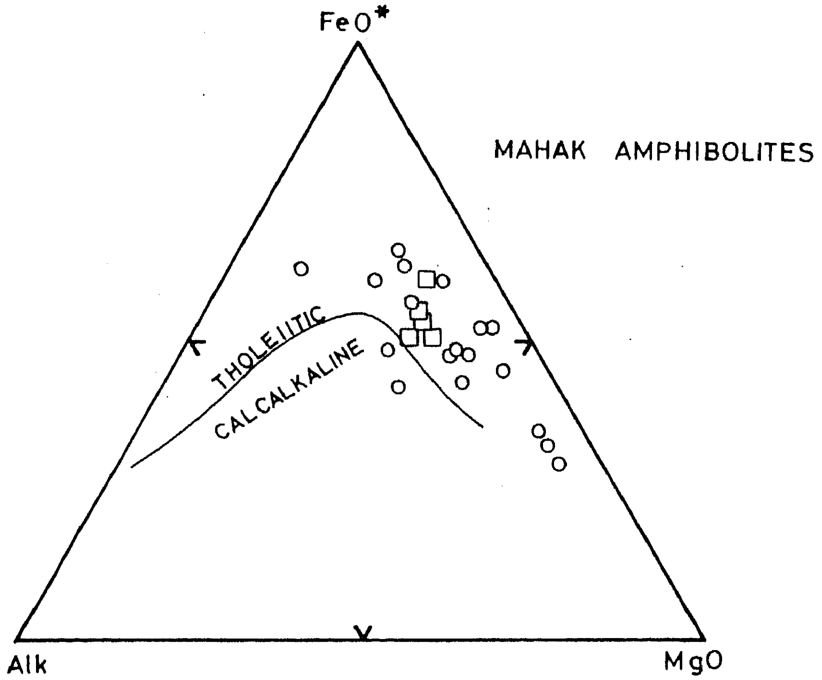


Fig.5.3. AFM plot for amphibolites of the Mahak area. The boundary lines are after Irvin & Baragar (1971).

Symbols ○ = Mahak amphibolites
□ = Greenland amphibolites

(Fig. 5.4) SiO_2 decreases with increasing S.I. at S.I. > 50 . At S.I < 50 , SiO_2 increase with decreasing S.I. The decrease in SiO_2 at S.I. > 50 indicate the fractionation of a SiO_2 saturated ferromagnesian mineral such as pyroxene at this particular stage of crystallization. The subsequent increase in SiO_2 is probably related to the fractionation of a SiO_2-poor phase like hornblende or magnetite. The presence of both ortho- and clinopyroxene, the higher proportion of green hornblende in the rocks with S.I. > 50 (Table 8, analyses 6, 7 and 14), and the higher proportion of magnetite in rocks with high Fe_2O_3 and FeO are consistent with this interpretation. The overall positive correlation on the MgO vs S.I. plot (Fig. 5.4) also indicates the fractionation of ferromagnesian phases like olivine, pyroxene, hornblende etc. The inflexion in the variation trend at S.I. 45 - 55 is probably related to the change from dominant clinopyroxene fractionation in the early stages and magnetite or hornblende and/or clinopyroxene fractionation in the latter stages.

The generally negative trends of the amphibolites on Fe_2O_3, FeO, and MnO vs S.I. plots at S.I. > 30 indicate iron enrichment in the liquid in the early and middle stages of crystallization, which reflects limited amounts of crystallization of an iron-bearing mineral at this stage. The positive correlations of these elements on the same plots at S.I. < 30 reflect the crystallization of an iron-rich phase such as magnetite in the latter stages. CaO shows a

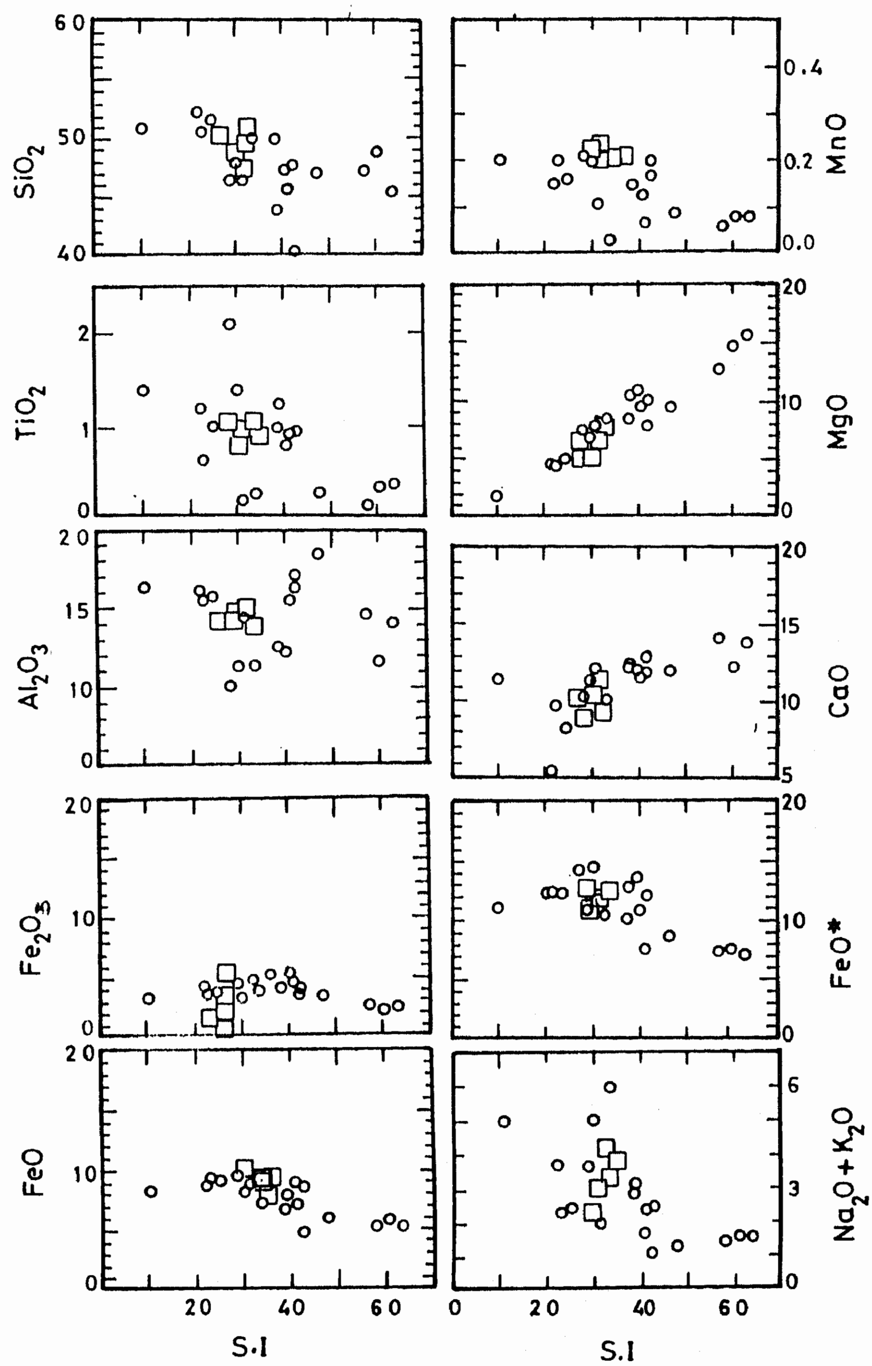


Fig. 5.4. Plot of various Oxides vs S.I. for amphibolites of the Mahak area.

Symbols ○ = Mahak amphibolites

□ = Greenland amphibolites

mild positive correlation at S.I.> 30 reflecting that CaO generally remained constant in the residual liquid, which inturn point to the crystallization of clinopyroxene. However at S.I > 30 a significant decrease in CaO content points to considerable fractionation of a Ca-bearing phase or phases.

The TiO_2 vs. S.I. plot display considerable scatter, but an overall negative correlation can be observed, which supports the view of iron enrichment until a considerablly later stage of crystallization.

The Al_2O_3 vs. S.I. plot shows considerable scatter with a generally negative trend indicating that plagioclase never remained a dominant fractionating phase. Plot points of rock between S.I 30 - 50 show a clear steep positive correlation which can be related to a high degree of plagioclase fractionation at this particular stage. The majority of the rocks at S.I. 30 - 50 are epidote-amphibolites (Table 8), the high proportion of epidote which is crystallized after plagioclase present in these rocks.

Both Na_2O + K_2O vs S.I. plots show a negative correlation, indicating that these elements were also generally concentrated in the residual liquids during fractionation.It also shows that biotite, orthoclase and sodic plagioclase never remained as dominant fractionating phase.

CMAS plots.

The analyses of the Mahak amphibolites were also plotted in the CMAS tetrahedral projection of O Hara (1976) (Fig.5.5,a-c).

The majority of the analyses plot parallel to the CAS_2-CMS_2 join, close to the CAS_2 end, but with a clear orientation of the basic end of the general trend towards the CMS2 end. In a projection from MS into the CAS_2-M_2S-CMS_2 plane, the analyses plot on a trend lying between the MS (enstatite) and CAS_2 (plagioclase) points. This trend also show affinities towards the CMS_2 (diopside) position. All these features indicate a dominant ortho and clinopyroxene fractionation in the early stages followed by a dominant plagioclase fractionation in the latter stages. The two feldspathic amphibolites do not plot within the triangle, and fall above the CAS_2 end, indicative of towards CaO enrichment. These interpretations are consistent with those obtained from the oxide vs S.I. plots. Clinopyroxene fractionation followed by plagioclase fractionation is also indicated by the data plot occuring parallel to CAS_2-CMS_2 join in a projection from S into the CAS_2-MS_2-CMS_2 plane, cross-cutting the M_2S-CMS_2 join with high affinities towards the CAS_2 position in a projection from CAS2 into CMS_2-M_2S-S planes.

It is clear from all these diagrams that the amphibolites of the Mahak and surrounding area follow an a

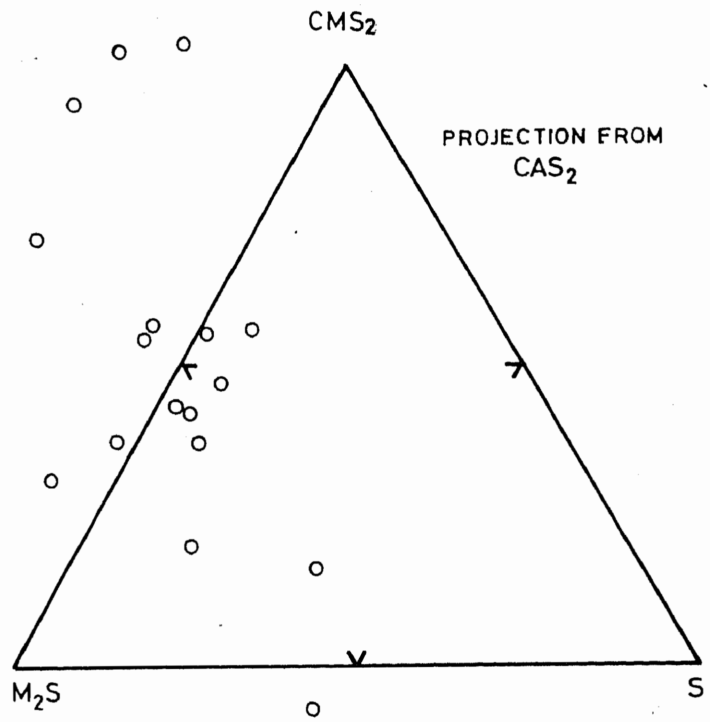
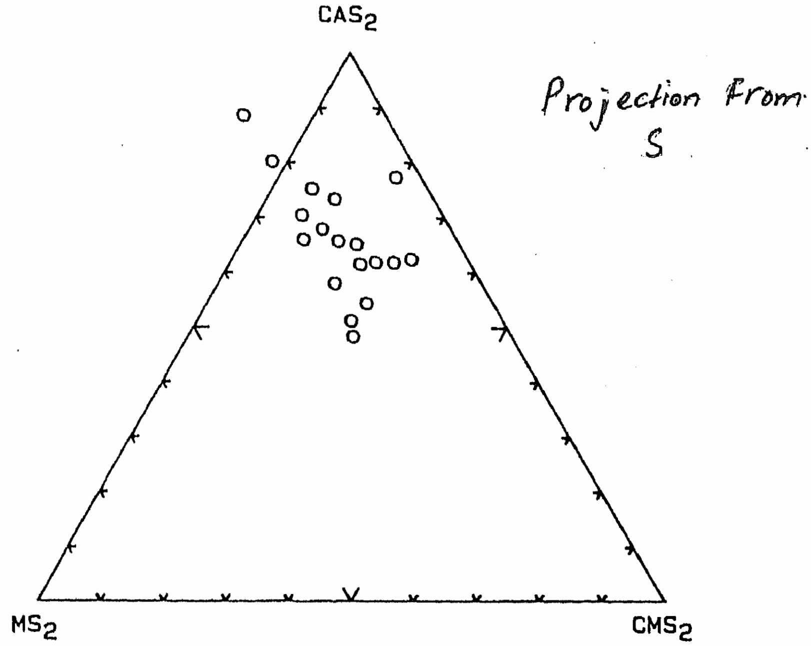
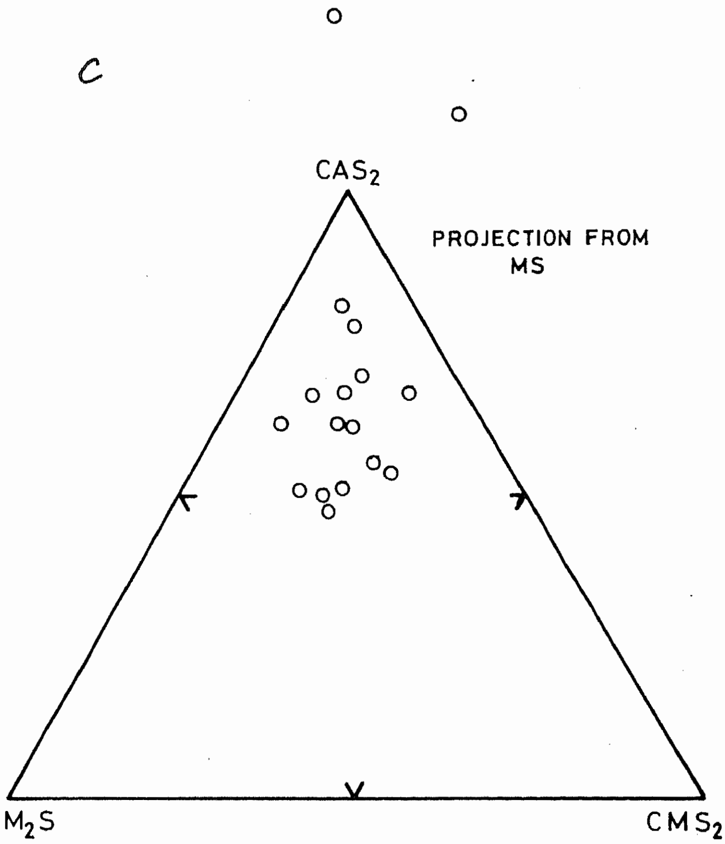


Fig. 5.5(a-C). CMAS plots for the amphibolites from Mahak area. C-M-A-S end members have been calculated from oxide wt.% following the method of O'Hara (1976).

b



C



It is clear from all these diagrams that the amphibolites of the Mahak and surrounding area follow an igneous fractionation trend. The banded appearance of some of the amphibolites, however, due to the process of metamorphism and segregation,or shearing.

To confirm the basic igneous parantage of the Mahak amphibolites, comparison with the representative average compositions from the metavolcanic amphibolites from South-West Greenland was carried out on the basis of the Alkali vs.silica (Fig.5.2),AFM (Fig.5.3), and Oxide vs. S.I.plots (Fig.5.4). Except for the minor differences shown by the relatively high Mno and low Fe_2O_3 in the latter group, the two suites show a remarkable correspondence on all these plots.The limited range of variation reflected by the Greenland amphibolites is due to their restricted range of differntiation and also because these analyses represent only average compositions.The correspondence however confirm the basic igneous nature of the Mahak amphibolites.

5.2 HORNBLENDITES

Fifteen samples of hornblendites from Mahak and the surrounding area were analysed for major elements and the data is presented in Table 8. The majority of the hornblendite analyses plot within the field, or just below the field, for Karroo dolerites on a niggli al-alk vs. c plot (Fig. 5.6a), indicating a probably igneous origin. However the hornblendites show relatively less al-alk as compared to the amphibolites. On a c vs. mg plot (Fig. 5.6b) the hornblendites show a continuous variation trend, and follow the trends of the Karroo dolerites and the Mahak amphibolites. The hornblendites also show continuous variation trends on the majority of oxide vs. S.I. plots (Fig. 5.7), indicating crystallization differentiation and an igneous parentage being responsible for the development of these rocks. Except for generally higher Fe_2O_3 and low Al_2O_3 in hornblendite, these rocks follow the trends of the Mahak amphibolites. The correspondence of the two groups on the basis of major element chemistry is indicative of their comagmatic origin. It also shows that the primary crystallization processes were generally the same in both these groups of rocks. The relatively higher Fe_2O_3 in hornblendites may point to the higher oxidation state during the transformation of amphibolites into hornblendites.

The overall correspondence of the hornblendites with the amphibolites is more prominent on an AFM plot (Fig. 5.8), where the majority of the analyses of the former

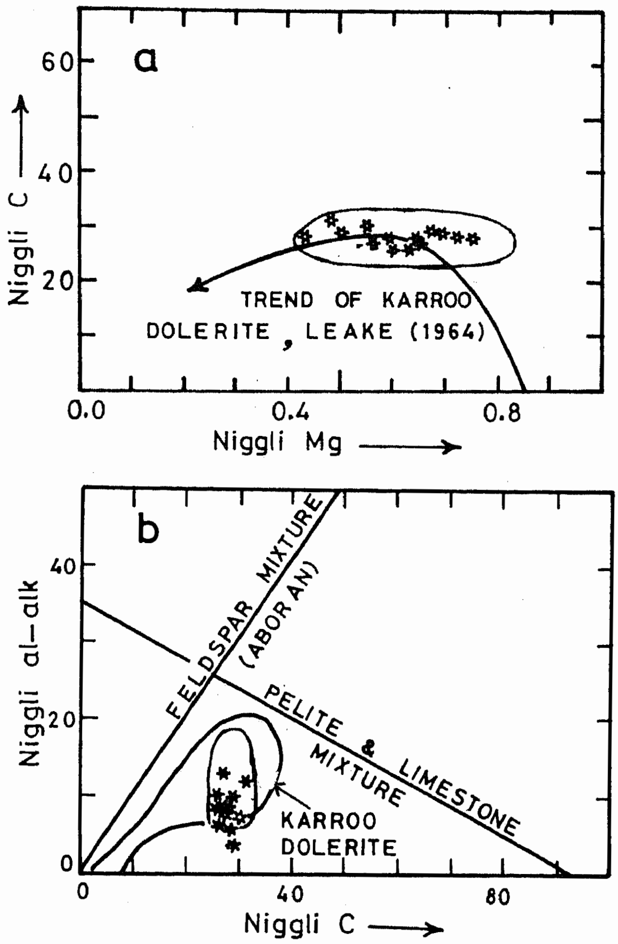


Fig. 5.6(a-b). Plots of niggli al-alk vs. c and c vs. mg for the hornblendites from Mahak area. Various fields are after Evans and Leake (1960).

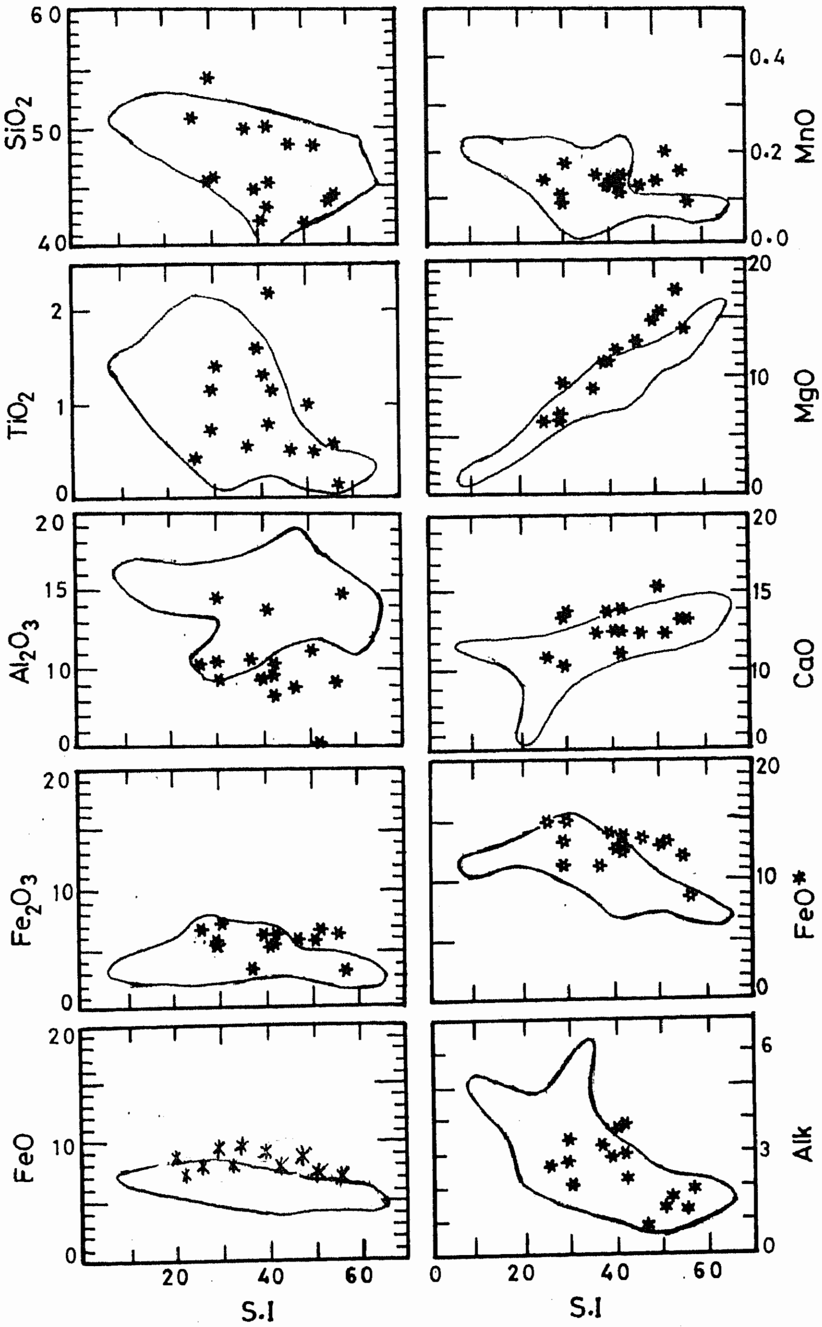


Fig. 5.7. Plot of various oxides against solidification (S.I) for the hornblendites from Mahak area.

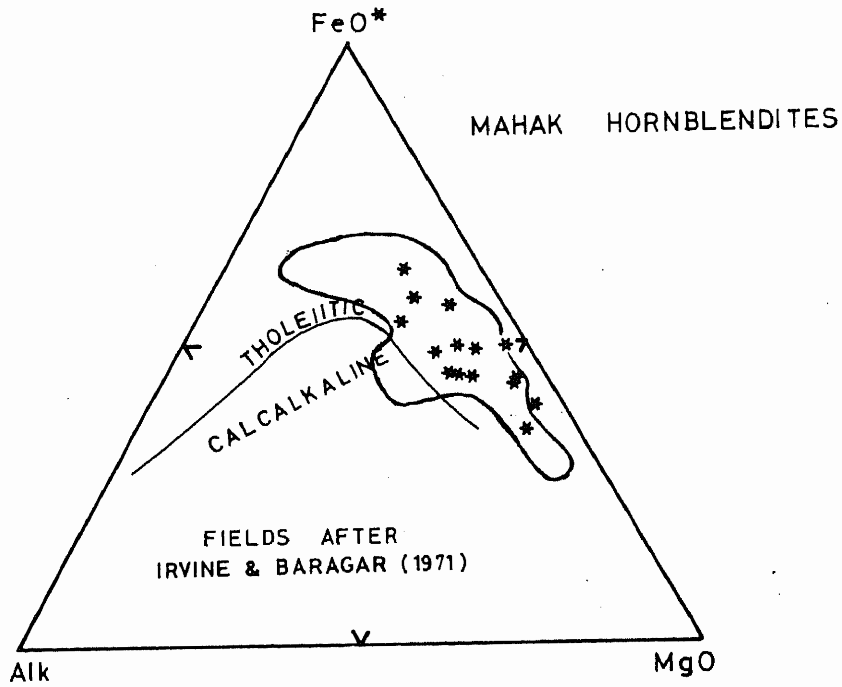


Fig. 5.8.. AFM plot for the hornblendites from Mahak area . The boundary lines are after Irvin & Baragar (1971).

type occur within the field for the latter type, and reflect the tholeiitic character of their parent magma.

CMAS PLOTS

The general correspondence of the hornblendites with the amphibolites is also reflected in the data plots of both these groups shown in various projections of the CMAS tetrahedron of O Hara (1976) (Fig.5.9,a-e). Clinopyroxene and/or orthopyroxene fractionation followed by plagioclase fractionation in the general crystallization sequence of the hornblendites is reflected by their trend lying parallel to the CAS_2-CM_2S_4 join in a projection from S onto CAS_2-MS_2-CMS_2 plane (Fig.5.9 a-e). The higher affinities of the hornblendites towards the CAS_2 position, then the amphibolites is probably related to the greater control of olivine fractionation in the early stages of crystallization. Similarities of hornblendites with amphibolites, and relatively greater affinities towards olivine in the early stages of fractionation in hornblendites are also reflected in the correspondence of their data plots in several other projections of the CMAS system; i.e., the projection from MS onto the CAS_2-M_2S-CMS_2 plane, the projection from M_2S onto the S-CAS_2-CMS_2 plane, projection from CMS_2 onto the S-M_2S-CAS_2 plane and projection from CAS_2 onto the CMS_2-M_2S-S plane.

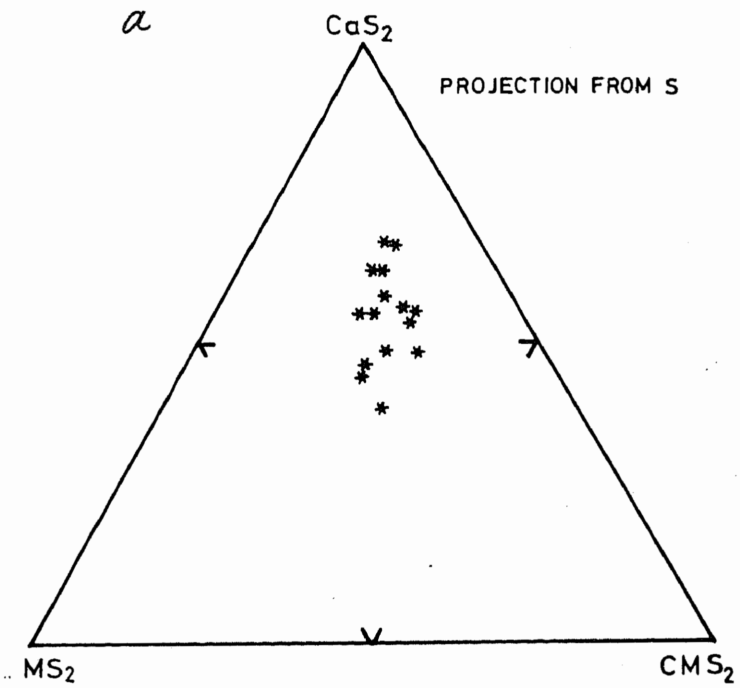
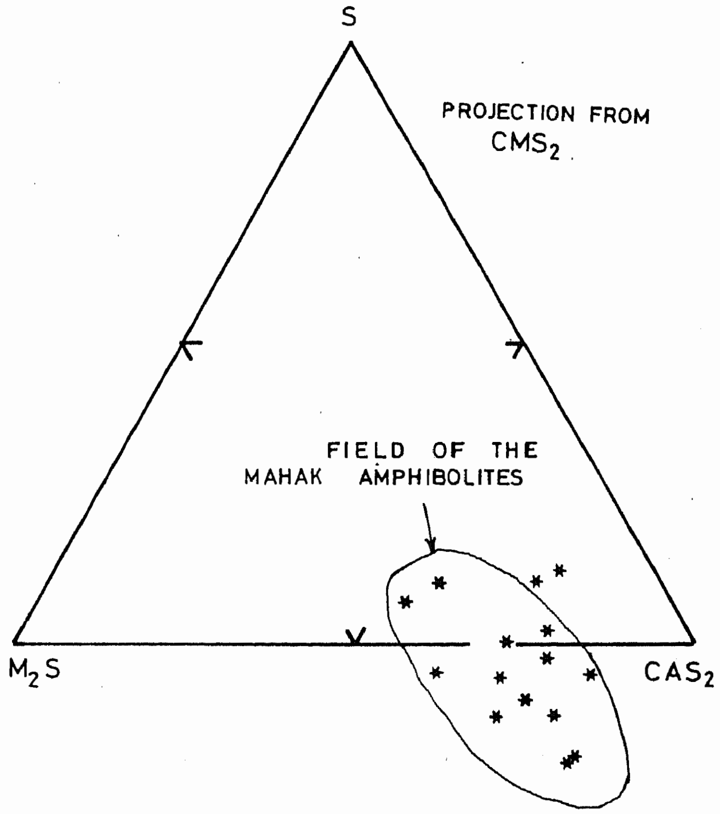
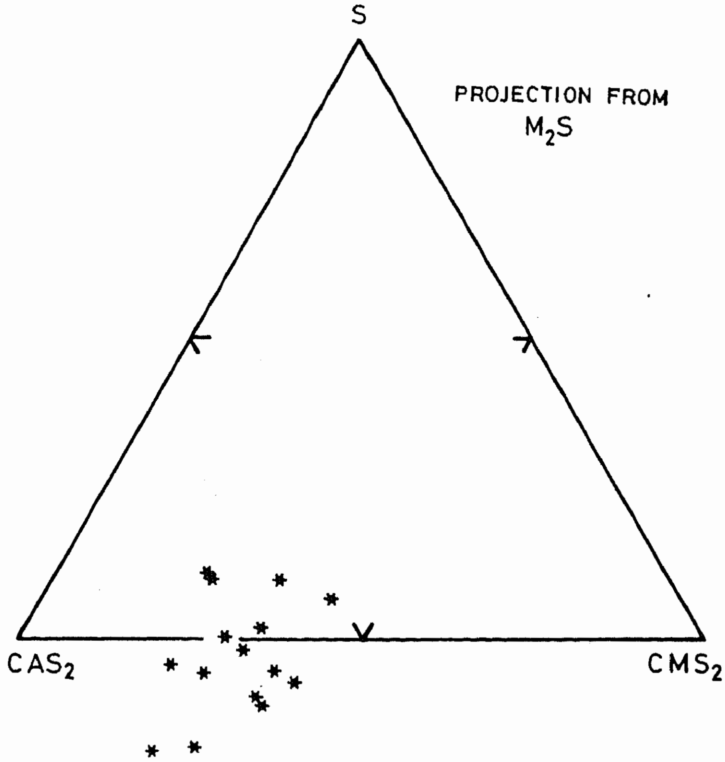


Fig. 5.9.(a-e). CMAS plots for the hornblendites from Mahak area. C-M-A-S end members have been calculated from oxide wt.% following the method of O'Hara (1976).

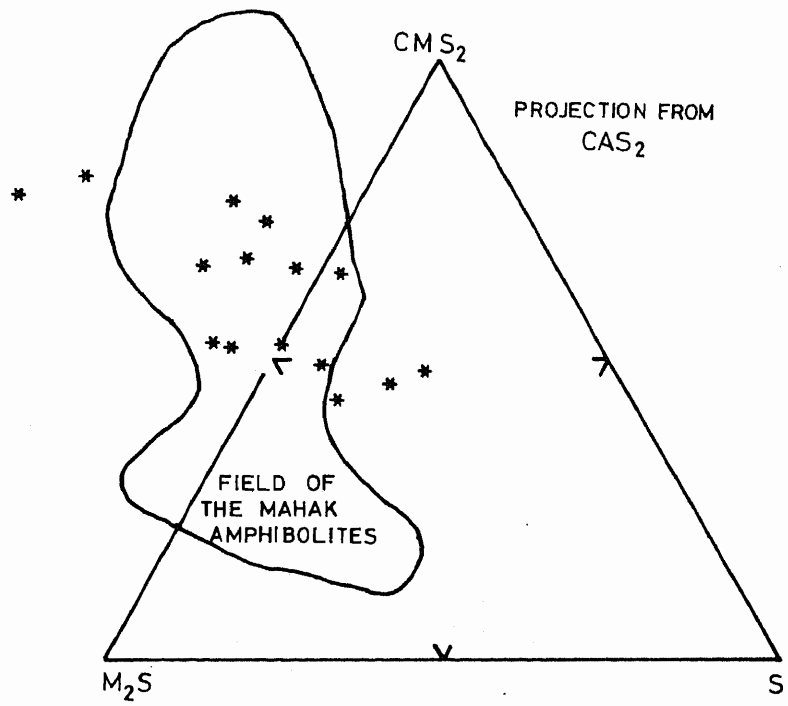
b


S
PROJECTION FROM
CMS2
FIELD OF THE
MAHAK AMPHIBOLITES
M2S
CAS2

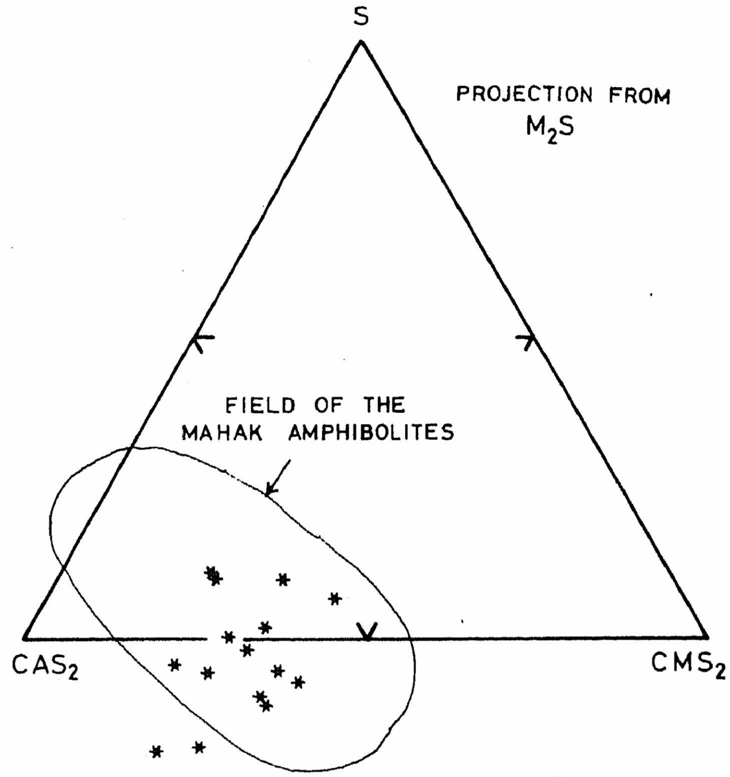
C



d


CMS$_2$
PROJECTION FROM CAS$_2$
FIELD OF THE MAHAK AMPHIBOLITES
M$_2$S
S

e


S
PROJECTION FROM
M2S
FIELD OF THE
MAHAK AMPHIBOLITES
CAS2
CMS2

CHAPTER-6

DISCUSSION AND CONCLUSIONS

On the basis of the petrography and field aspects, the amphibolite belt rocks of Mahak and the surrounding area comprise amphibolites, hornblendites, hornblende-pegmatites, diorites, metagabbros and metapyroxenites.

Amphibolites are the most abundant rocks of the investigated area, and are generally homogeneous and foliated although banded types are also present locally. The rocks generally show uniformity in composition, with mineralogical differences arising due to the presence or absence of plagioclase and epidote. Three types of amphibolites, including epidote-amphibolites, plagioclase-amphibolites and epidote-plagioclase amphibolites, are distinguished. All three types generally grade into one another.

The petrography shows that the amphibolites have evolved through a major stage of epidote-amphibolite facies metamorphism, represented by the development of hornblende+epidote after ortho/clinopyroxene and plagioclase (Table 1, sections M2, M10, M12), and probably a very minor stage of retrogression represented by the development of some chlorite after hornblende (Table 1, sections, M5, M6, M8, M9). Garnet is absent, which can be attributed either to a low pressure environment or low Fe^{+2}/Mg ratio of the rocks

(Miyashiro, 1973, p.259). These features discriminate the Mahak amphibolites from those of Allai Kohistan reported by Shah (1986), where a major stage of epidote-amphibolite and garnet-epidote-amphibolite facies metamorphism was followed by a considerable retrogressive stage of greenschist facies metamorphism represented by a high proportion of chlorite in association with another generation of epidote(Shah, 1986). These features show that temperatures did not fall considerably in the Mahak area during retrogression, probably due to the intrusion of granites.

On the basis of field data, petrography and geochemistry, the amphibolites and hornblendites are considered to be the product of crystallization differentiation of a tholeiitic magma with olivine, pyroxene and plagioclase playing a major role in the fractionation history of these rocks. The field relationship and the petrography also show that amphibolites have transformed into hornblendites locally at many places. Contacts of amphibolites with hornblendites are both graditioinal and sharp. Hornblendites are generally developed in amphibolites where quartzofelspathic veins/dykes are common. Hornblendite chemistry is more reflective of the olivine and pyroxene fractionation. Amphibolites differ from hornblendites only on the basis of high Fe_2O_3 and low Al_2O_3 content. This feature has been attributed to metasomatic phenomenon of amphibolite-hornblendite transformation during which Al_2O_3 has been probably replaced by Fe_2O_3 or the rocks were probably low Al_2O_3 in the first place due to their richness in olivine or ortho/clinopyroxene. It also shows that the amphibolite to hornblendite transformation was of selective type on the basis of rock composition. Basic and ultrabasic rocks were prone to this metasomatic transformation in the area. This conclusion is consistent with the relatively high MgO in the hornblendites as compared to amphibolites on the S.I Vs MgO plot.

The amphibolite to hornblendite transformation is generally prominant where quartzofelspathic veins/dykes are common. These veins/dykes are the off shouts of larger granitic bodies within amphibolites, like those present at Shah Dheri and Taghma areas. The Shah Dheri China clay deposits are an alteration product of the granitic intrusions in the area. Amphibolites to huornblendites transformation is more prominent in the vicinity of these granitic bodies only if the amphibolites are course grained (Hamidullah pers. comm.). Therefore the material utilised in the metasomatic transformation of amphibolites to hornblendites comes most probably donated by the quartzofelspathic veins associated with amphibolites and hornblendites in the area. In many places the hornblendites are themselves crosscut by deformed quartzo-felspathic veins. These features shows that the transformation probably occured during the initial stages of quartzofelspathic veins which by itself continued after transformation. The high Fe_2O_3 in hornblendites shows that probably only oxygen played a major rule and it might be the very early stage volatile rich front advancing along the weak zones and causing transformation.

The quartzofelspathic veins generally associated with hornblendites are altered to kaolinite/China clay deposits of Shah Dheri, which is 5 km NW of Mahak. Therefore the occurance of huornblendite can be considered as an indicator of kaolinite deposits within the southern amphibolite belt rocks.

The uniform coarse grained texture, the scarcity of banding, the relic ortho and clinopyroxene in the amphibolites indicate these to be of plutonic nature. However pillow structure have been noticed near Taghma village and lavas have been found associated with amphibolites in the belt (Shah, 1986). The amphibolite belt is a wide horizon of rocks developed in arc type environment and therefore plutonic, volcanic and sedimentaqry rocks are not unexpected to be present. Sedimentary features have not been noticed in the studied area. Data on the ages of amphibolites has reflected at least 76 M a age, which is considered a metamorphic age. Therefore the intrusion/

extrusion of the tholeiitic parent magma for amphibolites was probably generated much earlier than the collision along MMT (55 M a). This feature shows that indian continent was at a considerable distance from the locality of arc in the ocean and continental sediments might have not associated with these lavas in the back arc types of environment. The amphibolite belt rocks are therefore considered to be mainly of plutonic parentage.

The amphibolite fbelt rocks have been attributed to low-k tholeiite (M.A. Khan pers. comm.). Considering the amphibolite belt as representing an independent arc, consisted of the Chilas Complex (Hamidullah and Jan, 1987). The structural data shows that amphibolites are older than the Chilas Complex (Coward, 1982). The Chilas Complex has considered at least 102 M a old (Coward et al, 1982, Hamidullah and Onstot in prep.). Therefore the amphibolite belt rocks can be considered older than 102 M a considering the interpreted age (> 102 M a) and the position of amphibolite belt in the Kohistan island arc provided that K2O has not been released during metamorphism and metasomatism and considering as low-k tholeiites.

CONCLUSION

1. The amphibolite belt rocks of the Mahak area have been derived from low-k early arc type of tholeiitic magma.
2. The hornblendites are formed from amphibolites due to metasomatic replacement.
3. Olivine, ortho and clinopyroxene and plagioclase played a major rule in the evolution of the fractionation trend of these rocks.
3. Epidote-amphibolite grade metamorphism prevailed for a considerable time followed by a minor stage of retrogression and transformed the igneous product into their metamorphic equivelents.
4. Selective transformation occured during the intrusion of granitic rocks in the area and coarse grained basic amphibolites were converted to hornblendites in the vicinity of quartzofelspathic veins. The amphibolite to hornblendite transformation occured due to the addition of Fe2O3 and subtraction of Al2O3 in the hornblendite.
5. The kaolinite/china clay deposits in the area are the product of alteration of quartzofelspathic and granitic materials in the amphibolite belt.
6. Deformation continued even after the intrusion of the quartzofelspathic veins.
7. Hornblendites can be used as a tracer for china clay deposits in the southern amphibolite belt rocks.

REFERENCES.

Ahmad,Z., 1978. Petrology of the Taghma area, Swat District, N.W.F.P.,Pakistan. Geol. Bull. Univ. Punjab. 15, 25-29.

Ahmad,Z.and Chaudary,M.N.,1976.Geology of Babusar area, Diamir district Gilgit, Pakistan. Geol. Bull. Punjab Univ. 12, 67-78.

Andrews-Speed, C.P. and Brookfield, M.E., 1982.Middle Paleozoic to Cenozoic geology and tectonic evolution of the northwestern Himalaya.Tectonophysics,82,253-275.

Ashraf,M.,1969. Magnetite-bearing amphibolites, near Mari Banda, Swat. 11th Annul. Conf., Sci. Soc. Pakistan, Multan. Geol. Abs. 22.

Bard,J.P.,Maluski,H.,Matte,Ph.and Proust,F.,(1980).The Kohistan sequence;crust and mantle of an obducted island arc.Geol. Bull. Univ.Peshawar (spec.issue)13,87-94.

Bard, J.P., 1983. Metamorphic evolution of an obducted island arc:Examples of Kohistan sequence (Pakistan) in the Himalayan collided range. 16.

Bowen, N.L., 1922. The behaviour of inclusions in igenous rocks. Jour. Geol. 30, 513-567.

Calkins,J.A, and Ahmad, M., 1968. Geologic map of the Tarbela Damsite area, Pakistan.

-------, Offield, T.W., Abdullah, S.K.M, and Ali, S.T., 1975.Geology of the Southern Himalaya in Hazara, Pakistan, and adjacent areas. U.S. Geol. Survey Prof. Paper,716.

Chaudhry, M.N. and Chaudhry, A.G., 1974. Geology of Khagram area, Dir district.Geol.Bull.Punjab Univ.11, 21-44.

Coward, M.P., Jan, M.Q., Rex, D, Tarney, J., Thirlwall, M. and Windley, B.F., 1982. Geotectonic framework of the Himalaya of N. Pakistan. J. Geol. Soc. London 299-308.

Davies, R.G., 1965. The nature of Upper Swat Hornblendic gruop of Martin et al. Geol. Bull. Punjab Univ. 5, 51-52.

Deer, W A., Howei, R.A., and Zussman, J., 1968.An Introduction to the Rock Forming Minerals. Longman, London.

Desio, A., 1964. Geological Tantative map of the Western Karakoram, 1:500,000, Inst. Geol. Univ. Milano.

Evans, B.W. and Leake, B.E., 1960. The composition and origin of the striped amphibolites of Connemara,Ireland. Jour. Petrol. 1, 337-363.

Gansser, A., 1964. The Geology of the Himalayas. New York, 289P.

---------- , 1974. Himalayas, in Mesozoic-Cenozoic orogenic belts. Geol.Soc. London. Spec.Publ. No. 40, 267-278.

Guiraud,M.,Leyreloup,A.F.,Proust,F.,in press.Petrology of the glaucophane bearing rocks from Khost,Afghanistan and from Kohistan,North Pakistan.

Hamidullah,S. and Boews, D.R., 1987. Petrogenesis of the Appinite Suite, Appin District, Western Scotland.Acta Universities Carolinae - Geologica No. 4, 295-396.

---------,and Jan,M.Q.,1986.Prelimenary petrochemical study of the Chilas Complex,Kohistan island arc,Northern Pakistan.Geol.Bull.Univ.Peshawar.19,157-182.

Harker, A., 1939. Metamorphism. Chapman and Hall, London, 2nd edition.

Heier, K.S., 1962. The possible origin of amphibolites in an area of high metamorphic grade.Norsk.Geol. Tiddeskr. 42, 152-165.

Irvine, T.N. and Baragar, W. R. A., 1971. A guide to the classification of the common volcanic rocks.Can J. Earth Sci. 8,523-49.

Jan, M.Q., 1977. Petrography of the amphibolites of Swat and Kohistan. Geol. Bull. Univ. Peshawar. 11, 51-64.

---------, 1979. Petrography of the pyroxene granulites from northern Swat and Kohistan. Geol. Bull. Univ. Peshawar. 11, 65-87.

------- , and Kemp, D.R.C., 1973. The petrology of the basic and intermediate rocks of upper Swat, Pakistan. Geol. Mag. 110, No. 3 , 285-300.

--------- , and Asif, M., 1981. A Speculative tectonic model for the evolution of NW Himalaya and Karakoram. Geol. Bull. Univ. Peshawar, 14,199-201.

--------- , and Howie, R.A., 1982. Hornblendic amphbolites from basic and intermediate rocks of Swat - kohistan, north west Pakistan. Amer. Mineral.67, 1155-1178.

---------,and Howie,R.A.,1981. The mineralogy and geochemistry of the metamorphosed basic and ultrabasic rocks ofthe Jijal complex,Kohistan. NW Pakistan Jour. Pet.22, 85-126.

---------,1980.Petrology of the obducted mafic and ultramafic metamorphites from the southern part of the Kohistan island arc sequence.Geol.Bull.Univ.Peshawar 13,95-107.

----- , and Asif,M., 1983. Geochemistry of tonalites and (quartz) diorites of the Kohistan Ladakh granite belt in Swat, NW Pakistan. In " Granite" of Hima laya, Karakoram and Hindukush (F.A. Shams, ed.) Institute of Geol. Punjab Univ. Lahore, Pakistan.

---------,and Symes,R.F.,1977. Piemontite schists from Upper Swat, N W Pakistan.Min. Mg. 41,537-540.

Kazmer, C., Hussain, S.S., and Lawerence, R.D., 1983. The Kohistan-Indian plate suture zone at Jawan Pass, Pakistan Geol. Soc. America. Abst with programms 15, 609.

Klootwijk, C., Sharma, M.L., Girgan, J., Tirkey, B., Shah, S.K. and Agarwal, V., 1979. The extent of greater India, II and paleomagnetic data from the Ladakh intrusive at Kargil, NW Himalaya. Earth Planet. Sci. Lett. 45, 47-64.

Kuno, H., 1968. Differentiation of basaltic magmas. Wiley, New York, 632-688.

----------, 1959. origin of cenozoic petro - graphic provinces of Japan and surrounding areas. Bull. Volcanol. Ser. II, 37 -- 76.

Leake, B.E., 1972. The mineralogical modification of the chemistry of metamorphic rocks. Geol. Mag. 109, 333-337.

----- , 1964. The chemical disinction between ortho and para amphiboltes. Jour. Pet. 5, 238-254.

----- , 1960. Origin of Amphibolites from North west Adirondacks, New York. Geol. Soc. Amer. Bull. 74, 1193-1202.

Majid, M., 1979. Petrology of diorites from the Kohistan sequence Swat, N. Pakistan. A genetic interpretation at plate scale. Geol. Bull. Univ. Peshawar. 11, 131-151.

--------,and Paracha, F.A.,1980. Calcalkaline magmatites at destructive plate margin in Kohistan,Northern Pakistan.Geol.Bull. Univ.Peshawar.13,109-120.

Martin, N.R., Siddiqui, S.F.A. and King, B.H., 1962. A geological reconnaissance of the region between the Lower Swat and Indus rivers of Pakistan. Geol.Bull. Punjab. Univ. 2,1-13.

Miyashiro,A.,1973. Metamorphism and metasomatic belts. Pub: George Allen and Unwin Ltd. London.254,249-304.

-----------, 1977. Subduction zone ophiolites and island arc ophiolites. (S.K.Saxena and Bhattachargi, S., Eds.)"Energetics of Geolgical processes" Springer - Verlag (N.Y).

Molnar, P.and Tapponnier , P , 1979. The Indian-Eurasian Suture zone in northern Pakistan:Synthesis and interpretation of data at plate scale.In 'Geodynamics of Pakistan',Geol.Surv.Pakistan,Quetta. 125-130.

Moores, E.M., 1973, Geotectonic significance of ultramafic rocks. Earth. Sci. Reviews, 9, 241-258.

Niggli, P., 1954. Rocks and mineral deposits. Freeman, San Francisco.

O'Hara M.J.,1976. Data reduction and projection schemes for complex composion. Expermental petrology,103-126.N.E.R.C. publication series D.6;Manchester.

Pearce, J.A.,Gorman,B.E.& Birkett,T.C.,1975.The Tio2-K2o-P2O5 diagram. A method of discimінating between oceanic and non oceanic basalt. Earth. Planet. Sci. Letters.24,419-426.

Poldevaart, A. and Hess, H.H., 1951. Pyroxene in the crystallization of basaltic magmas. Jour. Geol. 59, 472- 489.

Powell, M.C.A., 1979. A speculative tectonic history of Pakistan and surroundings; some constraints from Indian ocean. "Geodynamics of Pakistan" spec. Pub. Geol. Surv. Pak. Quetta., 5-24.

Rehamn, J. and Zeb, A. , 1970. The geology of the Shah Dheri, Kabal area, Swat. Geol. Bull. Univ. Peshawar. 5, 96-110.

Rivalenti,G.,1976 .Geochemistry of metavolcanic Amphibolites from South-west Greenland. In:B.F.Windley (Editor), The Early History of the Earth.Wiley,London,213-223.

Schwarzer, R.R.& Rogers, J.J.W.,1974. A world wide comparison of alkali olivine basalts & their differentiation trends. Earth Planet. Sci. Letters 23, 286-296.

Shah, M.T.,1986.Petrochemistry of the rocks From Shergarh Sar Area Allai Kohistan, North Pakistan. unpublished M.Phil Thesis , Peshawar University.

Shams,F.A.,1975.The petralogy of the Thak valley igneous complex Gilgit Agency, N. Pakistan.Accad. Naz. Lincei.Ser.8,59,453-564.

Sharma, K.K. and Kumar, s. 1978. Contributions to the Himalayan Geology of Ladakh, North West Himalayas. Himalayan Geol. 8, 252-287.

Sillitoe, R.H., 1979. Speculations on Himalayan geology based on evidence from Pakistan. A Farah and K.A. De Jong, eds."Geodynamics of Pakistan". Geol. Surv. Pakistan, Quetta, 167-179.

Tahirkheli, R.A.K. 1979. Geology of Kohistan and adjoining Eurasia and Indo - Pakistan continents, Pakistan. Geol. Bull. Univ. Peshawar, Sp. Iss., Vol.11, 1-31.

Wilson, A.D., 1960. The micro determination of ferrous Iron in silicate minerals by a volumetric and colourimetric method. Analyst 85, 823.

-------, 1955. A new method for the determination of ferrous iron in rocks and minerals. Bull. Geol. Survey, G.B. 9, 56.

Winkler, G.G.F., 1967. Petrogenesis of metamorphic rocks. Springer Verlag, New York.

Yoder, H.S., 1969. Calc-alkaline andesites: experimental data bearing on the origin of their assumed charac-teristics. Proceeding of the Andesite Conference (A.R. Mr. Birney, ed.) Oregon Dept. Geol. Mineral Indust. Bull., 65, 77-89.