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PETROLOGY OF THE SOUTHERN AMPHIBOLITE BELT ROCKS FROM MAHAK AND SURROUNDING AREA, KOHISTAN ARC, NORTH PAKISTAN

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ABSTRACT

The various rock types at Mahak are medium- to coarse-grained amphibolites, hornblendites, hornblende pegmatite, diorite, meta-gabbro, metapyroxenite and quartzo-feldpathic veins and dykes. Amphibolites are the most abundant rocks of the area. These are distinguished into epidote amphibolite and plagioclase amphibolite. The major element chemistry of the amphibolites suggests their derivation from a basic igneous parent of tholeiitic character, but field data also indicate some of them to be hybrids having been developed as a result of reaction between hornblendites and the granitic magma. The true amphibolites contain mineral assemblages indicating amphibolite grade metamorphism followed by the prevailance of epidote amphibolite facies and a minor phase of green shist facies environments. Hornblendites are usually monomineralic. Two types of hornblendite occur, i.e. (a) pre-granitic and the common ones and (b) sys-granitic. Field and laboratory data show that the former types may be representing early cumulate for the basic amphibolites or rocks having been formd in the loci of fluid phases during the amphibolite grade metamorphism. However, field evidence show that the sys-granitic hornblendites are the product of reaction between amphibolites and the granitic magme.

INTRODUCTION

The Kohistan island arc sequence of rocks covering an area of about 36000 sq km and acquiring a maximum length of 400 km, is located in the northern part of Pakistan. It is considered to be representing the crust and mantle of a fossil arc (Tahirkheli, 1979a,b; Bard et. al., 1980). It is delineated by the Main Karakoram Thrust (MKT) in

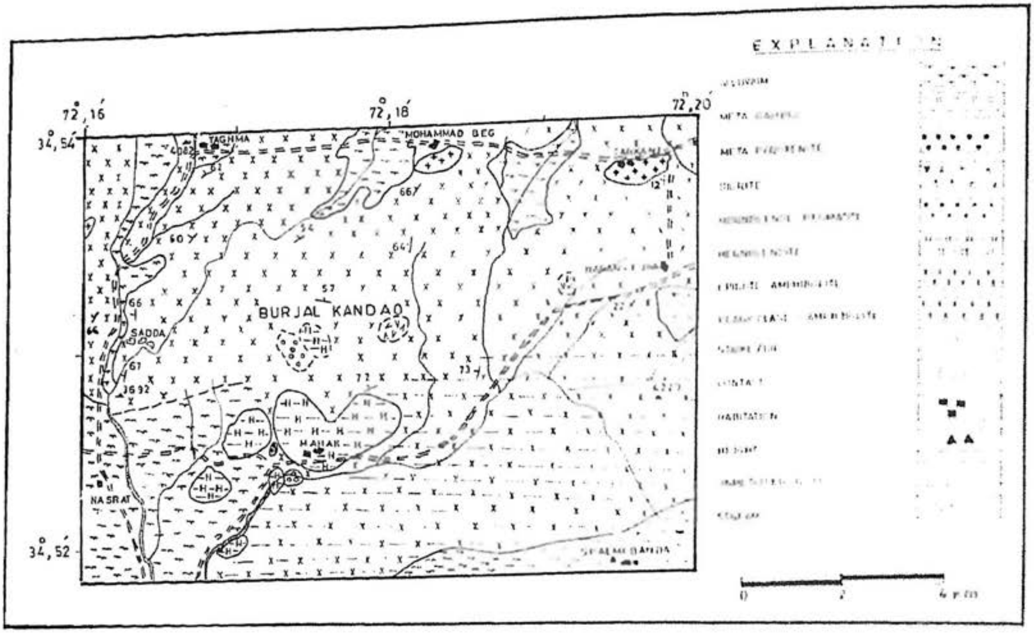

Fig. 1. Geological map of Mahak and surrounding area.

the north and the Main Mantle Thrust (MMT) in the south. Desio (1964) considered it for the first time as a tectonic zone of the Karakoram. The general sequence of rocks established from north towards south in Kohistan is (a) Chalt ophiolitic melange, (b) Yasin group, (c) Laddakh intrusives, (d) the Chilas complex, (e) the southern amphibolite belt, (f) the Jijal complex and (g) the MMT melange zone rocks (blueschist etc.) (see Jan, 1979; Tahirkheli, 1979a,b; Bard et al., 1980; Coward et al., 1982). These rock types are dominantly plutonic and volcanic, ranging in composition from ultrabasic to acidic, and are principally Cretaceous to Eocene in age.

The southern amphibolite belt, also known as the Kamila amphibolites, is a sequence of rocks extending from Nanga Parbat in east, through Babusar, Indus Valley, Swat, Dir, and Bajawar to Afghanistan in the west (maximum breadth 50 km; length 350 km; see Jan, 1991). In Dir, where the Chilas complex terminates before extending into Afghanistan, the amphibolites become thicker (see Hamidullah et al., 1991a, fig.1). The most preliminary studies in the southern amphibolite belt were performed by Martin et al. (1962). Davies (1965) considered them a product of metamorphic rather then igneous processes. Jan (1979) working in Swat and along the Karakoram highway, distinguished (a) massive and homogeneous amphibolites and (b) banded and sheared amphibolites, on the basis of field features. He considered them as the products of prograde metamorphism of basic to intermediate plutonic and volcanic rocks and associated oceanic sediments and tuffs. He regarded the massive and homogeneous types as dominantly plutonic, ranging in composition from ultrabasic to acidic and in age principally from Cretaceous to Eocene.

Ahmed (1978) described hornblende gneisses, amphibolites, intrusive diorites, ultramafic rocks and hornblendite from Taghma area (Fig. 1) and considered the epidote amphibolite facies metamorphism as the major factor for evolving the amphibolites from their parent basic to intermediate igneous rocks. He considered the ultramafic rock to be of allogenic origin and the hornblendites as the products of metamorphic segregation. Khattak et al. (1985) described the petrography of the rocks from the area under the present investigation. They considered the amphibolites as meta-igneous and possibly plutonic. Hornblendites and hornblende pegmatites are regarded by these authors as the product of metamorphism in the presence of a fluid phase during amphibolite facies conditions.

Shah (1986), Shah et al. (1991) and Hamidullah et al. (1991b), working on the amphibolite belt rocks in Allai Kohistan, differentiated epidote amphibolite, and garnet epidote amphibolites, both derived from the metamorphism of a tholeiitic-arc-related protolith.

The present work was performed to construct a detailed geological map and carry out petrographic and preliminary geochemical studies of the southern amphibolite belt rocks at Mahak and the surrounding areas (Fig. 1; also see Ahmed, 1978). Out of a total of 200 samples, 100 representative ones were selected for petrographic and geochemical studies.

FIELD RELATIONSHIP

On the basis of field features supplemented by petrographic data, the major rock types distinguished at Mahak and its surroundings are amphibolites, hornblendites, hornblende pegmatite, metadiorite, metagabbro, metapyroxenite and quartzo-feldspathic veins and dykes (Fig. 1).

Amphibolites are the dominant rock type in the area. These are locally and variably foliated and/or banded in E-W and NE-SW directions with a moderate northwards dip, similar to those along the Indus Valley (Jan, 1979). Fine- to coarse-grained amphibolites in the area are irregularly intermixed. Epidote amphibolite and plagioclase amphibolite are distinguished. Patches of garnet within plagioclase amphibolite are, however, present.

The epidote amphibolite, occupying the southern part of the area, is medium- to coarse-grained (1-6 mm across grains) and has dark green epidote, white plagioclase and prismatic black amphibole visible in hand specimen. The plagioclase amphibolite forms the northern part and has a highly variable proportion and grain size of white plagioclase and black prismatic amphibole. This variety of amphibolite is highly weathered, fractured and jointed. At Burjal Kandao and Narang Pora, the plagioclase amphibolite is emplaced by metadiorite and metagabbro and at Taghma, Mohammad Beg, Tarkani and Chuntar villages by coarse pegmatite containing large (1-5 x 1-10 cm across) crystals of hornblende and feldspars. The metagabbro and metadiorite display a mildly gneissose fabric, becoming more prominent at the margins of the intrusions.

Making the third most voluminous rock in the area (cf. Fig. 2), hornblendite bodies (up to 1.5 x 3 km) are concentrated in a NE-SW trending zone around Mahak. These rocks are predominantly coarse grained, containing hornblende crystals ranging from 1 to 8 cm in length. Fine- to medium-grained varieties (grain size <1-1 mm across) with hornblende crystals up to 20 cm in length are also present locally. A variation from fine-, through medium- to coarse-grained hornblendite is sometime noticed in a single outcrop. A similar variation is reported by Jan et. al. (1983) in the hornblendites of Tora Tigga ultramafic complex from southern Dir district. The rocks are fractured and jointed, and quartzo-feldspathic and epidote veins are developed along these fractures. The hornblendite is devoid of any layering or banding, and is generally massive and non-foliated in nature. It is intermitted with amphibolites. Generally, the contacts of hornblendites with amphibolites are gradational and in the large stream west of Naranj Pora, hornblendites seemingly replace amphibolite.

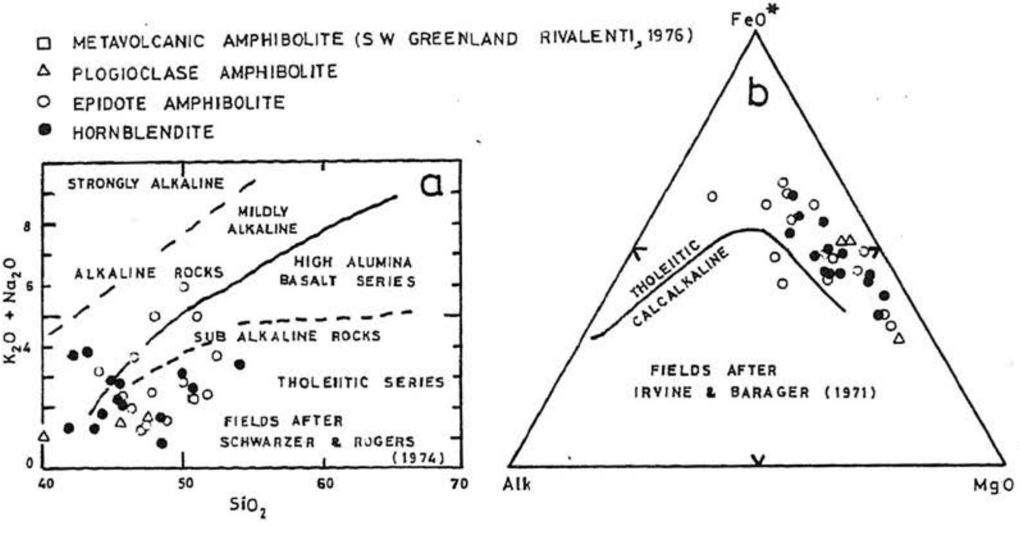

Fig. 2(a-b). Alk. vs. SiO_2 plots of amphibolites and hornblendites from the studied area.

The hornblende-pegmatites occur as separate bodies of variable sizes having gradational contacts with the surrounding amphibolites at Taghma, Mohammad Beg, Tarkani and Chauter villages (cf. Fig. 1). In the field the hornblende pegmatites can be recognised by large prismatic crystals of hornblende (1 to 10 cm long), plagioclase, quartz and dark green epidote.

Two dioritic intrusions with sharp contacts occur within the amphibolites at Burjal Kandao and Narang Pora village (Fig. 1). They have fresh and equigranular cores, and gneissose and weathered margins. Plagioclase, hornblende and epidote can be identified in the hand specimens.

Two outcrops of metagabbro are exposed within the amphibolites at Burjal Kandao, just north of Mahak village (Fig. 1). The two rock types can not be easily distinguished from each other, but the metagabbro is generally hard, compact and fresh as compared to the host amphibolites. The contacts of metagabbro with amphibolites are sharp with local development of patches of hornblendite at certain places.

Only one small exposure of metapyroxenites occurs just east of Mahak village (Fig. 1). It is a medium- to coarse-grained (grain size >1-1mm across), hard and compact rock having sharp contacts with hornblendites and a moderately sheared and deformed contact with amphibolites.

Quartzo-feldspathic veins and dykes with sharp contacts and of variable thickness and length (see Hussain, 1991) intruding amphibolites and other rocks are fairly common. Plagioclase can be frequently recognized in hand specimen. Some of these rocks contain large hornblende crystal (1 cm across) partially altered to epidote. Deformation reflected in folding, faulting and the development of gneissosity can be observed in these dykes and veins.

PETROGRAPHY

The following petrographic features have been noticed in the various rocks of the amphibolite belt at Mahak and in its surrounding.

Amphibolites

Amphibolites can be classified into plagioclase-amphibolites and epidote-amphibolites.

In thin sections, the plagioclase amphiblites are porphyroblastic to xenoblastic rocks with an inequigranular texture. It contains plagioclase (~30-50%) and hornblende (30%) as the dominant constituents. Epidote, chlorite, sphene, quartz, rutile and opaque minerals occur as accessories.

Plagioclase is generally cloudy, but fresh plagioclase (oligoclase-andesine) with weakly developed zoning is also present. Hornblende is homogeneously pleochroic from green to brownishgreen and contains inclusions and blebs of cloudy plagioclase, quartz and opaque minerals, all showing vermicular intergrowths. Epidote occurs as subhedral crystals in granular and columnar aggregates. It contains small inclusions of cloudy plagioclase, sphene and hornblende. The general texture reflects epidote to be developed at the expense of cloudy plagioclase or plagioclase + hornblende in certain cases. Chlorite, occurring as anhedral flakes, is generally associated with hornblende and occasionally with epidote. Quartz (traces-3%) occurs as small inclusions in hornblende and plagioclase, or in the form of micro-veins cross-cutting the rock. Rutile and ore minerals (magnetite/limonite) occur in variable amounts as small inclusions in hornblende along fractures, cleavages and grain boundaries, but independent grains of these accessory phases are also not uncommon. The close association of hornblende and plagioclase indicates their equilibrium crystallization under the amphibolite facies of environment.

In thin section the epidote amphibolite reflects a uniform model composition with abundant epidote and hornblende as well as substantial amount of cloudy plagioclase (10-20%), clinopyroxene (~1-5%), quartz (< 1-2%), sphene (3-8%), chlorite (2-5%), rutile (2-3%) and opaque minerals (3-5%). The texture is generally inequigranular to subequigranular and hypidioblastic to xenoblastic.

Epidote occurs as elongated subhedral grains as well as small anhedral aggregates. The former are zoned, having anomalous blue cores and greenish or brownish margins. The epidote and hornblende are closely associated and may be intergrown, indicating equilibrium crystallization.

Hornblende occurs as subhedral to anhedral grains of various sizes. The smal grains are generally fresh but the large ones are occasionally uralitized at boundaries. Hornblende shows evidences of growth prior to as well as along with epidote. It is generally pleochroic from light green to brownish green, but in some cases displays only a faint pleochroism from light green to green, probably due to a high Mg/Fe ratio (*see* Jan & Howie, 1982). Locally it also displays zoning with bluish green cores and greenish-blue margins. In some rocks hornblende surrounds or is surrounded by epidote. Blebs and small inclusion of hornblende within large hornblende crystals are also commonly observed. Plagioclase is generally cloudy, but in a few rocks, well developed, fresh and twinned plagioclase of albite range is also found. Sphene is a common accessory, generally developed along the fractures, cleavages and grain boundaries of hornblende. Bluish green tabular chlorite also occurs along the margins and within the fractures of the hornblende crystals. Opaque minerals generally occur in the cores and at grain boundaries of the crystals. Rutile is generally associated with magnetite, suggesting that the two have developed at the expense of ilmenomagnetite during metamorphism. Clinopyroxene relics are generally associated with hornblende and the latter shows development at the expense of the former.

Whether the epidote-hornblende equilibrium assemblage developed after an igneous or a metamorphic protolith is subject to a difference of opinion. But the presence of plagioclase amphibolites associated with epidote amphibolite in the area, and the scarcity of An-rich plagioclase, show that the igneous rocks were not directly responsible for the development of epidote amphibolites. Rather the stage of (plagioclase) amphibolite facies metamorphism followed igneous crystallisation and preceded retrogression into epidote amphibolite facies conditions. This is supported by zoning is amphibole as well as epidote (*see* Miyashiro, 1973, p.254). The Ca-rich clinopyroxene may be, however, representing an igneous phase which escaped transformation to hornblende during metamorphism. The reasons for the general confinement of the epidote amphibolite to the south are not clear and need further investigation.

Hornblendites are generally monomineralic with hornblende >95%. However, plagioclase hornblendite (plagioclase 5-8%) and epidote hornblendite (epidote 5-10%) are also present.

The monomineralic hornblendite contains hornblende with accessory plagioclase (0-3%), epidote (0-3%), chlorite (0-2%), sphene (0-2%), quartz (traces), rutile (0-2%) and opaque minerals (0-3%). It is generally a medium- to coarse-grained rock with euhedral, subhedral as well as anhedral crystals. The hornblende grains are strongly pleochroic from light to brownish green or dark green. The brownish green variety displays zoning as well as twinning. The dark green variety indicates development after the brownish green variety. Most plagioclase is cloudy, but some is fresh and displays albite twinning. 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. The plagioclase hornblendite and epidote hornblendite are similar to monomineralic hornblendite except for the high proportion of plagioclase and epidote, finer texture, and the absence of pleochroism and multiple twining in hornblende in the former two types. Plagioclase is very cloudy and shows alteration to epidote particularly in the epidote hornblendite.

Hornblende-pegmatite

Hornblende-pegmatite is hard and compact rock with large crystals of hornblende (c.~85%; 1-10cm x 1-5cm across) and plagioclase (c.~15%; 1-4 cm x 1-2cm across). Epidote, quartz, sphene, muscovite, rutile and opaque minerals occur as accessories. Hornblende occurs as long, prismatic crystals, strongly pleochroic from yellowish green to dark bluishgreen and contains quartz, muscovite, rutile and opaque minerals along fractures, cleavages and grain boundaries. Plagioclase is generally cloudy, contains small inclusions of quartz and hornblende and shows alteration to kaoline and secondary epidote. Fresh plagioclase (An $_{25-40}$) is also present. Epidote is generally colourless and grown from plagioclase. Sphene occurs as pale-yellow to brownish anhedral grains, mostly within hornblende crystals. Chlorite, rutile and opaque minerals generally occur along cleavages and grain boundaries of hornblende.

Diorite

Diorite is generally medium- to coarse-grained and homogeneous rock with an inequigranular xenomorphic texture. It contains plagioclase (40-55%), hornblende (15-13%) and epidote (15-25%) as the dominant constituents with minor proportions of opaque minerals (traces), sphene (2-5%), quartz (3-5%) and rutile (traces). Plagioclase, both fresh and partially altered to epidote and kaoline, and hornblende pleochroic from light green to dark green, occur as subhedral and anhedral grains. Epidote, which is colourless and shows anomalous birefringence, is associated with plagioclase and hornblende as well as occurs along microveins cross cutting the rock. Quartz is interstitial to plagioclase and hornblende whereas, sphene, chlorite, rutile and opaque minerals occur as inclusions/minute grains within epidote, plagioclase and hornblende grains and in the groundmass.

Metagabbro

The metagabbro is medium- to coarse-grained, hypidioblastic to xenoblastic and subequigranular rock, containing hornblende (30-60%), clinopyroxene (15-30%), orthopyroxene(5-15%), plagioclase (5-10%). Hornblende is pleochroic from light green to brownish green and commonly contains clinopyroxene relics. Some of the hornblende grains are fractured and have inclusions of opaque minerals (magnetite).

Though fresh plagioclase crystals are not uncommon, most of the plagioclase grains are marginally cloudy and show alteration to epidote and kaoline. Clinopyroxene is colourless, nonpleochroic and seems to be augitic in composition. Orthopyroxene is pleochroic from pink to green and is surrounded by secondary hornblende. Sphene, chlorite, quartz, rutile and opaque minerals occur in trace amount in the groundmass, along fractures, cleavage planes and at grain boundaries of the hornblende crystals.

Metapyroxenite

The metapyroxenite is massive, medium- to coarse-grained, light to dark grey in hand specimen, and under microscope predominantly composed of clinopyroxene (80%)

with subordinate proportion of hornblende (<20%) and accessory chlorite, sphene, epidote and opaque minerals. Clinopyroxene is colourless and subhedral in form. Hornblende is pleochroic from lightgreen to brownishgreen, generally developed along the fractures, cleavages and margins of clinopyroxene. Sphene (maximum 5%) generally occurs in association with clinopyroxene and hornblende, in the form of granular aggregates.

GEOCHEMISTRY

As the amphibolites and hornblendites are dominant rocks in the area, the present geochemical studies were restricted only to these varieties. Thirty three representative samples from the amphibolites and hornblendites of the amphibolite belt at Mahak were analyzed for major elements using wet chemical and X-Ray Fluorescence techniques. The data fall in range of ~40-54 wt.% SiO_2; corresponding to igneous suites of basic compositions (see Table 1; Fig. 2a). On several chemical discriminatory and other diagrams both the amphibolites and hornblendites plot in the fields described for igneous rocks and show trends reflecting crystallization differentiation. Selected plots are represented in Figs. 2 and 3. On the alkali vs. SiO_2 and AFM plots (Figs. 2a,b), majority of the amphibolites and hornblendites occupy the field of tholeiitic rocks. Keeping in view that the amphibolite grade metamorphism may have mobilized the alkalies and the data may not be representing the true liquid composition, other discriminant diagrams including the Al_2O_3 vs An% and FeO/MgO vs SiO_2 plots (not represented) were also used for discrimination, and conclusion similar to those derived from Figures 3a,b were obtained. Constraints resulting from the effect of olivine and pyroxene and/or plagioclase fractionation on the use of the latter plots for the present data cannot be ruled out, however, it is worth mentioning that on all the discriminant diagrams majority of the data shows tholeiitic characters.

Oxides were plotted against solidification Index (S.I.) for reasons described by Cox et al. (1979) for basic igneous suites.

Oxide vs. S.I. plots

Continuous variation indicating crystallization differentiation from a common parent magma is shown by majority of the oxide vs. S.I. plots of the amphibolites (Fig. 3). Generally SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, FeO* and total alkalies increase while MgO and CaO decrease with decrease in S.I. Such features indicate the crystallization differentiation of ferromagnesian minerals and plagioclase on the liquidus. The presence of both ortho- and clinopyroxene (and a relatively high proportion of hornblende) in certain amphibolites (see Hussain, 1991) are consistent with this interpretation. The overall positive correlation shown by the data on MgO vs. S.I. plot

TABLE 1. MAEN CHEMICAL ANALYSES OF EPIDOTE AMPHIBOLITES (ANAL. 1; MEAN OF 15 ANALYSES), PLAGIOCLASE AMPHIBOLITES (ANAL. 2; MEAN OF 3 ANALYSES) AND HORNBLENDITES (ANAL.3; MEAN OF 15 ANALYSES) OF MAHAK AND SURROUNDING AREAS

	1	2	3
SiO_2	48.54	44.40	46.51
TiO_2	0.87	0.71	0.93
Al_2O_3	13.31	14.36	10.37
Fe_2O_3	2.90	3.93	5.72
FeO	7.45	7.51	7.56
MnO	0.13	0.12	0.13
MgO	8.03	12.23	11.48
CaO	11.12	13.00	12.77
Na_2O	2.73	1.45	2.04
K_2O	0.31	0.02	0.42
P_2O_5	.06	0.13	0.12
H_2O^+	2.01	2.51	1.92
H_2O^-	0.30	0.15	0 .20
Total	97.76	100.52	100.17

also indicates the fractionation of ferromagnesium phases like olivine, pyroxene, and hornblende, etc.

The generally negative trends of the amphibolites on Fe_2O_3, FeO and MnO vs. S.I. plots indicate the accumulation of iron in the liquid, during fractionation. Amphibolites, showing low Fe_2O_3 and FeO than expected on these plots (S.I. ~ 10), do not seem to be a product of fractionation processes described for the other rocks. A lower MgO, K_2O and high Na_2O in these rocks may be a reflection of metamorphic/ metasomatic mobility of the elements or of analytical errors.

The TiO_2 vs. S.I. plots are scattered but an overall negative correlation can be observed, which supports the view of iron enrichment until a considerably late stage of crystallization.

The Al_2O_3 vs. S.I. plot shows a considerable scatter with a generally negative trend (A-A') in amphibolites, indicating that plagioclase never remained a dominant fractionating phase. Plot points of rock within S.I. range of 30-50 however, show a clear steep positive correlation (B-B') which can be related to a high degree of plagioclase

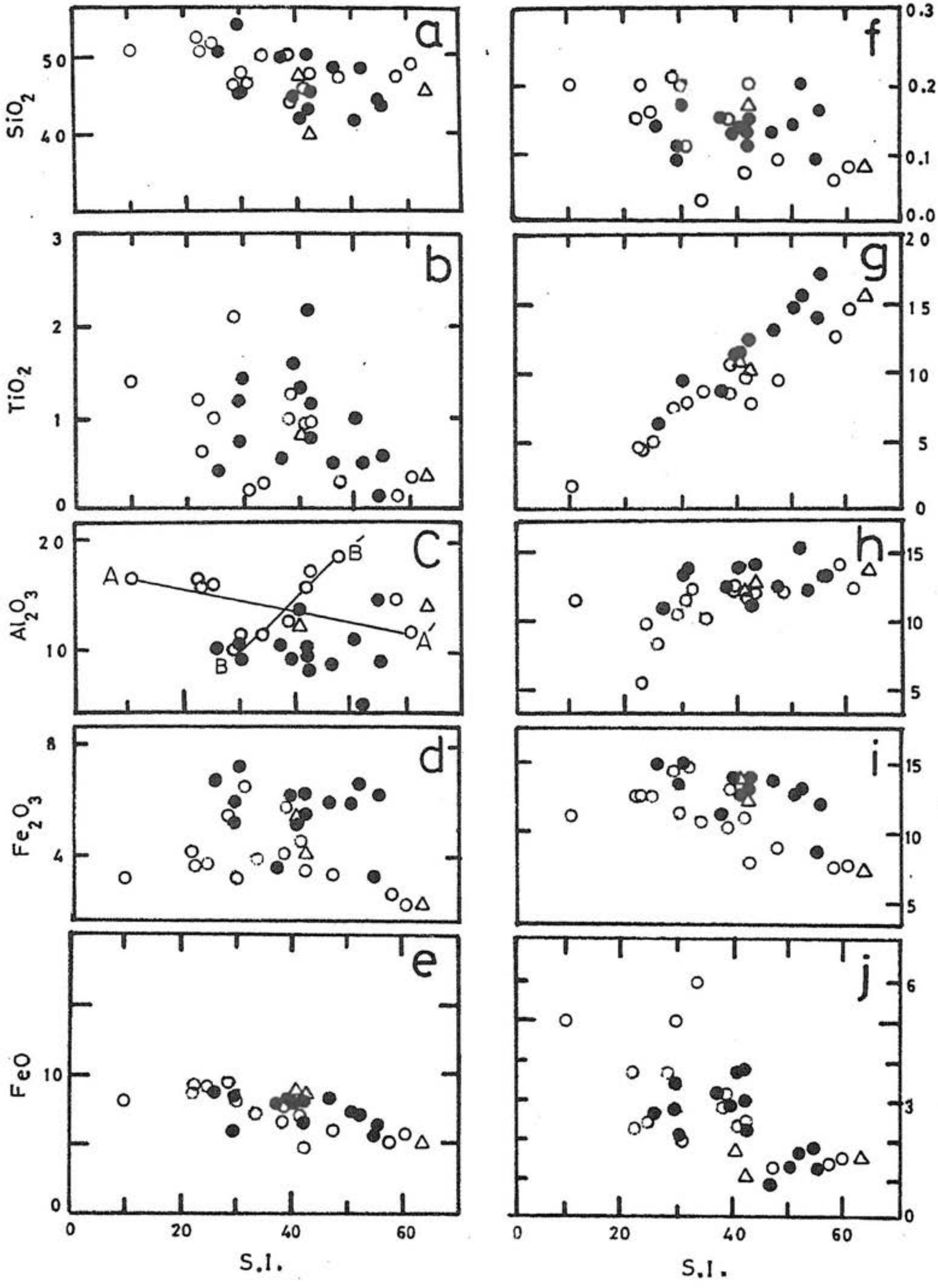

Fig. 3 (a-j). Oxide vs S.I. plots of amphibolite and hornblendites.

fractionation at this particular stage. Such a view is supported by the petrography of the majority of these rocks, containing a considerable proportion of epidote and or plagioclase (both metamorphic, but most probably formed after an igneous plagioclase).

The total alkalies vs. S.I. plots of amphibolites reflect a negative correlation, indicating that these elements also generally concentrated in the residual liquids during fractionation. Their correlation also shows that these elements have not remained very mobile under the described circumstances of amphibolite facies metamorphism and thus the interpretation based on alkali vs. SiO_2 and AFM plots, that the parent magma for the protolith of amphibolites was tholeiitic, does not seem to be unrealistic.

CMAS plots

Analyses from the Mahak amphibolites were also plotted in the CMAS tetrahedral model of O'Hara (1976) (Fig. 4a,b). 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 CMS_2 end, in a projection from S (quartz) into MS_2-CAS_2-CMS_2 plane (Fig. 4a). In a projection from MS into CAS_2-M_2S-CMS_2 plane (Fig. 4b), the analyses plot on a trend lying between the MS (Enstatite) and CAS_2 (plagioclase) positions. All these features indicate a dominant orthopyroxene and clinopyroxene fractionation in the early stages followed by a dominant plagioclase fractionation in the latter stages (Hamidullah & Jan, 1986; Hamidullah & Bowes., 1987). These interpretation are consistent with those obtained from oxide vs S.I. plots.

As discovered on the basis of alkali vs. SiO_2 and AFM plot, the hornblendites also show a remarkable correspondence with amphibolites on the basis of oxide vs S.I. and CMAS plots (Figs. 2,3,4), except for the relatively lower Al_2O_3 and higher Fe_2O_3 in the former types (Figs. 3c,d). At S.I. 40, hornblendites show a little high MgO than their corresponding amphibolites at a particular S.I. (Fig. 3g). The mobility of MgO during metasomatic transformation seems to be unlikely. The difference may be, therefore, due to the high Fe_2O_3 in hornblendites lowering their S.I. values. The general correspondence of the two groups however, strongly supports the view of their genetic relationship. The minor chemical difference on the basis of Al_2O_3 and Fe_2O_3 between the two groups can be related to an R^{3+} type ($Fe^{3+} = Al^{3+}$) substitution during the evolution from one type to the other. Addition or removal of water must have also played a rule in this phenomenon.

DISCUSSION

The petrographic features of the amphibolite belt rocks at Mahak and its surroundings show that the amphibolite and hornblendite are the dominant rock types in the area, accompanied by hornblende pegmatite, diorite, metagabbro and metapyroxenite locally. The petrography of amphibolites, their homogeneous nature, the association of metagabbro, metapyroxenite and diorites with these rocks all indicate them to be the descendants of a basic plutonic igneous parentage. Pillow structures of Taghma village (cf. Fig. 1), however, also show incorporation of a volcanic component. The chemistry of amphibolites reflects differentiation and the control of pyroxene and plagioclase on the liquidus, indicating that the relic orthopyroxene and clinopyroxene in epidote amphibolites most probably represent primary igneous phases.

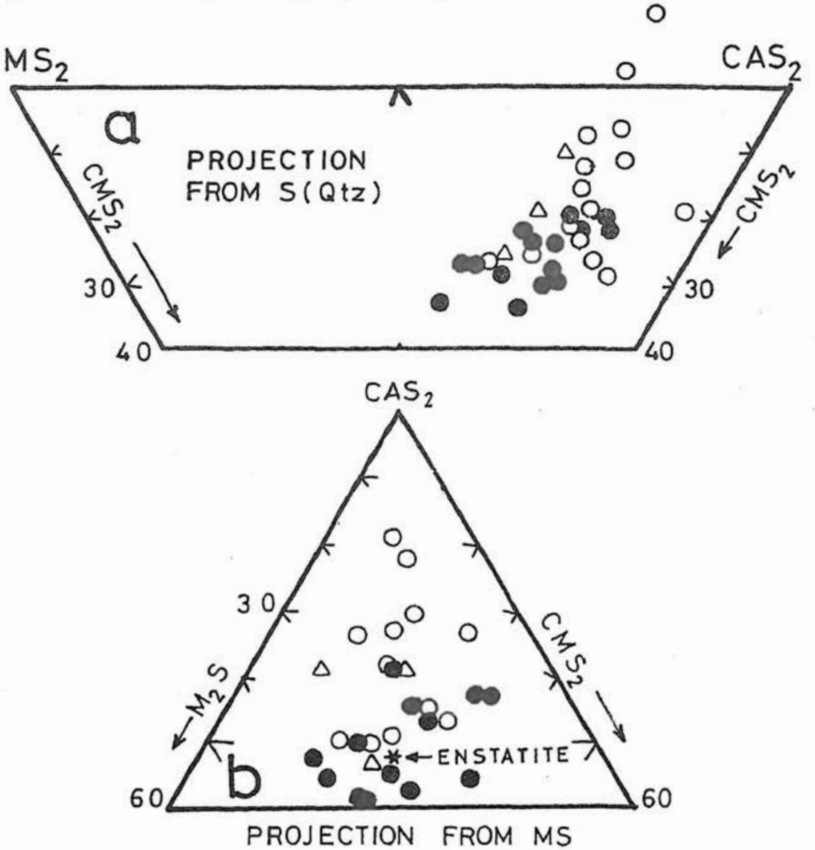

Fig. 4(a-b). Amphibolites and hornblendites analyses shown in projections of the CMAS tetrahedron model of O'Hara (1976). Calculation to C-M-A-S end members were carried out following the method of Cox et al. (1974).

Amphibolites have been classified into two major types, i.e. plagioclase amphibolite and epidote amphibolite. Plagioclase amphibolite is the dominant type and all sorts of gradation occur between these two types on the basis of mineralogy. The close association of hornblende and plagioclase, the pleochroic colour of hornblende being green to brownish green, the oligoclase to andesine compositional range of the plagioclase, in the plagioclase amphibolites, all indicate equilibrium crystallization of hornblende and plagioclase under the amphibolites facies environment. The presence of garnet in certain plagioclase amphibolite can be related to very localized compositional control (Myashiro, 1973, p.259). On the other hand, the close association of hornblende which is pleochroic from light green to green, with well developed subhedral epidote crystals and plagioclase of albite range in epidote amphibolite, indicate equilibrium crystallization of a second generation of hornblende and epidote under the epidote amphibolite facies environment. Plagioclase amphibolite and epidote amphibolite do not show any difference in the major element chemistry. Metamorphic grade cannot be different in the two types of rocks at the scale of the studied area at the same time. Therefore, on the basis of the studied features it is highly recommended that amphibolite facies metamorphism preceded an epidote amphibolite grade metamorphism in the amphibolite belt rocks of the Mahak area. This conclusion is supported by the presence of mineralogical gradation from the amphibolite facies assemblage (greenishbrown hornblende and plagioclase) to that of the epidote amphibolite facies assemblage (lightgreen to green hornblende, and epidote) within the same rocks.

The occurrence of chlorite after hornblende and epidote and of fine-grained epidote after plagioclase in all amphibolites are likely to be due to low pressure alteration during uplift.

Gradational contact are common between amphibolites and hornblendites and in certain cases transformation of hornblendite to amphibolite or a reverse of that is noticed in the field. In a recent visit to the area it was discovered at the northeastern vicinity of Shah Dheri granitic body (NW of Nusrat; Fig. 1; see also Rehman and Zeb, 1970) that the formation of this so called amphibolite (we call it pseudo-amphibolite) is clearly as a result of reaction between hornblendite and the granitic material, locally. A similar phenomenon together with the formation of a second generation of hornblendite due to reaction between amphibolites and the granitic/quartzo-feldspathic liquid is noticed in the Mahak stream (Fig. 1). The quartzo-feldspathic dykes and veins at Mahak are considered to be the off-shoots of the granitic liquid that also produced the granitic bodies at Shah Dheri and Nusrat. Therefore, some of the hornblendites appear to be older than the granitic/quartzo-feldspathic rocks and probably cogenetic with the true amphibolites while others probably represent the product of metasomatic reaction between the amphibolites and the granitic liquid, in the presence of volatiles. The samples collected during the present study belong to the former type of hornblendites which are more common in the area. Their similarity to amphibolites on the basis of chemical data (Figs. 2-4) may, therefore, be due to their genetic relationship with the latter. Considering the corresponding range of SiO_2 in amphibolites and hornblendites (i.e. 42-52 wt.%; Fig. 3a), the pre-granitic hornblendites may be either representing ultramafic cumulates (peridotites, pyroxenites) of the igneous series from which amphibolites were derived or, as suggested by Khattak et al. (1985), the loci of the fluid phase during metamorphism. The types of transformation, i.e. (a) pre-granitic hornblendite + granitic liquid = pseudo-amphibolite and (b) amphibolite + granitic liquid = syn-granitic hornblendites, therefore, indicate the establishment of strong geochemical gradients between the pre-existing rocks and hot granitic liquids, followed by the exchange of the particular elements selected by the surrounding physiochemical environments. More chemical data are however, needed to support these interpretations.

Deformed quartzo-feldspathic veins cross cutting the amphibolites and hornblendites present in the area indicate that deformation continued after the emplacement and crystallization of the granitic magma.

CONCLUSIONS

1. The Mahak amphibolites are generally the product of crystallisation differentiation probably from a basic tholeiitic magma. However, certain amphibolites represent hybrids formed after reaction between hornblendites and the granitic magma.

2. Orthopyroxene, clinopyroxene and plagioclase fractionation played a major role in constructing the chemical evolutionary trend of the true amphibolites.

3. An amphibolite (or garnet-amphibolite) grade metamorphism followed by an epidote amphibolite grade metamorphism and some minor retrogression, all indicating obducting environments, are shown by the various mineral assemblages in the area.

4. Some of the hornblendites are formed from the metasomatic transformation of the amphibolites due to granitic intrusions in the area whereas majority of them probably represent early cumulates or development in the loci of fluid phases during metamorphism.

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