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MINERALOGY AND MINERAL CHEMISTRY OF THE AMPHIBOLITE BELT AND MAIN MANTLE THRUST ROCKS FROM GANTAR AREA, ALLAI KOHISTAN, NORTH PAKISTAN

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ABSTRACT

Petrographic and mineralogical studies are performed for the Kohistan island arc, MMT melange zone and Indian plate lithologies at Gantar village and in its surroundings, in Allai Kohistan, Hazara. Petrographic studies reveal that locally, the Kohistan island arc lithology is exclusively comprised of amphibolites and epidote amphibolites with certain patches of hornblende pegmatites. The MMT melange zone includes greenschist and blueschist whereas the Indian plate sequence is made up of a variety of schistose rocks and siliceous marble. Petrography and mineral chemistry indicate that amphibolites have an igneous parentage and have undergone successive metamorphic episodes of amphibolite facies, epidote-amphibolite facies and greenschist facies, in a temperature range of 530-$\leq$500^{o}C and a pressure range of 6-$\leq$4.5 kb, whereas the MMT melange zone rocks show signatures of amphibolite facies, blueschist facies (7kb) and greenschist facies matamorphic episodes. The hornblende pegmatite patches in amphibolites are interpreted as products of low pressure metasomatism, on the basis of lower ^{vi}Al content in hornblende as compared to that in amphibolites. Small outcrops of metagabbro and metanorite found in the area are regarded as part of the island arc system, on the basis of their clinopyroxene chemistry. Structural, petrographic and "minera-chemical" features indicate a subduction-obduction related petrogenesis for these rocks.

INTRODUCTION

The Southern Amphibolite Belt of the Kohistan Island Arc extends East to West along the Indus Suture or Main Mantle Thrust (MMT) for more than 350 km between

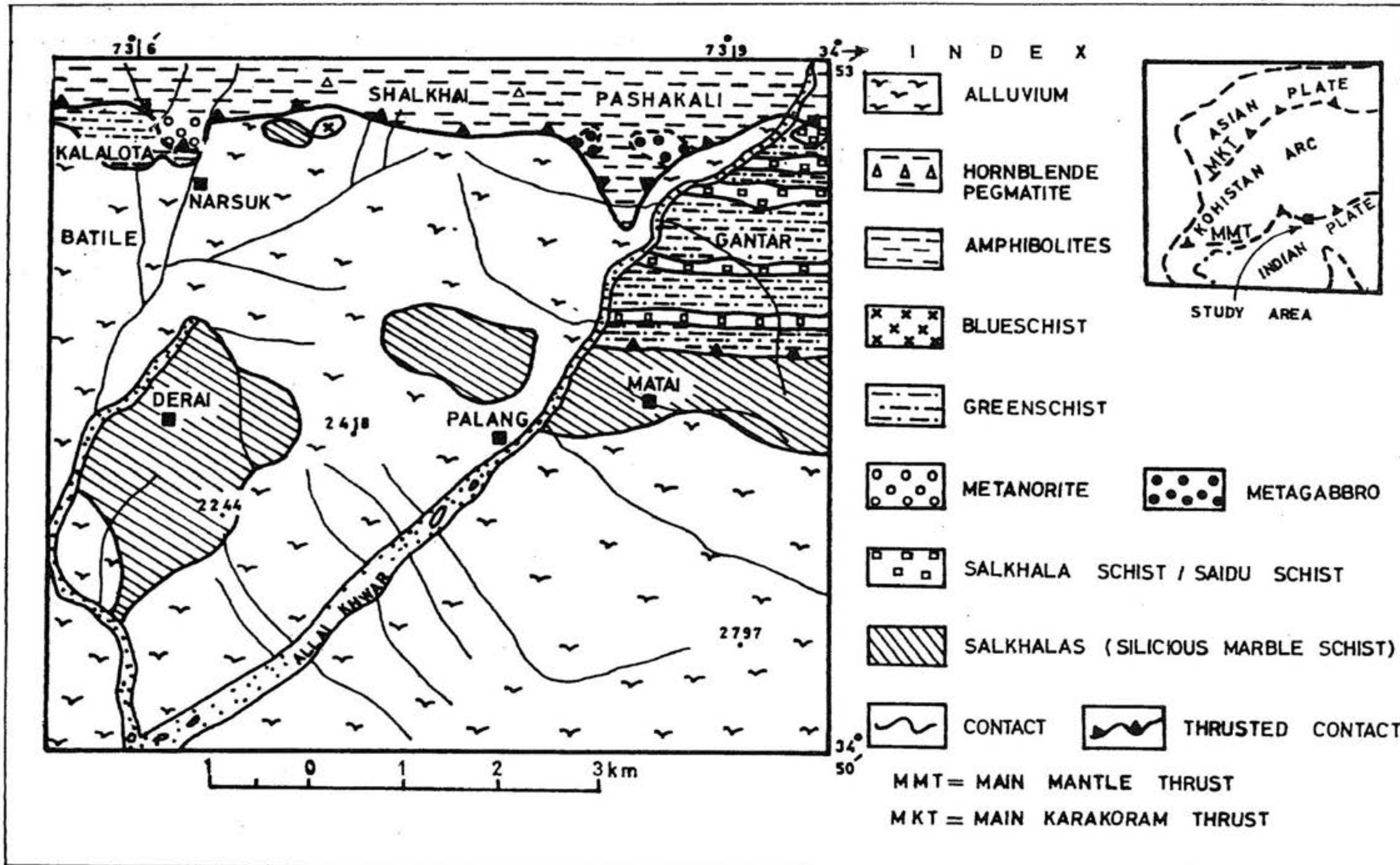

Fig. 1. Geological map of Gantar and surrounding areas, Allai Kohistan, Hazara, North Pakistan.
Inset shows locality of the study area in the Kohistan arc.

Nanga Parbat and Afghanistan (Tahirkheli et al., 1979; Coward et al., 1982; Bard, 1983). It attains a maximum width of 50 km in Indus Valley (Fig. 1). It is comprised of a variety of rock types including the dominant amphibolites together with dunites, peridotites, pyroxenites, hornblendites, metapillows, gabbros, norites, tonalites, trondhjemites, granites, hornblende and granite-pegmatites, aplites and other types of veins (Jan, 1979, 1988, 1990; Hamidullah et al., 1990). Previous investigations indicate that the amphibolites are mainly massive and homogeneous with local banding, reflecting plutonic characters. In addition, these studies shows (a) chemical features corresponding to those of basic plutonic and volcanic rocks of non-alkaline affinity, (b) metamorphic episodes of amphibolite facies, epidote-amphibolite facies and greenschist facies together with episodes of deformation, (c) a possible metasomatic origin for certain 'hornblende-rich amphibolites' or hornblende pegmatites, (d) intrusive characters of diorites, gabbros, norites, granitic rocks, dykes and veins, (e) the occurrence of pillow lavas, and (f) the presence of kaolinite (locally known as china clay) after granite (Jan, 1990; Hamidullah et al., 1990).

The MMT melange zone immediatly to the south of the amphibolite include ultramafics, volcanics, greenschist, blueschist, metagrawacks, limestones and chert, etc. described from Shangla, Allai Kohistan, Jijal and several other localities (Desio and Shams, 1980; Kazmi, et al., 1984; Shah, 1986; Jan, 1988). Precambrian rocks of the Indian plate just south of the melange are composed mainly of pelitic and graphitic schists.

In Allai Kohistan the Southern amphibolite belt, MMT, and the Indian plate rocks occur north, north-east and east of Banna at several localities (Shergarh Sar, Liwanai Sar, Mir Ali Qila, Pushtu Keli; see Shah et al., 1991). The area has been investigated by Hamidullah et al. (1977), Yousafzai et al. (1977), Ashraf et al. (1980), Baig (1989) and Zahid (1991). Shah (1986) and Shah et al. (in press) presented a detailed petrographic and geochemical account of the Southern amphibolite belt and MMT melange zone rocks in the vicinity of the Shergarh Sar area, Allai Kohistan. The present study is performed to elucidate the P-T path and other petrogenetic characters of the amphibolite belt and MMT rocks further east of Shergarh Sar, at Gantar and its surrounding areas (Fig. 1).

FIELD RELATIONSHIP

Amphibolites

Amphibolites, exposed north of Pashakali, Shalkhai and Kalalota (Fig. 1) are generally massive but display local banding, foliations, discordant quartzo-feldspathic veining and minor faulting. They contain, hornblende pegmatitic patches of various sizes. In addition, small outcrops of metagabbro and metanorites are also exposed at

Pashkali and Kalalota, respectively. The contact relations of these outcrops with the melange zone rocks are however, not clear.

Melange zone rocks

The MMT melange zone includes greenschist, blueschist and chert in the study area (Fig. 1). Greenschist is the most voluminous rock in the area, having direct contacts with the amphibolites at Gantar and Kalalota and with the graphitic schist and siliceous marble of the Indian plate Salkhala series at Matai, in the south. Small patches and outcrops of graphitic schist and other schistose rocks probably related to the Salkhala series (Tahirkheli, 1979) or to the Saidu schist (Kazmi et al., 1984) are noticed within the greenschist at various places manifesting tectonic emplacement (Zahid, 1991). The greenschist is itself highly fractured, and weathered; it displays ptygmatic folds, faults and boudinage structures and contains layers of carbonaceous material, quartzo-feldspathic and calcite veins, all characteristics of the melange zone.

The blueschist is exposed as a small outcrop north-east of Narsuk village in the alluvium, with amphibolites to the north and Indian plate metasediments to the south.

Indian plate rocks

The Indian plate rocks of the study area are quartz-muscovite-chlorite-carbonate schist, quartz-actinolite schist, calcareous schist, graphitic schist and siliceous marble. The contacts of these rocks with the amphibolites and melange zone rocks are highly sheared. The schistose rocks are by themselves highly fractured, weathered, tightly folded and occasionally crushed and mylonized, resulting in intermixed lithalogies. Concordant and disconcordant calcite veins are commonly present in these rocks.

PETROGRAPHY AND MINERAL CHEMISTRY

Kohistan Island Arc rocks

Amphibolites: The amphibolites are medium to coarse grained (grain size 0.5mm-5mm) with inequigranular, xenoblastic to subidioblastic texture containing amphibole (30-45%), plagioclase (20-45%), quartz (0-30%), epidote (2-7%), Chlorite (0-7%), actinolite (0-5%) and opaque ore (0-12%) with traces of sphene, rutile and carbonates. Amphibole is generally pleochroic from brownish-green to pale-green and varies in composition from tschermakite to tschermakitic hornblende (Table 1; Fig. 2a). However, at margins and along cracks it has transformed into bluish green and non-pleochroic amphibole of magnesio-hornblende and actinolitic composition, respectively (Fig. 2a). The amphibole is generally intergrown with plagioclase and poikilitically

TABLE 1. MEAN AND STANDARD DEVIATIONS OF MINERAL COMPOSITIONS FROM GANTAR

	CALCIC AMPHIBOLES		ALKALI AMPHIBOLES				CLINOPYROXENE	
	Amphibolites		Greenschist		Blueschist		Metagabbro	
	MEAN (19	STD	MEAN (6	STD	MEAN (6	STD	Mean (8)	STD
SiO2	44.53	4.25	54.95	0.83	55.90	0.97	50.046	0.836
TiO2	0.99	0.70	0.09	0.07	0.50	0.96	0.154	0.140
Al2O3	12.70	2.51	8.04	1.84	8.23	0.81	2.866	0.157
Fe2O3	6.38	5.05	6.58	2.58	4.65	2.11	5.208	0.457
FeO	10.76	3.07	13.81	1.70	10.48	1.78	7.773	0.570
MnO	0.20	0.11	0.09	0.05	0.16	0.10	0.470	0.740
MgO	10.23	0.93	6.92	0.89	9.26	0.28	11.754	0.225
CaO	11.34	0.35	1.20	0.82	1.45	0.35	20.600	1.202
Na2O	1.77	0.39	6.68	0.80	6.60	0.64	0.450	0.069
K2O	0.00	0.00	0.16	0.27	0.49	0.92	0.000	0.000
Total	98.90	1.01	98.85	0.59	97.72	0.68	98.965	1.628
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Si	6.454	0.494	7.817	0.037	7.873	0.106	1.920	0.019
Ti	0.109	0.078	0.010	0.008	0.053	0.102	0.004	0.004
Fe3+	0.701	0.557	0.705	0.280	0.491	0.222	0.162	0.269
Fe2+	1.306	0.376	1.644	0.208	1.236	0.219	0.347	0.040
Mn	0.025	0.014	0.011	0.006	0.020	0.011	0.015	0.024
Mg	2.210	0.178	1.466	0.188	1.943	0.069	0.677	0.019
Ca	1.765	0.069	0.183	0.126	0.220	0.055	0.847	0.048
Na	0.499	0.117	1.842	0.220	1.803	0.184	0.034	0.005
K	0.000	0.000	0.090	0.185	0.088	0.167	0.000	0.000
Al4	1.546	0.494	0.183	0.037	0.128	0.106	0.069	0.028
Al6	0.632	0.319	1.163	0.307	1.239	0.147	0.045	0.022
Mg#	0.635	0.082	0.472	0.057	0.614	0.035	1.347	0.040

encloses a high number of quartz grains adopting a sieve structure. Plagioclase(An 16%) occurs as anhedral to subhedral crystals and partialy altered to epidote, and finally to sericite imparting a cloudy appearance to it. Quartz grains are commonly strained and occur as anhedral crystals of various sizes and occasionally as fine-grained aggregates. Sphene and rutile are generally associated with opaque ore.

Epidote amphibolite is in general similar to amphibolite except for the presence of a higher proportion of large anhedral to subhedral grains of epidote and zoisite intergrown with green hornblende and for the occurrence of accessory biotite (after hornblende), muscovite and apatite. Polygonal grains of hornblende are more sieved and corroded whereas plagioclase crystals are kinked in these rocks.

Mineralogically hornblende pegmatite is also similar to amphibolite, except for its larger grain size and higher proportion of amphibole (65%). The ^{vi}Al content of

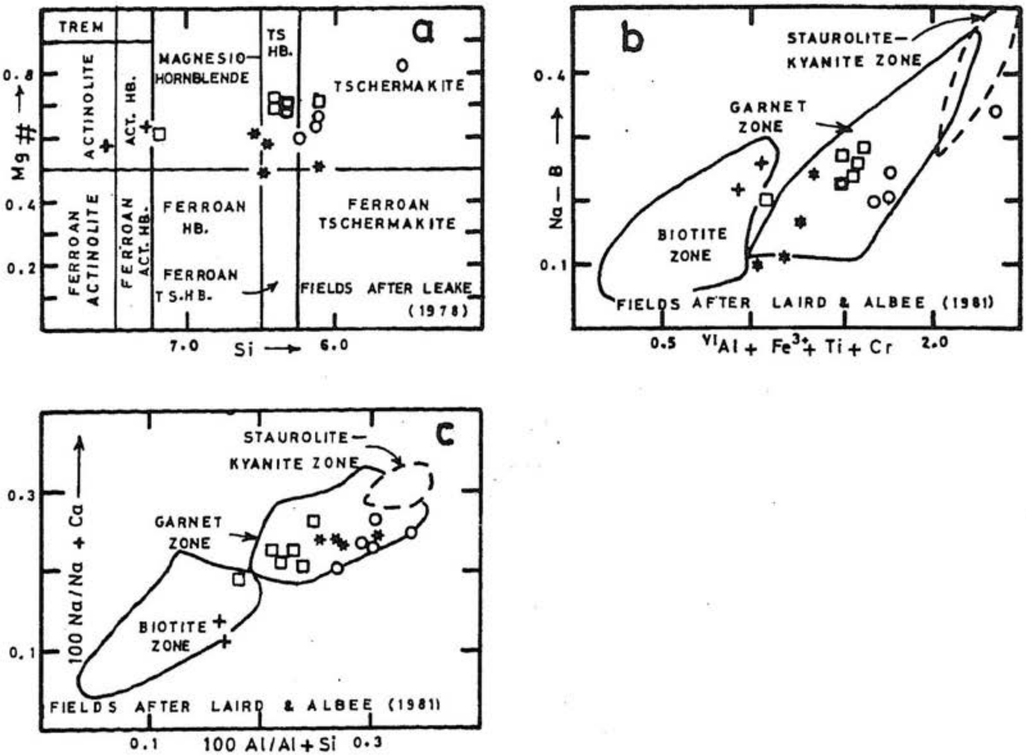

Fig. 2(a-c). Amphibole composition from Gantar amphibolites plotted on (a) classification diagram of Leake (1978) and (b-c) diagrams showing metamorphic zones after Laird and Albee (1982b). Symbols: astrisk = amphibolites, & plus = epidote amphibolite, circle = hornblende pegmatite.

hornblende in the pegmatite (0.13-0.22) is also much lower than of that in the amphibolite (0.36-1.04).

Metagabbro-metanorite: The metagabbro and metanorite are medium to coarse grained massive rocks with inequigranular, xenoblastic to subidioblastic texture containing plagioclase (45-55%), clinopyroxene (5-15%), orthopyroxene (0-25%), hornblende (3-20%) and quartz (2-15%). Besides, biotite, muscovite, epidote, sphene, talc, actinolite and opaque ore are also present.

Plagioclase (labradorite), when fresh, exhibits excellent twinning and some grains display deformation lamellae. Partial alteration to saussurite and epidote are noticeable. Clinopyroxene is diopside (salite) and Ca-rich augite (Table 1; Fig. 4a). It occurs as anhedral or prismatic grains commonly intergrown with orthopyroxene. Pale-green to brownish pleochroic hornblende has grown at the expense of clinopyroxene and plagioclase. Quartz generally occurs as inclusions in clinopyroxene. When fresh, clinopyroxene appears to be homogeneous with no exolution lamellae. Orthopyroxene (hypersthene, ferrohypersthene) has anhedral to subhedral grains with brownish-green to pale-green pleochroism occasionally showing alteration to talc. Hornblende and some biotite seem to have developed at the expense of orthopyroxene and plagioclase. Corona structure with a plagioclase core, hornblende middle rim and orthopyroxene outer rim also show a similar phenomenon. Fibrous minerals (mostly urelite) have commonly formed after ferromagnesium minerals. The metanorite can be discriminated from metagabbro on the bases of the high proportions of pleochroic hypersthene (25%) and plagioclase(An_{69}%).

Main Mantle Thrust rocks

Greenschist: It is a fine-to medium-grained rock with well- developed schistocity. It contains amphibole (10-25%), chlorite (10-20%), cloudy albite (15-30%), quartz (10%), graphite (0-5%) and muscovite (0-10%). Biotite, apatite, tourmaline, calcite, sphene and opaque minerals occur as accessories. Amphibole (actinolite and magnesio-hornblende) occurs as prismatic crystals, acicular needles and flakes, randomly as well as along the general fabric of the rock. In certain varieties, brown green hornblende partialy transformed to actinolite also occurs. In other varieties of greenschist lilac to blue pleochroic glaucophane (Table 1; Fig. 3a) occurs as columnar crystals and flakes, intergrown with epidote and chlorite. Epidote, chlorite and actinolite are generally associated together but chlorite intergrown with muscovite and graphitic material is also noticed. Magnetite is associated with sphene. Traces of aegirine(?) are also present. Lenticular and spindle-shaped patches of quartzo-feldspathic material surrounded by fine-grained schistose matrix exist, indicating cataclastic deformation (see Higgins, 1971; Shah 1986; Ahmed et al., 1991).

Blueschist: The blueschist from Narsuk contains glaucophane (50%), muscovite (25%) and actinolite (10%) as large crystals which can be identified in hand specimen. The rock is generally homogeneous, and massive but fractures filled with epidote veins are also present. Variation in grain size from fine to coarse and in colour from bluish-green to yellowish-green on weathered surfaces can be seen in hand specimen. Glaucophane (Table 1; Fig. 3a) is the most abundant mineral associated with muscovite and actinolite. Individual crystals are pleochroic from faint-blue to purple at cores and from dark-blue to dark-purple at margins. Saponite up to 10% is also noticed in one of the blueschist specimen.

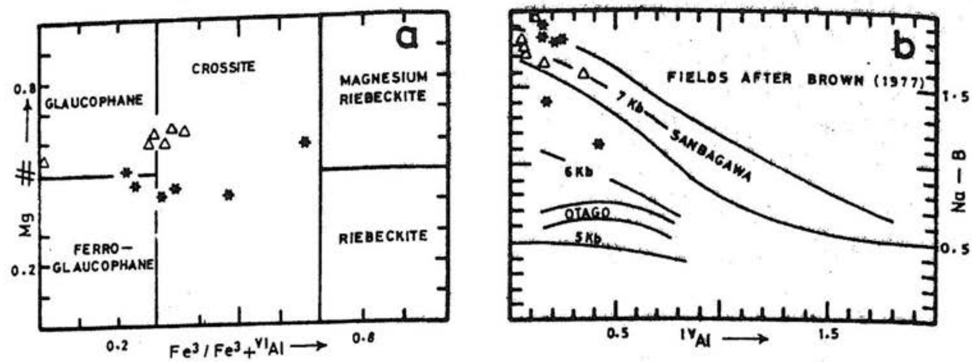

Fig. 3 (a-b) Amphibole compositions from greenschist [astrisk], and blueschist [triangle] of Gantar area plotted on (a) classification diagram of Deer et al. (1966) and (b) Na_B vs ^{iv}Al plot of Brown (1977).

P-T ESTIMATES

Amphibolites

As mentioned earlier, both hornblende (brownish green and pale green cores) and plagioclase in amphibolites are intergrown indicating crystallization under equilibrium and are thus considered a suitable pair for P-T estimation. Following the "An% vs total Al in hornblende method" and the "mole% An method" of Plyusnina (1982), a temperature of 500°C was obtained for tschermaketic hornblende in amphibolites. However, temperatures of 530°C and 510°C were obtained for the tschermakitic hornblende and actinolite, respectively, on the basis of their wt.% Al_2O_3 method of Plyusnina (1982). The latter two methods also yielded 4 and 5.5 kb pressures, respectively, for the tschermakitic hornblende in amphibolites. On Na_B vs $^{vi}Al+Fe^{3+}+Ti+Cr$ and on 100 Na/Na+Ca vs 100 Al/Al+Si diagrams (Figs 2b-c) of Laird and Albee (1982b), the tschermakite and tschermakitic hornblende compositions plot in the fields of amphiboles from garnet zone whereas the actinolite compositions appeared in those of biotite zone, indicating a higher metamorphic grade environment for the former types than for the latter, and thus confirming the P-T estimates based on the method of Plyusnina (1982).

Greenschist and blueschist

Alkali amphiboles in greenschist and blueschist classify as glaucophane, ferro-glaucophane, crossite, eckermanite, and richterite according to Leake (1978)(Tables 1; Fig. 3a) and thus represent a wider compositional range than reported by Shah and

Majid (1985) from the Shergarh Sar area, west of Gantar (cf. Fig. 1). Zoning reflected in pleochroic colours with glaucophane cores and crossitic margins is confirmed on the basis of chemical data of these amphiboles. Certain zoned glaucophane-crossite crystals also have additional outer rim(s) of magnesio-hornblende and/or actinolitic composition, all indicating lowering of pressure. Using the Al_2O_3 wt.% method of Plyusnina (1982), the magnesio-hornblende in the greenschist indicates a temperature of 490°C. However, on the basis of "An% vs total Al in hornblende method" of Plyusnina a temperature of 450°C and a pressure of 4 kb are obtained. Glaucophane from both the greenschist and blueschist on the other hand indicate a pressure of about 7 kb on the Na-M4 vs ^{iv}Al plot of Brown (1977; Fig. 3b). The absence of lawsonite and the average Si content of muscovite (6.9 cations per 22 oxygens) associated with glaucophane in the blueschist are also consistent with development under a pressure of 7kb (Velde, 1965). The crossite content of glaucophane in greenschist shows a wider compositional range than that of the blueschist. The former rock type also contains a greater proportion of alteration product (i.e. low pressure minerals, actinolite, magnesio-hornblende, chlorite etc.). These features can be related to a wider range of pressure in greenschist as compared to blueschist.

MAGMATIC AFFINITY

As mentioned above, it is difficult to ascertain field relationships of the metagabbro and metanorites with the amphibolites or with MMT rocks. However, the clinopyroxene compositions from metagabbro at Pashkali turned out to be of salite and Ca-rich augite composition, and when plotted on the Na and Ti vs X_{Fe} (= $Fe^{2+}/Fe^{2+}+Mg$) plot of Papike (1982), these showed a clear correspondence with the Island arc compositions (Fig. 4a-c). On the SiO_2 vs Al_2O_3 plot of LeBas (1962), majority of these data occur in the field of non-alkaline rocks whereas on the Ti vs Ca+Na, Ti+Cr vs Ca and Ti vs total Al plots of Leterrier et al. (1982), majority of the analyses show non-alkaline, orogenic and tholeiitic characters, respectively (Fig. 4d-g). Therefore, the metagabbro and metanorite from the study area may be corresponding to similar rocks intruding into amphibolites else where (i.e. Mahak; see Hamidullah et al., 1990), or may be representing the un-metamorphosed protolithic material for amphibolites which also show non-alkaline affinities (see Shah, 1986; Zahid, 1991; Shah et al., in press).

DISCUSSION

In amphibolites, the relic clinopyroxene in the cores of certain brownish green to pale green hornblende (tschermakite and tschermakitic hornblende) sieved with quartz

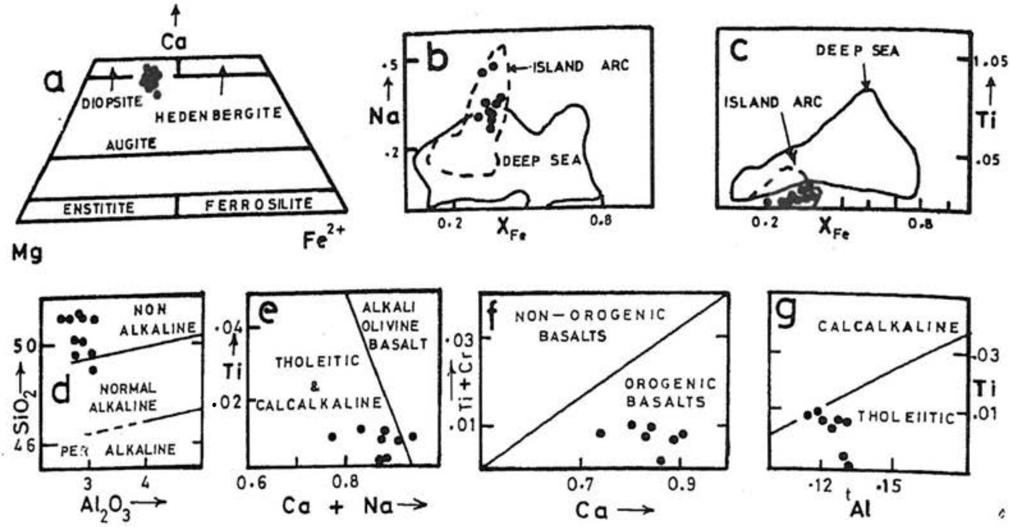

Fig. 4(a-g). Clinopyroxene compositions from metagabbro/ metanorite of Gantar area, plotted on various classification (Morimoto et al., 1988) and affinity-discrimination (LeBas, 1962; Leterrier et al., 1982; Papike, 1982) diagrams; $X_{Fe} = Fe^{2+}/Fe^{2+} + Mg$.

probably represents primary igneous crystallization of the former followed by metamorphic transformation into the latter two phases. The brownish green to pale green hornblende together with plagioclase(An_{16}) indicate amphibolite facies metamorphism. On the other hand, the association of bluish-green magnesio-hornblende and non-pleochroic actinolite with epidote, after the brownish-green hornblende and plagioclase, respectively, show lower epidote-amphibolite grade or upper greenschist facies metamorphism. Normally plagioclase is more calcic in rocks of the amphibolite facies than that noticed in these rocks, but metabasites recrystallized in amphibolite facies containing plagioclase with An as low as 10% are not uncommon (see Miyashiro, 1936). Also the formation of epidote after plagioclase in the Gantar amphibolites may have played a role in lowering the Ca content of the latter phase. All these features reflect retrogressive metamorphic environment, most probably related to uplift. Sericite after epidote and plagioclase indicates further retrogression. These interpretations are in accordance with the P-T data (T= 530-500°C; P=6-$\leq$4.5 kb) obtained on amphiboles from some amphibolite facies rocks (see Miyashiro, 1973, fig.3-12; Plyusnina, 1982). The amphibole from hornblende pegmatite patches in the amphibolites contains lower ^{vi}Al and probably reflects development under a lower pressure. Similar rocks with possible metasomatic origin have been reported from elsewhere in the amphibolite belt (i.e. Mahak; Hamidullah et al., 1990). The existance of the fibrous minerals (urelite), deformation lamellae in plagioclase, undulating extinction in quartz and minor faulting and folding locally in amphibolites of the study area as well as the evidence of intense shearing further east in the Southern Amphibolite Belt rocks, all indicate cataclasis and tectonic deformation. The petrographic characters of the Southern Amphibolite Belt rocks at Gantar thus represent a history of igneous crystallization and subduction-related metamorphism, followed by an uplift-related retrogression.

Relics of brownish green hornblende in the greenschist suggest an initial amphibolite or epidote amphibolite facies metamorphism followed by retrogression to green-schist assemblage (actinolite+epidote). However, the presence of glaucophane + muscovite assemblage both in the greenschist and blueschist is the critical indicator of high pressure i.e. blueschist facies, whereas the transformation of this assemblage into actinolite + chlorite + epidote assemblage is a reflection of low pressure, i.e. greenschist facies; all indicating subduction followed by an uplift. The absence of the greenschist assemblage from the blueschist indicates the escape of this material from transitional environment probably indicating a rapid uplift/obduction rate. The wider P-T range shown by the greenschist as compared to the blueschist might be possibly due to the former representing a part of the subducting slab which went down to relatively deeper level and obducted earlier but slowly as compared to the latter.

Considering the textural characters of metagabbro and metanorite, and the presence of plagioclase, clinopyroxene and orthopyroxene in these rocks most probably represent a primary igneous assemblage. The development of pale green to brownish pleochroic hornblende and some biotite grown at the expense of pyroxenes and plagioclase indicate the prevailence of the amphibolite facies metamorphism while the development of actinolite and epidote can be attributed to the greenschist facies environment, respectively. On the other hand fibrous minerals like uralite and talc after ferromagnesium minerals, and the deformation lamellae in plagioclase signify cataclasis and shearing. Chemical features of the metagabbro and metanorite suggest their island arc affinity. These probably represent relics of the rocks from which the amphibolites and epidote amphibolites were derived. The retention of a high proportion of primary mineralogy in the relics can be related to a lower degree of shearing and hydration as compared to the amphibolites.

CONCLUSIONS

1. Amphibolites of the study area are derived from igneous protoliths which have undergone amphibolite facies metamorphism, followed by epidote amphibolite and greenschist facies metamorphism, in a temperature range of 530-$\leq$500°C and a pressure range of 6-$\leq$4.5 kb, indicating retrogression due to uplift.

2. Metagabbro and metanorites of Pashakali and Kalalota villages have comparable history to amphibolites except for the retention of a high proportion of primary mineralogy and most probably represent relic protoliths for the amphibolites.

3. Hornblende pegmatite patches in amphibolites reflect development under lower pressure as compared to the latter type and are therefore, considered the product of late stage metasomatic phenomenon.
4. The greenschist of the MMT melange zone in the study area has undergone through amphibolite facies, blueschist facies (7kb) and greenschist facies metamorphism due to subduction/obduction-related retrogressive environment. The latter rock type indicate a wider P-T range as compared to the former.

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