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PETROLOGY OF A HORNBLENDE-RICH PEGMATITE AND HOST AMPHIBOLITES NEAR MATTA, UPPER SWAT

M. QASIM JAN and M.U.K. KHATTAK
NCE and Department of Geology, University of Peshawar

ABSTRACT

The 500x30m pegmatite near Matta consists of hornblende+ epidote± garnet lithology and hornblendite, with a small proportion of leucocratic, deformed dykes and veins. It is hosted by epidote amphibolites derived from gabbroic rocks and belonging to the southern amphibolite belt of the Kohistan zone. The hornblende-epidote lithology of the pegmatite is chemically identical to the amphibolites and is, therefore, neither a younger intrusion in nor a metasomatic product of the amphibolites. The coarse-grained fabric of the pegmatite may have developed locally in response to a higher concentration of fluid phase, mainly water but some fluorine. The hornblendite, which is coarser grained (with up to 35cm long crystals) and may cut the hornblende-epidote lithology, may be a product of metamorphic differentiation or, more likely, metasomatism. The amphibolites are tholeiitic in affinity and probably represent the Tethyan oceanic crust.

INTRODUCTION

The southern amphibolite belt of the Kohistan tectonic zone is lithologically heterogeneous (Tahirkheli and Jan, 1979). It consists principally of banded and homogeneous amphibolites, with a subordinate quantity of calcareous and siliceous metasediments. A whole spectrum of plutonic rocks, more or less deformed and metamorphosed, has also been reported from the belt. These include ultramafites, gabbros, norite, (quartz) diorites, granodiorite, granites, tonalite and trondhjemite (Jan, 1979a; Butt *et al.,* 1980; Coward *et al.,* 1982; Bard, this volume). It is being gradually realised that the southern amphibolite belt has a very complex tectonic, structural, magmatic and metamorphic history (Jan, 1977).

The ultramafic rocks range from dunite to peridotites, pyroxenites, and hornblendite, the latter being coarse-grained to pegmatitic in a number of cases. In addition to hornblendites, the belt also contains pegmatites consisting of hornblende, plagioclase and/or epidote, with garnet in a few. These pegmatites are scattered throughout the amphibolite- as well as the pyroxene granulite belts of Kohistan stretching from Nanga Parbat to eastern Afghanistan (Jan, 1979b; Shams, 1975). The hornblende crystals in the pegmatites reach up to 50x25cm and one of them, from the pyroxene granulite belt of Swat, has yielded a K/Ar age of 67 million years (Jan and Kempe, 1973).

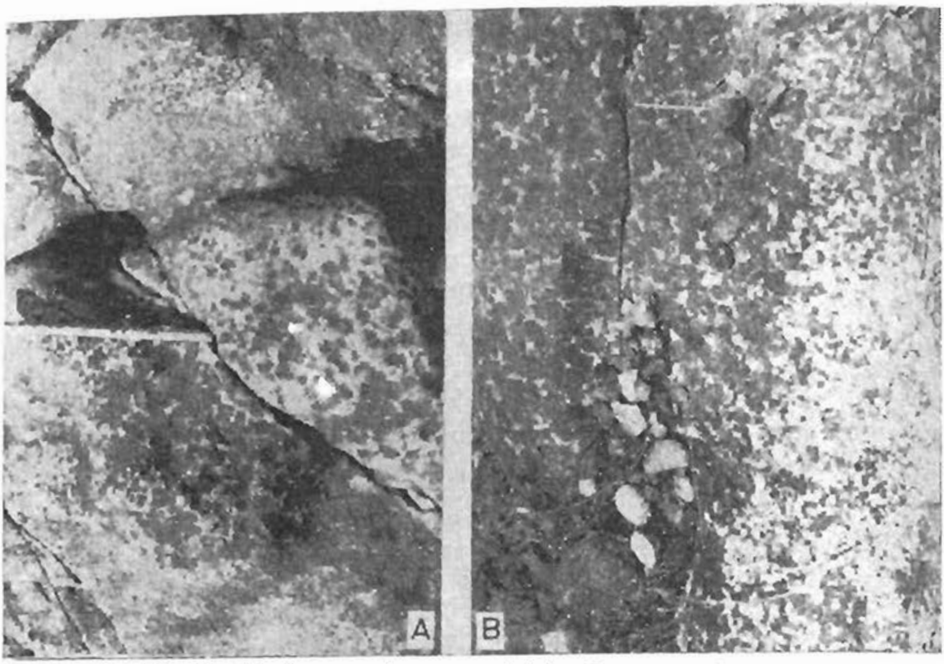

PLATE 1 A. Epidote-hornblende pegmatite surrounded by finer grained (?)sheared material of the same composition.
B. Matta pegmatite showing variation in grain size as well as epidote-hornblende ratio.

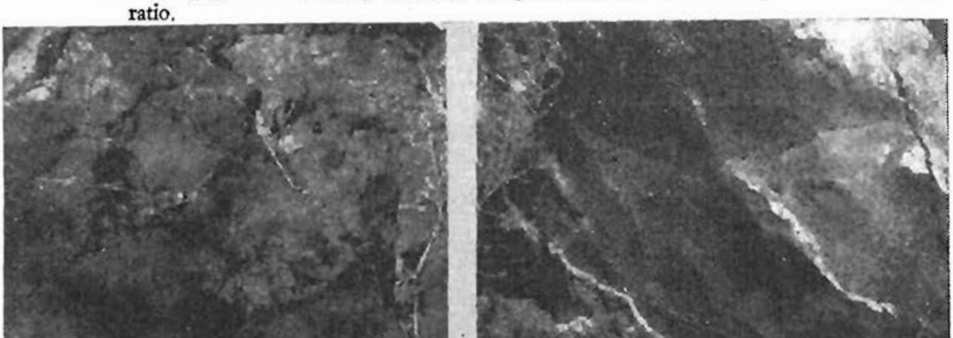

PLATE 2 A. Coarse-grained pegmatitic epidote-amphibolite enclave in pure hornblendite (upper right-half of the picture).
B. Folded and sheared felsic material in the hornblendite.

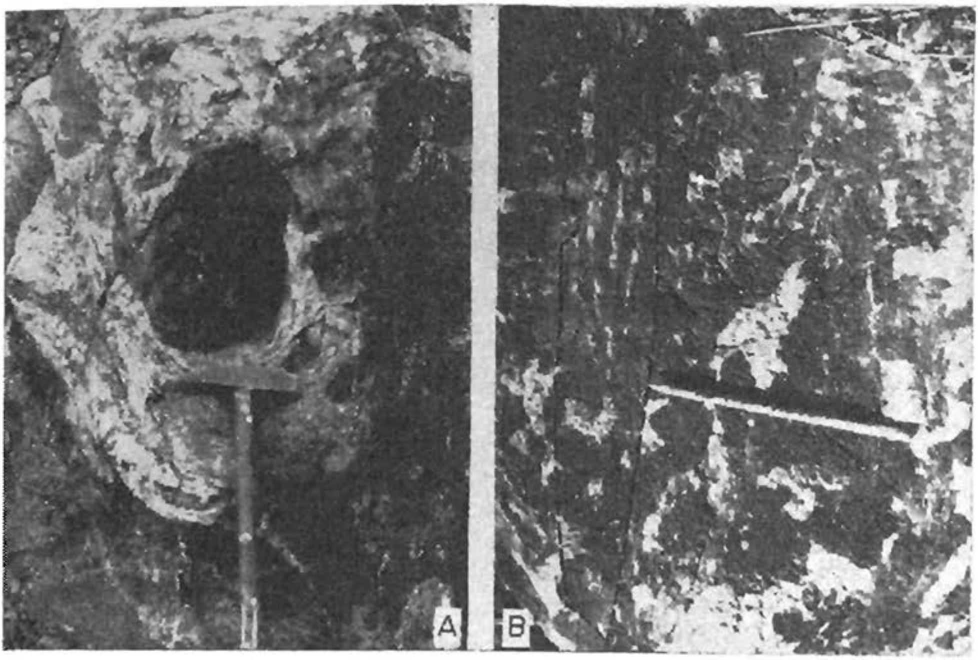

PLATE 3 A. Hornblendite enclave in folded and sheared felsic dyke.
B. Pegmatitic hornblende crystals with felsic material in the interstices and along cleavages and fractures. The outlined hornblende crystal towards the pointed end of the pencil is about 35cm long.

The hornblende pegmatites display variation in modal composition and texture from one to another body, but sometime within the same body. Mostly mesocratic, they range from leuco- to melanocratic and the latter may appropriately be termed hornblendite. The 'non-pegmatitic' hornblendite bodies, particularly common in Dir (for locations, see Banaras and Ghani, 1983), are also variable and their contact relations with the neighbouring rocks may be far from simple. Some of them are closely associated with other ultramafic rocks whereas others may be associated with amphibolites and dioritic (metagabbroic) rocks.

Different origins have been proposed for the hornblendites and hornblende pegmatites of Kohistan (Jan, 1979b; Shams, 1975; Banaras and Ghani, 1983). However, none of the bodies has been studied in sufficient detail from a petrogenetic point of view. The Tora Tigga hornblendites in southern Dir, studied in detail petrographically, have been considered metasomatic by Jan *et al.* (1983). In this paper, we describe a relatively simple pegmatite and its host rocks with the help of petrographic data and chemical analyses. SiO_2 was determined gravimetrically, TiO_2 and P_2O_5 by spectrophotometer, FeO by titration and the remaining elements by atomic absorption. The pegmatite extends N–S for 500x30m and is exposed along the road, about 5km S of Matta in Upper Swat.

FIELD RELATIONS AND PETROGRAPHY

The Matta pegmatite is a mixture of hornblenditic and hornblende+epidote ±garnet lithologies, with a minor amount of deformed felsic dykes or segregations (Pl. 1, 2 and 3). The country rocks are epidote amphibolites, generally medium-grained and metagabbroic in appearance, with local garnet porphyroblasts and segregations. The contact between the two is mostly gradual, but locally sharp due probably to dislocation. In some places the gradual passage between the two is via an epidote amphibolite containing coarse hornblende crystals. For many tens of meters within the host amphibolites, clots, patches and veins of medium- to coarse-grained hornblenditic material are also observed.

The pegmatite is homogeneous neither modally nor in grain size. It consists of hornblende, hornblende+epidote, and hornblende+epidote+garnet assemblages. Garnet is very local and forms small patchy segregations (with minor epidote and iron oxide) and porphyroblasts. Opaque iron oxide, rutile (usually as inclusions in hornblende) and, in a few cases, quartz and pyrite are the accessory minerals. Retrograde alteration, although not intense, has produced chlorite, secondary epidote, sphene, white mica, hematite and, in rare cases, albite. These minerals have developed under greenschist facies conditions, probably during obduction/uplift. The modal composition of the amphibolites is similar to that of the pegmatite, consisting essentially of hornblende+epidote±quartz±plagioclase±garnet. It is, therefore, obvious that the pegmatite and amphibolites were metamorphosed in Barrovian-type amphibolite facies conditions.

The northern and eastern parts of the pegmatite body are dominantly hornblenditic, the rest has an abundance of hornblende+epidote lithology. The two lithologies may be intimately mixed, they may show a gradual passage or the hornblendite may form veins and dykes cutting through, and containing enclaves of, the hornblende-epidote lithology. Hornblende in the body shows a drastic overall variation from a couple of milimeters to 35cm in length; but the very coarse grain size is invariably restricted to pure hornblendites, generally in veins and small dykes. In the hornblende+epidote lithology, the epidote is generally medium-grained but it clusters in aggregates over a centimeter across. The associated hornblende, on the other hand, forms larger grains, commonly 1 to 3 cm in length. The hornblendites usually contain a small quantity of felsic components (Fe-poor epidote±quartz±white mica), distributed interstitially or in clots. In the very coarse-grained hornblende crystals, such material grows along fractures and cleavages.

The hornblende of the pegmatites has a brownish green to olive γ-colour. Chemical analyses of two purified samples from the pegmatite are presented in Table 1. That from the hornblendite (anal. 1) is a pargasite whilst the one from the hornblende-epidote lithology (anal. 2) is alumino-tschermakite according to IMA classification (Leake, 1978). The high V and F contents of the first analysis and the OH+F totals of the two are noteworthy. For comparison are also given the analyses of a magnesio-hornblende from a hornblende pegmatite north of Bahrain (Jan and Kempe, 1973) and of a pargasite from garnet "hornblendite" (granulite facies) of the Jijal complex (Jan and Howie, 1982). The primary epidote of the pegmatite, generally, has a 2V of about 90° and appears to have a pistacite ($Ps=100\ Fe'''/(Fe'''+Al)$) content of 12 to 18 mol. percent (Deer *et al.*, 1962). One chemical analysis of purified sample has a Ps value of 15.24 (Table

TABLE 1. CHEMICAL ANALYSES OF TWO HORNBLENDES AND AN EPIDOTE FROM THE PEGMATITE BODY OF MATTA

	1	2	3	4	5
SiO_2	41.38	41.31	45.09	40.98	38.22
TiO_2	1.35	1.11	0.87	1.47	0.24
Al_2O_3	16.15	16.52	11.64	16.33	27.13
Fe_2O_3	3.55	4.52	4.87	3.46	7.61
FeO	7.68	10.15	10.56	8.33	0.65
MnO	0.13	0.15	0.29	0.06	0.11
MgO	13.18	10.79	12.33	12.26	0.28
CaO	11.51	10.93	11.24	11.36	23.58
Na_2O	2.18	2.01	1.40	2.90	0.10
K_2O	0.42	0.26	0.39	0.31	0.02
H_2O+	1.97	2.10	1.64	2.28	1.92
P_2O_5	0.00	0.00	—	0.00	0.00
F	0.81	0.29	0.01	0.06	—
–O=F	0.34	0.12	—	0.02	—
TOTAL	99.97	100.02	100.33	99.78	99.86
IONS ON THE BASIS OF 24 (O, OH, F) IN 1–4 AND 13 (O, OH) IN 5.					
Si	5.979	6.023	6.592	5.956	2.990
Al[iv]	2.021	1.977	1.408	2.044	0.010
Al[vi]	0.730	0.863	0.598	0.754	2.492
Ti	0.147	0.122	0.096	0.161	0.014
Fe'''	0.386	0.496	0.536	0.379	0.448
Fe''	0.928	1.238	1.291	1.012	0.042
Mn	0.016	0.018	0.036	0.007	0.008
Mg	2.839	2.345	2.687	2.656	0.032
Ca	1.782	1.708	1.761	1.769	1.977
Na	0.611	0.568	0.397	0.817	0.015
K	0.078	0.049	0.073	0.058	—
OH	1.898	2.042	1.600	2.211	1.002
F	0.370	0.134	0.005	0.028	—
T	8.000	8.000	8.000	8.000	Z= 3.00
C	5.000	5.000	5.000	4.969	Y= 2.95
B	2.000	2.000	2.000	2.000	X= 2.07
A	0.517	0.407	0.475	0.644	Ps=15.24

(Source of data: Jan, 1977; Jan and Kempe, 1973; Jan and Howie, 1982)

1. Pargasite from the hornblenditic pegmatite (US 19) of Matta.
2. Alumino-tshermakite from the hornblende-epidote lithology of the pegmatite (US 19A) of Matta.
3. Magnesio-hornblende from a coarse hornblende-plagioclase pegmatite in pyroxene granulites, Swat Kohistan, for comparison.
4. Pargasite from a garnet 'hornblendite' (granulite), Jijal, Indus Kohistan, for comparison.
5. Epidote coexisting with 2 in Matta pegmatite.

1, anal. 5). The epidote is generally colourless but close to the contact with hornblende or chlorite grains it has a yellowish colour due to a higher Fe‴ content. However, in at least one thin section, it appears that colourless (?)zoisite is in stable coexistence with a yellow clino-epidote. Lack of chemical data hinders the estimation of physical conditions from the two epidotes (cf. Enami and Banno, 1980).

Felsic veins and thin dykes occur in the amphibolites as well as pegmatite. They appear to be of two generations one of which pre-dates and the other post-dates the pegmatite. Those in the pegmatite consist of epidote, quartz, (?)feldspar, white mica and minor honrblende; they contain hornblende enclaves and are cut by greenish epidote veins. Although the pegmatite generally looks undeformed, the 'felsic' dykes have a gneissose fabric, are deformed and in some places have diffused contacts with the host rocks. A similar situation occurs in the Tora Tigga, Dir hornblendites (Jan *et al.,* this volume). Whatever the origin of these dykes, their deformation suggests that the pegmatite formed before at least the final episode of deformation. The mono- or bimineralic mode, coarse texture and lack of platy minerals may have been a hinderance in the development of a foliated fabric in the pegmatite as a whole. Less likely, localized deformation (shearing) may have continued along the same weak zones that were earlier followed by the felsic veins.

CHEMISTRY AND PETROGENESIS

Five rock samples were chemically analysed to know (a) the relationship of the pegmatite with the amphibolites, and (b) the tectonic environments of the rocks. The first three analyses in Table 2 are of the epidote amphibolites and the last two of pegmatite. Of the latter, analysis 4 represents the hornblende-epidote- and 5 the hornblendite lithology. Among the amphibolites, analysis 3 is of a sample from an 'enclave' (>1x3m) lying in the western part of the pegmatite. This rock (named as pegmatitic amphibolite) deviates from the other two in that it contains hornblende crystals reaching over 2cm in length (thus approaching the pegmatite), however, it can still be grouped with the amphibolites.

The chemical analyses of the rocks, in general, are very similar with the exception of the hornblendite. The analyses and their norms suggest that the rocks are gabbroic but all are low in SiO_2 and high in Al_2O_3, CaO. They also have rather higher Na_2O/K_2O and Fe_2O_3/FeO ratios than basic rocks of similar aspect and might suggest an increase in the two ratios due to metamorphism. Jan (1982), for example, found that the oxidation ratio of the Swat amphibolites is higher than that of their parent noritic granulites. The MgO/(MgO+FeO+MnO) content of the normative olivine and pyroxenes is high (86 with one value of 77) and the anorthite content of the plagioclase ranges from 64 to 85. The presence of highly magnesian (mg 86) silicates with a plagioclase of An_{64-68} in the norms of two rocks (anal. 1 and 2) is rather unusual. Analyses 1 has a minor amount of nepheline in the norms due possibly to an underestimation of silica.

TABLE 2. CHEMICAL ANALYSES OF THE MATTA PEGMATITE AND HOST AMPHIBOLITES

	1	2	3	4	5
SiO_2	42.86	43.61	42.52	42.83	39.60
TiO_2	1.40	1.43	0.95	1.08	1.26
Al_2O_3	16.13	17.45	18.16	17.76	13.80
Fe_2O_3	5.87	5.66	6.11	5.70	5.21
FeO	6.25	5.91	5.72	6.69	7.43
MnO	0.22	0.19	0.15	0.10	0.13
MgO	9.47	7.68	7.88	5.93	12.77
CaO	11.90	11.54	14.41	13.06	13.34
Na_2O	2.10	1.93	0.86	1.57	2.59
K_2O	0.20	0.10	0.00	0.05	0.22
P_2O_5	0.33	0.37	0.30	0.40	0.33
H_2O-	0.11	0.11	0.06	0.06	0.06
Ig. Loss	1.40	1.85	3.71	3.80	2.13
TOTAL	98.24	97.83	100.83	99.03	98.87
CONCENTRATION IN PPM					
Cr	410	115	162	65	73
Cu	60	65	80	106	35
Ni	250	100	65	77	60
Zn	175	185	185	154	160
MINERALOGICAL NORMS (AFTER BARTH, 1962)					
Ap	0.77	0.77	0.61	0.96	
Il	1.96	2.10	1.40	1.66	
Or	1.15	0.60	—	0.30	
Ab	18.83	18.15	8.15	15.20	
An	35.12	40.62	47.67	44.00	
Mt	6.31	6.22	6.63	6.34	
Di	18.84	13.80	20.12	17.88	
Hy	—	13.16	12.36	12.64	
Ol	16.56	4.59	3.06	1.02	

Analysts : M. Tahir Shah and M.U.K. Khattak.

1. Medium-grained amphibolite contained in the pegmatite. Norms contain 0.46% nepheline.
2. Coarse-grained amphibolite enclosing the pegmatite body from south.
3. Fine-grained amphibolite (with upto 2.5 cm, uniformly distributed hornblende crystals) within the pegmatite body; having two epidotes, chlorite and ore.
4. Pegmatitic epidote-amphibolite, having two epidotes.
5. Coarse-grained pegmatitic hornblendite with minor chlorite, epidote, ore and rutile.

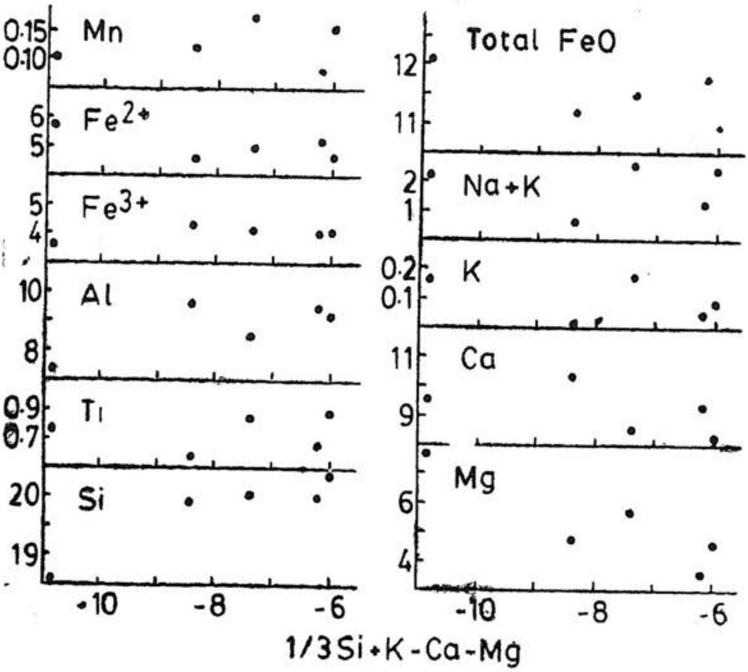

Fig. 1. 1/3Si+K—Ca—Mg *vs.* different cations plots for the rocks of Matta pegmatite body. The rocks seem to be magmatically related, however, the hornblendite plots fall off the general trends formed by the remaining rocks. The lowest value of 1/3 Si+K—Ca—Mg represents hornblendite.

The Matta pegmatite may have formed by crystallization from a magma, by metasomatic alteration of the amphibolites, by metamorphic differentiation, a combination of the last two, or even a more complex process. A number of features oppose its derivation directly from a magma intrusive in the amphibolites. These are: presence of garnet patches and porphyroblasts; the abundance of epidote; variation in modal mineralogy, texture and grain size; and the very coarse hornblende veins. Indeed we cannot propose that the pegmatite represents *in situ* cumulates, residual liquid or a direct product of crystallization of a magma of the pegmatite composition. The hornblende-epidote lithology of the pegmatite seems to be related to the amphibolites and is not a product of magmatism post-dating the formation of amphibolites.

We also considered the possibility that the pegmatite may be a metasomatic product of the amphibolites via the pegmatitic amphibolite enclave (anal. 3). However, the analyses of the two amphibolites, the enclave and hornblende-epidote lithology of the pegmatite are remarkably similar. A number of plots, including those of Niggli (1954) fail to reveal metasomatism. Figure 1 is a chemical variation diagram showing the plots of various cations against 1/3Si+K–Ca–Mg. It can be seen that with the exception of hornblendite, the remaining rocks constitute trends suggestive of magmatic relationships. The similarity of the hornblende-epidote pegmatite, the pegmatitic amphibolite and the two amphibolite analyses opposes the idea that the pegmatite is metasomatic or that it represents an igneous intrusion not related to the amphibolites. This similarity also disfavours a metamorphic differentiation origin for the hornblende-epidote pegmatite lithology, quite independent of the restraint that this process does not normally lead to the production of such large bodies.

What, then, is the explanation for the coarse-texture of the pegmatite and the difference in the chemistry of the hornblendite when compared to the other rocks? We think that the pegmatitic grain size developed during amphibolite facies metamorphism due to an abundance of fluid phase, mainly water but some fluorine (as revealed by the high F content of the two hornblende analyses in Table 1). The site of the pegmatite development may originally have been a structural sink for the fluids, or there might have existed 'chimneys' or fractures for fluid transport during metamorphism. The hornblendite portions of the pegmatite might be a product of metamorphic differentiation, its monomineralic mineralogy having a control over its chemistry (cf. Leake, 1972).

The hornblendite, more likely, is a product of metasomatic activity connected with the fluid transport. The generally much coarser grained fabric of the hornblendite and its occurrence in dykes and veins in the hornblende-epidote pegmatite substantiate this view, as does the close association of felsic veins and dykes with the hornblendite. During metasomatism, soda and potash seem to have been enriched and silica, alumina, Cr, Cu, (?)Ni depleted. It is possible that during hornblendite formation under amphibolite facies conditions, the fluids affected the neighbouring amphibolites, thus producing coarse-grained fabric—the hornblende-epidote lithology of the pegmatite. Subsequent deformation may have caused obliteration of the contact relations and mixing of the two lithologies of the pegmatite. The felsic dykes and veins may be the final products of the metasomatising solutions or, less likely, they may have been produced during metamorphic/metasomatic segregation, that is, the latter process may have led to the production of complimentry hornblendites and felsic veins at the expense of the hornblende-epidote pegmatite. The main problem with this mechanism is that the quartz content of the felsic veins is rather high unless it has been introduced by the fluid phase.

Tectonic Environments of the Rocks.

Chemical analyses of the three amphibolites and the hornblende-epidote pegmatite were compared with rocks of different tectonic settings. Butt (1983) suggested that the ultramafic rocks of the southern Kohistan with Ni- mineralization are komatiitic in nature. Therefore, particular attention was paid to this problem during our comparison and our data do not favour a komatiitic origin for the four rocks, nor can an alkaline affinity be suggested.

When compared with the komatiite series of Munro Township (Arndt et al., 1979), the rocks have lower MgO, NiO, Cr_2O_3 and higher TiO_2, $FeO^T/(FeO^T+MgO)$ and Al_2O_3/MgO. On Al_2O_3 *vs.* $FeO^T/(FeO^T+MgO)$ diagram they plot in the komatiite field (although this diagram is not an efficient discriminator of the two) whereas on TiO_2 *vs.* MgO diagram (cf. Naldrett and

Cabri, 1976) they straddle the komatiite and tholeiite fields. On Jensen's (mol. proportions Al–Mg–Fe^T+Ti) diagram (Laurent *et al.,* 1979), all the analyses plot along the boundary of the rocks of komatiitic and tholeiitic affinities. On Al_2O_3–CaO–MgO and MgO–FeO^t–CaO plots of Hallberg and Williams (1972), showing the fields for komatiites, tholeiites, dolerites-gabbros and other rock suites, the Matta rocks plot in the overlapping fields of tholeiites and dolerites-gabbros. Their TiO_2 *vs.* P_2O_5 plots lie a little above the ocean-floor basalts (Bass *et al.,* 1973) but this might be due to a relative overestimation of P_2O_5 in our rocks as we suspect. The TiO_2 against Al_2O_3 and CaO plots of the Matta rocks are akin to those of mid-oceanic ridge basalts (Nesbitt *et al.,* 1979) and on Ti *vs.* Cr plot they fall in the field of ocean-floor basalts (Pearce, 1975). We thus conclude that the Swat rocks have crystallized from a tholeiitic magma of oceanic character. They probably represent a segment of the Tethyan oceanic crust.

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