Geol. Bull. Univ. Peshawar, 1983, Vol. 16, pp. 11–29

THE TORA TIGGA ULTRAMAFIC COMPLEX, SOUTHERN DIR DISTRICT

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ABSTRACT

The ultramafic rocks of Tora Tigga near Munda are emplaced in amphibolites of the Kohistan tectonic zone along the Main Mantle Thrust. The amphibolites are represented by metamorphosed gabbros and norites of the Chilas layered complex, and garnet-bearing mafic to intermediate plutons. The ultramafites include dunites and a variety of peridotites, pyroxenites, and hornblendites. The hornblendites are the most abundant of these, are coarse-grained to pegmatitic, and contain deformed felsic dykes and veins. The origin of the olivine- and pyroxene ultramafites is not clear; they might be alpine-type or, more probably, cumulates of the Chilas complex and related to the metamorphosed gabbros and norites. Field relations and textural features suggest that the hornblendites have formed by metasomatism of the various rocks in the area.

INTRODUCTION

The Tora Tigga Complex is one of a number of mafic-ultramafic rock occurrences along the Main Mantle Thrust (MMT), which is the westwards extension of the Indus suture. We named the complex after Tora Tigga (black rock) point occupied by a black hornblendite. It is located near Gosam village at a distance of 6km E of Munda town along the road to Timurgara (34°49'N; 71°44'E). Exposures of the complex also occur near Hashim, 1.5km NE of Munda. The Tora Tigga ultramafic exposures measure about 5.5km^2 and those of Hashim about 0.25km^2. The two are separated by amphibolites which constitute the country rocks.

The ultramafic rocks have been emplaced in a thick sequence of amphibolites along the MMT whose trace is, probably, followed by the Jandul Rud in the south of the complex. The amphibolites belong to the southern amphibolite belt of the Kohistan zone and extend from Nanga Parbat to eastern Afghanistan (Jan, 1977). They have been obducted over the Indo-Pak plate along the MMT. The amphibolites in the area are principally represented by meta-gabbros/norites and garnet amphibolites. The ultramafic rocks range from olivine ultramafites (olivine > 40%) to pyroxene (> 50%) ultramafites and hornblendites, the latter cut by felsic dykes and veins. A preliminary account of these rocks was presented by Kakar *et al.* (1971).

This paper presents a geological map (Fig. 1) and petrography of the rocks. A total of four weeks field work was carried out in two phases, mainly by two of us (A.G. and M.B.). The first phase consisted of preliminary mapping and sample collection and the second, based on a study of 177 rocks under the microscope, consisted of improvement of the map in the field and other details. Modal composition of representative rocks is given in Table 1. The geology of the neighbouring Timurgara and Jandul valleys has been discussed at length by Kakar *et al.* (1971), Khan and Saleemi (1972), Arbab and Khan (1973) and Chaudhry *et al.* (1974). The regional geology of the Kohistan tectonic zone has been presented by Jan (1977, 1980), Tahirkheli *et al.* (1979), Bard *et al.* (1980), Butt *et al.* (1980), Coward *et al.* (982) and Tahirkheli (1982).

It is now agreed upon that the Kohistan zone represents a Late Mesozoic island arc. The arc was probably welded to India during the Early Tertiary from when onwards an Andean-type cordilleran margin situation prevailed before the final closure of the Tethys remnant between the former arc and the Karakoram plate (Jan and Asif, in press; Andrews-Speed and Brookfield, 1982). However, some people suggest that closure first took place between the arc and Karakoram plate and then between these and Indo-Pak plate. This paper is not related to the problems of regional geology and tectonics; interested readers may consult the above-given references.

THE AMPHIBOLITES

Three types of amphibolites occur in the investigated area: garnet amphibolites in the NW, metamorphosed gabbros and norites in the SE, and banded amphibolites in a 200m broad and NE-trending shear zone in the middle. Not all of the northwestern amphibolites are garnetiferous, and some resemble the metagabbros, but most appear to be metaplutonites. The banded amphibolites may be a product of their shearing or, less likely, volcanic. The contacts of the banded rocks with garnet amphibolites are highly sheared but the two have modal similarity. The contacts of garnet amphibolites and Hashim hornblendites are generally sharp and sheared, the two being locally separated by thin mylonite and associated calc-silicate rocks. This, however, may be a local phenomena of small scale movement, since hornblendite patches and veins similar to the main body have been found in the garnet amphibolites. The latter also contain fine-grained amphibolite xenoliths or autoliths.

TABLE 1. MODAL COMPOSITION OF REPRESENTATIVE ROCKS.

No.	Rock Name	Pg	Hbl	Cpx	Opx	Oli	Serp	Ore	Others**
14*	Amphibolite	65.0	12.7	2.7	15.8	—	—	3.2	Ap (0.6)
20	Amphibolite	61	20	—	16	—	—	3	Ap
93	Amphibolite	89	10	—	—	—	—	Tr	Epi(1), Rt, Ap, Chl, Sph.
42	Amphibolite	61	21	5	6	—	—	2	Epi, Qz(5), Ap, Rt.
107	Amphibolite	30	69	—	—	—	—	Tr	Epi, Qz, Rt, Chl.
64	Banded-Amphibolite	24	18	—	—	—	—	Tr	(a)
		39	—	—	—	—	—	—	(b)
130	Gt-Amphibolite	50	19	—	—	—	—	Tr	(c)
7	Dunite	—	—	—	5	87	3	5	—
55	Serpentinite	—	—	—	—	1	85	14	—
70	Peridotite	—	5	7	10	70	3	5	CO_3''
45	Amph. Peridotite	—	25	15	2	48		10	—
155	Amph. Peridotite	—	40	2	—	53		5	—
9	Clinopyroxenite	—	10	90	—	—	—	Tr	—
11	Hbl-Clinopyroxenite	—	20	80	—	—	—	Tr	Epi, Sph.
84*	Hbl-Orthopyroxenite	—	16.4	0.7	75.7	—	—	5.8	Tc(1.4)
52	Oli. Hbl. Websterite	—	13	53	11	20		3	—
29	Oli. Clinopyroxenite	—	1	88	—	10	1	Tr	—
80	Hornblendite	—	99	—	—	—	—	Tr	Epi, Qz, Rt, Ap, CO_3''
39	Hornblendite	—	96	—	—	—	—	1	Epi, Chl(3), Sph, Preh.
126	Pg. Hornblendite	2	96	—	—	—	—	1	Epi, Qz, Rt, Chl.
131	Pg. Hornblendite	24	75	—	—	—	—	Tr	Epi, Qz, Rt.
23	Pxn. Hornblendite	—	69	20	10	—	—	1	—
110	Pxn. bearing Hblite	—	90	9	—	—	—	1	Chl.
44b	Felsic vein	98	—	—	—	—	—	—	Epi(1), Qz(1), Gt, Bio.
101b	Felsic vein	98	1	—	—	—	—	Tr	Epi, Rt, Chl, white mica.

* Based on point counts. ** Others in traces, unless otherwise specified.

(a) Dark band contains Qz(41), Bio(15), Epi(2) with Tr of Ap, Sph, Ore and Zr.

(b) Light band contains Qz(59), Epi(2), Ap and Sph in Tr. (c) Qz(20), Gt(10), Epi(1) and mica in Tr.

The meta-gabbros/norites are intimately associated with the ultramafic rocks and, by analogy to the Chilas complex (Khattak and Parvez, 1982), they may be comagmatic. However, their contacts are sharp, although not always with the hornblendites. In the vicinity of the latter, the meta-gabbros/norites contain an increasing number of dykes, veins and patches of hornblendite. The meta-gabbros/norites locally contain felsic veins which may be isoclinally folded, with axial plane of the folds parallel to the host-rock foliation. They are intruded by fine-grained dykes (20cm x many meters); these may be dolerites metamorphosed to amphibolites. Such dykes are common in the noritic granulites of the Chilas complex in the Indus valley. The meta-gabbros/norites are mostly mesocratic but range from melano- to leucocratic. Those with high plagioclase content (> 85% may be anorthositic layers and dykes as in Swat and Chilas. It appears to us that these rocks are the westerly extension of the Chilas complex (Jan, 1980; Coward *et al.*, 1982).

The amphibolites are generally medium-grained but fine-grained texture occurs in the banded type and coarse-grained in the other two. Bands in the banded amphibolites range in thickness from streaks to several centimeters, but most are < 4cm. They are alternating amphibole- and quartzofeldspar-rich stripes, the latter being thinner and isoclinally folded, with fold axes parallel to foliation which in turn is parallel to banding. The amphibolites are composed of various proportions of plagioclase, hornblende, quartz, and small amounts of opaque minerals, epidote, apatite and, in some, biotite, sphene, rutile and secondary chlorite, muscovite and (?)prehnite. The amount of quartz in the meta-gabbros/norites is insignificant but it may be an important mineral in the other two, along with relatively more common biotite.

The plagioclase composition shows some variation; it is An45 in the garnet-, An38 in the banded amphibolites, and An40–43 in the meta-gabbros/norites. The hornblende is light green to olive or bluish green. In the meta-gabbros/norites it is poikiloblastic and contains relics of strongly pleochroic

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PLATE 1

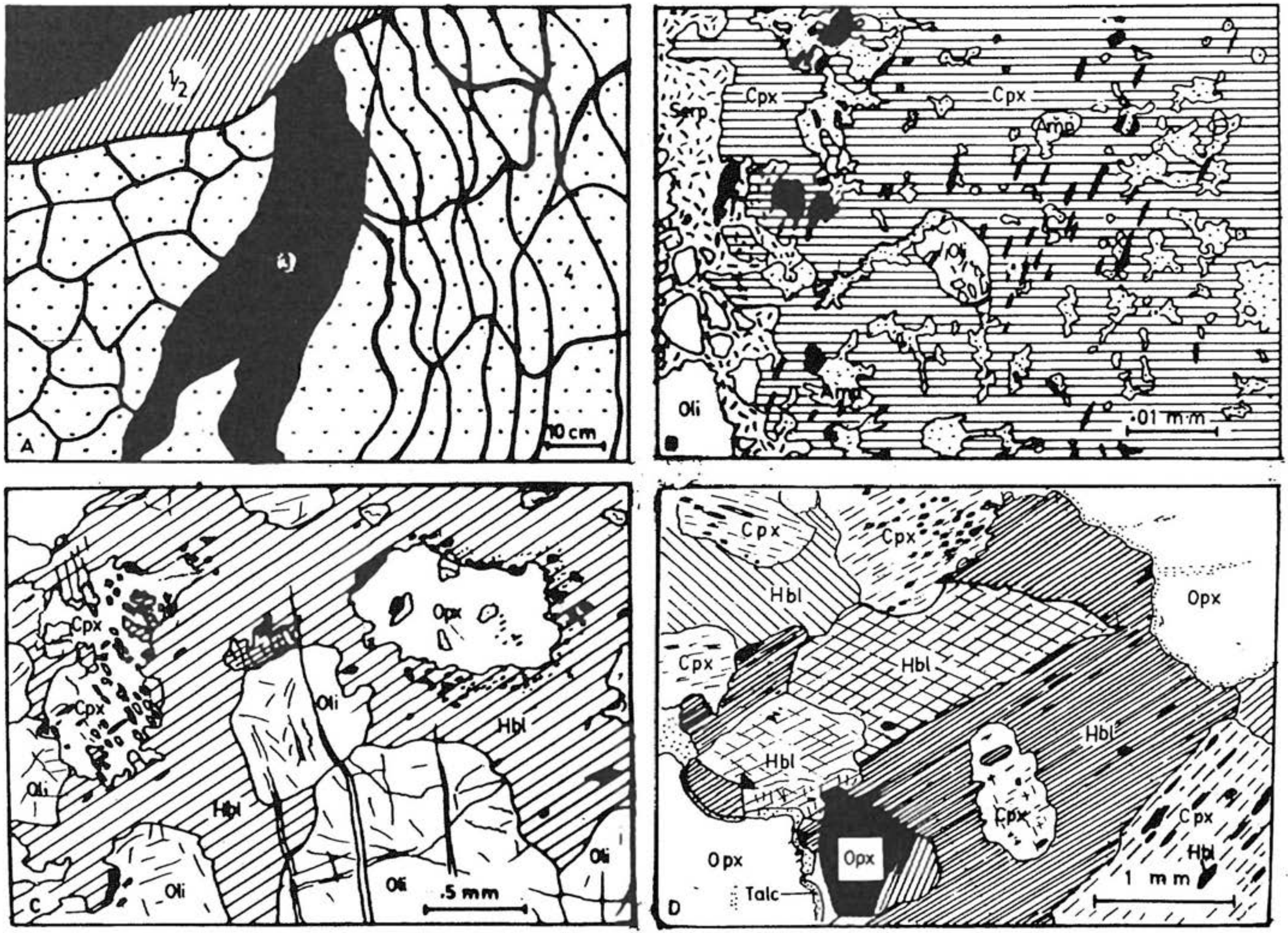
A. The 'olivine-clinopyroxene-ultramafite mixed zone' in the Gosam stream shows complex relations. Pyroxene-ultramafite(4) is cut by dykes and veins of hornblendite (3 & black lines). The whole seems to have been off-set with (?)tectonic emplacement or squeezing in of peridotite and dunite (1 and 2) along the fractures. Elsewhere the relationships are different from this example.

B. Amphibole peridotite displaying a large spongy clinopyroxene grain with amphibole and inclusions of olivine and (?)secondary magnetite. The olivine on the left is serpentinized.

C. Amphibole peridotite showing replacement type features. The poikiloblastic hornblende contains a girdle of magnetite granules surrounding coroded (and replaced) orthopyroxene. Hornblende in the spongy intergrowth in clinopyroxene is in optical continuity with the poikiloblast and both may be a product of replacement.

D. Hornblende websterite showing a poikiloblast of hornblende (Hbl) containing a large hornblende inclusion (with rhombohedral cleavage). The clinopyroxene (Cpx) is spongy with hornblende. The hornblende "inclusion" in the oval grain (lower centre) is in optical continuity with the larger hornblende grain. The orthopyroxene (Opx) has been altered to talc (Tc) along the fractures while that in the centre bottom is twinned.

PLATE 1


A
1/2
4
10 cm
B
Serp
Cpx
Cpx
Amp
Oli
Amp
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C
Cpx
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Cpx
Hbl
Hbl
Hbl
Cpx
Cpx
Hbl
Opx
Opx
Talc
1 mm

hypersthene (up to 16%) and clinopyroxene (up to 5%). The epidote is monoclinic and in the banded rocks it may be zoned with brown (? alanitic) cores. The garnet is restricted to garnet amphibolites but even here some rocks are devoid of it. The high quartz content of some garnetiferous rocks and the absence of garnet in some rocks suggest that they represent basic to intermediate plutons in which garnet development was controlled by bulk chemistry. The garnet may be in small grains but much of it is in porphyroblasts reaching over 3cm in size. They are generally subhedral, are surrounded by a felsic corona, and contain many tiny inclusions of quartz. Near Hashim, some rocks display banding, with a few bands rich in garnet.

OLIVINE ULTRAMAFITES

These rocks form elongated to subcircular bodies and small irregular patches. In some cases, as in the mixed zone, they are intimately associated with other ultramafic rocks on such a small scale that they cannot be shown separately on the map (Pl. 1A). The contact relations of these with other rocks are not clearly understood due to the presence of overburden. However, with some of the pyroxene ultramafites they have sheared contacts that extend E-W and dip steeply N. The rocks range modally from dunite to peridotite to amphibole peridotite, locally arranged in 'concentric' zones in this order.

These ultramafites are generally medium-grained, hypidiomorphic to allotriomorphic and subequigranular. Some show deformational features such as granulation and kink bands, and all are varyingly altered along at least three sets of fractures. Serpentine and magnetite are the alteration products, developed more readily after olivine than after other minerals. The dunites have $\geq 90\%$ olivine+serpentine and minor magnetite, chromite and, in some cases, orthopyroxene. The latter may somewhere grow into large patches containing many inclusions of olivine. Composition of olivine, determined by R.I. method, in a dunite is $Fo_{86.5}$. The other rocks show wide variation in their modes. The peridotites contain $\geq 70\%$ olivine+serpentine, the rest being one or two pyroxene, amphibole, opaque minerals and traces of secondary carbonate. The amphibole peridotites contain 40 to 60% olivine+serpentine, 1 to 15% clino- and 2 to 15% orthopyroxene, 7 to 40% amphibole, and minor opaque minerals and carbonate.

The clinopyroxene and hornblende may form spongy intergrowths (Pl. 1B) or the amphibole may grow into large poikiloblasts with or without clinopyroxene relics. The colour of the amphibole (colourless to light green or green) in the sponges is the same as that of the poikiloblasts and the two are in optical continuity in some cases. The orthopyroxene inclusions in the amphibole may be girdled by magnetite granules (Pl. 1C). In some cases, large amphibole grains contain inclusions of amphibole, in others large amphibole grains may be surrounded by smaller amphibole grains, or the large patches of amphibole may consist of aggregates of smaller grains. These features suggest a complex interplay of replacement and deformation and are discussed further in the following sections. There also is the possibility of more than one generation of hornblende.

PYROXENE ULTRAMAFITES

These constitute the second most abundant ultramafic rocks after hornblendites. They vary in texture and composition and can be divided into: 1) hornblende websterite, the most common and grading into 2) hornblende orthopyroxenite, 3) hornblende-olivine websterite, 4) olivine clinopyroxenite, 5) clinopyroxenite, the least common and passing into 6) hornblende clinopyroxenite. The olivine-bearing types are closely associated with olivine ultramafites. The rocks extend in E to W-trending bodies with intervening meta-gabbros and hornblendites. The largest body is up to 400m broad and extends for 2km. They contain numerous small to large patches and veins of hornblende, the situation being particularly intricate in the mixed zone. The contacts of these rocks with hornblendites are gradational.

The pyroxene ultramafites are composed of various proportions of pyroxenes, hornblende (up to a third of total amount) and olivine (up to 20%). Small amounts and traces of opaque minerals, green spinel, chlorite, sphene and (?)epidote may also be present. In an olivine clinopyroxenite, the R.Is. suggest a forsterite content of 87.5% in the olivine. Orthopyroxene composition in two hornblende websterites is En86 and En87. In a number of cases olivine and pyroxenes may be altered to serpentine and talc. The rocks are generally medium-grained, hypidiomorphic and subequigranular but in rare cases they are granulated and the texture is inequigranular. In a few cases the texture is coarse-grained with hornblende poikiloblasts reaching a centimeter in size.

The hornblende may be colourless (?magnesio-hornblende), green or brownish green. It forms poikiloblasts containing pyroxene, magnetite and, in some case, hornblende. It also occurs interstitially and in spongy intergrowths with clinopyroxene, that may rarely be optically continuous with the poikiloblasts. The hornblende may penetrate and extend into pyroxenes along cleavages (Pl. 1D), fractures and exsolution lamellae. The orthopyroxene contains hornblende blebs which may have grown at the expense of exsolved clinopyroxene. The inclusions of pyroxene in hornblende mostly lack crystal boundaries and are finer grained than the independent pyroxene grains. These may actually be relics. Some of the inclusions of orthopyroxene are completely or partially surrounded by a girdle of magnetite grains probably representing excess iron over that accommodated in hornblende. In rare cases, an orthopyroxene 'relic' may be shared by more than one hornblende poikiloblasts.

These features have also been recorded for the olivine ultramafites and we consider that much of the hornblende in Tora Tigga rocks is of replacement (metasomatic) origin, formed probably during high-grade amphibolite facies conditions. The spongy clinopyroxene grains, in rare cases, are aligned in trails, the remaining parts of the section being devoid of it. In such cases the hornblende-forming solutions seem to have penetrated along microfractures. In general hornblende has grown more readily at the expense of clino- than orthopyroxene due probably to a lesser difference in the chemistry of the former two. The unaltered clinopyroxene grains show fine exsolution lamellae and twinning but zoning is rare. The orthopyroxene is fractured and often altered to talc+magnetite, the alteration postdating the hornblende formation; steatization of pyroxene is particularly common in hornblende orthopyroxenite. The orthopyroxene may be strongly pleochroic as in granulite facies rocks of the Chilas complex. The olivine is mostly anhedral, fractured, often serpentinized and may be partially or completely enclosed in hornblende.

HORNBLENDITES

Hornblendites constitute the principal lithology of the ultramafic rocks in Hashim as well as Tora Tigga area and mostly occupy high points and ridges. Those of the Tora Tigga are about 700m broad in the west, but branch into four or five E–W extending bodies with an average width of about 100m. The northern of these branches extends for 3km whilst the extension of the southern bodies is obscure under alluvium. In addition to these large bodies, numerous veins, pools and patches of hornblendite also occur, especially in the pyroxene ultramafites (Pl. 1A). These patches are variable in shape and they range from less than a meter to several hundred meters.

The ocntacts of the hornblendites with pyroxene ultramafites are gradational, with veins, patches and dykes of hornblendites in the pyroxene ultramafites and enclaves of the latter in the hornblendites. A similar relationship may also be seen with the meta-gabbros/norites, however, some contacts here are sharp. If the hornblendites are replacive and metasomatic, as regarded by us, the sheared and sharp contacts can best be explained by assuming that some movements along the contacts took place after the hornblende formation.

The hornblendites display grain-size heterogeneity. They are predominantly coarse-grained with up to a few centimeter long crystals. However, they are locally medium- or even fine-grained, whereas the pegmatitic varieties contain up to 25cm long crystals; a single outcrop may display all the textural types. In some places the pegmatitic hornblendites seem to be the last and cut through finer-grained rocks but elsewhere this relationship is not clear. They are cut by felsic dykes, quartzofeldspathic and epidote veins which are generally not found in the other ultramafites.

Except along shear zones and some contacts, the hornblendites generally do not display a parallel alignment of minerals. This may have to do something with the generally monomineralic nature of the rocks than to lack of deformation. Deformation is suggested by granulation, kinking and bending of the grains, growth of fine-grained hornblende along deformation planes in large grains, and by the parallel growth of secondary chlorite in the hornblendites. That they must have passed through episode(s) of deformation is documented by the foliated and strongly deformed aspect of the felsic dykes.

The rocks are essentially composed of hornblende (with variable amounts of plagioclase and pyroxene in some), and minor amount of opaque minerals (mostly magnetite) and, locally, apatite, rutile, quartz, sphene, chlorite, epidote and carbonate, the last three or four minerals being the products of alteration. They can be arbitrarily divided into monomineralic-, plagioclase-, and pyroxene hornblendites. The plagioclase (An40–45) content in the second variety is generally in the range of 1 to 10% but in some rocks it may reach 25%. This variety is mostly found in the vicinity of felsic dykes and is thus common in the Hashim area. Conversely, it may be said that the felsic dykes are associated with and (?) genetically related to the plagioclase hornblendites. The pyroxene hornblendites show a considerable variation in the proportions of hornblende and pyroxene and are associated with and gradational to the hornblende pyroxenites of Tora Tigga.

Pyroxene Hornblendites. Forming a gradational lithology between pyroxene ultramafites and hornblendites, these consist of 65 to 97% hornblende, relics of clinopyroxene (up to 35%) and, in some, orthopyroxene (up to 10%). Opaque minerals and, locally, epidote, sphene, chlorite and carbonate are found in trace amounts. The hornblende features are the same as in the pyroxenites: it occurs in poikiloblasts, in spongy replacement of clinopyroxene as well as interstitially and penetrating the pyroxene. Relationships between hornblende grains are also similar to the other rocks and the hornblende-rich rocks are akin to hornblendites in many respects. The colour of the hornblende is the same as in the pyroxene ultramafites.

The orthopyroxene is commonly altered to talc, magnetite and carbonate. In rare cases, thin envelopes of fibry actinolitic amphibole separate the pyroxene from the enclosing hornblende. The fibry amphibole seems to be a lower grade alteration of pyroxene following hornblende formation. In some of the less altered pyroxeneites, felsic veins with subordinate apatite have produced hornblende on both sides. The textural details presented for the ultramafic rocks of Tora Tigga favour a replacement origin for most, if not all hornblende. For some of such features alternate explanations can be presented (cf. Park and MacDiarmid, 1964), but metasomatic replacement at high temperature (upper amphibolite-facies) seems to be the only process which can explain most of the textural as well as field aspects.

Monomineralic Hornblendites. These rocks display textural variations from pegmatitic to medium-grained facies. They are mostly hypidiomorphic and subequigranular, but allotriomorphic and equigranular textures also occur. The boundaries of the hornblende grains are straight or slightly curved and they tend to form triple point equilibrium angles of 120°. Such angles are attributed to result from static balance of three equal interfacial tensions (Smith, 1948, in Spry, 1969), annealing and recrystallization during metamorphism (Jackson, 1961; Moore, 1973). Deviations to lobate, dentate, embayed, and irregular boundaries also occur, the latter being more common in granulated rocks.

In a number of cases a hornblende grain may penetrate another, occasionally all the way through. In rare cases, veins consisting of medium-grained euhedral hornblende pass through coarse grains of hornblendes. More common are inclusions (euhedral to anhedral) of hornblende in hornblende (see Pl. 2A, B, C). These may represent complex deformational and metamorphic features or inclusions of magmatic– in secondary hornblende. More likely, the hornblende grains here may have enlarged themselves by using most of the units of adjacent hornblende by replacement (cf. Spry, 1969), possibly after fracturing of earlier grains. We do not know of such features in magmatic hornblendes but Harker (1932) has reported such inclusions in kyanite grade hornblende schists from Forfshire. Other "inclusions" found in hornblende are magnetite, ilmenite, rarely rutile, and secondary chlorite, epidote and sphene, however, opaque oxides also occur interstitially.

The hornblende is generally green or brownish green but some have thin margins of bluish green or greenish colour. Twinning is common and often multiple. It may be continuous, partial, or edge-type but a single grain usually contains only one of these types.

Plagioclase Hornblendites. These rocks contain fresh hornblende and up to 25% plagioclase (An40–45) that is mostly cloudy and commonly altered. The minor components of these rocks are the same as in the monomineralic hornblendites along with traces of rutile (some as inclusions in plagioclase) and quartz that do not appear to be secondary. Hashim body, the principal exposure of these rocks,

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PLATE 2

A. Microsketch of a hornblendite showing a large hornblende grain with two sets of fractures (F). The grain is crosscut by a vein consisting of euhedral to subhedral hornblende grains (Hbl) and magnetite (black).

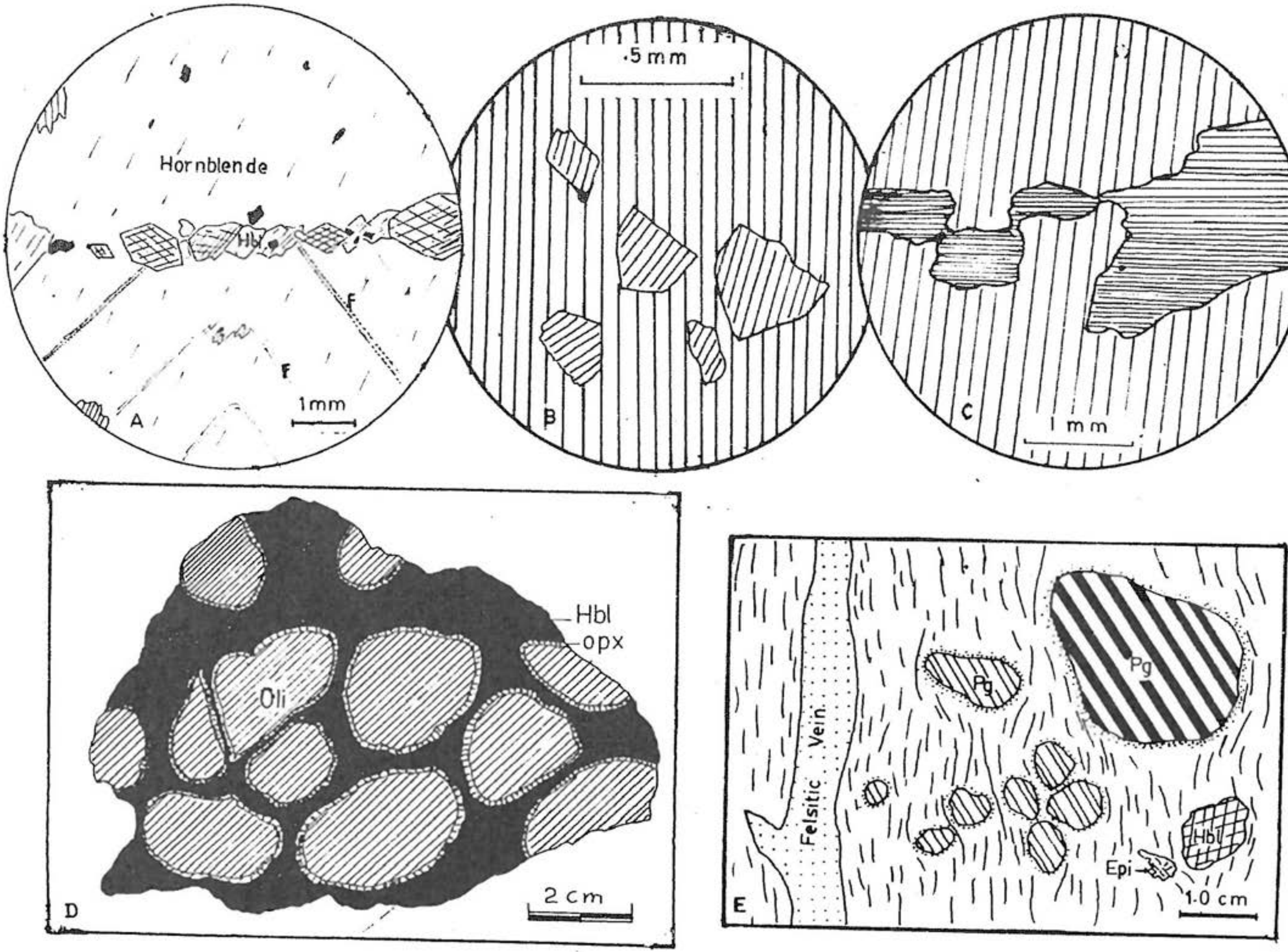
B. Angular inclusions of hornblende showing that the poikiloblastic hornblende here developed after granulation.

C. Complex relationship between two hornblende grains of similar colour and pleochroism. Is the smaller grain cross-cutting the larger and displays fracture-filling, is it a complex deformational feature or a replacement phenomenon? The last possibility appears attractive although it cannot be ascertained whether the smaller grain replaces the large (as we think) or vice versa.

D. A boulder from the southwestern part of Tora Tigga ultramafics. Hornblende matrix contains ellipsoidal aggregates of olivine surrounded by a thin shell of orthopyroxene.

E. A sketch showing mylonitic texture in the felsic dyke. Large porphyroclasts of plagioclase (Pg) and hornblende (Hbl) are embedded in abundant fine-grained matrix. The felsitic vein (very fine-grained texture) is parallel to the foliation of the matrix (small broken lines).

PLATE 2



Hornblende
Hbl
F
F
1mm
A
.5 mm
B
1 mm
C
Hbl
opx
Oli
2 cm
D
Felsitic Vein
Pg
Pg
Hbl
Epi
1.0 cm
E

shows a considerable variation in the plagioclase content; some parts are like the monomineralic hornblendites with only a percent or so of plagioclase. Compared to monomineralic hornblendites, these rocks seem to be less deformed and lack fine-grained textures, their hornblende is generally devoid of euhedral hornblende inclusions and multiple twins. Relics of pyroxenites have been found in some places in the Hashim as well as Tora Tigga bodies.

The anorthite content of the plagioclase is surprisingly low if it is assumed that the hornblendites are early cumulates of a layered intrusion along with the pyroxene- and olivine ultramafites. This observation, along with the occurrence of rutile inclusions in plagioclase, the presence of quartz, the complete lack of layering and other details are not in harmony with the idea of direct magmatic (cumulate) origin for the plagioclase hornblendites.

A thin mylonite zone bordering the Hashim body on the north consists of epidote, hornblende, plagioclase and quartz in a fine-grained matrix of these, opaque mineral(s), a turbid material, and epidote veins. This is a greenschist facies assemblage either derived from the amphiobolites or the hornblendites. Associated with this zone is a thin band of calc-silicate rock containing garnet, clinopyroxene, quartz, epidote and sphene. The origin of this rock is not clearly understood yet.

Enclaves. Ultramafic enclaves, texturally similar to the pyroxene ultramafites and having gradational contacts with the enclosing hornblendites, have been noted in some places. These range from pyroxene + hornblende ± olivine assemblages with a small degree of alteration to those completely altered to talc-tremolite-serpentine-chlorite. Although they have not been carefully studied, they appear to be relics rather than xenoliths. In a rare case in Tora Tigga, over 2cm large grapes of olivine aggregates are separated from the surrounding hornblende by a thin corona of orthopyroxene (Pl. 2D). The dunitic grapes contain green hornblende (that cuts the olivine and forms spongy poikiloblasts) and minor ore. Different mechanisms (late igneous, metamorphic, metasomatic) have been suggested for corona development (cf. Jan and Howie, in press). Those containing orthopyroxene + hornblende ± clinopyroxene are commonly considered to result from a reaction between calcic plagioclase and olivine, probably during obduction (Griffin and Heier, 1973). The total lack of plagioclase and spinel in the Tora Tigga rock and the abundance of hornblende can be better explained by regarding that metasomatism during obduction may have played the prinicpal role. This does not imply that orthopyroxene is also metasomatic; an earlier event may have produced an envelope of orthopyroxene (+other minerals) around olivine, followed by metasomatism.

FELSIC DYKES AND VEINS

Dykes and veins of felsic material, generally confined to the hornblendites, are found in the area. The entire Hashim body is cut through by a set of three more or less parallel dykes. These trend N26°E with northwesterly dips and reach up to 1.5m in thickness. The Tora Tigga hornblendite and peridotite are also cut by two dykes up to a meter thick, with NE strike and NW dip. Xenoliths of hornblendite are found in the dykes. Many veins, less than a centimeter thick generally, and forming networks in some places, are also found in the hornblendites, especially in the vicinity of the dykes. Some of these felsic and quartz-epidote veins appear to post-date deformation.

The dykes are gneissose and deformation has produced a mylonitic fabric consisting of over 75% groundmass, the remainder being porphyroclasts (Pl. 2E). The rocks appear to be "tonalitic" in composition, consisting essentially of plagioclase (~ An40), quartz, hornblende, and minor amounts of magnetite, apatite and epidote. The plagioclase reaches up to 55% and is usually cloudy; the hornblende is brownish green and contains apatite inclusions. In the Hashim dykes, some rocks consist of quartz+epidote+tremolite/actinolite+chlorite+ore±sphene±plagioclase. These may represent greenschist facies retrograde products of the dykes, but some epidote is of the earlier prograde episode. The felsic veins are medium- to fine-grained and comprise more than 90% plagioclase (An30–39), with small amounts of quartz, hornblende, epidote, rutile, biotite, garnet, ore, chlorite, apatite and white mica+(?)prehnite present in different rocks.

In addition to, and associated with, these rocks, fine- to very fine-grained felsitic rocks also occur. These consist of quartz and feldspar with minor magnetite. They display grain-size variability and very fine-grained parts may be "invaded" by fine-grained material. These veins may show branches that cut the matrix and plagioclase porphyroclasts of the felsic dykes. No chemical analyses are available and the fine-grained texture hinders the identification of the component minerals. There are two possibilities for the origin of the felsitic rocks. They may be pseudotachylite (later "devitrified") produced due to extreme deformation of the felsic dykes. On the other hand, if found to be truly rhyolitic, they might represent partial melting products accompanying amphibolite facies high-grade metamorphism.

ORIGIN OF THE TORA TIGGA ULTRAMAFITES

Due to lack of sufficient data, a definite and systematic scheme for the origin of the rocks cannot be codified. Chemical analyses of the rocks and their component minerals are particularly needed. However, some ideas based on our field and petrographic observations are presented here. The severe Himalayan tectonics have obscured the early history of the rocks and the growth of abundant hornblende has added further to the complexity, as in the Tinaquillo complex (MacKenzie, 1960).

The Olivine- and Pyroxene Ultramafites. A comparison with various types of ultramafic rocks associations (Wyllie, 1967, 1969; Jackson and Thayer, 1972; Moores, 1973) suggests that the Tora Tigga complex belongs either to alpine-type or stratiform complexes. Despite some zonal arrangement, petrographic and other details do not permit to classify the complex as concentric. Distinguishing criteria of alpine and stratiform complexes have been listed by a number of workers but the distinction is not always easy. Stratiform complexes caught in strong orogenic and deformational episodes may develop certain field features akin to those of alpine complexes, for example the Chilas complex (Khattak and Parvez, 1982). A number of deviations from the classic definition of alpine complexes have been reported from various parts of the world. Upadhyay and Neale (1979), thus, concluded that the special tectonic conditions necessary for the transport and emplacement are the only features which alpine rocks have in common.

Discordant contacts and disorderly distribution of rocks when compared to typical stratiform complexes; and the lack of chilled margins, cumulate textures and plagioclase phase are features akin to those of alpine ultramafic rocks. The occurrence of alpine ultramafites along the suture (MMT) near Shangla, Babusar, Jijal and elsewhere lends further support to this idea. The various alpine-type ultramafic rocks from north Pakistan have yet not been studied in sufficient detail to suggest whether they are the ultramafic cumulates of tholeiitic or komitiitic magma (cf. Naldrett and Cabri, 1976), or upper mantle slabs/diapirs; Jan and Howie (1981) suggested the latter alternative for the Jijal ultramafites. Nevertheless, it is generally agreed upon that they were obducted along the suture during the collision of the Kohistan island arc with the Indo-Pak plate.

Despite the above mentioned similarities, other features typical of alpine ultramafic rocks (e.g., podiform chromite deposits and abundance of olivine over pyroxene) are missing in the Tora Tigga complex. The meta-gabbros/norites also do not resemble alpine (oceanic) gabbros (cf. Coleman, 1971). As an alternative, it can be suggested that these rocks belong to the basal part of the Chilas layered complex. This complex, caught up in the Himalayan orogenic and metamorphic episodes, possesses a number of features of alpine rocks (e.g. discordant and re-intruded ultramafic rocks, deformational features, recrystallization and general lack of cumulate textures, and so on). All the lithologies in Tora Tigga (except hornblendites) are abundant in the Chilas complex, as are olivine coronites. The meta-gabbros/norites, with strongly pleochroic hypersthene and anorthositic associates, are identical to those of Chilas. The magma of the Chilas complex has been considered (high-alumina) calc-alkaline (Jan and Kempe, 1973; Jan, 1977, 1980; Bard *et al.,* 1980) or tholeiitic (Shams, 1975). Jan (1980), Jan and Asif (in press) and Bard (this volume) regard that the Chilas magma was intruded in the southern amphibolites during the early stages of formation of the Kohistan island arc.

Hornblendites. These constitute more than 50% of the ultramafites in Tora Tigga and well over 90% in Hashim exposures. Patches, pools, veins, dykes and larger bodies of such rocks have also been reported from other parts of the southern amphibolite belt, especially in Timurgara area (Kakar *et al.,* 1971; Khan, 1969; Khan and Saleemi, 1972; Arbab and Khan, 1973; Chaudhry *et al.,* 1974; Ahmed, 1978; Jan, 1979). The largest of these bodies measures 9km^2 near Assagai village in the Timurgara quadrangle. Some of these bodies are closely associated with olivine- or pyroxene ultramafites, others occur in dioritic (meta-gabbroic) rocks and (banded)amphibolites. A common origin for all these bodies is eminent irrespective of their location and rock association.

Hornblendites can originate from:

A) Solidification of a basic (hornblenditic) magma under high water pressure.

B) As cumulate rocks, possibly accompanying olivine- pyroxene ultramafites, at the bottom of a differentiated magma chamber.

C) Metamorphic segregation.

D) Metasomatic replacement of pre-existing rocks.

Field and petrographic studies preclude the first three possibilities for the Tora Tigga hornblendites. Neither of the two magmatic origins (A and B) is compatible with most of the following observations: 1) the highly variable size of the hornblendite bodies and their contact relationship with host rocks, 2) considerable variability in the modal composition of the rocks, 3) drastic variation (from fine-grained to 30cm) in the size of the hornblende, sometimes in close distances within one outcrop, 4) lack of chilled margins, 5) replacement textures, and penetrating and other complicated relations between adjacent hornblende grains, 6) gradual increase of hornblende towards the margins of some neighbouring rocks, 7) variability in the associated rocks of different hornblendites of the region, 8) presence of interstitial or enclosed magnetite seemingly related to hornblende formation, 9) presence of rutile and quartz, locally as inclusions, in the plagioclase hornblendite, 10) the low anorthite content of the plagioclase for rocks that, if of cumulate origin, formed in early stages of crystallization, and 11) the lack of bodies of the size of Tora Tigga hornblendites in the Chilas and other stratiform complexes.

Metamorphic differentiations/segregation is brought about by the gradients of chemical and/or mechanical potential. In normal cases, the expelled material usually contains cations of larger sizes (K, Na, Ca, etc.), while the remaining material contains smaller cations (Mg, Fe, Cr, Ni, etc.) (Cotrell, 1948). Following this rule, the formation of monomineralic hornblendites in different associations is difficult to explain. Many of the features presented in this paper are incompatible with this idea. Besides, metamorphic differentiation involves small distances and bodies of squares of kilometers are difficult to originate as such. However, such a process may have been active in the banded amphibolites.

Ultramafic rocks can be produced by metasomatism, as in Greenland (Sorensen, 1967), and there are many well-documented examples in which metasomatic/metamorphic processes have been invoked to explain the concentration of hornblende in veins and pockets. The appinitic (hornblende-plagioclase) rocks of Glenelg-Ratagain complex (Nicholls, 1951), and Scottish Highlands (Bowes and

McArthur, 1976), appinitic pockets in the diorites of Jersey (Key, 1977), the hornblende-rich rocks of Glen-Tilt (Deer, 1950), hornblendic spots and meladiorite layers in Channel Island (Bishop and French, 1982), the hornblendites of Grabal Hill-Glen Fyne (Nockolds, 1941) and the hornblende-rich pegmatites of upper Swat (Jan, 1977) and Canyon Mountain, Oregon (Thayer and Himmeiberg, 1968) have all been considered metasomatic in origin. The hornblenditic rocks of the Jijal complex are regarded by Jan and Howie (1981) to represent internally metasomatised cumulates during granulite facies metamorphism.

Metasomatism seems to be the most reasonable means for the formation of the Tora Tigga hornblendites. It is the only process which is not at odds with the textural and field features, and to the general restriction of felsic dykes and veins to hornblendites. The sharp contacts of the hornblendites with their host rocks in some cases may be a reflection of minor structural adjustments post-dating their formation. It appears that the hornblendites were produced in at least two major phases with the final product being very coarse-grained (pegmatitic) hornblendites cutting through the coarse-grained hornblendites. The source of the solutions responsible for metasomatism is not clear, but they could be the precursors of the felsic dykes and veins. Conversely, the latter may themselves be the final products of metasomatism, or partial melting during upper amphibolite facies metamorphic conditions. Bishop and French (1982) have described such veins from Channel island and related them to metasomatism and melting under high gas pressure. A geochemical investigation is planned in near future for a better understanding of the complex.

Acknowledgements: M.U.K. Khattak is thanked for his useful suggestions and Tazeem Tahirkheli for help in petrography, and Mujeeb-ur-Rehman for constructively reading an earlier draft of this paper. We would also like to thank Prof. B.E. Leake and Drs. R.F. Symes, M.J. Le Bas, K.A. Butt and R.N. Khan for their comments on origin of hornblenditic rocks. M.B. and A.G. wish to express their gratitude to Mr. Sharifullah Khan of Munda for his hospitality and help during the field-work. The research was partially financed by the National Centre of Excellence in Geology, University of Peshawar.

REFERENCES

Ahmed, Z., 1978. Petrology of the Taghma area, Swat district, N.W.F.P. Pakistan. Geol. Bull. Univ. Punjab, 15, 25–29.

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

Arbab, M.S.H. & Khan, R.N., 1973. Geology of Dir and northern part of Timurgara quadrangle, N.W.F.P., Pakistan. Geol. Surv. Pak. Inf. Rel. 49.

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

———, Maluski, H., Matte, Ph. & Proust, F., 1980. The Kohistan sequence: Crust and mantle of an obducted island arc. Geol. Bull. Univ. Peshawar (Spec. Issue) 13, 87–94.

Bishop, A.C. & French, W.J., 1982. Nature and origin of meladiorite layers in northern Gurnsey, Channel Islands. Min. Mag. 46, 301–321.

Bowes, D.R. & McArthur, A.C., 1976. Nature and genesis of appinite suite. Krystalinikum 12, 31–46.

Butt, K.A., Chaudhry, M.N. & Ashraf, M., 1980. An interpretation of petrotectonic assemblage west of W. Himalayan syntaxis in Dir district and adjoining areas in northern Pakistan. Geol. Bull. Univ. Peshawar (Spec. Issue) 13, 79–86.

Chaudhry, M.N., Kausar, A.B. & Lodhi, S.A.K., 1974. Geology of Timurgara Lal Qila area, Dir district N.W.F.P. Geol. Bull. Punjab Univ. 11, 53–74.

Coleman, R.G., 1971. Plate tectonic emplacement of upper mantle peridotites along continental edges. J. Geophys. Res. 76, 1212–1222.

Cotrell, A.H., 1948. "Effect of solute atoms on the behaviour of dislocations" in Report of a conference on strength of solids. Phys. Soc. London, 30–38.

Coward, M.P., Jan, M.Q., Rex, D., Tarney, J., Thirlwall, M. & Windley, B.F., 1982. Geo-tectonic framework of the Himalaya of N. Pakistan. J. Geol. Soc. Lond. 139, 299–308.

Deer, W.A., 1950. The diorites and associated rocks of the Glen Tilt Complex, Perthshire–II. Diorites and appinites. Geol. Mag. 87, 181–195.

Griffin, W.L. & Heier, K.S., 1973. Petrological implications of some corona structures. Lithos 6, 315–335.

Harker, A., 1932. Metamorphism: A study of the transformation of rock-masses. Methuen & Co. Ltd., London.

Jackson, E.D., 1961. Primary textures and mineral association in the ultramafic zone of the Stillwater Complex, Montana. U.S. Geol. Surv. Prof. Paper 358, 111–132.

——— & Thayer, T.P., 1972. Some criteria for distinguishing between stratiform, concentric and alpine peridotite-gabbro complexes. Proc. 24th Int. Geol. Cong. Montreal 2, 289–296.

Jan, M.Q., 1977. The Mineralogy, Geochemistry and Petrology of Swat Kohistan, NW Pakistan. Unpub. Ph.D. Thesis, Univ. London.

——— 1979. Petrography of pyroxene granulites from northern Swat and Kohistan. Geol. Bull. Univ. Peshawar (Spec. Issue) 11, 65–87.

——— 1980. Petrology of the obducted mafic and ultramafic metamorphites from the southern part of the Kohistan island arc sequence. Geol. Bull. Univ. Peshawar (Spec. Issue) 13, 95–108.

——— & Asif, M., In press. Geochemistry of tonalites and quartz (diorites) of the Kohistàn-Ladakh ('Transhimalayan') granitic belt in Swat, NW Pakistan. In Granites of Himalaya, Karakoram and Hindukush (F.A. Shams, ed.).

——— & Howie, R.A., 1981. The mineralogy and geochemistry of the metamorphosed basic and ultrabasic rocks of the Jijal complex, Kohistan, NW Pakistan. Jour. Petrology 22, 85–126.

——— & ——— 1982. Hornblendic amphiboles from basic and intermediate rocks of Swat-Kohistan, NW Pakistan. Amer. Mineral. 67, 1155–1178.

——— & ——— In press. Some minor olivine gabbros and metamorphosed ultramafic rocks from Swat, NW Pakistan. Geol. Bull. Univ. Punjab. (Spec. Issue).

——— & Kempe, D.R.C., 1973. The petrology of the basic and intermediate rocks of Upper Swat, Pakistan. Geol. Mag. 110, 285–300.

Kakar, S.K., Badshah, M.S. & Khan, J., 1971. The geology of the Jandul valley, western Dir. Geol. Bull. Univ. Peshawar 6, 54–73.

Key, C.H., 1977. Origin of appinitic pockets in the diorites of Jersey, Channel Islands. Min. Mag. 41, 183–192.

Khan, R.N., 1969. Geology of Timurgara quadrangle, Dir, NW Pakistan. Geol. Surv. Pak. Unpubl. Rept.

Khan, R.N. & Saleemi, B.A., 1972. Geology of Kotegram and Akhagram quadrangle, Dir district and Swat, N.W.F.P., Pakistan. Geol. Surv. Pak. Inf. Rel. 80.

Khattak, M.U.K. & Parvez, M.K., 1982. A petrographic account of the east-central part of the Chilas Complex, northern Pakistan. Unpub. M.Sc. Thesis, Univ. Peshawar.

MacKenzie, D.B., 1960. High-temperature alpine-type peridotite from Venezuela. Geol. Soc. Amer. Bull. 71, 303–318.

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

Naldrett, A.J. & Cabri, L.J., 1976. Ultramafic and related mafic rocks: Their classification and genesis with special reference to the concentration of nickel sulfides and platinum group elements. Econ. Geol. 71, 1131–1158.

Nicholls, G.D., 1951. The Glenelg-Ratagain igneous complex. Quart. J. Geol. Soc. Lond. 106, 309–344.

Nockolds, S.R., 1941. The Garabal Hill-Glen Fyne igneous complex. Quart. J. Geol. Soc. Lond. 96, 451–511.

Park, C.F., Jr. & MacDiarmid, R.A., 1964. Ore Deposits. W.H. Freeman & Co. San Fransisco.

Shams, F.A., 1975. The petrology of the Thak valley igneous complex, Gilgit Agency, northern Pakistan. Accd. Naz. Lincei, Ser. 8. 59, 453–464.

Spry, A. 1969. Metamorphic Textures. Pergamon Press, New York.

Sorensen, H., 1967. Metamorphic and metasomatic processes in the formation of ultramafic rocks. In "Ultramafic and Related Rocks". (P.J. Wyllie ed.), Wiley, New York, 204–211.

Tahirkheli, R.A.K., 1982. Geology of Himalaya, Karakoram and Hindukush in Pakistan. Geol. Bull. Univ. Peshawar (Spec. Issue) 15, 1–51.

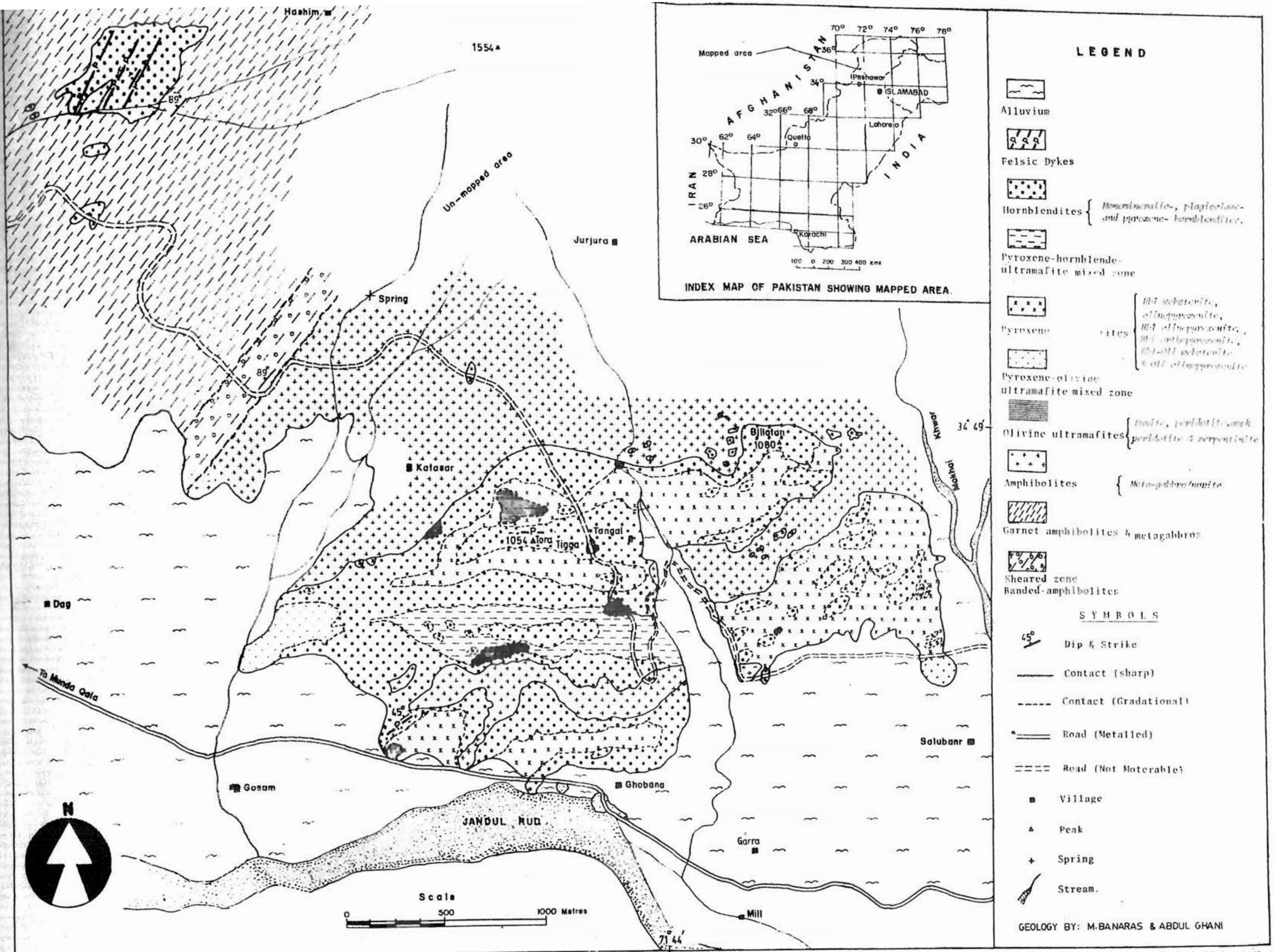
———, Mattauer, M., Proust, F. & Tapponier, P., 1979. The India-Eurasia suture zone in northern Pakistan: Synthesis and interpretation of recent data at plate scale. In 'Geodynamics of Pakistan' (A. Farah & K.A. DeJong eds.). Spec. Publ. Geol. Surv. Pak., Quetta, 124–130.

Thayer, T.P. & Himmelberg, G.R., 1968. Rock succession in the alpine-type mafic complex at Canyon Mountain, Oregon. 23rd Int. Geol. Cong. 1, 175–186.

Upadhyay, H.D. & Neale, E.R.W., 1979. On the tectonic regimes of ophiolite genesis. Earth and Plan. Sci. Lett. 43, 93–102.

Wyllie, P.J., 1967. Ultramafic and Related Rocks. Wiley, New York, 19–38.

——— 1969. The origin of ultramafic and ultrabasic rocks. Tectonophysics, Spec. Issue 7, 437–456.



Hashim
1554
89°
Un-mapped area
Jurjura
Spring
89°
Katasar
Bjiloton
1080
34° 49'
Khwar
Mokhai
Tangai
1054 Tora Tigga
Dag
To Munda Qala
45°
Salubanr
Gosam
Ghobana
JANDUL RUD
Garra
N
Scale
0
500
1000 Metres
Mill
71° 44'
70° 72° 74° 76° 78°
Mapped area
36°
34°
Peshawar
ISLAMABAD
AFGHANISTAN
32° 66° 68°
Lahore
30° 62° 64°
Quetta
INDIA
IRAN
28°
26°
ARABIAN SEA
Karachi
100 0 200 300 400 Kms
INDEX MAP OF PAKISTAN SHOWING MAPPED AREA.
LEGEND
Alluvium
Felsic Dykes
Hornblendites
Monominoralic-, plagioclase- and pyroxene- hornblendite.
Pyroxene-hornblende-ultramafite mixed zone
Pyroxenites
Pyroxene-olivine ultramafite mixed zone
Olivine ultramafites
Amphibolites
Garnet amphibolites & metagabbros
Sheared zone Banded-amphibolites
SYMBOLS
45°
Dip & Strike
Contact (sharp)
Contact (Gradational)
Road (Metalled)
Road (Not Moterable)
Village
Peak
Spring
Stream.
GEOLOGY BY: M.BANARAS & ABDUL GHANI