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ULTRAMAFIC AND MAFIC ROCKS OF THURLY GAH AND THEIR RELATIONSHIP TO THE CHILAS COMPLEX, N. PAKISTAN

M. ASIF KHAN[1], M. HABIB[2] & M. QASIM JAN[3]
[1]Deptt. of Geology, Imperial College of Science and Technology, London.
[2]Oil and Gas Development Corporation, Pakistan.
[3]NCE in Geology, University of Peshawar.

ABSTRACT

Detailed field and petrographic studies in Thurly area substantiate the idea of a two-fold subdivision of the Chilas Complex. Much of the area is occupied by the association of "Main Norites" with subordinate pyroxenites and anorthosites displaying only local layering. Apparently intrusive into these is the association of ultramafic-mafic rocks occurring principally in a 2.5x1 km lensoid body. These possess well-developed sedimentary features, especially layering, and comprise dunite, peridotites, pyroxenites, troctolite, norite, anorthosite, and olivine/pyroxene pegmatites. There are distinct differences in the mineralogy of the two associations, especially in the composition of plagioclase and oxide minerals. It is suggested that the ultramafic-mafic association was derived from a picritic magma emplaced in the floor of a crystallizing (main) noritic magma. There is a strong concordance in the planar structures of the two associations and the crystallization of the ultramafic-mafic rocks apparently preceded all deformational events.

INTRODUCTION

The Chilas complex, a 300 km long and up to 40 km wide lopolithic body of norites and associated rocks is probably the largest single mass of its type in the world. It holds a significant geological position in the Kohistan sequence, a recently recognized remnant of a Mesozoic intra-oceanic island arc entrapped between the colliding Indian and Eurasian plates (Tahirkheli *et al.*, 1979; Bard *et al.*, 1980; Bard, 1983a, b; Coward *et al.*, 1982, 1985). The predominantly noritic complex locally contains several isolated bodies of ultramafic rocks, especially in the vicinity of Chilas. These, accompanied by a series of mafic differentiates, constitute an association whose field, petrographic, and chemical characteristics are distinct from those of the main noritic rocks of the complex (Jan *et al.*, 1984; Asif Khan *et al.*, in prep.).

Petrographic accounts have been presented from various parts of the Chilas complex (i.e. Jan, 1970, 1979; Desio, 1974; Shams, 1975 from the Indus Kohistan; Jan and Mian, 1971; Jan and Kempe, 1973 from Swat Kohistan; and Chaudhry *et al.*, 1974 from Dir Kohistan). Recently, Jan *et al.* (1984) have given a comprehensive field and mineralogical account of the constituent rock-types of the Chilas complex. The present study is a further attempt to elaborate these aspects of the complex, with emphasis on the study of

(1) mode of emplacement of the ultramafic and associated mafic rocks in the earlier main norite rocks of the complex, and

(2) mutual relationship between the differentiated ultramafic and mafic rocks, and of these rocks with the main noritic rocks of the complex.

During the course of this work, we have restricted ourselves to a detailed study of a single occurrence of the ultramafic and associated mafic rocks exposed at the mouth of Thurly Gah. These were selected due to their easy access and reasonably large aerial extent (Fig. 1). The studied area is located on the Karakoram Highway (KKH), about 30 km west of Chilas (long. 73° 50′ E., lat. 35° 35′ N.). A field work of two weeks was carried out during Christmas 1983, followed by several short revisits, and consisted mainly of geological mapping on a scale of 1 cm = 200 m. Most of the 90 samples collected from different lithological units were cut into thin sections for textural and modal studies. Additionally, a number of microprobe and whole rock analyses were carried out by M.A.K. (at Leeds and Leicester Universities and, lately, in the Imperial College, London) and by M.Q.J. (at Leicester and Peshawar Universities); details of these would be presented subsequently.

PETROGRAPHY

Association of the main noritic rocks

The bulk of the Chilas complex is formed of rocks belonging to this association. These are medium-grained rocks, mostly homogeneous and at places well-foliated. Layering is only local and not well-developed. In the studied area, like elsewhere in the complex, the predominant rock-type is gabbronorite, generally comprising of plagioclase (labradorite to andesine), orthopyroxene (5–25%), clino-pyroxene (15–20%), magnetite and titanomagnetite (up to 6%), and apatite (1%) (Table 1). Due to variations in the proportions of the plagioclase and ferromagnesian minerals, the norites locally grade into either leuco- or mela-gabbronorites. Pyroxene anothosite and plagioclase pyroxenite are relatively uncommon and restricted to rare layered zones, where they occur in rhythmically alternating layers.

The gabbronorites locally contain quartz, generally less than 5% but in one sample reaching up to 13%. Minor amounts of biotite (< 2%) are normally found in the quartz-bearing gabbronorites. About 2 km upstream in Thurly Gah, there is a restricted occurrence of tonalites. These rocks contain hornblende and

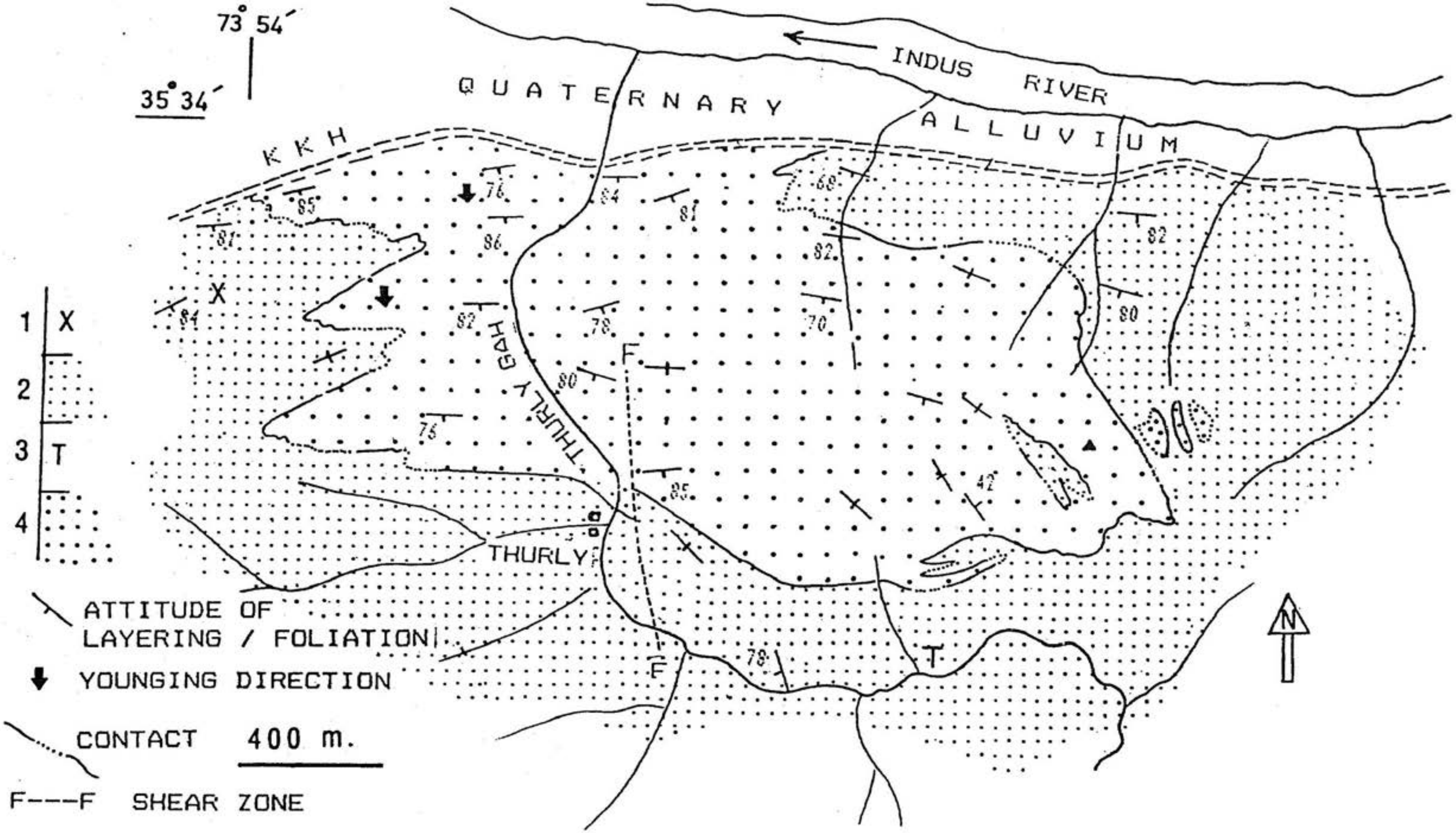

Fig. 1. Geological map of a part of the Chilas complex around the Indus River-Thurly Gah confluence showing disposition of the ultramafic and associated mafic rocks in the main noritic rocks. 1) Calc-silicate xenoliths (gar, cpx, qz, or, scap, ct, ore, epi). 2) Rocks of the main noritic association. 3) Tonalites. 4) Ultramafic and associated mafic rocks. (Geology by M. Asif Khan, M. Habib, Shahbaz Khan, S. Rehman and J. Pervez).

biotite instead of pyroxenes (Table 1). The relationship of these rocks with the noritic rocks is obscured by intense deformation and it is not clear whether they represent local differentiates of the main noritic association or separate intrusions belonging to the Kohistan batholith. Hornblendic amphibole, though a primary phase in the tonalites and some quartz-bearing gabbronorites, mostly occurs as a retrogressive product of the pyroxenes. It is generally less than 10% but in some samples may reach up to 40%.

TABLE 1. MODAL COMPOSITION OF THE NORITIC ASSOCIATION ROCKS.

Sample Code	CH111 1	CH107 2	CH146 3	CH153B 4	CH153A 5	CH132 6
PG	55.0	48.0	50.0	70.0	0.0	51.0
OPX	20.0	18.0	26.0	18.0	15.0	0.0
CPX	15.0	18.0	20.0	7.0	60.0	0.0
HB	0.0	0.0	3.0	5.0	25.0	8.0
QZ	5.0	13.0	1.0	0.0	0.0	30.0
ORE	4.0	2.0	0.0	0.0	0.0	0.0
BIO	1.0	1.0	0.0	0.0	0.0	11.0
AP	tr	tr	tr	tr	0.0	tr
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

1) Gabbronorite. 2) Quartz-bearing gabbronorite. 3) Mela-gabbronorite. 4) Anorthositic norite. 5) Pyroxenite. 6) Tonalite.

PG: Plagioclase; OPX: Orthopyroxene; CPX: Clinopyroxene; HB: Hornblende; QZ: Quartz; BIO: Biotite; ORE; Magnetite and titanomagnetite; AP: Apatite; tr: trace amounts.

Association of the ultramafic-mafic rocks

The rocks of this association in the studied area include dunites, peridotites, pyroxenites, troctolite, norites, anorthosite and pyroxene/olivine pegmatites. They show layering and some are distinctly foliated.

Ultramafic rocks

These rocks form the bulk (> 70% by volume) of the association in the studied area and consist principally of olivine-rich rocks such as dunites and peridotites. Minor members include chromitites and pyroxenites. Modal compositions of some of these, together with representative mafic members of the association, are given in Table 2.

The dunites are mostly monomineralic, comprising almost exclusively of medium-sized anhedral olivine grains in a cumulus framework. In some of the dunites, minor proportions of sulphides and chrome spinels occur both as included

TABLE 2. MODAL COMPOSITION OF THE ULTRAMAFIC AND ASSOCIATED MAFIC ROCKS.

Sample Code	CH116 1	CH124 2	CH151A 3	CH129 4	CH238B 5	CH238B 6	CH144 7
PG	0.0	0.0	0.0	64.0	0.0	81.0	45.0
OL	95.0	20.0	10.0	30.0	0.0	0.0	0.0
OPX	2.0	78.0	35.0	5.0	15.0	18.0	18.0
CPX	0.0	0.0	45.0	0.0	81.0	1.0	27.0
HB	2.0	0.0	5.0	0.0	4.0	0.0	8.0
ORE	1.0	2.0	5.0	1.0	0.0	0.0	2.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1) Dunite. 2) Olivine orthopyroxenite. 3) Olivine websterite. 4) Troctolite.
5) Websterite. 6) Noritic bytownite-anorthosite. 7) Bytownite norite-gabbro.
O1: Olivine; Ore: Spinels and/or sulphides. The rest of the abbreviations are the same as in Table 1).

as well as interstitial minerals, suggesting a coprecipitation with olivine. Although minor amounts of orthopyroxene and clinopyroxene occur interstially in some of the samples, these dunites can overall be defined as adcumulates (Wager, 1960; Irvine, 1982) on the basis of the low contents of the intercumulus minerals.

Some of the dunites contain up to 10% of short, prismatic clinopyroxene grains dispersed in the granular mass of olivine. Being coarser than the olivine grains, they furnish the rock with a spotty appearance. Their euhedral form and lack of olivine inclusions point to a cumulus cotectic precipitation with olivine.

Both the varieties of the dunites may rarely contain large orthopyroxene that, like clinopyroxene grains, may have inclusions of olivine. These poikilitic grains probably developed at the expense of local pockets of intercumulus liquid, locally entrapped in the cumulus framework of olivine grains.

The peridotites, in contrast to the dunites, do not occur as discrete, continuous outcrops, and are restricted to thin (milimeter-scale) layers alternating with the dunites. These rocks are relatively finer grained and are composed principally of olivine and one or two pyroxenes. The modal proportions of these minerals are highly variable even within the entity of a single layer. Amphibole and spinel are minor but common constituents. The two phases may occur in intergrowths, surrounding plagioclase in a few cases, suggesting that they are a product of a reaction between calcic plagioclase and mafic phases (Jan *et al.*, 1984). Texturally the peridotites can be described as allotriomorphic, since all the phases are characterized by anhedral polygonal grains. Where subordinate in proportion, the olivine occurs as an interstitial phase between the pyroxene grains.

The chromitites constitute less than 0.1% of the ultramafic exposures and occur as small irregular patches, lenses, veins and deformed and discontinuous layers. They tend to be monomineralic, however, olivine (in some altered to chlorite/serpentine) may occur as an interstitial mineral, exceeding 10% in some of the chromitites. Some layers show a gradation from chromitite base to chromite-bearing dunite top. The texture is characteristically adcumulus, similar to the dunites.

The pyroxenites are uncommon and are restricted to thin layers, mostly around 1mm in thickness but reaching up to 2 cm in rare cases. They are normally found interlayered either with bytownite-norites or bytownite-anorthosixes, but rarely also with other ultramafic members. The pyroxenites are texturally granoblastic, comprising mostly of polygonal grains of orthopyroxene and clinopyroxene, having straight to curved grain boundaries and triple junctions. In some pyroxenites, larger grains of pyroxene are set in the overall granoblastic mosaic of finer grains. These porphyroclasts have survived recrystallization but display deformation features such as kinking, undulose extinction and deformation twinning. The pyroxenites contain a variable but subordinate amount of plagioclase. Trace amounts of sulphides and, depending upon retrogression, amphibole occur in some rocks.

Mafic rocks

The mafic rocks of the association are of two types, defined by the presence or absence of olivine. The olivine-bearing ones have a simple primary mineral assemblage comprising olivine, plagioclase, clinopyroxene and orthopyroxene. Amphibole and amphibole-spinel symplectites, together with some orthopyroxene, are later reaction products, developed at the expense of plagioclase and olivine. The mutual proportions of plagioclase and ferromagnesian minerals are variable, furnishing a range of mafic rocks from mela-troctolites to olivine-anorthosites.

The olivine-free rocks of the association include norites and anorthosites. The mineral assemblages in these are almost the same as those of the norites and anorthosites of the main noritic association (Tables 1 & 2), but there are substantial chemical differences (Table 3). The most conspicuous distinguishing feature is the composition of plagioclase, being bytownitic (very rarely anorthitic) in the mafelsic rocks associated with the ultramafic rocks and labradorite/andesine in the rocks of the main noritic association. Hereafter in this paper we will term the norites and anorthosites associated with the ultramafics as "bytownite-norites and "bytownite-anorthosites" for the sake of clarity. Texturally, the mafic rocks of this association may be homogeneous, foliated and layered. They occur most commonly as interlayers (some a few meters thick) with the ultramafic members of the association. However, some of them form dykes cutting mafic-ultramafic rocks. Their texture is mostly medium-grained granoblastic with rare pyroxene porphyroclasts.

TABLE 3. A COMPARISON BETWEEN THE ROCKS OF THE MAIN NORITIC ASSOCIATION AND ULTRAMAFIC-MAFIC ASSOCIATION.

MAIN NORITIC ASSOCIATION	ULTRAMAFIC-MAFIC ASSOC.
1) Restricted range of rock types, gabbronorites with subordinate amounts of Qz-bearing leuco-gabbronorite, mela-gabbronorites, Pg-bearing pyroxenites, pyroxene-bearing anorthosites, Hyp-Qz diorites and ?tonalites.	1) Broader range of rock types including dunites, peridotites, chromitites, pyroxenites, troctolites, norites, anorthosites, and pyroxene/olivine pegmatites.
2) Quartz, biotite, and apatite may be amongst the constituent minerals.	2) Characteristic absence of minerals like quartz, biotite, and apatite.
3) Olivine is altogether absent.	3) Olivine is an essential constituent of ultramafic rocks and troctolites.
4) Opaque minerals characteristically being iron- or iron-titanium oxides (magnetite, titanomagnetite, ilmenite).	4) Iron oxides are only rarely present. The predominant opaque phases include chromite, spinels, and sulphides.
5) Composition of the main mineral phases : PG: An 45-61 Cpx: En 38-43, Fs 14.7-6.5, Wo 47-50 Opx: En 54-69	5) Composition of the main mineral phases : PG: An 95-69 En: 61.5-88 Cpx: En 43-47.8, Fs 7.5-1.9, Wo 49.3-50.3
6) General scarcity of the sedimentary type features.	6) Abundance of sedimentary structures, particularly layering.

Mineral abbreviations same as in Table 1 and 2.

MODE OF EMPLACEMENT AND FIELD FEATURES

Association of the main noritic rocks

The main noritic rocks of the Chilas complex as a whole are fairly homogeneous and monotonous. In the studied area, they are mostly medium-grained and granular to foliated. Along the top of the ridge on the western side of Thurly Gah, however, these rocks are moderately to strongly foliated, the foliation being defined by the tabular grains or lenticular aggregates of pyroxenes. Alternating isomodal layers of pyroxene-anorthosites and plagioclase-pyroxenites are observed at places.

As a whole this association is made up of a single continuous mass, but about 1 km east of the Thore bridge on KKH there is about a meter thick norite dyke with xenoliths of the host norite (Fig. 2). The dyke-rock is not much different from the host rocks in composition except for a slightly higher proportion of amphibole and lesser of pyroxenes. Similar minor dykes have also been reported from Swat (Jan, 1979). The occurrence of such cross-cutting noritic bodies, in our opinion, suggests subsolidus mobility (i.e. plastic flow of crystal mush) of the noritic rocks, but it is also possible that they represent intercumulus liquid or there were more than one phase of the noritic magma.

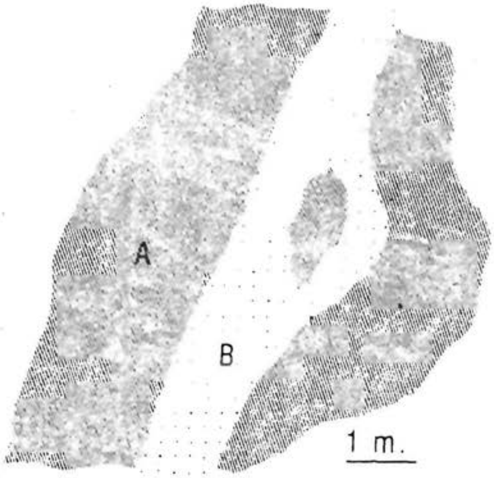

Fig. 2. An amphibole norite dyek (B) intruding and carrying a xenolithic block of the gabbronorite (A), suggesting the presence of more than one phase of noritic magma or syn-crystallization mobility of the intercumulus liquid into contemporary fractures.

Association of ultramafic and mafic rocks

This association of rocks displays some spectacular and interesting field features. The rocks constitute an E-W elongated mega-lens measuring 2.5x1 km (Fig. 1). Most of the northern half of the lens is eroded and concealed under river alluvium and sand. The southern contact is sharp (Fig. 3) and apparently conformable to the attitude of foliation in the main noritic rocks as well as to

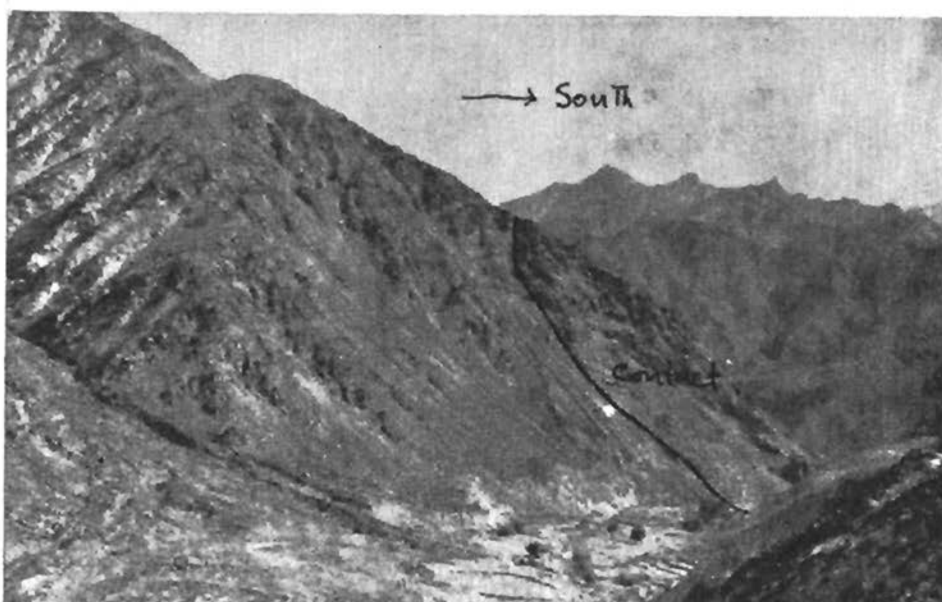

Fig. 3. A broad view of the ultramafic-mafic body (left 2/3 of picture) exposed in the Thurly Gah. Note the steeply oriented southern contact.

that of foliation and layering in the lens itself. The lateral terminations of the lense are characterised by several "appophyses" extending outward from the main core. These projections are wedge-shaped, gradually tapering and pinching outward into the surrounding noritic rocks. Although such a mode of emplacement suggests an intrusive relationship between the rocks of the ultramafic-mafic association and those of the main noritic association, there is an incredible concordance amongst the planner structures present in the two associations. There also are large blocks of the main noritic rocks in the ultramafic rocks and, several meters south of the southern contact, small "plugs" and dykes of the ultramafic rocks intrusive into the main noritic rocks.

The other field features of the ultramafic and associated mafic rocks include

a) sedimentary-type structures such as layering and syn-sedimentary deformation (Fig. 4), and

b) cross-cutting field relations between the various members of the association.

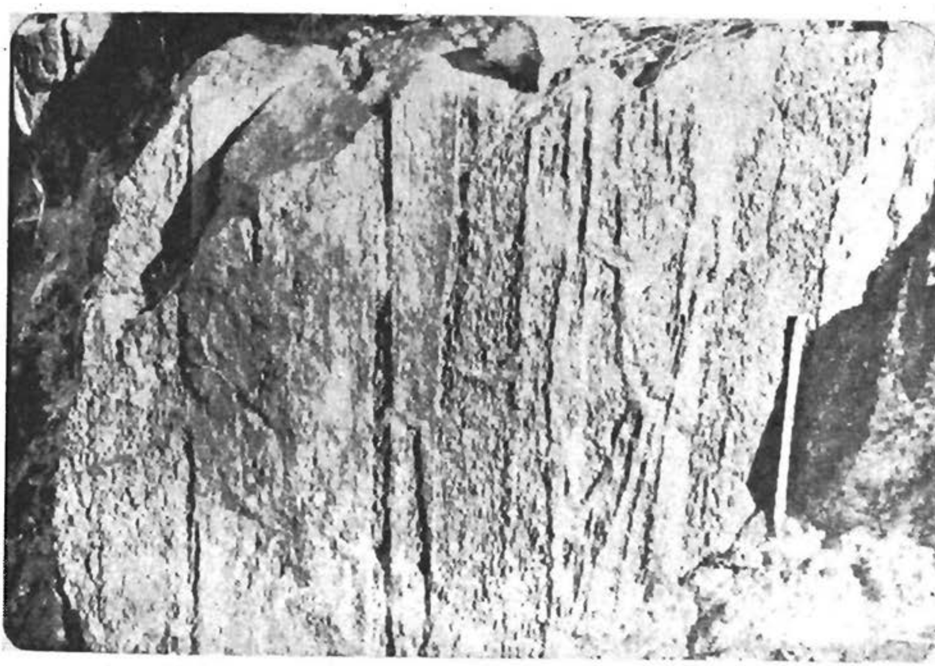

Fig. 4. Syn-depositional deformation features as observed in an interlayered plagioclase-bearing pyroxenite and bytownite-norite sequence. In the right half of the sequence, a syn-depositional fault disturbs part of the sequence, and in the lower central part an S-shaped slump fold can be observed.

Sedimentary-type features

Unlike the main noritic rocks, this association displays a good number of structures typical of stratiform complexes. Layering is the best developed sedimentary feature in the studied part of the complex. It occurs both in the ultramafic and mafic rocks but quite a large part of the dunites in the core of the mega-lens is massive. Two types of layering have been recorded in the studied area.

1) Layering comprising a set of rhythmically alternating isomodal layers of contrasting composition. This type of layering is common between the ultramafic and mafic members of the association forming thick sequences exposed at the western face of Thurly Gah (Fig. 5). The individual layers in these sequences may reach up to 2 m, but normally are between 2 to 20 cm thick. Isomodal inter layering also occurs between various ultramafic members. In such cases, however, the individual layers hardly exceed a few centimeters in thickness, most being on milimeter sacle.

2) Layering comprising sequences of graded layers. This type is a common feature of the ultramafic and associated mafic rocks elsewhere in the Chilas complex. However, in the Thurly area, graded layers are uncommon and when present are only vaguely developed (Fig. 6). Some of the chromitite layers, however, show well-developed gradations from pure chromitite base grading upward into chromite-bearing dunites. These graded layers generally alternate with isomodal dunite layers, a style of layering common in the Skaergaard intrusion and defined as intermittent layering by McBirney and Noyes (1979). The thickness of both the individual layers as well as that of the layered zones is limited, reaching up to 2 cm and 1 m respectively.

Cross-cutting field relations

The discordant relationships between the various members of the association are fairly complex, and are imprinted on the predominant relationships of conformable interlayering. The following types of discordant relations have been noted in the ultramafic and associated mafic rocks.

1) At several places in the studied area both layered as well as homogenous ultramafic rocks are injected by erratic veins, dykes and small plugs of mainly ultramafic composition (Fig. 7). These normally have a much coarser grain size than the host rocks and comprise mainly of orthopyroxene and amphibole, with subordinate clinopyroxene, olivine, and in some cases minor plagioclase. The phase chemistry of the intruding ultramafic rocks broadly corresponds to that of host rocks, suggesting that the ultramafics represent injections of intercumulus liquid, squeezed out of the consolidating ultramafic cumulates rather than being a younger and separate phase of ultramafic magma. Alternatively, they may represent intrusions of ultramafic crystalline mush.

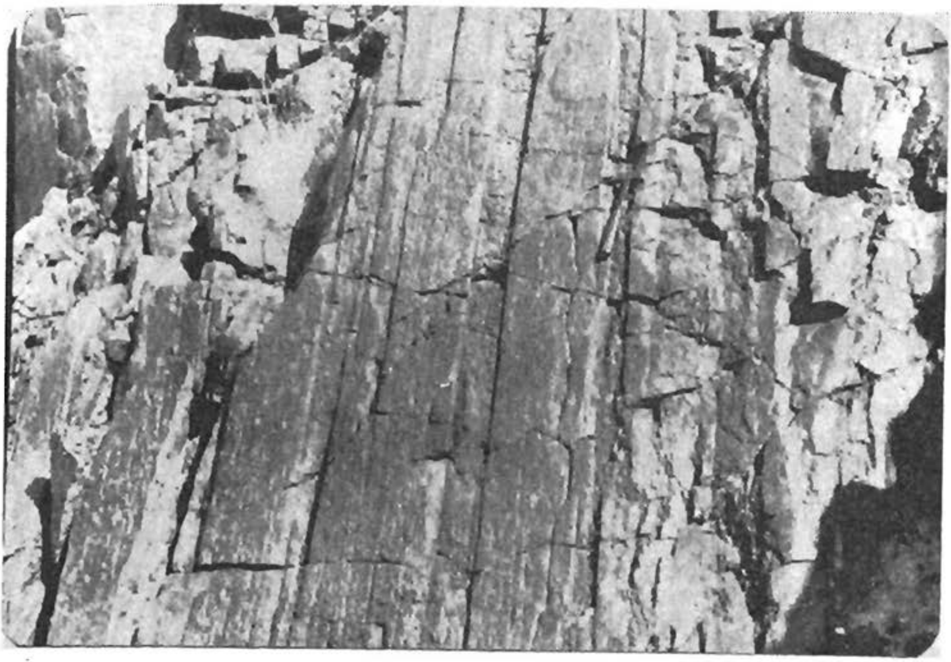

Fig. 5. Alternating isomodal layers of dunite (weathered) and bytownite-norite. Note the wedge-shaped terminations of some of the layers in the central part of the figure, a common feature of layers in the Chilas complex.

Fig. 6. Vaguely developed layering between the bytownite-norites, bytownite-anorthosites, and plagioclase-bearing pyroxenites. A 10 cm layer in the middle of the figure shows gradation (N to S) from plagioclase pyroxenite at the base, norite in the middle, towards anorthositic top.

2) In one outcrop, a thick layer of the bytownite-norites is brecciated into a number of angular blocks. The intersticies are occupied by the dunites from the adjacent layers (Fig. 8). Again this feature probably represents a syn- or early post-consolidation phenomenon (? slump breccia).

Fig. 7. An example of small-scale discordant ultramafic bodies of erratic outlines cross-cutting the layered dunite-peridotite sequences.

Fig. 8. Bytownite-norite (grey) with fractures occupied by dunite (dark) from the adjacent layer.

3) The interlayered dunite and bytownite-norite sequences generally maintain their overall conformable characteristics. Locally however, as on the western slope of Thurly Gah, dykes issuing from bytownite norite layers cut through the adjacent ultramafic layers and join the bytwonite-noritic layer on the other side.

STRUCTURE

Grossly, the structure of the studied area is fairly straightforward. The body of ultramafic and associated mafic rocks has an upright to south dipping steep orientation (Fig. 1), and so is that of the layering and layer-parallel foliation (F0), defined by the tabular crystals and lenticular aggregates of mafic minerals (mostly pyroxenes). The F0 foliation is pervasive through the rocks of both associations and in our opinion developed during the crystallizing stages, under a considerable weight of the overlying pile of magmatic and crustal rocks together with a cumulus mode of mineral settling. Microscopic structure at this stage is characterized by annealing, resulting in the development of granoblastic textures. There are evidences that F0 foliation was locally accompanied by strong shearing, resulting in a layering-cum F0 parallel fabric (F1), and at places stretching and boundinaging of the ultramafic layers in interlayered dunite-bytownite norite sequences (Fig. 9). The plagioclase in these rolks is again annealed to granoblastic texture concealing any signs of deformation but the pyroxenes still retain deformation features such as flow elongation of orthopyroxene and deformation kinking of both the pyroxenes, reflecting strong plastic flow (Fig. 10). The F1-related deformation features are very similar to the ones recorded from the lower crustal intrusions of Kalka and Gosse Pile, Giles complex of central Australia (Goode, 1978; Moore, 1973; Goode and Moore, 1975), which are considered to be the result of simple shear under conditions of high temperatures and pressures.

The layer-parallel fabrics (F0, and F1) are well-developed in the studied body of the ultramafic and related mafic rocks. Similar bodies, elsewhere in the complex, are devoid of any signs of deformation and thus lack both F0 anl F1 fabrics. This layer-parallel deformation might have resulted in an overall layer-parallel shortening of the studied body. However, the lensoid shape and lateral terminations may be original magmatic manifestations rather than a tectonic pinching, as suggested by the presence of original igneous contacts and associated undeformed apophyses and dykes.

Apart from the F0 and F1 fabrics, the studied part of the complex is characterized by a number of shear zones oblique to layering (as well as to F0 and F1). These shear zones are characterized by a fairly wide range of temperature and pressure conditions extending from granulite to greenschist facies, with a corresponding range in the style of deformation from ductile to brittle. These shears have been classified into two broad age groups, pre-Eocene and post-Eocene, related respectively to the collision of the Kohistan island arc with that of Karakoram plate (100–80 m.y. ago according to Coward *et al.*, in press), and obduction and uplift following Eocene collision of the already accreted Kohistan

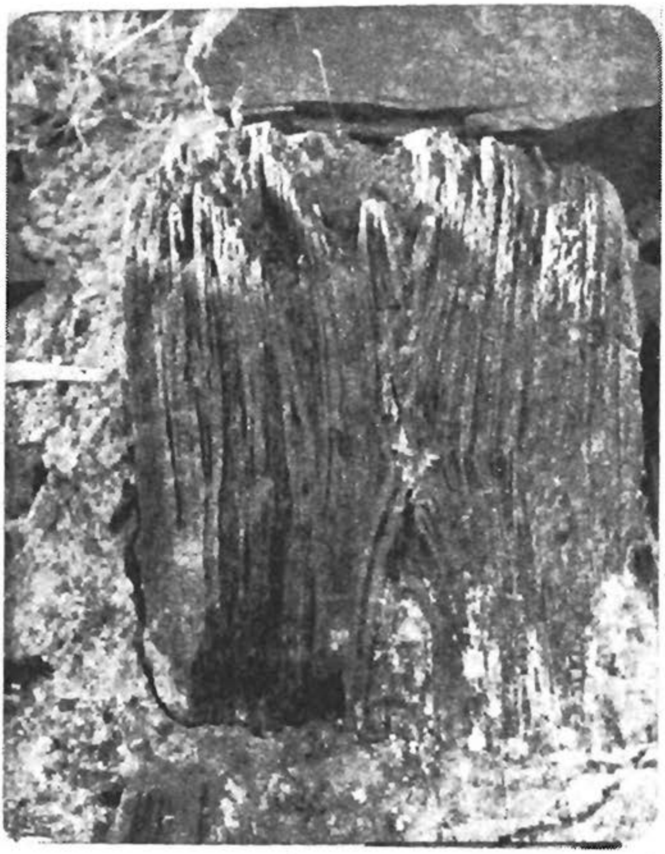

Fig. 9. Boundinaging of a thinly layered sequence of bytownite-norite and dunite, probably a result of high-temperature, high-strain rate shearing accompanying the F1 foliations.

and Karakoram plates over the Indian plate. The wide range and rather continuous variation in temperature and pressure conditions found in various shear zones, however, suggest that the Chilas complex rocks remained under continuous shear deformation conditions since the 80–100 m.y. collision event, making the two-fold classification of the deformation events (Bard, 1983a, b; Coward *et al.*, in press) rather meaningless.

ECONOMIC ASPECTS

The Chilas complex as a whole, and the studied part of the complex in particular, is characterized by a rock-assemblage most suitable for the mineralization of ore minerals, both oxides and sulphides. This possibility is further strengthened by an overall stratiform nature of the complex, an environment famous for crystallization and segregation of metallic minerals (e.g., stratiform

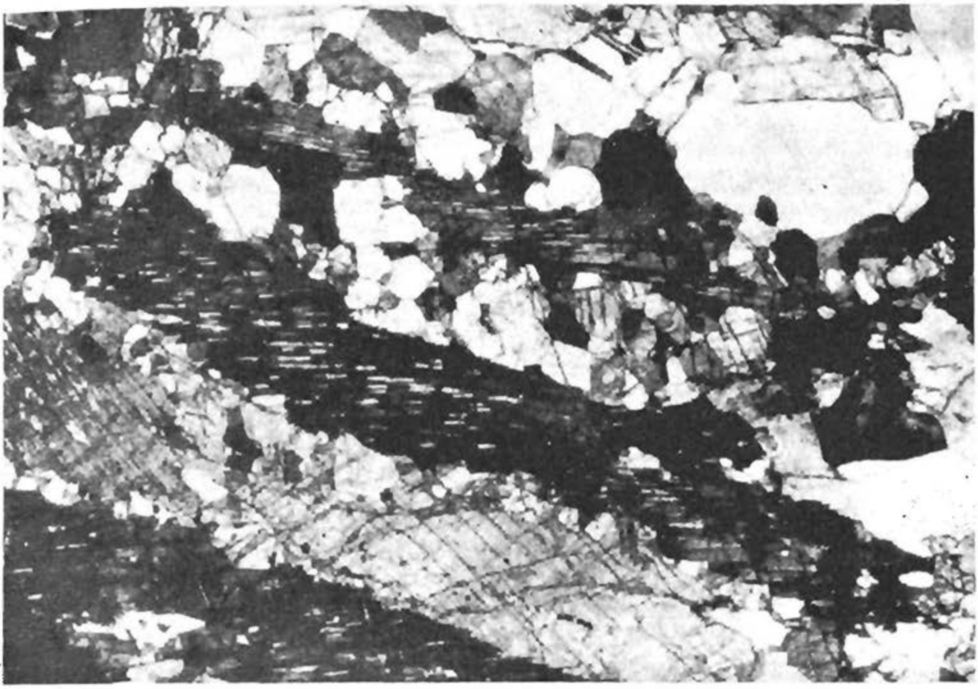

Fig. 10. Photomicrograph showing F1 related high-temperature, hign-strain rate deformation of a microscopically interlayered bytownite-anorthosite and pyroxenite rock. Note the recystallization of plagioclase and some of the pyroxene to polygonal grains. Some of the orthopyroxenes, probably because of their suitable crystallographic orientation relative to the shear direction, have flown plastically instead of recrystallization. Also note the presence of deformation features such as bending, kinking, deformation twinning, and break in the orientation of the exsolution lamellate at the kink band boundaries.

complexes of Bushvelled, Stillwater, Skaergaard; Buchanean, 1976; Jackson, 1961; Wagger *et al.,* 1957). In the Chilas complex, inspite of all these attributes, no significant ore showings have hitherto been observed. In fact, recently concluded field work in most of the accessible parts of the complex around Chilas by one of us (M.A.K.) shows that somehow the complex is depleted in the metallic minerals.

The two rock associations of the complex are characterized by distinct sets of metallic minerals (Table 3). The main noritic rocks normally contain magnetite, titanomagnetite and/or ilmenite. These oxides are disseminated in the gabbronorites as minor and accessory phases, hardly exceeding 10% (normally 5%) by volume. No segregations of these oxides, either as pockets or seams, have so far been noted. The ultramafic and associated mafic rocks rarely contain magnetite and titanomagnetite but instead contain either chrome spinel or chromite, or both.

The chrome spinels are of two types, depending upon the mode of origin. There is a primary chromite type, crystallizing as cumulus or inter-cumulus phase along with olivine, and occurring either as inclusion in the olivine or occupying interstices in the cumulus mossaic. In some rocks, individual chromite grains have been variably affected chemically due to reactions with neighbouring minerals. The secondary chrome spinel occurs as blebs or vermicules included either in clinopyroxene or amphibole in the form of symplectites. This spinel is a product of subsolidus reaction between olivine and plagioclase (Mongkoltip and Ashworth, 1984; Tomeon, 1979; Jan *et al.,* 1984) and is generally poor in or completely lacks Cr_2O_3. Both types of spinel have restricted modal abundances, mostly below 2%.

Chromite is the only oxide that forms segregations. It occurs either in the form of irregular patches and veins, or distinct isomodal to graded layers, interlayered with dunites. Although a number of chromite lenses and layers have been noted in the core of the ultramafic body, none is of any significant thickness or lateral extent. Most of the layers range from a few millimeter to 2 cm in thickness and less than a few meters in length. One lens in the area, measuring 20x90 cm, is the largest so far observed in the complex.

Sulphides, like the chrome oxides, are restricted to the ultramafic and associated mafic rocks. They too are of very restricted modal proportions ($\leq 0.5\%$), and occur as disseminated grains, included in olivine or clinopyroxene. The princapital sulphide phase is pyrite, however, pyrite with inclusions of chalcopyrite ($CuFeS_2$), and pentlandite ((Fe, Ni) S) have also been observed. The absence of discrete segregations of the sulphides and their inclusions in the ferromagnesian silicate phases suggest that immiscible separation of the sulfide components, if any, was on a rather limited scale in the earliest stages of crystallization. This also points out to the high temperature nature of the sulphide immiscibility process. Such a genetic mode of the sulphide minerals, as also recorded in other stratiform complexes (e.g., in the basal zone of Kapalagulu stratiform complex, Tanzania; Almohandis, 1980), is contrary to the general belief that sulphide immiscible liquids are of a late magmatic nature (Wager *et al.,* 1957; Jensen and Bateman, 1981).

DISCUSSION AND CONCLUSIONS

As in the Chilas area, ultramafic and related rocks are emplaced in noritic rocks in Thurly Gah area. Our study leads to the following results which are also applicable to the Chilas complex as a whole.

1) The petrological division of the Chilas complex into two associations, a main noritic association and a subordinate association of the ultramafic and mafic rocks (Jan *et al.,* 1984; Asif Khan *et al.,* in prep.) is supported by field and petrographic characteristics (Table 3).

2) The ultramafic and associated mafic rocks are emplaced in the form of isolated, lensoid bodies rather than, as found in the type stratiform complexes, in continuous stratigraphic horizons.

3) Inspite of an overall intrusive mode of emplacement of the ultramafic and associated mafic rocks, there is a strong concordance in the planar structures (such as foliation, layering, contacts) of the two associations. Parallelism of layering suggests that the magma of the younger group of rocks was emplaced before tilting of the main norites.

4) Both the associations are characterized by the presence of minor discordant bodies, grossly within their respective compositional ranges. These bodies probably represent subsolidus mobility of the magmatic liquids or crystal mushes, being squeezed out into fractures and other weak zones produced by the burden of overlying magmatic rocks and other crustal material. But some may also have developed as a consequence of slumping. The abundance of orthopyroxene and amphibole in the discordant ultramafic bodies, and the frequency of amphibole in the noritic dykes suggest a major contribution of the intercumulus material in these discordant bodies.

Similar discordant bodies in other stratiform intrusions are also considered to be contemporaneous to layered cumulates (Stillwater Complex, Raedak and McCallum, 1984; Duke of Island Complex, Irvine, 1974).

5) The prevasiveness of the tectonic foliation through the rocks of both the associations suggests that the emplacement of the ultramafic and associated mafic rocks predated all the deformational events in the complex.

It is hoped that the field and petrographic aspects outlined here will provide a better understanding of the relationships amongst the constituent rocks of the Chilas comlex. However in the absence of detailed isotopic and geochemical work it is difficult to sort precise genetic inter-relationship between the two associations. Jan *et al.* (1984) invoked chemical zoning of the magma chamber into a picritic basal part and a noritic main part, followed by intrusion of the picritic basal liquid into crystallized norites. Naslund (1983) has also suggested chemical zoning to have operated in the case of the Skaergaard intrusion. Nevertheless, an attempt can be made here to outline a model for the magmatic evolution of the Chilas complex (Fig. 11).

Taking into consideration the volume proportions and the field and petrographic aspects (outlined in this paper and in that of Jan *et al.,* 1984), we suggest that the ultramafic and associated mafic rocks may represent isolated pulses of a relatively primitive (? picritic) magma emplaced at the crystallizing floor of a previously existing magma reservoir corresponding to the main noritic association of the Chilas complex. This sort of replenishment of the cumulusly crystallizing magma chambers by later pulses of relatively primitive magma are well documented in recent literature from the stratiform complexes (Rhum ultramafic complex, N.W. Scotland, Huppert and Sparks, 1980; Hettash Intrusion, Labrador, Berg, 1980), and have been successfully simulated in laboratory experiments (Huppert and Sparks, 1980, 1984). There is, however, a major difference in these models and the one being suggested for the Chilas complex. Whereas in both Hettash and Rhum intrusions it is considered that replenishing phases of a rela-

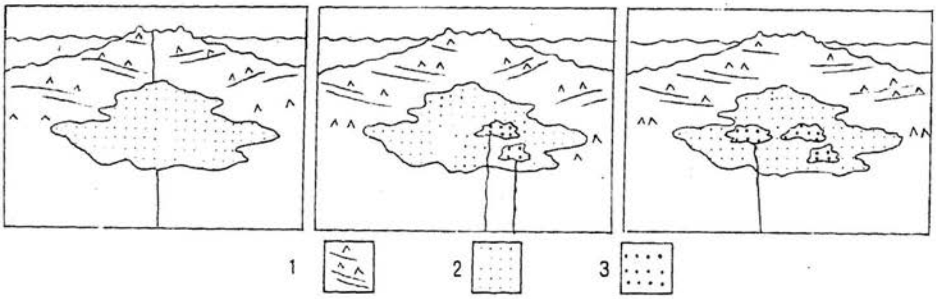

Fig. 11. A speculative model for the magmatic evolution of the Chilas Complex. It is suggested that the magma corresponding to the noritic rocks of the complex first intruded the lower crust of the predominantly volcanic island arc forming a large magma chamber. The magma corresponding to the ultramafic and associated mafic rocks was emplaced at crystallizing floor at various stages of crystallization, in the form of isolated pulses of comparatively primitive compositions. 1) Island arc volcanics/amphibolites of Kamila, Jal, and Jaglot, 2) magma/rocks of the noritic association, 3) magma/rocks of the association of ultramafic and mafic rocks.

tively primitive magma (although keeping their entities during most of the course of crystallization) ultimately merged with the host magmas, in the Chilas complex there are no evidences of such mixing. On the contrary even the most differentiated members of the association of the ultramafic and mafic rocks are substantially different from the main noritic hosts (Asif Khan, unpublished data). In the light of these considerations it is suggested that the two associations of the Chilas complex crystallized simultaneously but from magmas of substantially different compositional and rheological properties, thus hindering any mixing or hybridization.

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