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THE CHILAS STRATIFORM COMPLEX: FIELD AND MINERALOGICAL ASPECTS

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ABSTRACT

The Chilas Complex in northern Pakistan stretches for about 300 km from Astor to western Dir and attains a width of 40 km in the middle. It was probably emplaced during the early stages of development of the Cretaceous Kohistan island arc. Field observations, supported by petrography and mineral chemistry, suggest that the complex is composed of two groups of rocks. Group A consists predominantly of noritic rocks with subordinate pyroxenites, anorthosites and hypersthene-quartz diorites. These cover most of the complex, are generally strongly foliated and display some layering. The mineral composition of these rocks varies as follows: orthopyroxene En_{75} *to* En_{51}*; clinopyroxene Mg= 43 to 27, Fe= 9 to 22, Ca= 42 to 50; plagioclase* An_{62} *to* An_{43}*.*

Group B rocks occur in the form of lenses (upto 5 km^2*) and smaller bodies showing complex contact relations, ranging from concordant to discordant, with their host (group A) rocks. These comprise dunite, peridotites, pyroxenites, troctolites, norite, anorthosite, and pyroxene pegmatites; of these the former two are the most abundant. The principal outcrops of these rocks are found in Chilas area but isolated, small bodies occur as far to the west as Swat. The range in the mineral composition of these rocks is: olivine* Fo_{88} *to* Fo_{73}*; orthopyroxene* En_{90} *to* En_{62}*; clinopyroxene Mg= 46 to 37, Fe= 5 to 17, Ca= 49 to 45; plagioclase* An_{93} *to* An_{77}*. Characteristic features of this group of rocks are the development of excellent layering and corona structure.*

The group A association may have evolved from a high-alumina basalt (calc-alkaline) magma. It is not clear whether the group B rocks represent magmatic cumulates of this magma or younger intrusions of a more basic (picritic) magma. Both groups were probably metamorphosed under pyroxene granulite facies, to be followed by amphibolite dykes and hornblende-plagioclase pegmatites.

INTRODUCTION

The 36000 km^2 Kohistan region in northern Pakistan comprises a variety of volcanic, plutonic and minor sedimentary rocks of Creto–Tertiary age. These rocks are bounded by the Main Karakoram Thrust (MKT) in the north and the Main Mantle Thrust (MMT) in the south (Tahirkheli & Jan, 1979; Tahirkheli *et al.,* 1979). The MKT and MMT are thrusted major sutures with associated ophiolites, tectonic melanges and, locally, blueschists. The two extend eastwards across Ladakh and join into the famous Indus-Zangbo suture zone in SW Tibet (cf. Sharma, 1983; Thakur & Misra, 1984). Rocks of the Karakoram plate occur to the N of the MKT, and those of the Indo-Pakistan plate to the S of the MMT. Recent investigations suggest that the Kohistan-Ladakh region between the MKT and MMT represents Cretaceous island arc(s) that became Andean-type margin(s) by Early Tertiary (Tahirkheli *et al.,* 1979; Klootwijk *et al.,* 1979; Bard *et al.,* 1980; Jan, 1980; Jan & Asif, 1981, 1983; Virdi, 1981; Andrews-Speed & Brookfield, 1982; Coward *et al.,* 1982, & in press; Honegger *et al.,* 1982; Bard, 1983a, 1983b; Windley *et al.,* in press).

A grossly simplified picture of Kohistan along a N to S traverse between MKT and MMT reveals the following principal petro-tectonic units (Fig. 1): (a) a thin belt of volcanoclastic and clastic sediments of the Cretaceous Yasin Group; (b) a belt of Cretaceous and (?) Late Jurassic calc-alkaline volcanics (the Chalt volcanics or Greenstone complex of Ivanac *et al.,* 1956); (c) the Kohistan-Ladakh (Transhimalayan) granitic belt (mainly Early to Middle Tertiary calc-alkaline plutons with associated metasediments and Chalt metavolcanics); (d) the Chilas complex (Early Cretaceous mafic complex, possibly forming a lopolith); and (e) the southern amphibolite belt (Cretaceous and (?) Late Jurassic metavolcanics and a variety of other rocks). Along the Indus, a 200 km^2 wedge of high–P mafic granulites and ultramafic rocks occurs between the amphibolites and MMT, followed southwestwards by blueschists and tectonic melange of the suture zone. In the Upper Swat-Dir areas, a belt of Cretaceous sediments and overlying Eocene calc-alkaline volcanics is found within the Kohistan-Ladakh granitic belt.

It was pointed out by Bard *et al.* (1980) and Jan (1980) that an understanding of the Chilas complex, the world's largest intrusion of basic magma, is of fundamental importance to the interpretation of the geology of Kohistan. Localised descriptions of the complex are presented by Jan (1969), Jan & Mian (1971), Jan & Kempe (1973), Chaudhry & Chaudhry (1974), Chaudhry *et al.* (1974), Desio (1974), Shams (1975), Jan (1980), Khattak & Parvez (1982), Jan *et al.* (1983), Arif *et al.* (1984) and Habib *et al.* (1984). The petrography and mineral chemistry of the rocks, especially the noritic members, were discussed in detail by Jan (1977, 1979, 1983), Jan & Howie (1980, 1982) and Bard (1983b). In this paper, we present additional details, especially the field features of the complex around Chilas, along with mineral chemistry of the various rock-types. More than 1000 thin sections have so far been studied and another 500 rocks have been

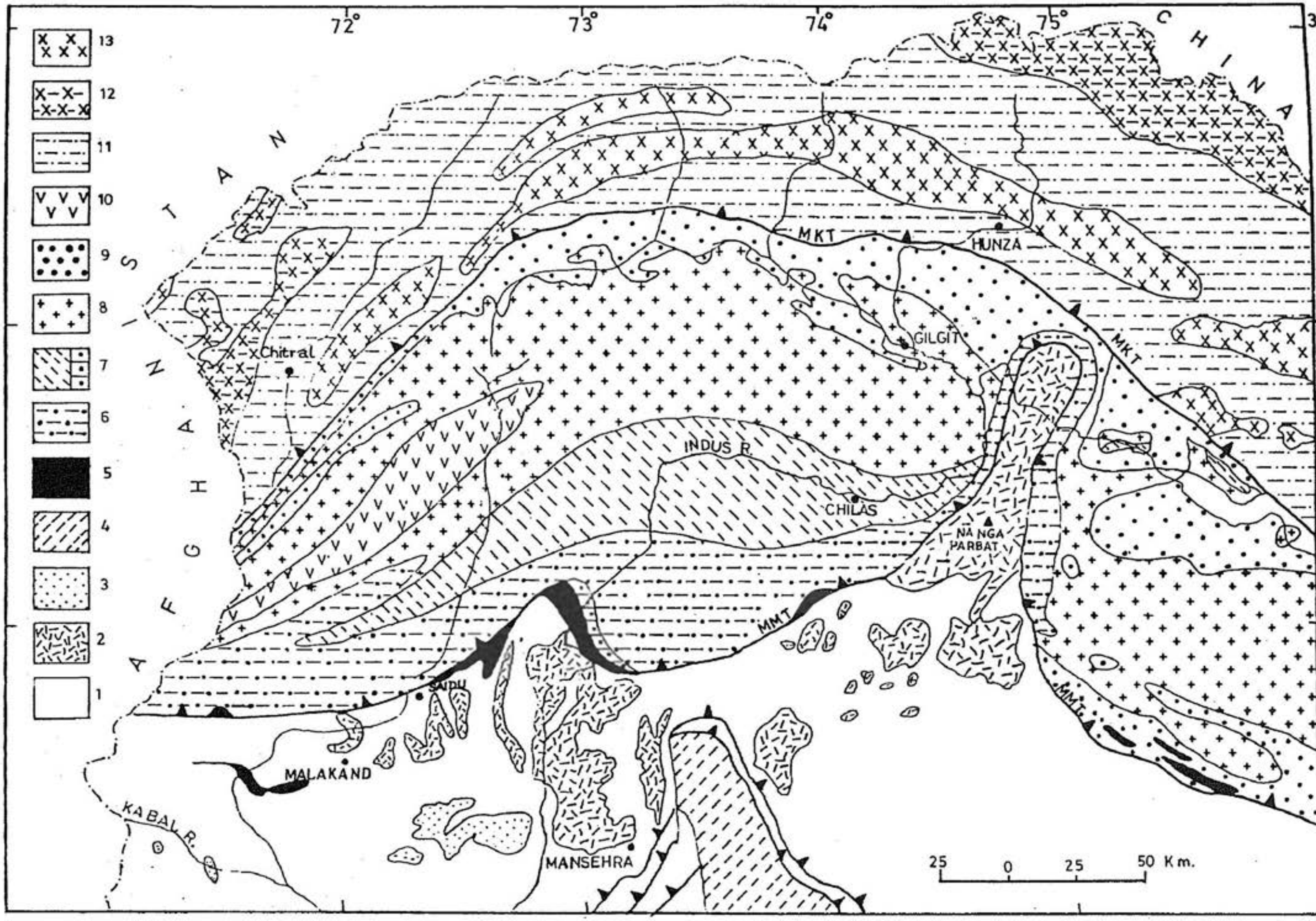

Fig. 1. Simplified geological map of northern Pakistan. (1) Precambrian to Mesozoic sedimentary rocks of the Indo-Pakistan Plate; (2) Cambrian granitic rocks; (3) Early Tertiary alkaline to subalkaline igneous rocks; (4) Middle Tertiary clastic sediments; (5) Ultramafic ophiolites; (6) Amphibolite belt; (7) Chilas-Jijal mafic complex; (8) Kohistan-Ladakh (Transhimalayan) granitic rocks; (9) Cretaceous sediments and volcanics of Yasin; (10) Creto–Eocene sediments and volcanics of Kalam-Dir area; (11) Sediments and Metasediments of the Karakoram Plate; (12) Khunjerab-Wakhan Tirichmir granites; and (13) Karakoram granitic belt. MMT: Main Mantle Thrust; MKT: Main Karakoram Thrust.

quickly checked in crushed grains. Some 550 mineral analyses were performed by M.Q. Jan, using an energy dispersive system, on a Cambridge Geoscan Microprobe at the University of Leicester. Further details of mineral chemistry will be presented in subsequent publications.

FIELD ASPECTS OF THE CHILAS COMPLEX

General Features.

The Chilas complex is a stratiform ? lopolithic body over 300km long and upto ?40 km wide. It extends west to east from Dir through Swat-Kohistan to Chilas, where onwards it follows the flanks of the S–N elongated Nanga Parbat-Haramosh dome and stretches beyond Astor. The Kargil complex in western Ladakh has the same rocks as the Chilas (Rai & Pande, 1983), and it has also been suggested that the garnet granulites of the Jijal complex may be related to Chilas (Jan & Howie, 1981a; Coward *et al.*, 1982; Bard, 1983b). The three complexes and their related rocks in the southern amphibolite belt collectively cover an area larger than that of the Bushveld complex of south Africa.

The complex is predominantly composed of (feldspathic) norites with subordinate ultramafic rocks, anorthosites, troctolites, gabbros and hypersthene-quartz diorites. These are intruded by pyroxene pegmatites, hornblende pegmatites, anorthosites (some pegmatitic) and amphibolite dykes. The complex was metamorphosed in pyroxene granulite facies at ~ 800°C, 5–8 kbar. This metamorphism may have taken place 20 to 30 m.y. after the emplacement of magma about 135 m.y. ago (Jan, 1980; Jan & Howie, 1980; Bard, 1983b). The rocks, especially the feldspathic members, were partially degranulitized under amphibolite and greenschist facies conditions, possibly during uplift. Jan (1977, 1980) and Jan & Kempe (1973) suggested that the complex was derived from a calc-alkaline (high alumina basalt) magma but Shams (1975) thought it to be tholeiitic. The Kargil complex, considered to represent cumulates in the magma reservoir for the Dras volcanics in Ladakh (Honegger *et al.*, 1982), is also regarded to be tholeiitic in chemistry (Rai & Pande, 1983).

The complex is intrusive into the volcanic rocks (now amphibolites) and associated metasediments of Kohistan. The southern margin of the main complex at Jal, Seo, and south of Fatehpur is in contact with garnetiferous calc-silicate rocks. However, it is not clear whether these represent metasediments or contact metasomatites, because noritic lenses and amphibolites derived from noritic and related rocks occur further south in the amphibolite belt (Jan, 1982). Xenoliths of garnet-clinopyroxene-scapolite also occur near Thorly Gah (M. Asif Khan, pers. comm.). The northern contact of the complex is also affected by amphibolitization and the intrusion of quartz diorite plutons. However, along the Indus near Bunji, noritic rocks intrude biotite schists, and near Astor (Casnedi & Ebblin, 1977) and along Skardu road they contain marble xenoliths.

Layering.

The noritic members commonly display a strong foliation produced during deformation (Jan, 1979; Khattak & Parvez, 1982). The foliation is generally parallel to layering which follows the E–W trend of the lopolith. Locally, however, it is oblique to layering and in some cases affects the amphibolite dykes, suggesting that it developed after the rocks had been metamorphosed. Although layering occurs throughout the complex (Chaudhry *et al.,* 1974; Shams, 1975; Jan & Mian, 1973; Jan, 1979; Khattak & Parvez, 1982), it is particularly spectacular in the neighbourhood of olivine-bearing rocks which are concentrated around Chilas town. Thus there is a possibility that the olivine ultramafites and the very well-layered rocks are cogenetic and slightly different from the main norites forming the bulk of the complex.

The layers range from over a meter to a few milimeters in thickness; as many as 60 fine-scale layers in a meter thickness were counted to the east of Chilas filling station. In general, the layering is defined by variations in the modal abundances of plagioclase and pyroxene; thus the layered rocks range from pyroxenite to anorthosite in most cases, with norites being the most abundant. The larger, dominantly ultramafic bodies around Chilas may also be stratiform at places, with layers of dunite, peridotite, pyroxenite, troctolite, gabbro, norite and anorthosite. In these, anorthosite layers and deformed chromitite bands may occur in otherwise massive dunite or peridotite.

The layered rocks display size and/or mineral grading, phase layering, rhythmic layering, current bedding, cross bedding, wedge layering and truncation of earlier layers by later ones, slump folds, syndepositional faults and dykes. The layers are generally of short lateral extent, particularly in Swat area where 25 cm thick layers may disappear within a few meters (Jan, 1979). In the Bushveld, Skaergaard and Stillwater complexes, on the other hand, even the thin layers may persist for long distances (Jackson, 1967). The short lateral extent of the Chilas layers may be due to syndepositional faulting, slumping, pinching and swelling during tectonic deformation, homogenization or, in some cases, selective remobilization during granulite facies metamorphism. There also is the possibility that some layers are not primary in origin but have beeen produced due to deformation and metamorphic differentiation. Clearly, further investigation is required.

Mutual Relations of the Rock-types.

Petrography and mineral chemistry reveal that the Chilas complex contains at least two types of rock associations which can be distinguished on the basis of plagioclase composition. The complex is principally composed of norites, with subordinate anorthosite and pyroxenite layers, and hypersthene-quartz diorite, containing a plagioclase of labradorite to andesine composition. In Chilas area, however, olivine ultramafite bodies with associated troctolite, norite, anorthosite and pyroxene pegmatite are characterized by a more calcic plagioclase (anorthite to bytownite). These rocks range from veins, dykes and plugs to bodies covering up to 5km^2 area and appear to intrude the norites with less calcic plagioclase.

There are many examples of discordant relations between the rocks of the two associations as well as in the different members of the same association. In addition to slump breccias, there are enclaves, megabreccia, broken layers, veins, and dykes of feldspathic rocks in ultramafites, and vice versa, as near Thorly. The rocks, especially norites, also contain veins, dykes, and patches of fine-grained norites of granulitic texture, pegmatites, and anorthosites. In rare cases, pegmatitic enclaves seem to have been incorporated in layered rocks while igneous sedimentation was in progress. In a number of cases the relations between the rocks are very complicated and puzzling. In Buto Gah, for example, layered and slump-folded anorthosite-feldspathic peridotite are cut by a dunite dyke. These are truncated by layered anorthosite-dunite (locally feldspathic) with intrusions or enclaves of pyroxene pegmatite. This whole association is, in turn, truncated by similar layered rocks with broken and slump-folded dunite layers and pyroxene pegmatite. The last phase of the intrusive activity is marked by an amphibolite dyke.

Although these complicated relations are found mainly in the vicinity of the large ultramafic bodies around Chilas, isolated examples also occur further west. Chaudhry *et al.* (1974) reported lenses and spindle-shaped bodies of pyroxenite in norites of Dir. In addition to pyroxenite layers, the Swat norites contain small plugs of peridotite and troctolite, some with corona structures as in Chilas (Jan and Howie, 1981b).

Possible Modes of Formation of the Complex.

The field features (Fig. 2, 3) demonstrate that the Chilas complex has passed through a very complex history. The rocks may have formed in a turbulent magma chamber in an area of active tectonism and deformation. Some relatively simple features can be explained by invoking slumping and, in a few cases, channelling. Complexities may have been added by possible selective remobilization of some lithologies during granulite facies metamorphism and deformation, or even pre-metamorphic serpentinization of some ultramafic rocks. The pyroxene $\pm$ olivine -bearing pegmatites may be magmatic, the anorthositic pegmatite dykes appear metamorphic, and the hornblende-plagioclase pegmatites and hornblendites (minor) are the products of metasomatism.

We follow Shams (1975) in assuming that the various rock-types of the complex, except the metasomatic ones and later amphibolite dykes, are magmatically related. It is logical to think that the huge Chilas complex resulted from several pulses of the same magma in a relatively short span of time and crystal-

Fig. 2. Some of the filed features of the Chilas complex. A: mineral-graded and size-graded bedding; B: graded bedding with laminae; C: disturbance of graded bedding due to incorporation of a xenolith; D: mega-breccia of norite in dunite matrix; E: slump folding of layers; F: synsedimentational faults; G: Faulting and ? channelling of layered rocks; H: multiple phases of dykes and veins in the foliated norite.

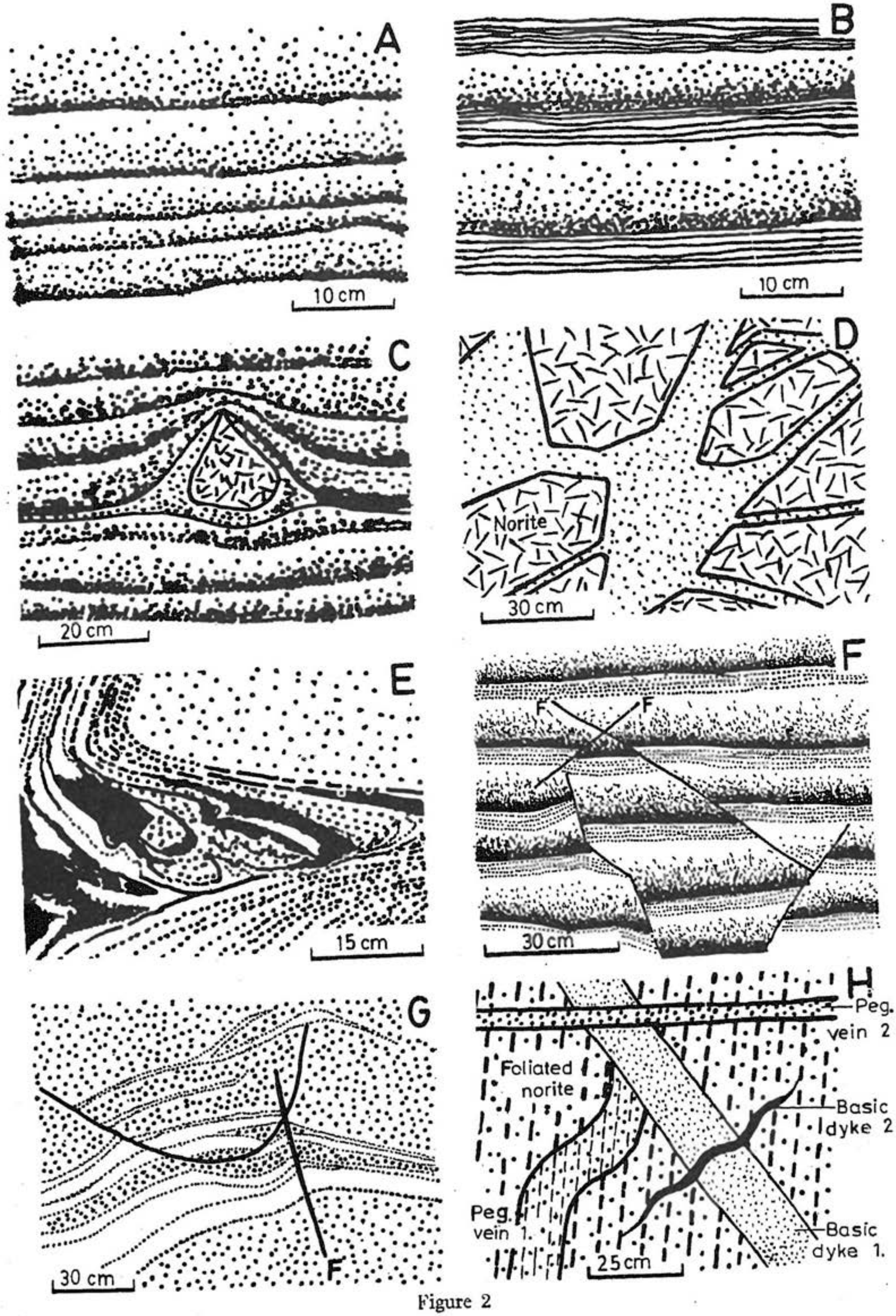
A
10 cm
B
10 cm
C
20 cm
D
Norite
30 cm
E
15 cm
F
F
F
30 cm
G
F
30 cm
H
Peg. vein 2
Foliated norite
Basic dyke 2
Peg. vein 1.
Basic dyke 1.
25 cm

Figure 2

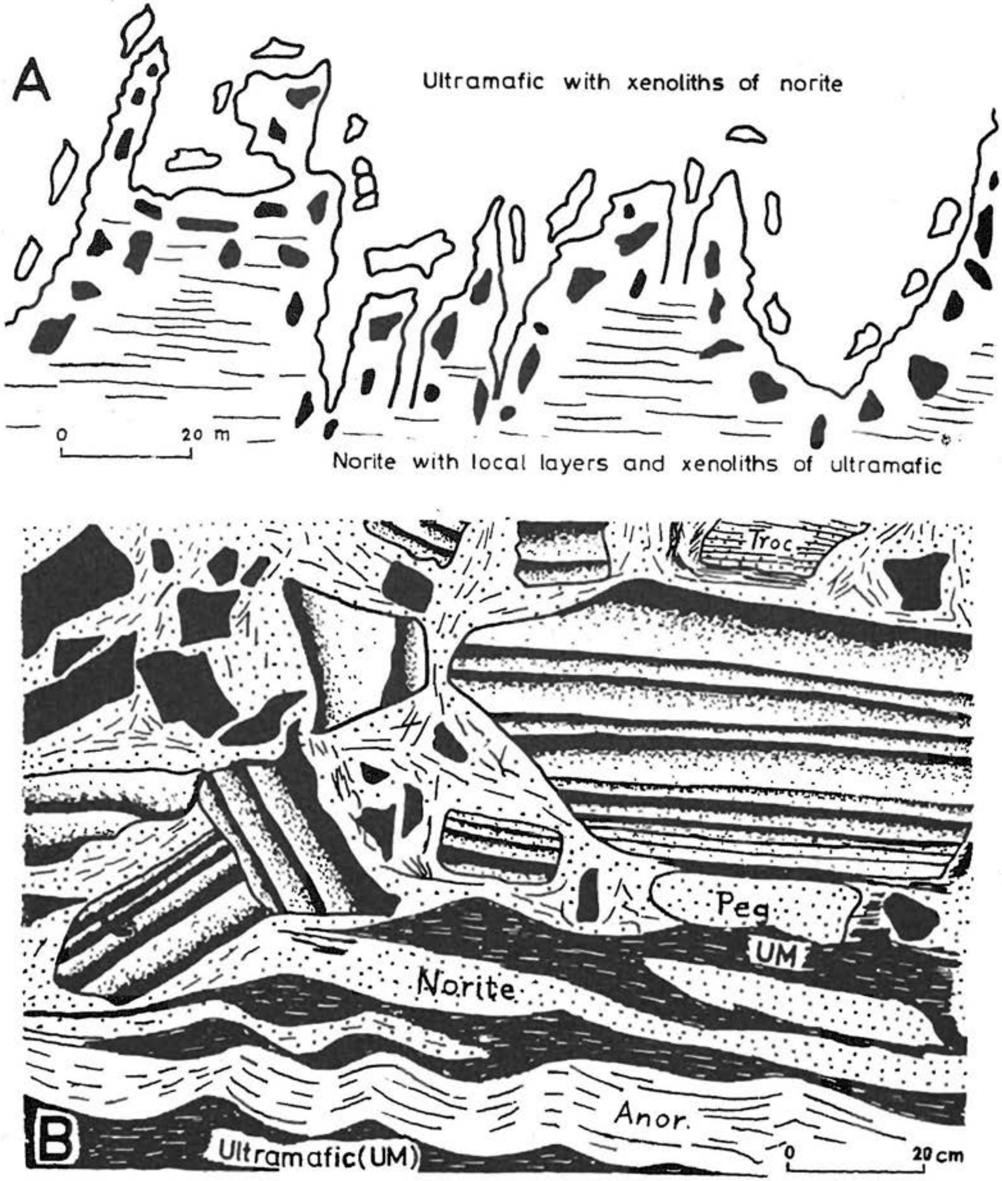

Fig. 3. (A) Xenoliths of ultramafics into norite and vice versa in the ~ 30 cm broad contact zone between the two (sketched from outcrop near Thak Gah confluence along KKH). (B) Complex features displayed in a boulder (5 x 3 x 2m) in Buto Gah having intermixed dunite, anorthosite, pyroxene pegmatite, graded layered norite, banded norite, alternately banded dunite-anorthosite, altered pegmatite, and coarse-grained norite.

lized under essentially similar conditions (Jan, 1977). In such an interpretation, the olivine-ultramafite bodies (with subordinate troctolites, norites and anorthosites, all characterised by the presence of a highly calcic plagioclase) may represent cumulates whose contacts with the host norites (containing medium plagioclase) have been complicated by severe tectonism, remobilization, sagging or diapirism. The discordant contacts, and lack of strong foliation in troctolites and norites as compared to the main norites, however, lead to other hypotheses also.

It is possible that the main norites evolved from an earlier magma that was different from that which produced the olivine-ultramafites and associated highly calcic plagioclase rocks, followed by metamorphism. There also is the possibility that deep-seated zonal differentiation led to the concentration of a feldspathic norite main melt in the upper part, and a feldspar-poor troctolitic (picritic) melt in the lower part of the magma chamber(s), followed by upward migration in that order. Geochemistry of the rocks in progress is hoped to provide answer to some of these riddles.

PETROGRAPHY AND MINERAL CHEMISTRY OF THE CHILAS COMPLEX

The Ultramafic Rocks.

The ultramafic rocks of the complex range from dunite to peridotites, pyroxenites, ultramafic pegmatites and rare hornblendites; there is a range from feldspathic peridotites to troctolites. The pyroxenites occur throughout the complex but the remainder are mostly confined to the east-central part around Chilas. The ultramafic rocks form clots, schlieren, segregations, veins, lenses, dykes, sheets, plugs and larger bodies. The pyroxenites are mostly associated with the main norites, commonly as lenses and layers but locally forming dykes. The remainder often display discordant relations with their host norites. The large ultramafic bodies may have internal layering ranging from dunite to subordinate troctolite, norite and anorthosite.

Prominent outcrops of the ultramafic bodies, 1 to 5 sq. km in area, occur in five places: (i) two bodies to the N and E of Singal, Thak Gah, (ii) NE of Khaya, Buto Gah, (iii) at the confluence of Indus and Thak Gah, (iv) at the Thorly Gah-Indus confluence, and (v) near Mashai, Buto Gah. The rocks in these bodies are mainly dunite with some peridotites, troctolites, norites, anorthosites, pyroxenites and ultramafic pegmatites; troctolites being more common in (i) and (ii). Distinct bodies of ultramafic pegmatites (locally feldspathic), with or without associated pyroxenite/peridotite of medium-grained texture, occur (a) along KKH to the W of Ginu Stream, (b) W of Dasar in Buto Gah, (c) S of Shamkoru in Giche Gah, and (d) W of Shatial (this ~ 400 m long body consists of coarse-grained rocks, gradationally ranging from peridotite to troctolite and norite). Since the complex has been visited only along KKH and a few major streams, we expect the presence of additional ultramafic bodies in the area. Jan and Howie (1981b) have reported small bodies of these rocks in the norites of Swat-Kohistan.

Dunites and Peridotites: Dunites are the principal components of the ultramafic bodies other than pyroxenites. These are essentially composed of olivine that is accompanied by minor chromite; one or two pyroxene, plagioclase, amphibole and green spinel are locally present. The peridotites occur in small independent bodies, as well as associated with dunites in the larger plutons, as marginal facies or layers. Their dominant component is olivine, accompanied by variable amounts of pyroxene(s), plagioclase, amphibole and green spinel. Thus the rocks are represented by one or two pyroxene–, amphibole– and plagioclase peridotites. The ultramafics are generally fresh but serpentine, chlorite, and carbonate have locally developed; a few samples also have chalcopyrite. Dunite fragments may rarely lie in a matrix of serpentine and/or carbonate.

The rocks have a granular xenoblastic texture. The olixine may be strained and a few rocks are partially granulated with a mortar-like texture. Symplectitic intergrowth of amphibole and green spinel, with or without a plagioclase core, is a common feature, especially in the plagioclase peridotites. This appears to have resulted due to a reaction between plagioclase and olivine. An ideal corona in the complex has the following arrangement of minerals: olivine → orthopyroxene — clinopyroxene — amphibole+spinel symplectite ← plagioclase (Jan *et al.*, 1984). The green spinel, much if not all amphibole, and at least some pyroxene are the product of this reaction. The coronites are discussed in detail by Jan *et al.* (1984) and will not be dealt with any more in this paper.

The olivine ranges in composition from Fo_{88} to Fo_{77} (Fo_{90} in a chromitite), and orthopyroxene from En_{84} to En_{74}. Clinopyroxene analyses show a range of Mg (46–40.5), Fe (5.4–11), and Ca (48–49.3). In almost all cases, the composition of the pyroxenes in coronas is identical to that in independent grains. This may suggest a re-equilibration under granulite facies metamorphism, following the growth of the coronas, or the coronas may have grown during the granulite facies metamorphism. The amphibole is pargasitic to edenitic hornblende, rarely magnesio-hornblende; magnesio-cummingtonite occurs as an additional amphibole phase in one dunite. The plagioclase is very calcic, ranging from An_{98} to An_{87}. It is reversely zoned, due probably to diffusion of Na from the margins that was consumed in amphibole during the development of corona. Composition of the plagioclase in a non-coronitic anorthosite layer in coronites is An_{88}. We think that this may represent the original composition. Because many of the plagioclase cores in coronites are more calcic than An_{88}, it is likely that outward diffusion of Na took place over the entire grains.

Chromite composition in the chromitite bands in dunite is around 26% Al_2O_3, 26% Cr_2O_3, 37% FeO* and 9% MgO. The composition of the disseminated Cr-spinel grains, especially in peridotites, is highly variable even within short distances in a single thin section. The range in major oxides is: Al_2O_3 = 2 to 54%, Cr_2O_3 = 4 to 36%, FeO* = 18 to 68%, and MgO = 1 to 10%. This variation is attributed to alteration and to selective solid-state diffusion of the oxides and exchange equilibrium with the neighbouring silicate phases. The vermicular spinel in the symplectites of the coronas, on the other hand, has a restricted compositional range: Al_2O_3 = 60 to 64%, FeO* = 17 to 20%, MgO = 15 to 18%.

Pyroxenites. These rocks occur as lenses, layers, rarely dykes and plugs in norites and less frequently in dunite–peridotite bodies. Many are websteritic but some are dominantly or entirely composed of only one pyroxene (Chaudhry *et al.*, 1974; Jan, 1979). There are variable amounts of plagioclase, hornblende and olivine and some resemble bahiite (Jan and Howie, 1981b). Opaque oxide may be present as an accessory, but some contain green spinel and a few have biotite, apatite, rutile and secondary serpentine, chlorite, talc, tremolite, carbonate or, rarely, quartz. The pyroxenites are generally medium-grained granoblastic but some contain poikiloblastic pyroxene, amphibole, or plagioclase. Coronas and symplectites may develop in those containing plagioclase.

The orthopyroxene ranges from En_{76} to En_{66}; one optically determined composition is En_{78}. Clinopyroxene analyses have the range Mg= 43 to 40%, Fe= 9 to 13, Ca= 45 to 50. Two optically determined compositions are: Mg= 35, Fe= 15.5 and 17, Ca= 49.5 and 48 (Jan and Howie, 1980). The amphibole analyses have the same compositional range as in dunite-peridotites. The plagioclase composition in the microprobe analyses ranges from An_{89} to An_{85}. Khattak & Parvez (1982) reported more calcic compositions (An_{90} to An_{95}) for seven pyroxenite plagioclases determined by maximum symmetrical extinction method. However, some pyroxenite layers associated with the foliated main norites contain labradorite.

Hornblendites. Medium- to coarse-grained hornblendites occur at several places in Kohistan, especially in the Dir district (for a review, see Banaras & Ghani, 1983). Many of these are monomineralic and confined mostly to the southern amphibolite belt. In the Tora Tigga complex of southwestern Dir in the north of MMT, an association of noritic rocks, peridotites, and pyroxenites grades into hornblendite. The hornblendites cover several kilometer area and have been considered metasomatic by Jan *et al.* (1983).

In the noritic and ultramafic rocks of the Chilas area, hornblendites occur locally in small, replacive bodies along fractures, openings, networks and patches. In addition to hornblende, Shams (1975) has reported minor cummingtonite, ore and natrolite in those from Thak Valley. One hornblendite occurs as a patchy replacement of dunite along the KKH, about 400 m W of Thak Gah. It contains edenite with subordinate green diopside ($Mg_{44.6}$ $Fe_{5.5}$ $Ca_{49.6}$) and traces of opaque oxide.

Ultramafic Pegmatites. Many veins and small bodies of these pegmatites intrude the norites and ultramafic rocks of the Chilas area. The bodies may have associated ultramafic rocks of medium-grained fabric. The largest of these, near Ginu Gah, measures over 400 x 15 m and is emplaced in well-layered rocks. The pegmatites consist of various amounts of one or two pyroxene, olivine, amphibole, and in some cases plagioclase (~ An_{90}), biotite, apatite and opque oxide. Chlorite, serpentine, talc, epidote, white mica and calcite may occur as secondary products. One of the pegmatites consists of normally zoned olivine ($Fo_{80.7}$ to $Fo_{79.5}$), orthopyroxene (En_{90}), pargasitic hornblende, chromian magnetite and chromian pleonaste.

The Feldspathic Rocks.

This group of rocks includes troctolites, olivine gabbros, norites, noritic gabbros, anorthosites, quartz diorites and the younger amphibolite dykes. Amongst these, norites are by far the most voluminous. The following account does not consider details of field and petrographic features of the rocks; these have already been described at length by Jan & Mian (1971), Chaudhry *et al.* (1974), Shams (1975), Jan (1979), Khattak & Parvez (1982), Jan *et al.* (this volume). Jan (1983), Jan & Howie (1980, 1982) and Bard (1983) describe the chemistry of the pyroxenes and amphiboles in the norites. More than six hundred old and new analyses of these minerals, plagioclase, biotite and oxide minerals enable as to give a complete account of the phase chemistry of the troctolites, norites and anorthosites.

Troctolites and Olivine Gabbros. These rocks usually form as minor facies of the olivine-ultramafite bodies around Chilas, but some also occur independently. Small, scattered bodies of these rocks are found in norites as far to the west as Madyan, and in the southern amphibolite belt near Kamila and Khwaza Khela (Jan & Howie, 1981b). These are generally coarse-grained with common development of coronas resulting from a reaction between plagioclase and mafic minerals, notably olivine (cf. Jan *et al.,* 1984). Much of the orthopyroxene, amphibole, green spinel, and some clinopyroxene owe their origin to corona growth. However, these phases may also occur in independent grains which, as in peridotites, have similar composition to those in the coronas. The mineral shells in the coronas are intact mostly, and the rocks generally do not present evidence of a strong penetrative deformation. However, in a few cases the shells may be incomplete, deformed or granulated.

Olivine composition in these rocks ranges from Fo_{77} to Fo_{73}. The orthopyroxene is bronzite (En_{78} to En_{73}) and clinopyroxene has the range Mg= 45–42, Fe= 9–12, Ca= 49–45. Amphibole is pargasite to pargasitic hornblende but actinolite has developed locally as a secondary phase. Plagioclase ranges from An_{98} to An_{83} and in coronites is invariably zoned reversely. A secondary plagioclase vein in a troctolite consists of labradorite (An_{53}). Chromian spinel, if any, has not been analysed. Several analyses of the spinel formed in the coronas contain 58 to 60% Al_2O_3 (with one value of 49%), 21 to 26% FeO*, and 13–15% MgO (with one value of 10%).

Norites and Hypersthene-Quartz Diorites. These rocks are mostly medium-grained granulitic in texture and consist essentially of plagioclase and two pyroxenes, with quartz as a major component in some diorites usually occuring in the northern part of the complex. Small amounts of magnetite, ilmenite and apatite are usual, along with hornblendic amphibole and biotite in many. In some rocks, particularly those affected by late or post-granulite facies retrogression, amphibole and, rarely biotite attain more than accessory proportions. A few contain small amounts of orthoclase (perthitic), pyrite, scapolite, green spinel, and garnet. Actinolite, epidote, chlorite, serpentine, talc, white mica, red Fe oxide/hydroxide may occur in altered rocks.

The norites associated with the dunite-peridotite-troctolite bodies are more basic than the main norites of the complex. In the former the plagioclase is An_{93} to An_{77}, in the latter it is An_{62} to An_{43} and in some cases antiperthitic. Unlike coronites, the plagioclase is mostly normally zoned. The overall range in the orthopyroxene is En_{78} to En_{51}, in clinopyroxene Mg= 41 to 28, Fe= 10 to 21 and Ca= 51–43; the more magnesian compositions being in norites associated with olivine ultramafites. The amphibole is mostly pargasitic- but in some magnesio- or tschermakitic hornblende. A few rocks contain a second amphibole (cummingtonite, tschermakitic hornblende or actinolite), developed later than the other variety. Three K-feldspar compositions contain an orthoclase component between 78 and 86 mol%. Four epidotes have a pistacite content of 17 to 20 mol% and one spinel contains 62% Al_2O_3, 24% FeO* and 13% MgO. The chemistry of minerals in anorthosite and norite veins may fall within the range displayed by their host norites but some have more calcic and a few less calcic plagioclase than the host rocks.

Anorthosites. These occur as layers and, rarely, lenses in the main norites as well as in the ultramafic masses. These are also found as small dykes and veins that may look undeformed (probably due to their mono-mineralic nature) and at places are coarse-grained to pegmatitic. In addition to plagioclase, the rocks may contain small amounts of one or two pyroxene, hornblende (similar range of composition as in norites), opaque oxide and, in rare cases, olivine and green spinel. The rocks are generally equigranular but in some the pyroxene grains may be much larger than plagioclase or the amphibole may be poikiloblastic.

As with norites, anorthosites associated with the ultramafic masses are more basic and have the following range in mineral chemistry. Plagioclase An_{92} to An_{83}, with reverse zoning, when present, due probably to pyroxene-plagioclase reaction; orthopyroxene En_{72} to En_{66}; clinopyroxene Mg= 42 to 38, Fe= 12 to 13, Ca= 48 to 49; olivine (one analysis) Fo_{75}; secondary zoisite (one analysis) Ps= 0.9; green spinel Al_2O_3 = 59 to 49%; FeO* = 26 to 22%, MgO= 13 to 14%. The anorthosite layers associated with the main norites are less basic in chemistry and contain labradorite or andesine.

Amphibolite Dykes.

These have intruded the remaining rocks of the complex and probably belong to a separate magmatic activity. These are rarely more than three meters in thickness and 100m in length. The rocks generally lack igneous textures (phenocrysts, ophitic or poikilitic texture, chilled margins), are equi- to sub-equigranular and, in some cases, foliated. Considering the general lack of pyroxene and abundance of amphibole, these may have intruded the Chilas complex between the earlier (granulite facies) and later (amphibolite facies) metamorphic episodes.

The dykes consist of variable proportions of plagioclase and amphibole, with small amounts of magnetite, ilmenite, apatite and, rarely, pyrite, hematite, carbonate and hypersthene. The plagioclase may be zoned normally or reversely and its composition ranges from An_{52} (with An_{31} outer zones) to An_{92} in different samples. The amphibole varies from magnesio hornblende to tschermakitic hornblende to ferroan pargasite. A hypersthene analysis contains 63 mol % En and an epidote has a pistacite content of 25.6. The textures and variations in the chemistry and proportions of the principal constituents, i.e. plagioclase and amphibole, of the dykes may suggest their reconstitution during metamorphism. There also is the possibility that the dykes have variable bulk chemistry.

DISCUSSION AND CONCLUSIONS

The Chilas complex is by far the largest of the world's stratiform complexes. More than 80% of it comprises norites and anorthositic norites, the remainder being durnites, peridotites, pyroxenites, troctolites, gabbros, anorthosites, hypersthene-quartz diorites and pyroxene pegmatites. The complex can be broadly classified into two types of rock association.

(A) Norite–anorthosite–pyroxenite–hypersthene-quartz diorite group. These constitute most of the complex, are generally strongly foliated and display some layering. The predominance of norites and anorthositic norites (like anorthosites in Duluth; Weiblen & Morey, 1980) may suggest equilibration of large volumes of rocks to a common temperature without successive fractionation. Jan (1977) suggested that these rocks were derived from a calc-alkaline (high-alumina basalt) magma.

(B) Dunite–peridotite–pyroxenite–troctolite–norite–anorthosite–pyroxene-pegmatite group. These occur in small bodies (upto $5km^2$) and appear mostly to be emplaced in the type-A rocks. Olivine ultramafites are the most abundant rocks in these; the rocks may have evolved from an olivine-rich troctolitic (picritic) magma, or representing "deformed" cumulates. The type-B rocks are principally concentrated within 25km of Chilas and there is a possibility that the well layered noritic rocks of that area belong to this group of rocks.

Considering the close association of type-A and -B rocks, possible short span of time in their formation, and systematic variation of mineral chemistry, they appear to be genetically related even if two magma fractions were involved in their formation. The rocks have broader similarity with stratiform rather than alpine (ophiolite) or concentric complexes (cf. Jackson & Thayer, 1972). However, some differences do exist between the minerals of the norites and anorthosites of the Chilas complex and the critical zone of the eastern Bushveld complex (Cameron, 1970). The clinopyroxene trend of Chilas is similar to that in the Gunflint and Sanju Lake intrusions of Duluch (Weiblen & Morey, 1980). Whether these comparisons are meaningful is debatable; some modifications in mineral chemistry may have taken place during corona growth and granulite facies metamorphism.

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