# Gabbronorite from Jijal Complex, Kamila Amphibolite Belt and Chilas Complex, Northern Pakistan: Implications for Arc Genesis

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**Abstract:** Rocks of gabbronoritic composition occur in three principal tectono-stratigraphic units forming the lower and middle parts of the Kohistan Island arc (KIA). These include the Jijal complex (JC), the Kamila Amphibolite belt (KAB) and the Chilas complex (CHC). The Jijal complex constitutes the lowermost part and hence is regarded as the root zone of KIA. Its north-eastern part adjacent to KAB contains gabbronorite as a minor component in the form of small irregular patches and layers within garnet granulite. The JC gabbronorite is sub-equigranular, medium to coarse grained, largely massive and consists of variable amounts of plagioclase (53-71 %), orthopyroxene (14-27 %) and clinopyroxene (11-19 %) as essential constituents and accessory to minor amounts of amphibole (1-9 %), opaque ore (1-6 %) and orthoclase (1-4 %). The occurrence and distribution of biotite, epidote, chlorite, clay, sericite, muscovite, quartz and actinolite in the studied samples suggest their formation through alteration and/ or reaction between pre-existing minerals. In many cases, these minerals are disposed such that a variety of simple and complex corona structures are produced. The principal petrographic features (modal composition, optical properties of the major mineral phases, exsolution in pyroxenes, products of alteration and reactions and the resulting corona textures) of the JC gabbronorite are broadly similar to gabbronorites from both the KAB and CHC. Although the observed similarities could reflect identical physico-chemical conditions during subsolidus or metamorphic re-equilibration, the possibility of a genetic relationship among gabbronorites from all the three tectono-magmatic units of the KIA (i.e. the JC, KAB and CHC) cannot be ruled out.

**Keywords:** Occurrence, mineralogy, texture, gabbronorite, Kohistan island arc

## Introduction

The ~36,000 km$^2$ intra-oceanic Kohistan island arc (KIA) occupies major parts of the northern region of Pakistan. It consists of genetically diverse rocks that are subdivided into several distinct groups (Fig. 1). The KIA has been studied extensively during the last almost five decades. Because of its complex origin, KIA has been the subject of several major geological investigations (Petterson, 2010). Despite all these efforts, the issue of petrogenetic evolution of KIA, especially the relationship among its different lithological units appears to be far from over as some of the important features and aspects still await adequate explanation. The widespread distribution of gabbronorite in different parts of the KIA constitutes one of these concerns.

Rocks of gabbronoritic composition occur in several localities of northwestern Pakistan (Fig. 1). From northeast to southwest, these include Chilas, Patan, Dasu and Jijal in Indus Kohistan, Khwazakhela area, Swat (Arif et al., 1983; Jan and Karim, 1992) and Khagram-Razagram area, Dir (Sajid et al., 2009). Geologically, however, all these occurrences are part of KIA and represent its different tectono-stratigraphic domains. For example, patches of gabbronorite occur within the Kamila Amphibolite belt (KAB) at Khagram-Razagram (Dir), Khwazakhela (Swat) and between Patan and Kamila (Indus Kohistan). Similarly, whereas

gabbronorite is one of the minor lithologies of the Jijal complex (JC), it constitutes the major bulk of the Chilas complex (CHC) (Figs. 1, 2).

It is important to highlight that petrographic descriptions of gabbronorite from almost all the localities, mentioned above, are available in published and/ or unpublished form. Although essentially aimed at furnishing further details regarding field association and petrographic characteristics of the JC (Patan) gabbronorite, the current investigation also included studying thin sections of gabbronorite from all the mentioned occurrences except CHC. Using a detailed petrographic comparison, an attempt is being made to assess the likelihood of a magmatic link among the gabbronorite occurrences in JC, KAB and CHC.

### Geology and Tectonics

The KIA is recognized to be a paleo-island arc that originated through subduction within the Neo-Tethys during the Cretaceous (Tahirkheli et al., 1979; Coward et al., 1986). Its accretion to the Karakoram micro-plate during 102-75 Ma (Le Fort et al., 1983; Treloar et al., 1989) transformed it to an Andean type margin prior to its collision with the Indian continent and closure of the Tethys at ~55 Ma (cf. Coward et al., 1987; Rehman et al., 2011). Contradicting this generally accepted model, it is suggested that KIA collided with India earlier than it did so with southern part (Karakoram) of the Asian plate (Khan et al., 2009). The Nanga Parbat-Haramosh

Table 1 Modal composition of the Jijal gabbronorite, northern Pakistan.

| | J-1 | J-2 | J-3 | J-4 | J-5 | J-6 | J-7 | J-8 | J-9 | J-10 | J-11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plagioclase | 71 | 63 | 67 | 58 | 55 | 54 | 58 | 53 | 57 | 55 | 54 |
| Orthopyroxene | 13 | 13 | 14 | 14 | 13 | 21 | 17 | 27 | 14 | 14 | 15 |
| Clinopyroxene | 11 | 14 | 11 | 13 | 11 | 16 | 12 | 11 | 13 | 19 | 13 |
| Hornblende (+Actinolite) | 1 | 2 | 1 | 1 | 6 | 2 | 2 | 1 | 2 | 2 | 9 |
| Alkali feldspar (Orthoclase) | 1 | 2 | 1 | 4 | 1 | 2 | 1 | 1 | 1 | - | 1 |
| Chlorite | - | 1 | 1 | 1 | 8 | 1 | 2 | 1 | 2 | 1 | 2 |
| Epidote | 1 | 1 | 1 | 5 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| Quartz | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 5 | 1 | 2 |
| Clay+Sericite+Muscovite | - | 2 | 1 | 1 | - | 1 | 1 | 1 | 4 | 1 | 1 |
| Opaque ore mineral(s) | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 6 | 2 |
| Biotite | - | - | - | - | 1 | - | 3 | - | - | - | - |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

massif, which is a loop like northward projection of the Indian plate, separates KIA from Ladakh arc in the east while the Main Mantle thrust (MMT) and Main Karakoram thrust (MMT) demarcate its southern and northern boundaries, respectively. Various KIA rock groups are a long narrow belt of metasedimentary rocks, known as Yasin group, form the northernmost part of KIA. These are regarded to be turbidites accumulated in the basin within or behind KIA (Pudsey, 1986). A variety of volcanic rocks has been described and compared in northern Kohistan. They are broadly grouped into two on the basis of age:

(i) the Chalt volcanics of Mid-Cretaceous age and (ii) the Utror-Shamran/ Teru volcanics of Paleogene age. The former are unconformably overlain (e.g. in Hunza area) by and inter-layered with the Yasin group metasediments (Matsushita and Huzita, 1965).

In addition to these, Treloar et al. (1996) have documented that volcanic-absent metasedimentary sequences also occur in northern Kohistan. Jaglot Group is a relatively recently recognized cross-KIA unit (Khan et al., 1997). It consists of high-grade metamorphosed sedimentary (meta-sandstones, siltstone, mudstone,

Table 2 Petrographic comparison among the different gabbronorite occurrences in northern Pakistan.

| | Feature | Chilas Complex | Jijal complex | Khwazakhela, Swat | Khagram-Razagram, Dir |
|---|---|---|---|---|---|
| **Modal Composition** | Essenntial Minerals | Plagioclase (45-65 %, Opx (10-27 %), Cpx (6-28) (Bilqees, 2005) | Pg (53-71 %), Opx (13-27 %), Cpx (11-19 %) | Pg (53-67 %), Opx (16-26 %), Cpx (11-21 %) | Pg (54-69 %), Opx (18-24 %), Cpx (12-17%) |
| | Accessory Minerals | K-fel, Qtz, Amp (brownish), opaque ore, spinel | K-fel, Qtz, Amp (brownish), opaque ore | K-fel, Qtz, Amp (brownish), ore mineral(s), spinel | K-fel, Qtz, Amp (brownish), opaque ore |
| **Alteration/ Reaction products** | | Biotite, Amp (bluish and colorless), Epi, Chl, clay, Ser, Mus, Qtz | Bi, Amp (bluish and colorless), Epi, Chl, clay, Ser, Mus, Qtz | Amph (bluish and colorless), Epi, Chl, clay, Ser, Mus, Qtz | Bi, Amp (bluish and colorless), Epi, Chl, clay, Ser, Mus, Qtz |
| **Mode of occurrence/ Nature of associated rock** | | Constitutes the major bulk of the Chilas complex | As patches within garnet granulite | As patches in amphibolites of the Kamila amphibolite belt | Bi, Amph (bluish and colorless), Epi, Chl, clay, Ser, Mus, Qtz |
| **Pg composition** | | $An_{48}$ to $An_{64}$ (Khan et al., 1989) | $An_{42}$ to $An_{68}$ | $An_{55}$ to $An_{65}$ | $An_{44}$ to $An_{62}$ |
| **Corona and/ or symplectite** | | 1. Opx → Amp → Pg<br>2. Opx → Amp ± spinel → Pg<br>3. Cpx → Amp ± Epi + Qtz → Pg<br>4. Fe-oxide → Amp → Pg<br>5. Fe-oxide → Amp-Epi + Qtz → Pg<br><br>(Jan et al., 1984) | 1. Opx → Amp + Qtz symplectite → Pg<br>2. Opx → Amp → Pg<br>3. Opx → Epi → Pg<br>4. Cpx → Amp →Pg<br>5. Ore → Amp → Pg | 1. Opx → Amp + Qtz symplectite → Pg<br>2. Opx → Amp →Pg<br>3. Opx → Epi → Pg<br>4. Cpx → Amp → Pg<br>5. Ore → Amp → Pg<br>6. Opx-Cpx + spinel symplectite<br>7. Cpx-Opx + spinel symplectite | 1. Opx → Amp + Qtz symplectite → Pg<br>2. Opx → Amp →Pg<br>3. Opx → Epi → Pg<br>4. Cpx → Amp →Pg<br>5. Ore → Amp → Pg |
| **Blebs in Cpx/ Opx** | | Oriented reddish brown blebs in both Opx and Cpx | None | None | Oriented reddish brown blebs in both Opx and Cpx |

Abbreviations: Amp = amphibole; An = anorthite content; Bi = biotite; Chl = chlorite; Cpx = clinopyroxene; Epi = epidote; K-fel = potash feldspar; Mus = muscovite; Opx = orthopyroxene; Pg = plagioclase; Qtz = quartz; Ser = sericite

carbonates, and turbidites) lithologies and locally occurring metamorphosed basaltic to rhyolitic rocks.
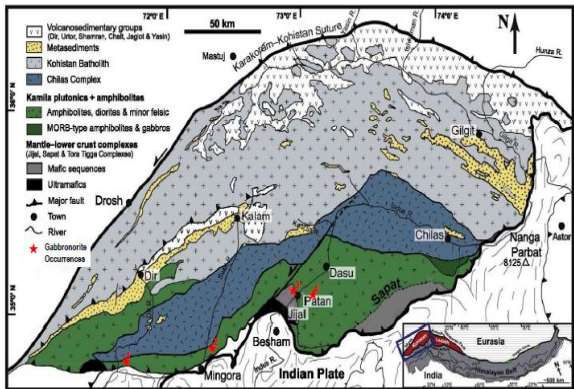


Fig. 1 Geological map of the Kohistan island arc, North Pakistan (after Jagoutz, 2014). The rectangular box encloses the Jijal complex and the stars show approximate locations of the gabbronorite occurrences other than the Chilas complex: 1, Lower Dir (Khagram-Razagram); 2, Swat valley (Khwazakhela); 3, northeast of Jijal (near Patan), Indus valley; 4, southwest of Kamila (east of Patan), Indus valley.

Another principal KIA component is the Kohistan batholith, which consists of a large number of small plutons and sheet-like bodies with compositions ranging from calc-alkaline gabbro to leucogranite (Petterson and Windley, 1985). Although spread over a long time period (154–26 Ma), the magmatic development of the Kohistan batholith has been distinguished into three major plutonic stages (Petterson and Windley, 1985; Schaltegger et al., 2002 and references therein). Recently, however, Jagoutz et al. (2009, 2018) have questioned this fabric-based three-stage genetic model for the Kohistan batholith and argued that gneissose structure in the older Kohistan plutons originated due to emplacement-induced stresses rather than collision related deformation.

The Chilas complex (CHC), which geographically forms the middle part of KIA, stretches for ~300 km from Raikot Bridge in northern Pakistan in the east right up to Afghanistan in the west (Fig. 1). The CHC is intruded into the volcanic and sedimentary rocks of the
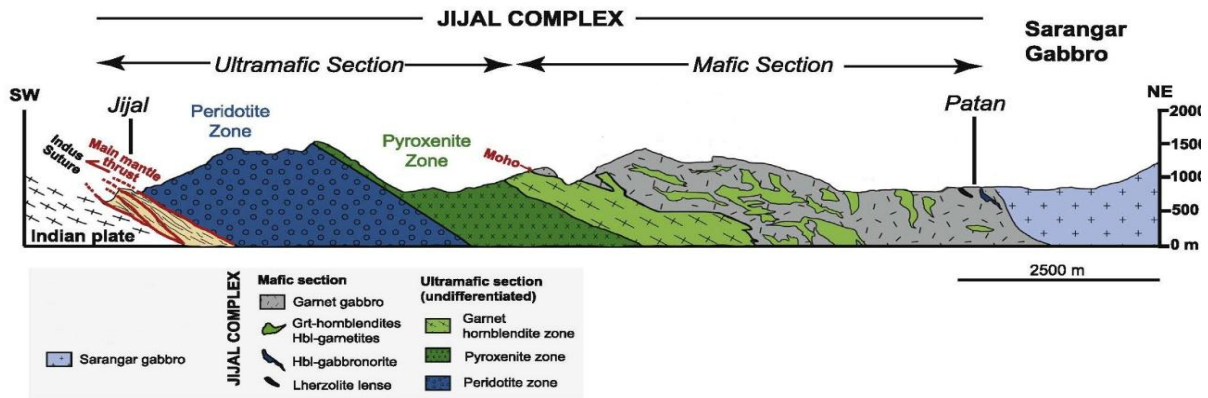


Fig. 2 A geological cross-section along the Indus Valley from the Jijal complex (at the Indus Suture contact) to the Sarangar gabbro (lower metaplutonic complex) (after Bard, 1983 and Zeilinger, 2002).
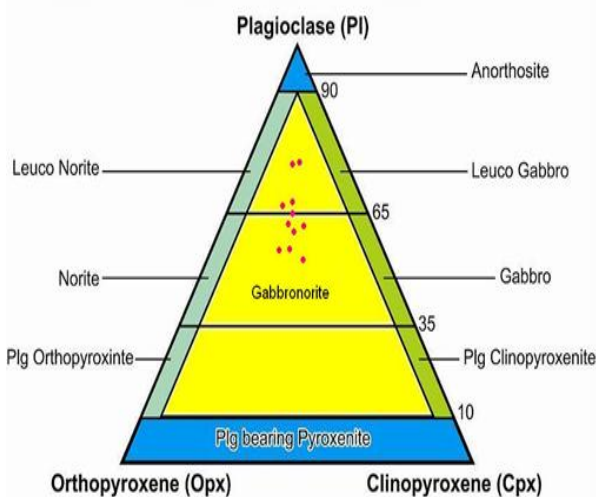


Fig. 3 Modal composition of gabbronorite from Jijal, northern Pakistan plotted on the ternary diagram of Le Maitre (2002).

back-arc basin to the north and medium-grade metamorphosed plutonic (gabbro and diorite) and volcanic rocks of KAB to the south (Khan et al., 1996; Treloar et al., 1996). The predominantly gabbronoritic CHC contains bodies of ultramafic rocks that are considered to be parts of up-warped mantle (Khan et al., 1989; Burg et al., 1998). There appears to be a general consensus that the age of CHC is ~85 Ma (Zeitler et al., 1981; Jagoutz et al., 2009).

The KAB, formerly termed as southern amphibolite (Bard, 1983), lies between CHC in the north and Jijal complex in the south (Fig. 1). Burg et al. (2005) have revived usage of the term southern amphibolite and regarded it as a continuation of, although intrusive into, the lower crustal section (granulite facies garnet metagabbro) of the Jijal complex and subdivided it into three units. From bottom to top from older to younger on the basis of intrusive contacts these include (i) the
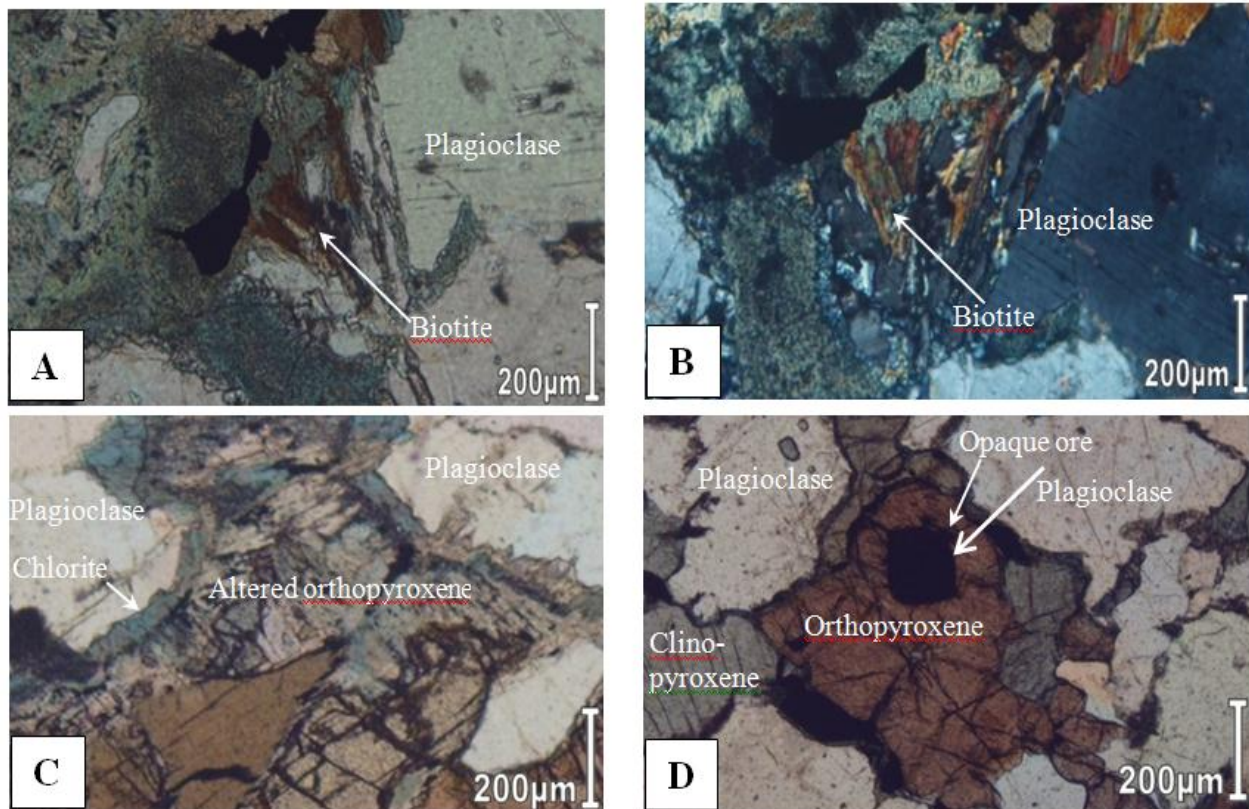
**Fig 4:** Photomicrographs showing (A, PPL; B, XPL) biotite formed between altered grains of orthopyroxene and plagioclase and along fractures within plagioclase, (C) chlorite formed around altered orthopyroxene (PPL) and (D) an opaque ore mineral inclusion in orthopyroxene (PPL).

Sarangar metagabbro (Patan complex), (ii) the Kiru amphibolite and (iii) and the Kamila amphibolite. Although largely composed of amphibolites, the belt at places contains patches of gabbronorite and bodies of mafic-ultramafic rocks (Figs. 1, 2).

The Jijal complex represents the root zone of the KIA and has been distinguished into mantle and lower crustal sections (Burg et al., 2005). The mantle part consists of dunite, stringers/ layers and small but mineable bodies of chromite, peridotite and pyroxenite, while the crustal section is predominantly mafic and consists of garnet-bearing gabbroic rocks (Jan and Howie, 1981; Jan and Windley, 1990; Burg et al., 2005). The latter (garnet granulites) were formed by high-pressure granulite facies metamorphism of gabbronorite during $91.0 \pm 6.3$–$95.7 \pm 2.7$ Ma (Yamamoto, 1993; Yoshino et al., 1998). This high-grade metamorphism (700–950 °C, > 1 GPa) was accompanied by melting through dehydration of amphibole (Yamamoto and Nakamura, 2000; Garrido et al., 2006). Accordingly, the gabbronorite occurs as relict patches within garnet granulite (Fig. 2).

## Result and Discussion

The Jijal gabbronorite is largely massive, however, foliation is observed at places. As a major part of the present investigation, eleven samples of gabbronorite were collected from the JC exposure near Patan (Figs. 1, 2). All these samples were examined using standard thin sections under polarizing microscope. Besides, thin sections of gabbronorite from the Khagram-Razagram and Khwazakhela areas were also studied. Average modal compositions were determined through visual estimation. Besides, textural relationships were noted and important petrographic features recorded.

## Modal Composition

The collected samples are equi-granular, medium to coarse-grained and display hypidiomorphic texture. They commonly consist of plagioclase, orthopyroxene and clinopyroxene as essential minerals and a number of accessory and secondary minerals (Table 1, Fig. 3). Plagioclase crystals are subhedral to euhedral and large in size. The composition of plagioclase ranges from $An_{42}$ to $An_{68}$ and its modal abundance ranges from 53 to 71%. Almost all the plagioclase grains show multiple twinning. Tiny grains of orthopyroxene, opaque mineral(s) and clinopyroxene are enclosed in most of them. Mostly the plagioclase is fresh, however, a few grains show cloudy appearance, which is due to its partial alteration to clay, sericite and infrequently, muscovite. Blebs of epidote and quartz also occur as alteration products. The deformation in plagioclase is illustrated by the occurrence of kinked twin lamellae and by the presence of small thin fractures, which are mostly filled with its own alteration products, i.e. clay, sericite and muscovite and, occasionally biotite (Figs. 4a, b).

The orthopyroxene is distributed as medium to large size grains and its modal abundance falls in the range of 13–27 %. Most of its grains display strong, light green to pink pleochroism. Exsolution lamellae, mostly of clinopyroxene, were observed in some of the orthopyroxene crystals. Along grain margins, orthopyroxene shows alteration to chlorite + quartz and clinopyroxene to epidote + quartz (Fig. 4c). Besides, thin rims of actinolite occur along the margins of some of the orthopyroxene grains. Occasionally opaque mineral(s) (magnetite and/ or ilmenite) occurs as inclusions in orthopyroxene (Fig. 4d). At places, extensive chloritization has also taken place whereby major parts of the grains are converted to chlorite leaving behind only relics of orthopyroxene. Most of the orthopyroxene grains display perfect cleavages and irregular fractures. At places, biotite has grown along the orthopyroxene-plagioclase grain contacts (Figs. 4a, b). Clinopyroxene (11 to 19 modal %) is medium to coarse grained. It is non-pleochroic to very weakly pleochroic. Tiny euhedral grains of orthopyroxene occur as exsolved lamellae within some of the clinopyroxene grains (Fig. 5a). Along some of the grain margins, it is converted to chlorite and actinolite. Locally, the individual crystals are largely transformed

to actinolite that contains clinopyroxene as small relics. Like the orthopyroxene, grains of clinopyroxene mostly exhibit perfect cleavages and irregular fractures. Among subordinate constituents, amphibole is the most commonly occurring one. Its modal abundance ranges up to 9%. Based on color in plane polarized light, three varieties of amphibole can be distinguished: bluish, colorless and brownish amphibole. The brownish amphibole is most likely hornblende and seems to be primary (magmatic). Whereas the bluish amphibole appears to be actinolite and secondary in origin, i.e. formed by alteration of the pyroxenes and hornblende and the colorless amphibole is most probably cummingtonite and metamorphic in origin. The alkali feldspar (largely orthoclase) is as much as 4 modal % and occurs as discrete grains, some of which display somewhat irregular microperthitic texture. Small quantities of magnetite and/ or ilmenite occur as small discrete crystals that are mostly surrounded by thin rims or broader zones of hornblende ± quartz. The modal abundance of the opaque mineral(s) ranges up to 6 %. Besides, up to 5 modal % quartz occurs as discrete grains as well as along grain margins of some of the other minerals. Quartz is also found as if formed by the
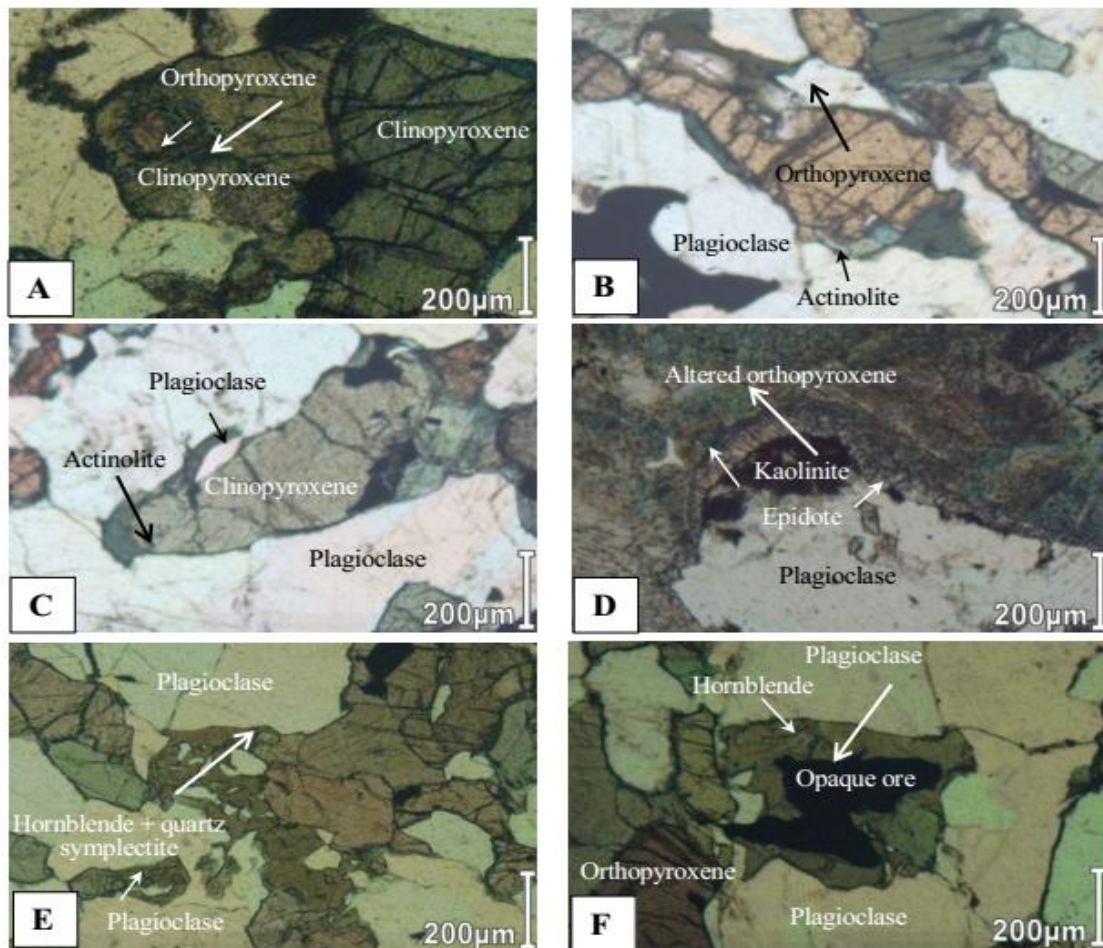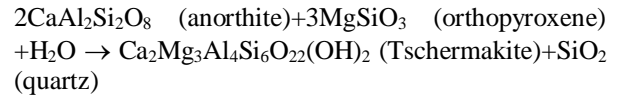


Fig. 5 Photomicrographs (PPL) of the Jijal complex gabbronorite showing (A) exsolved orthopyroxene in clinopyroxene, (B) actinolite around orthopyroxene, (C) actinolite around clinopyroxene, (D) a rim of epidote along plagioclase–altered orthopyroxene contact, (E) hornblende–quartz intergrowth (symplectite) between orthopyroxene and plagioclase, and (F) hornblende formed between an opaque ore mineral and plagioclase.

alteration of pyroxene and plagioclase. At places, the quartz grains show undulose extinction.

The mode of occurrence and association of epidote (up to 5 modal %) indicates that it is mostly formed by the alteration (saussuritization) of plagioclase. Occurrence of chlorite (up to 8 modal %) along margins of the orthopyroxene and clinopyroxene grains suggests its derivation through alteration of the latter two minerals. At places, it has almost totally replaced some of the orthopyroxene grains and therefore contains small relics of the latter. The modal abundance of biotite does not exceed 3% and its occurrence is restricted to fractures within grains of plagioclase and along contacts between grains of orthopyroxene and plagioclase. The occurrence of accessory to trace amounts of clay mineral(s) (up to 4 modal %), sericite and muscovite is confined to the altered plagioclase grains so as to reflect progression of plagioclase transformation in the following order: clay mineral(s) $\rightarrow$ sercicite $\rightarrow$ muscovite.

to have developed as a result of reaction of plagioclase with (1) ferromagnesian minerals (orthopyroxene and clinopyroxene) and (2) an opaque mineral(s) (magnetite/ ilmenite). The following five types of corona textures have been observed in the studied samples (Table 2; Figs. 5b-f): 1) orthopyroxene $\rightarrow$ hornblende $\rightarrow$ plagioclase, 2) clinopyroxene $\rightarrow$ hornblende $\rightarrow$ plagioclase, 3) orthopyroxene $\rightarrow$ epidote $\rightarrow$ plagioclase, 4) orthopyroxene $\rightarrow$ hornblende + quartz (symplectite) $\rightarrow$ plagioclase, 5) opaque ore $\rightarrow$ hornblende $\rightarrow$ plagioclase. A possible reaction for the development of the combination (4) is as follows (Claeson, 1998).

$2CaAl_2Si_2O_8$ (anorthite)+$3MgSiO_3$ (orthopyroxene) +$H_2O \rightarrow Ca_2Mg_3Al_4Si_6O_{22}(OH)_2$ (Tschermakite)+$SiO_2$ (quartz)

Although corona textures with or without symplectite may form as a result of simple hydration or due to reactions between two previously adjacent mineral
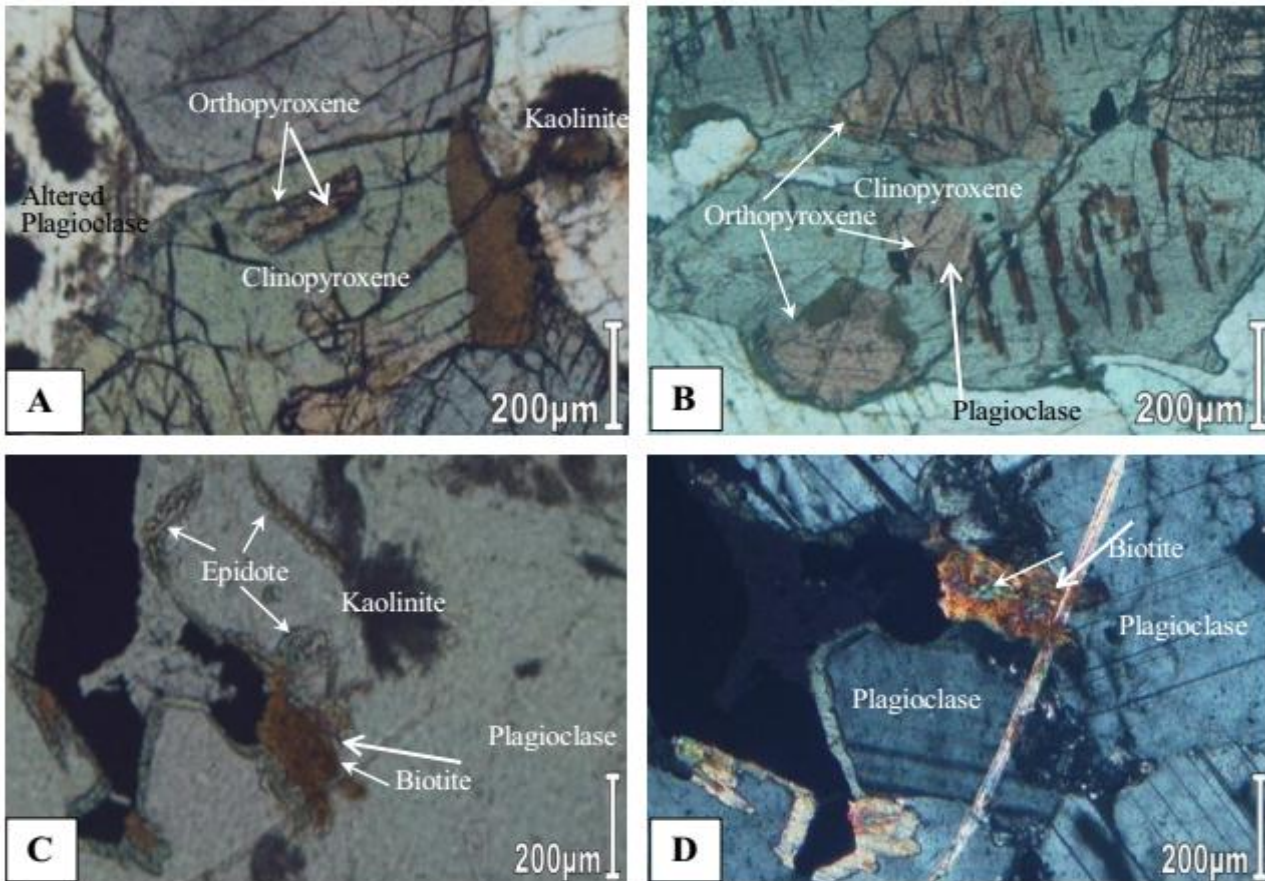


Fig. 6 Photomicrographs showing exsolved orthopyroxene in clinopyroxene in gabbronorites from Khwazakhela area, Swat (A, PPL) and Khagram-Razagram area, Dir (B, PPL), and biotite in gabbronorite from Khagram-Razagram area, Dir (C, PPL and D, XPL).

**Textural Features**

A few of the investigated thin sections exhibit corona textures and/ or symplectites. Being too small to be seen megascopically, coronas in the Jijal gabbronorite are deciphered only under the petrographic microscope. The corona textures in the investigated samples appear

grains, the reaction zones reported here appear to have formed by reaction between formerly adjacent mineral grains facilitated and mediated by a largely hydrous fluid component (Larikova and Zaraisky, 2009).

Three major lithological groups of KIA host gabbronorite, i.e. JC, CHC and KAB (Khagram-

Razagram area, Dir and Khwazakhela area, Swat). The Jijal gabbronorite does not constitute a separate body. Rather, it occurs as thin layers and small irregular patches within garnet granulite. The gabbronorite in both the Swat (Khwazakhela) and Dir (Khagram-Razagram) areas also exhibits an almost similar mode of occurrence and relationship with the associated rocks, i.e. the Kamila amphibolite. In contrast, gabbronorite is the most abundant lithology and hence constitutes major bulk of the Chilas complex.

The Jijal gabbronorite contains variable amounts of plagioclase, orthopyroxene and clinopyroxene as essential minerals, while hornblende, alkali feldspar, quartz, magnetite and ilmenite are its most common accessory constituents. Gabbronorites from the other three localities also contain the same minerals in more or less the same modal proportion (Table 2). All the mentioned gabbronorites also host the same kind and quantities of accessory minerals, except spinel. The latter was not observed during the current investigation of the gabbronorite samples from both the Jijal complex and Khagram-Razagram area. The type, color and degree of pleochroism displayed by orthopyroxene and hornblende in the studied samples from Jijal also duplicate the corresponding features observed in the gabbronorites from Chilas, Swat and Dir (Figs. 5a, b). Likewise, the type and extent of exsolution in pyroxenes and the range of plagioclase composition are broadly similar in all the four occurrences of gabbronorite. Besides, the products of alteration and the nature of their precursors in the studied samples from Jijal are also similar to those found in Chilas, Swat and Dir gabbronorites (Table 2).

Among the newly formed ('secondary') minerals, biotite occurs in all but the Khwazakhela gabbronorite samples (Figs.6b-d). Biotite in the Jijal gabbronorite occurs in very small amounts and has grown along fractures within plagioclase and along the contact between grains of orthopyroxene and plagioclase. The formation of biotite is believed to be a result of reaction between ferromagnesian mineral(s), especially orthopyroxene and plagioclase during metamorphism (Jan, 1979). The plagioclase most probably supplied the potash required for the formation of biotite. Further investigation might lead to finding biotite also in the Khawazakhela gabbronorite. Alternatively, the absence of biotite from the Khawazakhela gabbronorite might be because of the relatively low potash content or K-free character of its plagioclase. A detailed investigation of the studied thin sections reveals the occurrence of features suggestive of mineral reactions and alteration. These include the development of corona textures and/or symplectites. Some of the corona/ symplectite textures observed in the studied Jijal samples also occur in the gabbronorites from the other three localities (Table 2). These include (i) orthopyroxene → hornblende → plagioclase, (ii) clinopyroxene → hornblende → plagioclase and (iii) opaque ore mineral (Fe-oxide) → hornblende → plagioclase.

## Conclusion

The remarkably similar petrographic features among the gabbronorites from Chilas and Jijal complexes and the Kamila amphibolite belt indicate the following two possibilities. (1) All the gabbronorite occurrences are genetically related, i.e. formed from the same magma, and the marked differences among them in terms of both the type and abundance of their associated rocks reflect significantly different conditions during either (i) crystallization, or (ii) subsequent re-equilibration including metamorphism. (2) Gabbronorites from the three different tectono-magmatic units of the KIA are magmatically unrelated but all of them underwent sub-solidus or metamorphic re-equilibration under similar conditions.

Whereas contact relationship and differences in ages support the second possibility (Burg et al., 2005), the occurrence, field relations and petrographic similarities strongly suggest that the Jijal garnet granulite (and the associated amphibolites) and Kamila amphibolite, especially its predominant metaplutonic variety, were derived from a gabbronorite protolith most probably the Chilas gabbronorite.

## Acknowledgements

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