# Trace element compositions of rocks and minerals from the Chilas Igneous Complex, Kohistan, northern Pakistan

Masumi U Mikoshiba†*, Yutaka Takahashi†, Kazuya Kubo†, Yuhei Takahashi†, Allah B Kausar‡ and Tahseenullah Khan‡

*† Institute of Geoscience, Geological Survey of Japan, AIST, 1-1-1, Higashi, Tsukuba 305-8567, JAPAN*
*‡ Geoscience Laboratory, Geological Survey of Pakistan, Chak Shahzad, P.O. Box 1461, Islamabad, PAKISTAN*

** To whom correspondence should be addressed. E-mail: masumi-mikoshiba@aist.go.jp*

The Kohistan terrane in the western Himalayan region is considered as a Cretaceous island-arc sequence sandwiched between the Asian and Indian continental crusts. It is a 300-km-long plutonic body that extends parallel to the general trend of the Kohistan terrane. Rocks of this complex are petrographically and compositionally similar to plutonic xenoliths found in island arcs (Khan et al. 1989). We report geochemical data of rocks and minerals in the Chilas Complex and discuss the melt compositions and magmatism in middle to lower arc crust.

The Chilas Complex is well exposed along the Indus and Swat Rivers. Most of the complex consists of generally homogeneous gabbronorite, pyroxene diorite and pyroxene quartz diorite, and these are called as the Main facies rocks. Some of the rocks were re-equilibrated under granulite facies conditions at 750-850 °C and 6-8 kbar (Swat valley, Jan and Howie 1980).

Rocks with layered structure are also found in the Chilas Complex, which often occur in km-scale masses. Some of the masses are abundant in peridotites associated with layered gabbroic rocks (ultramafic-mafic association), which are deduced to be crystal accumulates. One of the bodies of the ultramafic-mafic association, Thak body just to the east of Chilas town, shows excellent outcrops. This body is included in the Main facies rocks, and consists of cyclic units of layered cumulate rocks, which is classified into olivine-dominant cumulate (dunite-wehrlite), plagioclase-dominant cumulate (troctolite-gabbronorite) and pyroxene-dominant cumulate (websterite-clinopyroxenite). Hornblende and spinel are often included in the rocks. Mg values of the pyroxenes and An content of plagioclase are high in these cumulative rocks, but systematic change of major chemical composition of the minerals are not recognized through the Thak body. In addition, one gabbronorite mass along the Indus River (Basehri body) is characterized by well-developed rhythmic layering, and most of the layers were overturned. The Basehri body is intruded by the Main facies rocks, which is considered as crystal cumulate from the magma of the Main facies.

Main facies rocks of the Chilas Complex have the characteristics of subduction-related calc-alkaline magmas with depletion of Nb relative to other incompatible elements (Khan et al. 1989). The concentrations of $K_2O$, Y, Zr, Th and rare earth elements (REE) in the Main facies rocks are positively correlative with $SiO_2$ content. In the chondrite-normalized diagram, the light REE are enriched relative to heavy REE in the rocks, and the REE patterns are slightly concave upward. The chemical variation of the most of the Main facies rocks can be explained by a weak segregation of melt and early-formed crystals composed of plagioclase, clinopyroxene and orthopyroxene.

The major element compositions of the rocks from the Thak body show the wide variation reflecting accumulation of early-stage crystals. Rocks are generally poor in REE and other incompatible elements, implying the separation of the melt and crystals are effective. Even the gabbroic rocks without olivine are still poor in REE and other incompatible elements relative to the Main facies rocks. REE concentrations of the layered rocks of the Basehri body are generally lower than those of the Main facies rocks.

For characterization of magmas of these layered rocks, trace element compositions of clinopyroxene and plagioclase are determined by ICP-MS after mineral separation. Clinopyroxene fractions from wehrlite and websterite, and whole-rock sample of clinopyroxenite in the Thak body have REE, Ba, Nb, Sr and Zr concentrations similar to each other. The clinopyroxenite and the clinopyroxene from websterite have weak negative Eu anomaly and REE concentrations slightly higher than the clinopyroxene from wehrlite. The clinopyroxene from a plagioclase-rich part of the layered gabbronorite of the Basehri body shows the REE concentrations 3-5 times higher than clinopyroxenes from the Thak body, with clear negative Eu anomaly. Plagioclase fractions from a troctolite in the Thak body and from the plagioclase-rich rock of the Basehri body have REE concentrations with positive Eu anomalies, and they have similar Sr concentrations although the plagioclase from the troctolite are poor in most of the incompatible elements.

The melts calculated from the clinopyroxenes of the pyroxene- and olivine-dominant cumulates in the Thak body are enriched in light REE relative to heavy REE, showing chemical characteristics closer to calc-alkaline or high-alumina basalt magmas in island arcs rather than depleted island-arc tholeiites. The calculated melts have REE, Sr and Zr concentrations similar to the Main facies rocks. The melts calculated from the plagioclase fractions have Sr, Ba and Rb concentrations similar to the Main facies rocks. These data suggest a possibility that the original magmas of the cumulates of the Thak body and the magma of the Main facies were derived from common or similar source materials, in spite of large petrographic variations. Trace element abundances in clinopyroxene and plagioclase from the Basehri body may have been affected by subsolidus equilibration, and also affected by a small amount of trapped melt.

## References

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