APATITE, PHLOGOPITE AND CLINOPYROXENE AS TRACERS FOR METASOMATIC PROCESSES IN NEPHELINE-OLIVINE MELANOGABBROS OF URALIAN-ALASKAN-TYPE COMPLEXES IN THE URAL MOUNTAINS, RUSSIA

Krause J.*,, Harlov D.E.***, Pushkarev E.V.****, Brügmann G.E.****
**Max-Planck-Institut für Chemie, Mainz, Germany*
e-mail: krause@mpch-mainz.mpg.de
***Institut für Geowissenschaften, Universität Mainz, Mainz, Germany*
e-mail: bruegmag@uni-mainz.de
****GeoForschungsZentrum Potsdam, Potsdam, Germany*
e-mail: dharlov@gfz-potsdam.de
*****Institute of Geology and Geochemistry UB RAS, Ekaterinburg, Russia*
e-mail: pushkarev@igg.uran.ru

RESULTS AND DISCUSSION

Nepheline bearing melanogabbros (tilaites) are assumed to represent the most fractionated products of the melt forming Uralian-Alaskan-type zoned mafic-ultramafic complexes in the Ural Mountains (Russia). These nepheline gabbros predominantly consist of coarse-grained clinopyroxene phenocrysts in a matrix of fine grained olivine, clinopyroxene, plagioclase, K-feldspar, and nepheline and titanomagnetite. Apatite occurs as idiomorphic inclusions (<15 μm) in the clinopyroxene and as xenomorphic grains (<100 μm) in the matrix.

Primary textures in idiomorphic clinopyroxene phenocrysts are preserved as magmatic oscillatory or hour glass zonation unveiled by titanomagnetite exsolutions and major elements like Cr, Fe, Mg, Al and Ti. This primary texture is partially overprinted by a complex, patchy distribution of titanomagnetite exsolutions. Here the clinopyroxene is enriched in Ti, Al, and Fe and depleted in Si and Mg (Fig. 1a). Compositional boundaries between the two textures are sharp. This overprint is interpreted to reflect a post-magmatic alteration.

Apatite inclusions located in the original magmatically zoned areas of the clinopyroxene phenocrysts are rich in F (2.4-2.7 wt.%) and SrO (0.5-0.6 wt.%) and poor in Cl (0.4-0.8 wt.%) and Na_2O (<0.1 wt.%). In contrast apatite inclusions from the altered areas of the clinopyroxene, as well as interstitial apatite from the matrix, are enriched in Cl (1.0-2.2 wt.%) and Na_2O (0.1-0.5) and depleted in F (1.7-2.3 wt.%) and SrO (<0.45 wt.%). The OH contents in all apatites are similar at 1.1-1.5 wt.% (Fig. 1b, c).

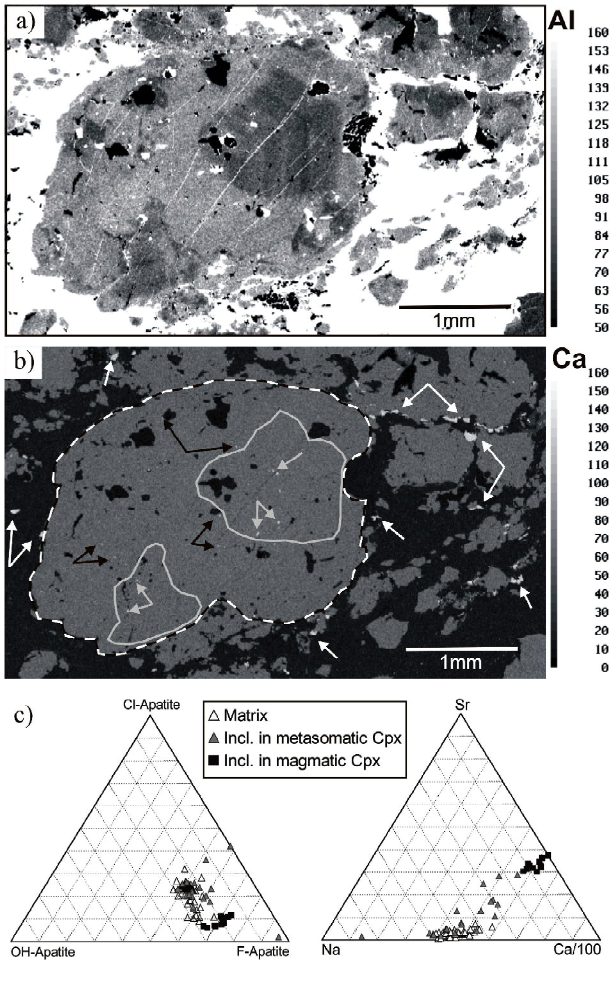

Fig. 1. Spatial distribution and chemical composition of apatite inside and around a partially metasomatized clinopyroxene.

*The X-ray element map of Al in a clinopyroxene (**a**) shows dark relics with an oscillatory magmatic zonation and hydrothermal overprinted light areas with elevated Al contents. The X-ray element map of the Ca distribution (**b**) shows apatite (bright spots) enclosed in the magmatic clinopyroxene (gray arrows) as well as in the overprinted clinopyroxene (black arrows) and in the matrix (white arrows). Note the different composition of apatite (**c**) in different textural positions. (Sample NT9b Nizhny Tagil-Complex).*

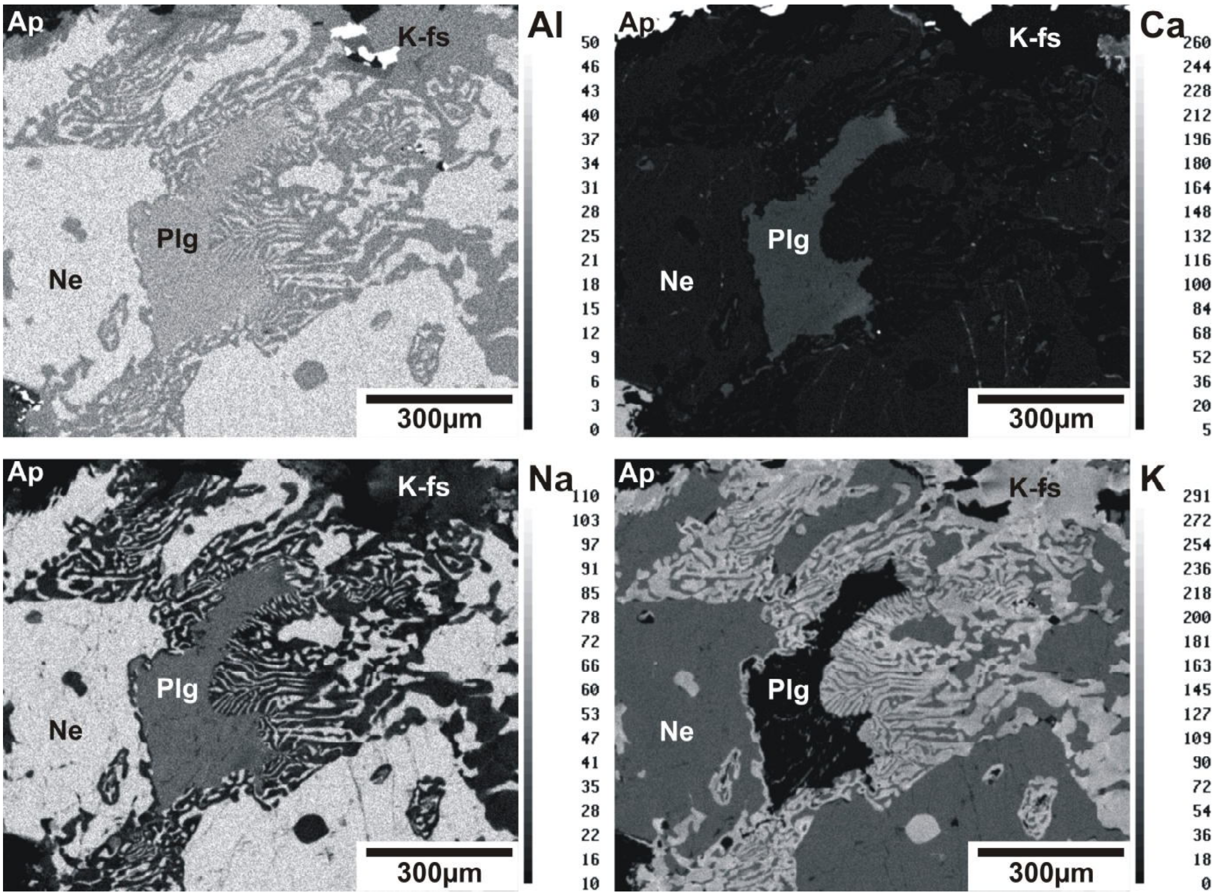

Fig. 2. *X-ray element distribution maps for Al, Ca, Na and K show a xenomorphic plagioclase (Plg) grain that is being replaced by a fine grained, symplectitic intergrowth of K-feldspar (K-fs) and nepheline (Ne). Apatite (Ap) is also present at the upper margin of the images. Note the slight zonation in the Ca content of the plagioclase and the lobate grain boundary of the plagioclase at the contact with the K-feldspar nepheline intergrowth. (Sample NT9b Nizhny Tagil-Complex).*

Like apatite, phlogopite occurs as inclusions in both the original magmatic and metasomatised areas of the clinopyroxene as well as in the matrix. As for apatite the chemical composition of the phlogopite is subject to its textural position [1]. Phlogopite enclosed in the magmatic part of clinopyroxene has elevated F and Cl contents (F = 0.6-1.1 wt.%, Cl = 0.1-0.5 wt.%), lower TiO_2-contents (TiO_2 = 1.7-4.5 wt%) and a wider range in the Mg# (Mg# = Mg/(Mg+Fe) = 0.67-87) compared to phlogopite in the matrix (F = 0.2-0.6 wt.%, Cl = 0.07-0.15 wt.%, TiO_2 = 3.0-7.5 wt.%, Mg# = 0.72-0.82). Phlogopite enclosed in the metasomatic areas of clinopyroxene has intermediate compositions (F = 0.4-0.9 wt.%, Cl = 0.1-0.25 wt.%, TiO_2 = 2.7-5.5 wt.%, Mg# = 0.72-0.84).

In the matrix, plagioclase (An 26-41) is replaced by a fine-grained intergrowth of nepheline and K-feldspar (Or 53-93) in the form of a symplectitic texture (Fig. 2). Coloured CL-images indicate the presence of two generations of K-feldspar. The first generation is a primary magmatic phase with a light blue luminescence. The second generation (gray luminescence) forms part of the symplectitic intergrowth with nepheline as well as rims around the magmatic K-feldspar cores. Nepheline also occurs as two different textural varieties, indicating the presence of two different generations. In places the symplectitic intergrowth is dynamically recrystallized.

Mass balance calculations imply that the replacement of plagioclase by nepheline + K-feldspar requires the addition of K_2O, Na_2O and Al_2O_3 and the removal of SiO_2 and CaO. Fine grained xenomorphic clinopyroxene and apatite in or close to the intergrowths of K-feldspar and nepheline can be interpreted as crystallisation products from this replacement. The high Cl content, seen in apatite inclusions from the altered regions of the clinopyroxene as well as apatite in the matrix, implies that these mafic cumulates have been metasomatically overprinted, presumably by a KCl-rich brine during which plagioclase was replaced by K-feldspar and nepheline. An additional potential source for Al_2O_3 and K_2O is phlogopite, whose partial breakdown and subsequent overprint in the matrix is indicated by lower contents of Cl and F and higher TiO_2-contents.

The partial metasomatic alteration of the clinopyroxene can be interpreted as being due to a fluid-aided dissolution-reprecipitation process. Thereby a Cl_2-enriched fluid mobilised Fe, Mg, Al, Si and Ti in the altered areas causing the breakdown and redistribution of the titanomagnetite inclusions and Cl-enrichment in the apatite inclusions. Inclusions in the non-altered areas, i.e. the original magmatic clinopyroxene, did not encounter this Cl-bearing fluid and retain their original composition and texture. This fluid phase probably was a $CaCl_2$-rich brine. It could be derived from the former K-rich brine which lost K but gained Ca during its reaction with plagioclase to form nepheline + K-feldspar.

Hence a metasomatic overprint explains the unusual mineralogical composition of some mafic cumulates in Uralian-Alaskan-type complexes in the Ural Mountains and might also explain the different whole rock ages given by the Nd and Sr isotopic systematics [2, 3].

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REVERSELY-ZONED MAFIC BODY AT THE BASE OF THE KOITELAINEN LAYERED INTRUSION, FINLAND: PETROLOGICAL SIGNIFICANCE FOR ORIGIN OF MARGINAL REVERSALS

Latypov R.M.*, Hanski E.*, Lavrenchuk A.V.**
**Department of Geosciences, Oulu University, Oulu, Finland*
e-mail: rais.latypov@oulu.fi
***Institute of Mineralogy and Petrography SB RAS, Novosibirsk, Russia*
e-mail: alavr@mail.ru

An unusual 160 m thick sill-like body of fine- to medium-grained pigeonite gabbro has been recently discovered in between Archaean basement gneisses and the Paleoproterozoic Koitelainen layered intrusion, NW Finland [1, 2]. It has a chilled lower margin but non-chilled upper contact with respect to the overlying chromite-bearing orthopyroxene cumulates of Koitelainen layered intrusion. The body is unique in showing remarkably systematic reverse fractionation trends from the base to the very top. These are exemplified by a significant upward increase in whole-rock Mg# (100*Mg/(Mg+Fe)) from about 30% to 80%, and in normative An (100*An/(An+Ab)) from about 20% to 70%. Especially noteworthy is the upward dramatic depletion in all incompatible trace elements. For instance, La reveals a 250-fold decrease from 27.5 ppm to 0.11 ppm and Zr shows a 340-fold decrease from about 170 ppm to 0.5 ppm. In addition, a systematic upward decrease in ratios of highly incompatible elements (e.g. Zr/Y from 9 to 1; La/Yb from 20 to 1) is observed. In comparison to common basal reversals in layered intrusions, the studied body has a smaller grain size and exhibits a non-cumulative texture precluding a simple dilution effect due to cumulus crystals. The finding of a magmatic body with such anomalous compositional features is puzzling since conventional mechanisms of magma differentiation are not