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

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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 Na₂O (<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 Na₂O (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).
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, symplectic 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).

**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, symplectic 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).
which plagioclase was replaced by K-feldspar and nepheline. An additional potential source for Al₂O₃
and K₂O is phlogopite, whose partial breakdown and subsequent overprint in the matrix is indicated
by lower contents of Cl and F and higher TiO₂-contents.

The partial metasomatic alteration of the clinopyroxene can be interpreted as being due to a fluid-
aided dissolution-reprecipitation process. Thereby a Cl₂-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 CaCl₂-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 Urals Mountains and might also explain the different
whole rock ages given by the Nd and Sr isotopic systematics [2, 3].

This study was funded by grant GK392 of the German Science Foundation to J. Krause and of grant RFBR
№ 09-05-00911 of the Russian Academy of Sciences to E. Pushkarev.

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

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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