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MAGMA MIXING IN MAFIC ROCKS OF URALIAN-ALASKAN-TYPE MAFIC-ULTRAMAFIC COMPLEXES IN THE URAL MOUNTAINS, RUSSIA: EVIDENCE FOR COEVAL MELTS FROM DIFFERENT SOURCES

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RESULTS AND DISCUSSION

The distinctive geologic and petrographic feature of classical Uralian-Alaskan-type zoned mafic-ultramafic complexes is a zonal distribution of mafic and ultramafic rocks, with a central dunite body that grades outward into wehrlite, clinopyroxenite and gabbroic lithologies (tilaites). This rock association is considered to represent cumulates of a single parental melt feeding a magma chamber system [1]. In this study we discuss the results of in-situ trace element analyses (LA-ICPMS) of clinopyroxene from mafic rocks of the Nizhny Tagil and Kytlym complexes in the Ural Mountains in Russia.

The tilaites have clinopyroxene phenocrysts in a matrix of olivine, clinopyroxene, feldspar ± phlogopite ± amphibole + minerals of the spinel group. Based on additional minerals and their spatial distribution three types of tilaites can be distinguished. The nepheline tilaites are silica undersaturated and contain in the matrix plagioclase$_{An28-48}$, K-feldspar$_{Or47-98}$ and nepheline. They are only observed in Nizhny Tagil and the south western part of the Kytlym Complex. The second type, the bytownite tilaites are silica saturated, contain up to 15% plagioclase$_{An56-89}$ and in places orthopyroxene as matrix phases. They coexist with the nepheline tilaites in Nizhny Tagil and south west Kytlym. The third group of tilaites at the Tilaysky Kamen Mountain massif in the central part of the Kytlym complex also consists of bytownite tilaites, but they do not coexist with nepheline tilaites and have distinct mineral and trace element compositions.

Gabbronorites, olivine- and hornblende gabbros in the eastern part of the Kytlym complex contain 15-35% plagioclase$_{An85-97}$ and a significant amount of orthopyroxene and amphibole. The large mass of gabbronorite and olivine gabbro forms separate bodies with an own internal structure and distinct geochemical features of rocks and minerals. According to [2] they are not genetically related to the mafic-ultramafic association in the western part of the Kytlym complex and therefore called external gabbros.

Clinopyroxene cores of nepheline and coexisting bytownite tilaites in Nizhny Tagil and the western part of the Kytlym Complex have high LREE/HREE (e.g. La/Lu 30-55) and Sr contents (195-470 ppm), if compared to the bytownite tilaites from Tilaysky Kamen Mountain (La/Lu = 5.5-16; Sr = 26-77 ppm). Clinopyroxene from the external gabbros has the lowest La/Lu (2.9-6.8) and low Sr contents (27-104 ppm). Positive anomalies of Ba and Sr and negative ones for the HFSE in the parental melts in equilibrium with clinopyroxenes imply that they crystallized from melts that formed in a subduction related geotectonic setting.

The nepheline tilaite is the most fractionated crystallization product of a suite of parental melts generated by different degrees of partial melting that also formed the ultramafic cumulates. Its mineral assemblage and its composition characterize this melt as silica undersaturated, with an alkaline affinity, low Al_2O_3 and high LREE/HREE, Sr, MgO and CaO ($CaO/Al_2O_3 > 1$). According to experimental results these kinds of melts can be generated from a wehrlitic, amphibole-bearing upper mantle source at 1 GPa and T > 1190°C [3]. A second suite of melts is parental to the external gabbros and found to be silica saturated, having low LREE/HREE, Sr and $CaO/Al_2O_3 < 1$ at high Al_2O_3 and shows affinities to island arc tholeiites. Such melts can be formed in the mantle wedge above a subduction zone at 2-4 GPa and 1200-1400°C. The cores of most clinopyroxenes of the Bytownite gabbros lie on a mixing line between the silica under-saturated nepheline tilaite and the silica-saturated external olivine- and hornblendegabbro. Hence, the continuous increase of La/Lu from silica-saturated to silica-undersaturated mafic rocks traces predominantly the mixing of two distinctively different parental magmas.

Strikingly, the LREE/HREE in most clinopyroxenes from all lithologies decreases from the core towards the rim with increasing HREE concentration – i.e. with increasing fractionation. This can not be explained by fractional crystallization of clinopyroxene and feldspar, but by adding and mixing of fractionated melts of arc tholeiitic composition to a residing melt in a magma chamber.

Magma mixing processes can be observed on the scale of a single thin section. Clinopyroxene cores, rich in inclusions have La/Lu of 13-16, whereas other clinopyroxene cores within the same thin section are poor in inclusions and have low La/Lu of 5-8 at similar Lu concentrations (0.15-0.2 ppm). Just outside of the core, both phenocryst types have intermediate and similar La/Lu of 9-11 and Lu (0.27-0.32 ppm). From there the La/Lu decreases towards the rim, which has the same composition as the matrix grains (La/Lu = 7-9, Lu = 0.35-0.52 ppm). The different core compositions indicate the coeval presence of the two different parental magmas. After mixing of these magmas the clinopyroxene cores were overgrown by clinopyroxene crystallizing from the hybrid magma. The addition of more fractionated tholeiitic magma explains the low La/Lu of the clinopyroxene rims and in the matrix grains.

CONCLUSIONS

The present study highlights the critical role of magma mixing which dominates the petrogenetic evolution of gabbroic and tilaitic rocks and what can be recognized on regional down to thin section scale. The mixing of parental magmas and their different fractionation products which are derived from two different sources is necessary in order to explain the observed variations in the composition of Uralian-Alaskan-type complexes. We propose that the coeval occurrence of magmas derived from different source compositions is a characteristic feature of this type of intrusions and might play an important role in magmatic systems at destructive plate margins worldwide.

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