METASOMATISM OF PERIDOTITE BY ALKALINE MELT AND COGNATE FLUID: MICROCHEMICAL AND ION PROBE EVIDENCE FROM THE LOW-P INAGLI DUNITE

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Introduction and Geology

Modal and chemical metasomatism of mantle peridotite has been demonstrated in a large number of xenolith studies. However, the nature of metasomatizing agents has been a matter of considerable debate: hydrous fluids, silicate melts and carbonatite melts have been proposed as agents in different metasomatized suites. However, as metasomatic agents are normally not preserved in mantle xenoliths, little is known about characteristic features suitable do distinguish between them. Especially the effects of metasomatism by highly alkaline silicate melts (e. g. lamproites) are not known in detail. Thus we investigated melt infiltration metasomatism in a crustal magma chamber, the Inagli complex, where the metasomatic agent is approximately known.

The Inagli Complex is located in the Aldan Shield, Yakutia, 30 km SE of the town Aldan. Its geology has been described by Kortschagin (1986). The circular Complex (3 km diameter), a magma chamber eroded to subvolcanic level, consists of a massive dunite core enclosed by a succession of marginal Cpx-rich cumulates (Wehrlite, Apatite-Phlogopite-Cpxite), and ring intrusions of alkaline, silica-undersaturated differentiates (shonkinites, malignites, pulaskites). The dunite core has accessory primary chromite and is cut locally by a stockwork of cm-thick veins of apatite-phlogopite-clinopyroxenite and syenitic pegmatoids. Our samples of dunite and veins come from drill cores in the area of this stockwork. The parental melt to the Inagli complex is assumed to be related to regionally occurring lamproite dikes and diatremes (Machotkin 1993). This lamproitic affinity is emphasised by the high Mg-# (up to 0.94) of dunite olivine and the occurrence of extremely Al-deficient phases like tetraferriphlogopite.

In the dunite, very minor amounts of intergranular Cpx (<2 to <0.1 vol%) form poikilitic networks on the grain boundaries of olivine, mimicking the morphology of a partial melt volume, and are associated with phlogopite replacing olivine, and minor magnetite as grain boundary films. This assemblage represents the infiltration of an alkaline silicate melt into the dunite originating from the clinopyroxenite veins. The syenitic pegmatoid veins have phlogopite + Cpx at vein margins, being replaced by aegirine + alkali amphiboles; the vein cores are albitized but have an undersaturated relic assemblage. A strongly halogenic hydrous fluid was released from these veins upon solidification. This fluid induced richterite blastesis in the dunite and clinopyroxenite veins, rims of tetraferriphlogopite on metasomatic phlogopite, and marked leaching of olivine and Cpx along grain boundaries (increase of Mg-# in olivine up to 0.98). Thus in the dunite, effects of melt infiltration and fluid infiltration are superimposed.

Analytical methods

Ultra-pure separates of olivine, Cpx, phlogopite, apatite, amphibole, spinel have been hand-picked for oxygen isotope analysis at the RHBNC, London, utilizing the laser fluorination method of Mattey & McPherson (1993). The trace element composition of Cpx and other phases has been analyzed in situ in five representative samples using the Cameca IMS 4f ion microprobe at the CSCC, University of Pavia, using the energy filtering technique. Analytical procedures were similar to those described in Bottazzi et al. (1991) and Rampone et al. (1993).

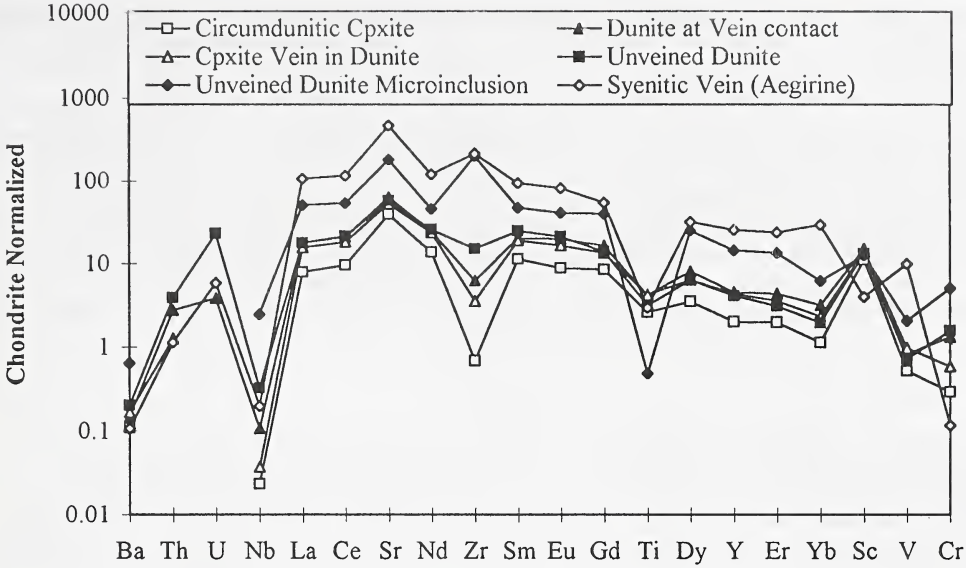

Fig. 1: Normalized trace elements of Cpx in the Inagli samples (representative individual ion probe spots). Chondrite composition of Anders & Ebihara (1982) employed. "Microinclusion" refers to small cpx inclusions along healed fractures in dunite. Note its similarity to Cpx in highly evolved syenitic veins.

Oxygen Isotopes

Oxygen isotope analyses have been carried out on 23 separates from 7 samples comprising dunite, clinopyroxenite and syenitic veins, and circum-dunitic differentiates. Precision of analyses according to double and triple determinations of separates was within ±0.1 ‰ in $\delta^{18}O$ in most cases. Within the dunites and clinopyroxenite veins, there is no variation in oxygen isotopic composition of phases: olivine, $\delta^{18}O$ = 5.4 ‰; Cpx, $\delta^{18}O$ = 6.2 ‰; phlogopite, $\delta^{18}O$ = 6.4 ‰; primary spinel, $\delta^{18}O$ = 3.2 ‰. Also, oxygen isotopy of Cpx in the syenite pegmatoids is not different ($\delta^{18}O$ = 6.2 ‰) at Mg-# as low as 0.40. The oxygen isotopic composition of fluid in equilibrium with Cpx (both metasomatic and within veins) calculated from the fractionation factors of Zheng (1993) is $\delta^{18}O$ = 8.0 ± 0.2 ‰, which is a primitive magmatic value. This indicates that the fluid is fully derived from the solidifying melt, and any external (crustal) component in the fluid (and in the melt) can be excluded.

Trace Element Compositions

Ion probe in situ analysis of phases (Cpx, phlogopite, amphibole, apatite) has been carried out on 5 samples: unveined dunite, dunite with clinopyroxenite vein (2 samples: vein/wallrock contact, and dunite 8 cm away of vein), dunite with syenitic vein, circumdunitic clinopyroxene cumulate. Analyses are heavily biased towards Cpx as trace element patterns of Cpx are frequently used in mantle xenoliths to infer melt characteristics; thus, we will discuss only Cpx here. Cpx of all samples is characterized by strong LREE enrichment (see Fig.1) and shows marked positive (Sr) and negative (Nb, Zr, Ti) anomalies (La_N/Nb_N = 100-200 in vein and dunite Cpx, up to 400 in circumdunitic cumulate Cpx). The overall pattern of Cpx is strikingly similar to HFSE-depleted patterns of mantle Cpx frequently attributed to metasomatism by carbonatite melts (e. g., Hauri 1994). The positive anomaly for Sr is regionally present in alkaline magmatism on the Aldan Shield, which is related to mesozoic subduction (Machotkin 1991). In syenitic pegmatoids, the Cpx trace element patterns evolve rapidly during crystallization to attain La_N = 100 and higher. During this development, Zr/Zr* fluctuates frequently between < 0.1 and 2, whereas Ti/Ti* increases monotonous from 0.04 to 1 in the youngest aegirines. This abnormal behaviour of Zr is controlled by melt alkalinity. From experiments (Watson & Harrison 1983) it is known that Zr forms Zr-Na-silicate complexes in silicate melts if their (Na +K)/Al >1, greatly increasing Zr solubility in melt [resp. decreasing D_{Zr}(Cpx/L)]. In the Inagli syenite pegmatoids, this coefficient can be estimated to have been ≈ 0.9 from amphibole compositions. Thus, mixing between non-peralkaline and peralkaline melt batches in the veins produces wild fluctuations in Zr content of Cpx. We invoke a similar effect to explain that, as can be seen from Fig. 1, the major difference in trace element contents of metasomatic Cpx in dunite and cumulus Cpx in clinopyroxenite veins is an increased Zr/Zr* in the former: As the stable spinel in the vein system is magnetite, the melt infiltrating the dunite must react with the encountered chromite (Cr# 0.8). This increases Al in the melt, lowers melt alkalinity and increases D_{Zr}(Cpx/L). Consistent with this is that the dunite Cpx is slightly, but systematically richer in Al_2O_3 than vein Cpx (1.0 vs. 0.5 wt%), and the chromites in dunite display increasing Cr# (up to 1.0) at their rims. Significantly, Ti/Ti* does not show similar variations, whereas Nb seems to be correlated with Zr.

Discussion

The composition of metasomatic phases (Cpx + phlogopite) produced in the Inagli dunite by infiltrating lamproite-like silicate melt is strikingly similar to Cpx + phlogopite formed in metasomatized mantle xenoliths from alkaline volcanic provinces (e. g. West Eifel, Lloyd et al. 1991; East Africa: Rudnick et al. 1993). In recent time, carbonatite has been favored as metasomatic agent in these and other metasomatized xenolith suites, based on the discovery of marked negative HFSE anomalies, which could not be reconciled with the trace element composition of associated volcanics, but were similar to HFSE anomalies known to occur in carbonatites (e. g., Hauri et al. 1994). Our results from Inagli demonstrate that similar HFSE anomalies do occur also in Cpx formed from an extremely Al-deficient, alkaline silicate melt. This implies that similar melts must be considered as alternative possible metasomatizing agents in the upper mantle. Further, if the partitioning of HFSE between a metasomatizing melt and its products (Cpx) is critically dependent on (Na+K)/Al in the melt, as our data seem to indicate, then the presence of negative HFSE anomalies in metasomatized mantle xenoliths may simply reflect melt alkalinity, which is high both in carbonatites and lamproites. In the Inagli Cpx moreover a different behaviour is displayed by Zr (and Nb?) compared to Ti, wich could be caused by their different affinities for complex formation in the melt. If this is correct, then slight changes in alkalinity of an alkaline metasomatizing mantle melt may be able to fractionate HFSE from each other.

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