INTEGRATED METHODOLOGIES FOR THE STUDY OF MANTLE ROCKS AND DIAMOND INCLUSIONS

Ph.D. candidate: LUCA ZIBERNA
Tutors: Prof. PAOLO NIMIS, Prof. FABRIZIO NESTOLA
Cycle: XXV

Abstract

Insights on evolution of cratonic mantle and diamond formation processes can be obtained from both diamondiferous and barren kimberlites. An interesting case can be the study of closely clustered, coeval kimberlites characterized by different diamond potential. An example are the Zagadochnaya (barren) and Udachnaya (highly diamondiferous) kimberlites, both located in the Daldyn kimberlite field (Yakutia, Russia). In this study I report major and trace element data for pyrope-rich garnet xenocrysts from the Zagadochnaya kimberlite. Sinusoidal REE patterns (CI-normalized) of some high-Cr garnets give strong evidence for the presence of peridotitic materials, not yet confirmed in the literature for this kimberlite. Other garnets show geochemical features similar to garnets from strongly metasomatized peridotite or magmatic segregates. Another garnet group shows an intermediate character, with nearly flat normalized patterns from Sm to Lu. Almost all garnets show patchy zoning, with development of Ca-Cr-poor domains associated with areas rich in secondary phases. Petrographical and geochemical data suggest that this zoning is probably related to a melt infiltration event, which occurred shortly before the eruption of the kimberlite.

Introduction

Kimberlite-hosted mantle xenoliths provide the strongest evidence of the composition of the cratonic lithospheric mantle. One difficulty in studying xenoliths is that many of them are strongly altered, with olivine and orthopyroxene partly or completely replaced by volatile-rich, low-temperature minerals. Moreover, most mantle rocks are disaggregated during violent transport to the surface in the host kimberlite. In some cases, xenocrysts (e.g.: garnet, clinopyroxene, chromite), may represent the only mantle fragments that can be used to map the vertical distribution of rock types and processes in the lithospheric mantle (Griffin et al., 2002, 2003; Schulze, 2003; O’Reilly and Griffin, 2006).

This case study concerns mantle xenocrysts from the on-craton, barren Zagadochnaya kimberlite (Yakutia, Russia). This kimberlite belongs to the Daldyn kimberlite field, which includes the more famous Udachnaya kimberlite, one of the most diamond-rich kimberlites of the Siberian craton. In addition to the absence of diamonds, Zagadochnaya kimberlite differs from classical diamondiferous Siberian kimberlites by the large content of chromian diopsides and abundance of kyanite-bearing eclogite xenoliths (Sobolev, 1977; Nimis et al., 2009). No discrete peridotitic xenoliths have been found, but the presence of individual grains of chromian diopside and pyrope-knorringitic garnet suggests the presence of peridotitic materials (Sobolev, 1977; Schulze, 1989). An origin of clinopyroxene and garnet grains by crystallization from kimberlite melts was proposed by Egorov (1992) and Kostrovitsky & de Bruin (2004). The latter authors also suggest a possible alternative origin of the garnets by kimberlitic metasomatism on garnet megacrysts. Nimis et al. (2009) studied diopside xenocrysts and concluded that at least some of the grains recorded two different metasomatic stages on garnet peridotite.

The aim of this work is to understand the origin of the xenocrysts grains and the processes that involved the mantle section beneath Zagadochnaya. In particular: 1) to verify the presence or absence of peridotitic material, 2) to verify the occurring of one or more metasomatic stages as proposed by Nimis et al. (2009) and 3) to understand why two closely occurring kimberlites (Zagadochnaya and Udachnaya) can be so different in terms of diamond potential.
In this first year, I have analyzed major and trace element compositions of 46 garnet grains and associated chromian diopside from the Zagadochanaya kimberlite.

**Materials and methods**

The 46 garnet grains (1 to 4 mm) were mounted in epoxy resin, cut to about two thirds their thickness and polished for chemical analysis. For all the grains back-scattered electron images were obtained, using a CamScan MX2500 scanning electron microscope (SEM) at the Dipartimento di Geoscienze, University of Padua. Major elements were analyzed using a CAMECA "CAMEBAX" electron microprobe at the IGG-CNR, Unit of Padua. In-situ trace element analyses of 26 representative grains were performed by laser-ablation inductively-coupled-plasma mass-spectrometry (LA-ICP-MS) at IGG-CNR, Unit of Pavia.

**Results and discussions**

The grains consist of coarse garnet xenocrysts, which sometimes contain or are intergrown with mm-sized, primary grains of clinopyroxene and a completely serpentinized mineral (probably former olivine or orthopyroxene). The garnets show broadly lherzolitic to megacryst-like major element compositions, with Cr$_2$O$_3$ = 1.3 ± 8.6 wt%, CaO = 4.2 ± 7.4 wt%, and mg# = 79 ± 82. On the basis of petrographic and geochemical features, the garnets can be subdivided into three main groups (referring only to the grains analyzed by LA-ICP-MS).

Group A garnets are unzoned and are associated with coarse, sub-round chromian diopside. They have moderate Cr$_2$O$_3$ contents (1.3 ± 5.2 wt%) and are characterized by progressively increasing CI-normalized REE from La to Lu, with HREE close to 10 xCI. In primitive-mantle-normalized multielement diagrams, they show strong negative Sr anomalies, no Zr-Hf anomaly, and small negative Ti anomalies. The associated diopside are moderately LREE-enriched, with La$_N$/Sm$_N$ ratios between 0.9 and 4.2, and exhibit an intermediate character between groups IIa and IIb studied by Nimis et al. (2009), which were interpreted as fragments of variably metasomatized lherzolites. This group broadly resembles garnets and clinopyroxenes from high-temperature coarse porphyroclastic lherzolites and megacrysts from the nearby Udachnaya kimberlite (Solov'eva et al., 2008), suggesting derivation from strongly metasomatized peridotites or, possibly, magmatic segregates (cf. Type II garnets of Burgess & Harte, 2004).

Group B garnets are variably enriched in Cr$_2$O$_3$ (5.4 ± 8.6 wt%) and are distinguished from group A by a less LREE-depleted composition and nearly flat normalized pattern from Sm to Lu. Grain to grain REE variations are larger than in Group A (HREE ca. 1 to 10 x CI). The most REE-rich samples show similarities with garnets from some high-temperature lherzolites from Udachnaya (Shimizu et al., 1997) and other kimberlites (cf. some cores of Type Ia garnets of Burgess & Harte, 2004).

Group C garnets are Cr$_2$O$_3$-rich (7.3 ± 8.4 wt%) and show similar Sr and Ti negative anomalies as groups A and B. The typical feature is the strongly sinusoidal REE patterns, with Yb$_N$ between 0.5 and 3.0. These compositions are typical for cratonic garnet lherzolites produced by refertilization of strongly refractory peridotites. Similar patterns characterize some high-temperature fine porphyroclastic garnet harzburgites from the nearby Udachnaya kimberlite (Solov'eva et al., 2008). To the author knowledge, no garnet with similar features has ever been reported in the literature for the Zagadochnaya kimberlite. Given the absence of peridotitic xenolith, such discovery has a crucial role on testifying the presence of peridottic material in the Zagadochnaya kimberlite.

Some garnets in groups B and C show areas rich in secondary chromian diopside + chromian spinel ± phlogopite ± amphibole inclusions. The distribution of the inclusions suggests formation by reaction with an infiltrating melt. These garnets show pronounced patchy zoning, with development of (Ca, Cr)-poor domains in the inclusion-rich areas. In such domains, the REE tend to show convex-upward patterns with a maximum at Eu and a negative slope for the HREE, associated...
with strong negative Sr, Hf and Ti anomalies. The secondary diopsides are enriched in Cr and Na (up to 13 mol% of kosmochlor component), which are negatively correlated with mg#, and show strongly LREE-enriched (La ~100), convex-upward patterns. Their compositions essentially correspond to those of group III diopsides of Nimis et al. (2009), thus supporting the interpretation of these clinopyroxenes as products of melt infiltration on metasomatized garnet lherzolites.

In order to estimate the time scale of the last metasomatic process, testified by the patchy zoning in group B and C garnets and associated secondary diopside + spinel ± phlogopite ± amphibole assemblages, Ca concentration profiles in the garnets have been used. Knowing the binary diffusion coefficient of Ca in garnet (e.g. Ganguly et al., 1998) and assuming a zonation formed by radial diffusion between a core and a shell overgrowth (Crank, 1975; Ganguly et al., 1996), one can model the concentration profile variation through time. Comparison of the model profiles with the measured Ca concentration profiles gives a maximum time-span of 10 ÷ 100 years between the formation of the overgrowth and the quenching of the garnet. Such geologically short time-span indicates that the last metasomatic event is probably the result of percolation of melts associated with the host kimberlite.

References

SUMMARY OF LAST YEAR’S ACTIVITIES

Courses:
SALMASO, L., CORAIN, L.: "Statistica applicata alla sperimentazione scientifica", Centro Studi per l'Ambiente Alpino, S. Vito di Cadore, Università degli Studi di Padova.
CAMARA, F.: "Risoluzione strutturale di sostanze inorganiche a struttura cristallina ignota", Dipartimento di Geoscienze, Università degli Studi di Padova.

Schools and workshops
STOPPA, WOOLLEY, A., F., WALL, F., BAILEY, K., ROSATELLI G.: "First carbonatite and alkali rock school". San Venanzo (TR), Italy.
BODNAR, R. J., DANYUSHEVSKY, L. V., WEBSTER, J. D.: "Short course on fluids in the Earth". Dipartimento di Scienze della Terra, Università di Napoli Federico II.

Communications:

Publications:

Other:
Major elements analysis by CAMECA "CAMEBAX" electron microprobe at the IGG-CNR, Unit of Padua.
In-situ trace element analyses by laser-ablation inductively-coupled-plasma mass-spectrometry (LA-ICP-MS) at IGG-CNR, Unit of Pavia.
Visit of Bayerisches Geoinstitut (Bayreuth, Germany) in May 2010, to learn the analytical technique for the determination of ferric iron by electron microprobe (Flank method) on garnets.