MINERALOGICAL AND GEOCHEMICAL CHARACTERISTIC OF A UNIQUE MANTLE XENOLITH FROM THE UDACHNAYA KIMBERLITE PIPE

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INTRODUCTION

Mineralogical and geochemical features of mantle xenoliths in kimberlites are essential to understanding of the evolution of the continental lithosphere. Recent studies have yielded information on the influence of young geochemical processes to lithospheric xenoliths. The study of zoning profiles in garnets of peridotites showed overgrowth of newly formed garnet crystallized from infiltration silicate melt (Smith et al., 1991, 1993). Young age of garnet formation is important for explanation of certain chemical zoning (Shimizy et al., 1994). Geochemical zoning profiles in garnets from mantle xenoliths were studied by several workers (Smith, Boyd, 1992; Shimizu, Pokhilenko, 1997; Pokhilenko et al., 1999; Griffin et al., 1999). The present paper reports geochemical and mineralogical characteristic of unique complex mantle xenolith Uv-404/86 from the Udachnaya kimberlite pipe (Yakutia), which provides evidence for multiple interaction between depleted ultramafic substrate and deeper high-temperature melts of deep-seated origin.

ANALYTICAL METHODS

Mineral compositions (major elements) were determined with electron microprobes "Camebax-MICRO" (United Institute of Geology, Geophysics and Mineralogy, Novosibirsk, Russia) and "Cameca Camebax JX50" (Macquarie University, Australia). Data on REE were acquired using a laser-ablation ICPMS microprobe at the GEMOC National Key Centre, Macquarie University, Australia. Methods and operating conditions have been described by Norman et al., 1996.

PETROGRAPHY

The xenolith has ovoid shape measuring approximately

Figure 1: Mantle xenolith Uv-404/86 from the Udachnaya kimberlite pipe (Yakutia).

6x6x12 cm (Fig. 1). A half of the sample is represented by the depleted garnet lherzolite, containing olivine (55%), orthopyroxene (28%), garnet (15%), subordinate clinopyroxene (3%) and single chromite grains. Pale greenish olivine grains (1-3 mm) are partially replaced by serpentine. Rounded garnet grains (1-5 mm) are often occurred as accumulations, sometimes they contain inclusions of orthopyroxene. Fine grains of bright green clinopyroxene, varying in size from 0.2 to 0.5 mm are heavily fractured and have the irregular shape. Another half of the sample consists of typical garnet orthopyroxenite, containing mainly (85%) coarse grains (up to 2.5 cm) of subidiomorphic orthopyroxene. Less common (15%) smaller garnet grains of irregular shape and rare grains of clinopyroxene occur as interstitial phase between orthopyroxene. Some of the orthopyroxene grains have thin clinopyroxene lamellae along the cleavage directions. The absence of the distinct boundary between lherzolite and orthopyroxenite is typical for this sample. Sometimes lherzolite deeply penetrates orthopyroxenite part of the sample. The sample is crossed by thin vein (0.7-1 cm), consisting of clinopyroxene (up to 80%), garnet (up to 20%) and single grains of sulphides and graphite. The vein cuts both lherzolite and orthopyroxenite parts of the sample. (Fig. 1).

MINERALOGICAL AND GEOCHEMICAL CHARACTERISTIC

MAJOR ELEMENTS

Olivine is the only homogenous mineral within this xenolith sample (Table 1). The major-element composition of olivine is typical of olivines from garnet

Table 1: Compositions of olivine and pyroxenes from sample Uv-404/86

Mineral Phase	Ol N=13[1]	Opx N=42	Cpx1 N=17	Cpx2 N=10
SiO_2	41.1(4)[2]	58.3(4)	54,7(3)	55.4(15)
TiO_2	0.01(1)	0.01(1)	0.02(1)	0.02(1)
Al_2O_3	0.01(1)	0.8(19)	1.4(1)	1.41(6)
Cr_2O_3	0.01(1)	0.4(10)	1.2(1)	1.46(7)
FeO	7.8(12)	4.7(14)	1.4(1)	1.4(1)
MnO	0.10(3)	0.11(3)	0.05(5)	0.07(2)
MgO	51.2(3)	36.0(4)	17.4(4)	17.2(3)
CaO	0.01(1)	0.35(8)	22.7(5)	22.1(4)
Na_2O	0.01(1)	0.04(2)	0.84(5)	1.07(5)
K_2O	0.01(1)	0.01(1)	0.21(3)	0.13(2)
NiO	0.34(5)	NA	NA	NA
Total	100.59	100.72	99.92	100.26

[1]The number of analyses. [2] The number in parentheses represents the one sigma precision of replicate analyses as expressed by the least digit cited. Abbreviations: Ol = olivine; Cpx = clinopyroxene (1–from a vein; 2–from the lherzolite and orthopyroxenite); Opx = orthopyroxene.

peridotites assemblage, averaging Fo_{91}. The Ni content of olivine ranges from 0.23 to 0.43 wt%. The composition of orthopyroxene is relatively homogenous too, with an enstatite component ranging between 92 and 93%. Some orthopyroxenes show increased contents of calcium (up to 1-2.2 wt% CaO) due to the presence of submicron exsolution lamellae, while in the majority of analyzed orthopyroxene samples the CaO content doesn't exceed 0.3-0.5 wt% (Table 1). Orthopyroxene samples contain Al_2O_3 (0.53-1.26 wt%) and Cr_2O_3 (0.25-0.56 wt%). There is no considerable difference in composition between orthopyroxene samples from orthopyroxenite and lherzolite. The average contents of major elements in clinopyroxene samples from different parts of the xenolith are relatively similar. Clinopyroxenes from lherzolite and pyroxenite parts of the sample contain higher Cr_2O_3 (1.3-1.6 wt%) and Na_2O (0.98-1.12 wt%) relative to that from the vein (0.97-1.39 wt% Cr_2O_3 ? 0.74-0.95 wt% Na_2O). Significant compositional variations in

Table 2: Compositions of garnet and chromite from sample Uv-404/86

Mineral Phase	Gr1 N=13[1]	Gr2 N=16	Gr3 N=18	Chr N=1
SiO_2	41.6(3)[2]	41.4(3)	41.6(3)	0.12
TiO_2	0.02(2)	0.03(2)	0.03(2)	0.12
Al_2O_3	20.8(8)	19.6(6)	19.8(2)	12.36
Cr_2O_3	4.1(7)	5.5(5)	5.2(2)	58.07
FeO	7.9(2)	7.8(2)	7.8(2)	16.07
MnO	0.36(6)	0.4(1)	0.4(1)	0.03
MgO	19.7(5)	18.7(5)	18.8(4)	11.32
CaO	5.7(3)	6.3(3)	6.1(2)	0.34
Na_2O	0.02(1)	0.02(1)	0.03(2)	NA
K_2O	0.00(1)	0.01(1)	0.01(1)	NA
NiO	NA	NA	NA	0.06
Total	100.2	99.76	99.76	98.5

[1] and [2] – see Table 1. Abbreviations: Gr = garnet (1-from vein; 2-from lherzolite; 3-from orthopyroxenite); Chr = chromite.

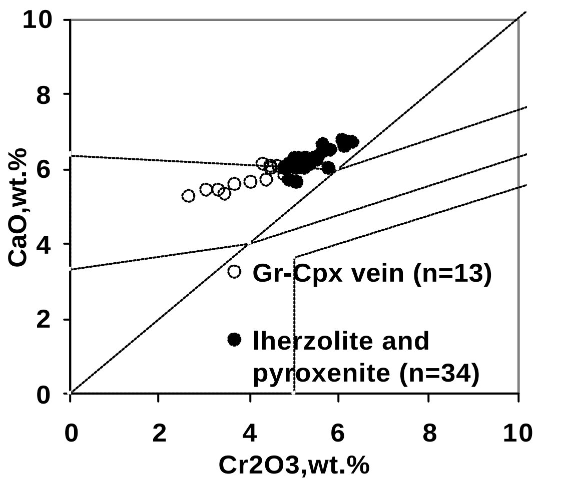

Figure 2: Cr_2O_3 vs. CaO for garnets from sample Uv-404/86

major elements are typical for the garnets from the studied xenolith. Garnets are heterogeneous, especially for Cr_2O_3 (Table 2, Fig. 2): 1. The Cr_2O_3 content in the garnets varies from 4.81 to 6.29 wt% in lherzolite, from 4.81 to 5.6 wt% in orthopyroxenite, and from 2.69 to 5.27 in the vein; 2. Garnets from lherzolite part show zoning in Cr_2O_3 and CaO. The Cr_2O_3 content rises from 4.8 wt% in the core to 6.23 wt% in the rim; the CaO content increases towards the rim from 5.95 to 6.66

wt%; 3. Garnets from the orthopyroxenite part of the xenolith didn't show evident compositional variations in Cr_2O_3 and CaO content within and between individual grains, what may be caused by noticeable smaller grain size compared to that in the lherzolite. The garnets from vein contain higher Mg# relative to that from both lherzolite and orthopyroxenite. The composition of chromite is typical of chromite from peridotites (Table 2). The sulphides in the garnet-clinopyroxene vein are represented by complex pentlandite-heazlewoodite composition ($(Fe, Ni)_9S_8$ - Ni_3S_2).

TRACE AND RARE EARTH ELEMENTS DISTRIBUTION

Trace element contents (La, Ce, Pr, Nd, Sm, Eu, Gd, Du, Ho, Er, Yb, Lu, Ti, V, Si, Y, Zr) were determined in 37 garnet grains within all parts of the xenolith sample. The most interesting data were obtained for rare earth elements (REE) distribution. Figure 3 shows

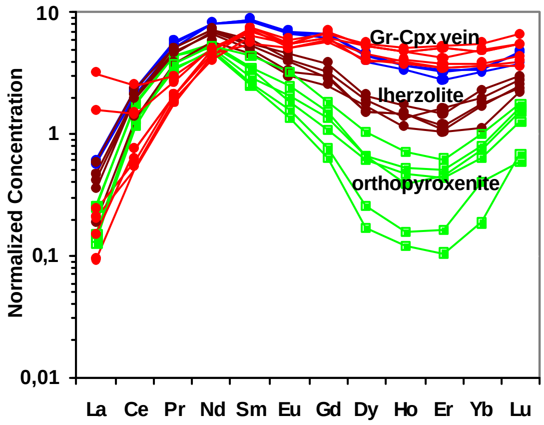

Figure 3: Chondrite-normalized REE pattern in garnets from sample Uv-404/86 (blue symbol – garnet from lherzolite in contact with Gr-Cpx vein). Only representative analyses are shown.

chondrite-normalized REE patterns of garnets from lherzolite, orthopyroxenite and garnet-clinopyroxene vein (only representative analyses are shown). Garnets from lherzolite and orthopyroxenite exhibit sinuous-shaped REE patterns. Similar REE patterns were described by Shimizu et al. (1997) for the garnets from all low-temperature and some high-temperature peridotites from Udachnaya kimberlite pipe. Garnets from orthopyroxenite are depleted in all spectrum of REE compared to that from lherzolite. The difference is especially significant for MREE and HREE, varying by a factor of 2-3 to 10. Two garnet grains from lherzolite exhibit reasonable zoning in REE distribution; all spectrum of REE decreases weakly from the core towards the rim (Fig. 4). Thus, REE pattern of lherzolite garnets rim is similar to that of garnets from orthopyroxenite. However, more detailed work,

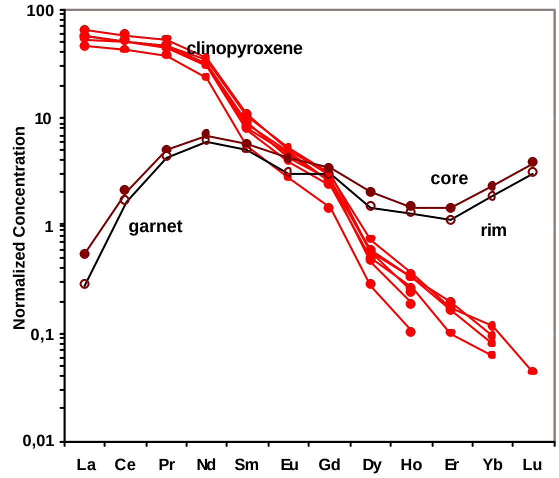

Figure 4: Chondrite-normalized REE patterns in clinopyroxenes from Gr-Cpx vein and in zoned garnet from lherzolite (sample Uv-404/86).

including additional analyses is necessary to confirm this conclusion. Garnets from garnet-clinopyroxene vein show most diverse REE patterns. The melt responsible for the vein formation evidently was enriched by both HREE and LREE. Interaction of the melt with the minerals from lherzolite have led to the REE redistribution in the minerals and occurrence of newly formed garnets. We have revealed three types of REE patterns in newly formed garnets, all of them are similar in the relative enrichment in the HREE (about 2-3 times that of garnets from the lherzolite): 1. LREE concentrations are almost similar or lower relative to

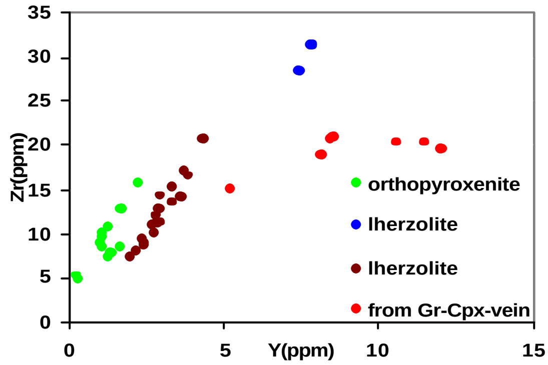

Figure 5: Zr vs. Y in garnets from Uv-404/86 (blue symbol – garnet from lherzolite in contact with Gr-Cpx vein).

garnets from orthopyroxenite; 2. LREE concentrations are similar relative to garnets from lherzolite; 3.

Garnets are enhanced in La contents, being 5-20 times that of garnets from lherzolite and orthopyroxenite. Evidently, the melt responsible for the garnet-clinopyroxene vein formation was enriched in LREE to the extent that some newly formed garnets contain increased concentrations of incompatible trace elements. This assumption is confirmed by chondrite-normalized REE patterns in clinopyroxene from garnet-clinopyroxene vein shown on Fig. 4. It is typical that clinopyroxenes are extremely enhanced in LREE and depleted in HREE. Similar REE pattern in clinopyroxene was reported by Shimizu et al. (1997) for only one clinopyroxene from representative collection of garnet peridotites from the Udachnaya kimberlite pipe. Among the other trace elements, Zr vs. Y relationship in garnets of the studied sample should be noted (Fig. 5). In general, Zr and Y concentrations are not high, but Zr vs. Y plot shows a significant difference between garnets from garnet-clinopyroxene vein and that from lherzolite and orthopyroxenite.

DISCUSSION

Numerous upper mantle xenoliths with signs of variable metasomatic changes of depleted ultramafic material of the lithospheric mantle were previously studied (Smith, Ehrenberg, 1984; Harte et al., 1987, 1993; Smith, Boyd, 1992; Shimizu, Pokhilenko, 1997; Burgess, Harte, 1999; Pokhilenko et al., 1999). A xenolith of complex composition described above has demonstrated that the interaction of melts of deep-seated origin and the ultramafic rocks of lithospheric mantle is of a multistage character and these deep-seated melts have different composition and geochemical characteristics. Petrographic observations have shown that a melt with the major elements content close to the contents for komatiites was injected into the depleted pyrope lherzolites, and crystallization of this melt produces orthopyroxenitic part of the studied sample. This melt was of high-T origin and the presence of exsolution textures of high-T orthopyroxenes (lamella of clinopyroxene and garnet) is good evidence supporting this conclusion. The comparative analysis of the REE and trace elements distribution in garnets from lherzolitic and orthopyroxenitic parts of the sample shows that the garnet of the latter part has been probably formed exclusively as a product of exsolution of high-T orthopyroxene (Fig. 3). A metasomatic treatment both of the depleted pyrope lherzolite and cooled orthopyroxenite has resulted in appearance of a sinusoidal REE pattern in garnets. The treatment took place after the exsolution of garnet from the cooled orthopyroxene. The garnet-clinopyroxene vein crossing both the lherzolitic and orthopyroxenitic parts of xenolith was a result of melt crystallization. The melt was injected later and had significantly different geochemical characteristics. Thus the obtained results of the detailed study of the xenolith of complex composition from Udachnaya pipe evidence for a multistage character of the injection processes of the deep-seated melts into dynamically activated parts of the kimberlite generating zones of the lithospheric mantle of the ancient platforms. They support the assumptions of possible significant transformations of the lithospheric mantle composition and the structure related to periods of tectonic and magmatic activation of ancient platforms (Harte et al., 1993; Griffin et al., 1995; Pokhilenko et al., 1999).

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