COARSE PERIDOTITE XENOLITHS OF UDACHNAYA KIMBERLITE PIPE, YAKUTIA: GARNETIZATION OF PERIDOTITES OF THE CENTRAL SIBERIAN PLATFORM LITHOSPHERIC MANTLE

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INTRODUCTION

The detailed study of the xenoliths of the most deep-seated mantle rocks from Yakutia kimberlites has revealed the presence of various solid phase and metasomatic transformations and the existence of vertical heterogeneity of the mantle matter (Pokhilenko et al., 1991; 1993; Boyd et al., 1997; Shimizu et al., 1997; Solov'eva et al., 1994). The complex of coarse peridotite xenoliths from Udachnaya kimberlite pipe (central part of the Siberian Platform) is represented by paragenesises varying in composition and the P-T parameters of their formation. Investigation of chemical composition of peridotite minerals and classification of heterogeneity of the mantle matter make it possible to construct a section of the lithosphere mantle under the pipe. The clearing up of peculiarities of the process of garnetization of spinel peridotites in the lithosphere mantle of the central areas of the Siberian Platform is one of the important problems of investigation of coarse rock xenoliths.

METHODS

More than 400 peridotite xenoliths from the Udachnaya kimberlite pipe have been studied. The chemical composition of rock has been determined with by x-ray fluorescent analysis using URA-20R x-ray analyzer. Mineral chemistry has been studied using Camebax-micro electron probe and Jeol Super Probe 7800. The content of trace and REE elements in garnets and clinopyroxenes from several samples has been determined with the use of ion microprobe Cameca IMS 3f (Oceanographic Institute, Wood Hole, USA).

PETROGRAPHY

Spinel, garnet-spinel and garnet lherzolites (85%) depleted to a various degree are the most widespread rocks of the studied collection of coarse peridotite xenoliths from Udachnaya kimberlite pipe. Rare depleted harzburgites-dunites with associated garnet and chromite represent about 11%, significantly enriched wehrlites - about 4% of the studied xenoliths. In single peridotite xenoliths, accessory graphite is established.

The coarse peridotite xenoliths are most often represented by the fragments of initially rounded xenoliths. Their sizes vary from 2,5-3 to 15-17 cm along the long axis.

In the least deep-seated spinel and garnet-spinel peridotites the primary hypidiomorphic grained structure is complicated by the areas of symplektite intergrowths of Al-spinel and high-alumina orthopyroxene. In more deep-seated rocks, the zones of plastic deformation covering significant areas of the rock and the reaction structures formed by Cr-spinel, orthopyroxene and garnet are observed. The lamella of clinopyroxene in orthopyroxene and interrupted rims of clinopyroxene around garnet are due to the disintegration of ortho- and clinopyroxenes.

MINERAL COMPOSITION

The minerals of coarse peridotites are characterized by significant variations of chemical composition. **Olivine** is the exception; its composition is rather constant and uniform in all the studied xenoliths. All olivines are highly magnesial (Mg#[100Mg/(Mg+Fe)] 88,4-93,7%). Ca admixture amounts to 0,01-0,08 wt.% CaO, which can be due to comparatively low temperature values of the rock equilibrium on the one hand, or to high pressures of their formation, on the other. In the xenoliths, containing chromite with Cr_2O_3 54-63 wt.%, the chrome admixture in olivines reaches 0,09 wt.%. It is the evidence of extremely reductive conditions of formation of these associations. The increased Ni admixture (0,28-0,42 wt.% NiO) correlates with general high magnesia content in the studied rocks. **Orthopyroxenes** contain 90-92 % of enstatite minal; Mg# varies within the range of 91,8-91,7 %. The Al admixture in orthopyroxenes from spinel peridotites is 0,15-4,18 wt.% Al_2O_3, Cr - 0,24-0,95 wt.% Cr_2O_3. In the most deep-seated garnet and garnet-spinel rocks, the enstatites with rather low Al contents (0,23-0,30 wt.% Al_2O_3) and increased Cr content (up to 0,80-1,42 wt.% Cr_2O_3) are determined. The orthopyroxenes of spinel peridotites are more aluminium and contain more Al^{IV} in comparison with the enstatites from garnet bearing peridotites. Ca (0,16-1,83 wt.% CaO) and Na (0,01-0,66 wt.% Na_2O) admixtures are observed in all enstatites. As a whole, orthopyroxenes are homogeneous in composition within the grain, but within the volume of individual xenolith mineral grains sometimes differ in ferocity and Al_2O_3, Cr_2O_3, CaO, and TiO_2 contents.

Clinopyroxenes of spinel peridotites are represented by low chromium Cr-diopsides with Cr_2O_3 0,34-3,20 wt.%, and Na_2O content 0,24-3,7 wt.% and K_2O 0,01-0,09 wt.%. The clinopyroxenes of garnet-bearing varieties are characterized by the greater fraction of enstatite solid solution, the contents of Cr_2O_3 4,20-4,81 wt.%, Na_2O – 3,80-6,07 wt.%, K_2O – up to 0,75 wt.%. Essential undercompensation of trivalent cations by Na, distinguished in the clinopyroxenes from spinel peridotites, reflects the increase of oligoclase component in their composition.

The majority of **garnets** from coarse peridotites belongs to chromium pyropes (Cr_2O_3 up to 11,8 wt.%, CaO 3,38-7,45 wt.%) and forms the trend which corresponds the lherzolite one. The garnets of harzburgite-dunite paragenesis with the content of CaO 2,53-2,91 wt.% and Cr_2O_3 4,14-11,8 wt.% have been found in some xenoliths. Pyropes from the most deep-seated chromite-pyrope harzburgites fall within the field of pyropes associated with diamond (Sobolev, 1977). The stable isomorphic admixture of Na (up to 0,07 wt.% Na_2O) and Ti (up to 0,58 wt.% TiO_2) occur in some of the garnets. In a number of xenoliths, a) garnets with wide variations of chemical composition, corresponding to different mantle paragenesises (harzburgite-dunite and lherzolite); b) zonal garnets with homogeneous nuclei enriched with Cr, Ca, and the peripheral zones depleted in these components and enriched in Ti, Fe and Na were established.

Spinellids from xenolites peridotites form a continuous series from significantly alumnus varieties (49,9 wt.% Al_2O_3 and 18,5 wt.% Cr_2O_3), characteristic for low-temperature spinel lherzolites, up to chromites (6,3 wt.% Al_2O_3 and 64,6 wt.% Cr_2O_3) from the most depleted Cr-pyrope dunites. The composition variations of spinellids from the garnet-free lherzolites amounted to 2,5-49,6 wt.% Al_2O_3 and 18,5-64,4 wt.% Cr_2O_3; from garnet-spinel peridotites – 4,94-32,9 wt.% Al_2O_3 and 31,4-64,6 wt.% Cr_2O_3. All spinellids are magnesial (Mg# 44,6-76,0 %) and characterized by low TiO_2 content (0,1-0,7 wt.%). The heterogeneity after Cr was revealed in two xenoliths of garnet-spinel lherzolites in chrome spinellids: Cr_2O_3 content in different grains changes for 10 wt.%.

PETROLOGY

Estimations of P-T parameters of equilibrium of the studied xenoliths, obtained with the use of Wells (1977) two-pyroxene thermometer and MacGregor's (1974) barometer, have shown that a combined temperature interval for grained peridotites with the coexisting garnet and chrome spinellid is 750-1120^{o}C, with pressure interval of 20-60 kbar, corresponding the depths range of 60-180 km. Highly aluminum spinel lherzolites are stable at 15-18 kbar and 720-780^{o}C.

The peculiarities of chemical composition of coarse peridotites from Udachnaya pipe evidence for the most depleted state of the mantle matter under the Siberian Platform. These rocks are highly magnesial (39,3-48,7 wt.% MgO), they are characterized by the lowered content of alumina (0,26-2,25 wt.% Al_2O_3), calcium (0,15-1,74 wt.% CaO), sodium (0-0,3 5wt.% NaO) and titanium (0,01-0,09 wt.% TiO_2).

The main types of heterogeneity found for nearly a quarter of the studied xenoliths are: a) significant variations of chemical compositions of the rock-forming mineral grains, homogeneous within the single grains but differing in composition within the xenolith bulk; b) variations in the composition of spinels and enstatites, which form symplektite intergrowth structures, and their single grains; c) zoning of large garnet grains from the most deep-seated garnet peridotites.

The character of distribution of trace and REE in garnets and clinopyroxenes from a number of coarse peridotite xenoliths of Udachnaya pipe confirms the complexity of the mantle rocks genesis and the mantle geochemical heterogeneity. For garnets and clinopyroxenes, broad variations of trace and REE concentrations, characterizing the transition from unmetasomatized ancient mantle up to significantly depleted mantle rocks, which have experienced several stages of metasomatosis, are typical. On the whole, the degree of metasomatic transformations combined with the secondary enrichment of depleted rocks with basic components increases with increasing depth of rocks formation.

DISCUSSION

One of the main peculiarities of mineral paragenesises of coarse ultrabasic rocks is their stability in rather a wide range of temperatures and pressures. The change of these paragenesises is determined mainly by initial chemical composition of medium rather than by P-T parameters. In practical aspect, the boundary between the spinel and garnet peridotites is most important.

Basing on the calculated data on the position of the conductive geotherm for the heat flow of 36-39 mWt/m^2 in the Daldyn-Alakit region (Pokhilenko et al., 1993) and according to evaluation of P-T conditions of the formation of the studied collection of equilibrium grained peridotites, one can propose the following variations in petrographic composition of the upper mantle with depth (Fig. 1).

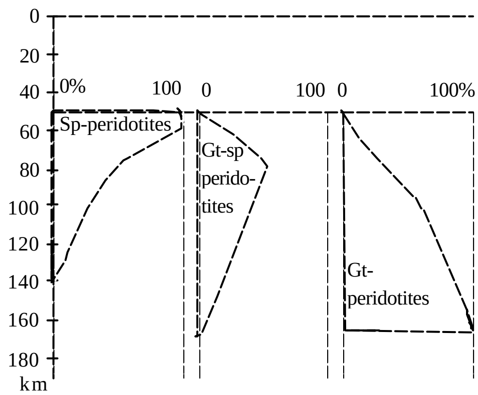

Figure 1: Arias of advantage spreading of spinel, garnet-spinel and garnet peridotites in Midddle-Paleozoic lithospheric mantle beneath Udachnaya kimberlite pipe.

In the upper parts of the vertical mantle cross section with Udachnaya pipe as an example, immediately under the Moho boundary (approximately from the depth of 45-50 km) highly alumina spinel peridotites are widely spread. Practically simultaneously, at the depths of 55-60 km, in the systems most enriched with iron and alumina, the process of garnetization starts, and the first garnet-spinel peridotites appear. These rocks are most abundant at the depths of 90-100 km. At greater depths the role of garnet peridotites being a final product of peridotite garnetization grows. The area of the development of greatly depleted garnet peridotites (harzburgite-dunites) reaches the depths of about 180-190km. Lower, the enriched pyrope lherzolites, characterizing the zone of lithosphere-asthenosphere transition, are developed.

Such change of mineral composition of coarse peridotites is explained by the development of the reaction of garnetization, the beginning and the end of which, along with pressure (depth), are controlled mainly by the temperature, magnesial content Mg# and the value of Cr#, connected with the degree of depletion of mantle matter.

With growth of the value of Cr#, occurring simultaneously with the temperature increase, the reaction of garnetization will develop with a successive shift of the system to the area of higher pressures and increase of general pressure interval needed to complete the reaction. Low-Ca garnets enriched with knorringite component can associate with chromite at the pressures, typical for the diamond stability area. Study of the composition of minerals of real xenoliths of coarse peridotites from Udachnaya pipe showed that the

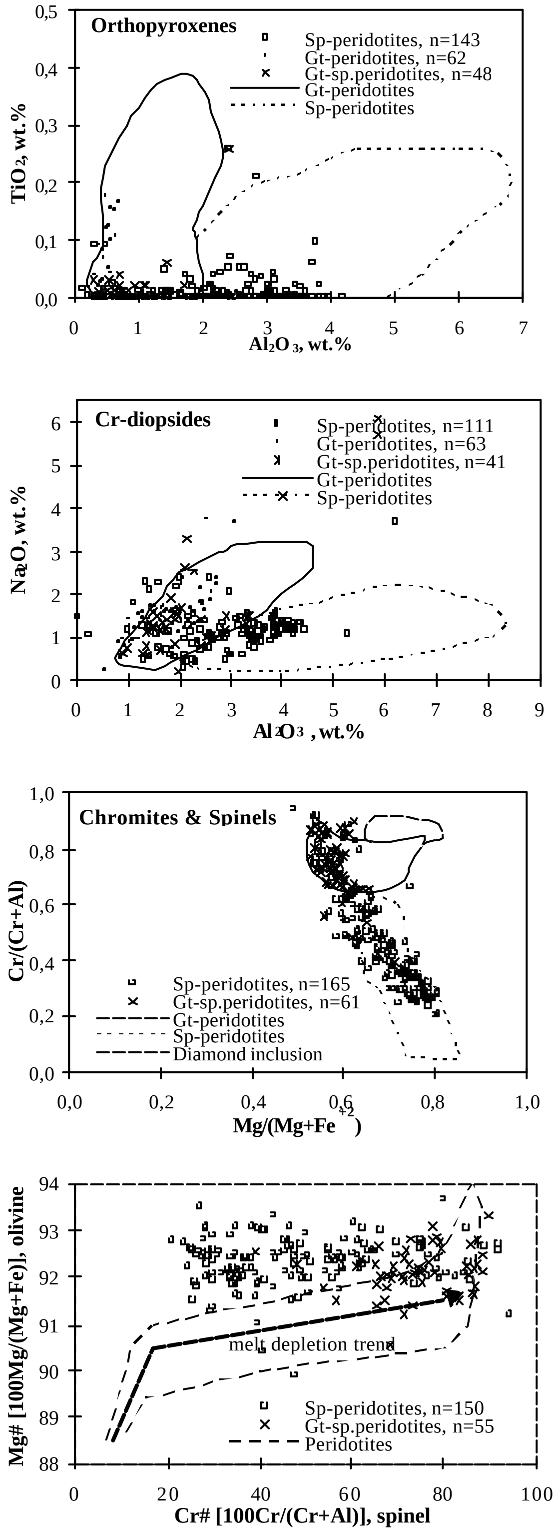

Figure 2: Peculiarities of composition of the coarse peridotite minerals from lithospheric mantle of ancient platforms. Discrete symbols are peridotites from Udachnaya kimberlite pipe, fields – from McDonough & Rudnick (1998).

composition of the rock-forming minerals of spinel, garnet-spinel and garnet-peridotites does not vary widely. Mineral associations from xenoliths of Udachnaya pipe form significantly overlapping fields of predominant development, and in a definite range of depths the whole complex of grained lherzolite paragenesis can be stable (Fig. 2).

The process of coarse peridotites formation is rather complicated and does not agree with the model of one-act partial melting of the primitive mantle (McDonoulgh, Rudnick, 1998), previously proposed to explain the origin of the depleted peridotites of the craton parts of the lithosphere. The model assumes significant variations in chemistry of the minerals of spinel and garnet-spinel peridotites, leading to the existence of independent practically non-overlapping levels of spinel and garnet peridotites in the mantle.

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