UNUSUAL MICA PERIDOTITES AND PYROXENITES FROM UDACHNAYA KIMBERLITE, YAKUTIA

SERGEY I. KOSTROVITSKY¹, LIDIYA V. SOLOVJEVA², LUYDA PH. SUVOROVA¹ & NATALY V. ALYMOVA¹

ABSTRACT The petrography and the mineral chemistry of four hitherto undescribed mica xenoliths were investigated from Udachnaya kimberlite pipe. Two complex xenoliths consist of the juxtaposed pyroxenites and spinel lherzolites and contain texturally equilibrated phlogopite, ilmenite and sulfides. Their primary phlogopite has high amounts of BaO (1,7 - 2,25 %), F (1,45 - 1,6 %), Cl (0,09 - 0,13 %), and is similar to primary mica from group A metasomatites from Udachnaya kimberlites. These samples may be interpreted as remnants of the intruded or cumulate pyroxenite series in the ancient craton lithosphere. The formation of phlogopite, ilmenite and sulfides is thought to be due to premetamorphic mantle metasomatism. The third xenolith is a megacrystalline garnet orthopyroxenite veined with fine-grained Gnt+Phl+Graph aggregate with rare clinopyroxene and sulfide grains. Primary and secondary minerals in this xenolith are highly magnesian and close in composition to minerals from Udachnaya metasomatites C with reactional Phl+Cr-Di+Cr-Sp. The rock is believed to have undergone complex history from the stage of monomineralic orthopyroxenite, possibly of magmatic nature, to the development of metasomatic Phl+Graph+Sulf, related with influx of the reducing fluids. A fourth xenolith exhibits breccia texture and consists of porphyroclasts of common garnet lherzolites and possibly megacrystalline dunites. Porphyroclasts occur in fine-grained phlogopite-rutile-diopside-olivine groundmass with carbonates, Ti-magnetite, ilmenite, perovskite, monticellite. All minerals from porphyroclasts and groundmass are strongly heterogeneous in composition. It is likely, that fracturing and brecciation took place at the level of mantle garnet facies, and peridotite debris were cemented by a high-Ti-K melt close to protokimberlite.

Keywords: mica peridotites, pyroxenites, metasomatites, mantle breccia.

INTRODUCTION Four mica-bearing peridotites with unusual relationships between the rocks of the different composition and metasomatic minerals related to the different mantle metasomatic processes were discovered in the Udachnaya pipe. Two of them (samples 00/165 and 11/84) reveal complex relationships between pyroxenites and websterites. Next one (00/177) is a megacrystalline garnet orthopyroxenite with metasomatic phlogopite, graphite and sulfides. The fourth sample (00/93-5) is represented by the unusual mantle breccia where the porphyroclasts of anhedral olivine, pyroxenes, garnet, Cr-spinel are cemented by a fine-grained aggregate consisting of late rutile, phlogopite, clinopyroxene, olivine, Ti-magnetite, monticellite and carbonate.

PETROGRAPHY Mineral definitions:

Cpx – clinopyroxene
Ol – olivine
Cr-Di – Cr-diopside
Opx – orthopyroxene
Cr-Sp – Cr-spinel
Phl – phlogopite
Gnt – garnet
Prvs – perovskite
Graph – graphite
Ru – rutile
Ilm – ilmenite
Sulf – sulfide
Mont – monticellite

Two compound samples (00/165 and 11/84) contain primary (Carswell 1975) or texturally equilibrated mica (Delaney *et al.* 1980, Boyd *et al.* 1997). The first is a mica-bearing spinel lherzolite enriched in clinopyroxene (3-5 % Phl; 25-35 % Ol; 15-20 % Opx; 40-50 % Cpx; <1 % Ilm; <1 % Sulf; <0,5 % Cr-Sp), which include shadow xenoliths of coarse-grained orthopyroxenites (<1 % Phl; ~15 % Cpx; 10-15 % Ol; 70-75 % Opx; <0,5 Sulf). In the center of these orthopyroxene segregations the amount of Ol, Cpx, Phl abruptly decreases. The orthopyroxene grains and intergranular aggregates of Ol+Cpx + Phl from the shadow orthopyroxenites enter into neighboring lherzolite. Lherzolite has granoblastic texture with little orientation parallel to its unclear layering. The layering is marked by the enrichment of some layers in clinopyroxene and phlogopite. The mica plates (1-2mm) are parallel to the foliation plane and are usually deformed. The rounded grains of sulfides (pyrrhotite + pentlandite with rims of djferfisherite), ilmenite (within perovskite rims) and fine irregular Cr-spinel are disseminated between the silicates.

The sample 11/84 consists of juxtaposed coarse-grained mica-bearing websterite (<1%Phl; <1% Sulf; 15 % Cpx; 80-85% Opx) and medium-grained spinel lherzolite (<1% Cr-Sp; 15-20% Opx; 80-85% Ol and rare fine Cpx grains). The contact between these rocks is distinct but not sharp. The grains of the both rocks enter into each other forming a granoblastic fabric. The mica plates (1-7 mm), grains of clinopyroxene and sulfides cement larger crystals of orthopyroxene in websterite.

In general the textural and petrographic features of the

¹ Institute of geochemistry, SB RAS, 664033, 1a Favorsky str., Irkutsk, Russia; e-mail: serkost@igc.irk.ru

² Institute of the Earth Crust, SB RAS, 664033, 128 Lermontov str., Irkutsk, Russia; e-mail: bazit@igc.irk.ru

samples 00/165 and 11/84 are close to that of the metamorphic metasomatites of group A from the Udachnaya pipe, where clinopyroxene, ilmenite, apatite, sulfides, graphite are found together with phlogopite (Solovjeva *et al.* 1997). As a rule, the metasomatic minerals in such rocks are texturally and chemically equilibrated with the primary minerals and often show spatial relationships with the pyroxenites (Solovjeva *et*

Figure 1 - Garnet veinlet with fine-grained phlogopite rims, which cross orthopyroxene megacryst. Garnet relics (light) are surrounded with black kelyphite. PPL, magnification $\times 40$; sample 00/177.

et al. 1994).

The sample 00/177 is represented by the megacrystalline garnet orthopyroxenite with graphite, phlogopite and sulfides ($\sim 1\%$ Graph; 10-12 % Phl; 5-7 % Gnt; 3-5 % Ol; $\sim 80\%$ Opx; single Cpx grains). Opx megacrysts (2-5 cm) are deformed and broken at the margins into the separate blocks, veined by garnet, phlogopite, graphite with the rare grains of clinopyroxene and sulfides. Megacrysts are cut off the veinlets, filled by Gnt + Phl + Graph (Fig. 1).

The puzzle of this rock is some well faceted olivine crystals and rare small regular garnet crystals, that may attest to the free growth conditions in fluid or melt (?) during the formation of intergranular aggregate. Graphite form two generations: 1) fine (<0.05 mm) laths, located near the thin Gnt + Phl veinlets within the Opx megacrysts; 2) larger (0.5-3 mm) flakes, located in the intergranular space, where hexagonal prisms with rounded planes and edges and the shapes similar to dipyramids and octahedrons are together with the irregular graphite grains. The hatching according to the prism and the triangle growth sculptures are obviously displayed on the pinacoids. Carbon isotope compositions of graphite were obtained at the Geochemistry Institute, Moscow via mass-spectrometer DELTA-plus, using standard techniques. Large graphite flakes C_1 from the intergranular aggregate show a value $\delta^{13}C = -5.1 \pm 0.1\%$ while small graphite laths in

Figure 2 - Relationship of mineral debris (light) and fine-grained cement in the sample 00/93-5. There are large olivine porphyroclasts, in the center there is an orthopyroxene fragment with thin reactional rim from late-metasomatic minerals. The black small prismatic grains are rutiles, which are almost entirely replaced by ilmenite and perovskite. PPL, magnification $\times 60$.

orthopyroxene megacrysts C_2 are isotopically lighter ($-5.8 \pm 0.1\%$). Both values lie within the $\delta^{13}C$ range for P-type diamonds from the Udachnaya pipe and coincide with isotopic composition of the carbon from the homogenous mantle source (Galimov 1991).

The sample 00/93-5 is the "mantle breccia". The rock has a brecciated texture and in 65-70% consists of rounded and subangular mineral debris of olivine (3-15 mm), orthopyroxene (1-3 mm) and rare garnet (4 mm) immersed in the fine-grained (0.05-0.2 mm) olivine-clinopyroxene-phlogopite cement with rutile, ilmenite, monticellite and other minerals (Fig. 2).

Rare garnet with the kelyphitic rims, clinopyroxene and Cr-spinel grains occur as fine fragments. Fine well shaped clinopyroxene crystals, rounded garnet grains and single grains of orthopyroxene occur as inclusions in olivine porphyroclasts. Approximate modal compositions of fragments larger than 0.5 mm is: $\sim 80\%$ Ol; 15-20 % Opx; $\sim 1\%$ Gnt + Cpx + Cr-Sp. The modal composition of the fine-grained matrix is the following: 30-40 % Phl; 25-30 % Cpx; 20-30 % Ol; 3-5 % Mont; 10-15 % Ru, nearly entirely substituted by Prvs and Ilm; 1-3 % of Ti-magnetite and $\sim 1\%$ of carbonates.

Olivine in the groundmass is represented by fine rounded grains and euhedral crystals. Phlogopite forms regular-shaped plates with narrow strongly pleochroic rims. Prismatic rutile grains are altered to fine-grained ilmenite-perovskite aggregate. Small sulfides tracing the fractures are likely to represent djerfisherite.

According to the mineral inclusions in olivine porphyroclasts it is possible to suggest that brecciated rocks were megacrystalline dunites or lherzolites, which are common among the Udachnaya xenolith population (Sobolev *et al.*, 1984; Solovjeva *et al.*, 1994). According to the cement

composition the described mantle breccia is close to the "polymict peridotites" from the Bultfontein and De Beers kimberlitic pipes, South Africa (Lawless *et al.*, 1979). All studied peridotite samples, except for the essentially serpentinized xenolith 11/84, are fresh.

MINERAL CHEMISTRY The minerals of the compound samples (00/165 and 11/84) in general are close in composition to those from pyroxenites and lherzolites with texturally equilibrated mica (group A, after Solovjeva *et al.* 1997).

Olivine is represented by the forsterite with $mg\# = 0,925$ in the both samples. The concentration of CaO, Al_2O_3 , Cr_2O_3 and TiO_2 are below detection limit. A sharp zonation was found in the narrow rims (50-150 μm) of olivine grains from the sample 00/165 (10,4 Fa in rim comparing with 7,3 in the center of the

Figure 3 - Plot of Cr_2O_3 versus TiO_2 in phlogopite from different types mica xenoliths from Udachnaya kimberlite. (1) - compound pyroxenite-lherzolite xenoliths with texturally equilibrated mica, samples 00/165 and 11/84. (2) - mica peridotite, pyroxenite with texturally equilibrated mica (Group A), (Solovjeva *et al.* 1997). (3) - graphite-bearing garnet orthopyroxenite with phlogopite and sulfide, sample 00/177. (4) rocks with reactionary association $Phl + Cr-Di + Cr-Sp$ (group C), (Solovjeva *et al.* 1997). (5) - secondary mica from peridotites and eclogites (Solovjeva *et al.*, 1997). (6) - mantle breccia 00/93-5.

grain).

Orthopyroxene is represented by enstatite: $mg\# = 0,927-0,932$; 2,8-3,3 % Al_2O_3 ; 0,24-0,46 % CaO.

Clinopyroxene is a Ca-diopside with $Ca/(Ca+Mg)$ at. = 0,478-0,507 (0,0-0,28 % TiO_2 ; 0,95-1,25 % Cr_2O_3 ; 3,4-4,4 %

Al_2O_3 ; 1,4-1,7 % Na_2O).

Cr-spinel from the sample 00/165 contain 39% Al_2O_3 ; 27 % Cr_2O_3 ; 17 % MgO and essential admixture of $Fe^{3+}/(Fe^{3+}+Fe^{2+})$ at. = 0,24).

Phlogopite has a high $mg\# = 0,939 - 0,953$ and high content of BaO, F and Cl (1,7-2,25 % BaO; 1,45-1,6 % F; 0,09-0,13 % Cl), with the evident decrease of the amounts of two first in the narrow marginal zones. The phlogopites from the samples 00/165 and 11/84 are grouped on the diagram $TiO_2-Cr_2O_3$ to the left and a few below the points of the texturally equilibrated phlogopite from the rocks of the group A (Fig. 3).

A temperature, calculated using the geothermometer of Finnerty and Boyd (1987), in the sample 00/165 is estimated as 835 °C.

The anhedral olivine grains in the sample 00/177 have homogeneous composition ($mg\# = 0.915$). The sharp zonation is found in euhedral olivine grain (center - 8,4 Fa and 4,4 Fa in the narrow rims). The outer magnesian rim usually overgrows on the primary olivine without the transitional zones but sometimes intermediate compositions are registered (6,7 Fa).

Garnet composition is characterized by high and varying Cr_2O_3 (6,7 - 7,4 %), CaO (4,5 - 5,8%) contents and lack of TiO_2 .

Clinopyroxene forms small fresh patches in strongly altered grain ($Ca/(Ca+Mg)$ at. = 0.464; 0,38% TiO_2 ; 0,57% Cr_2O_3) and is probably closer to the primary composition.

Phlogopite reveal low Cr_2O_3 content (0.75%), lack of TiO_2 and small amounts of BaO (0,0 - 0,3 %), F (0,0 - 1,4 %), and Cl (0,0 - 0,14 %). Points of phlogopites from the sample 00/177 plot within the field of mantle metasomatites from Udachnaya pipe, with the reactional association $Phl + Cr-Di + Cr-Sp$ (group C, Solovjeva *et al.* 1997) - Fig. 3.

Cr-Spinel from the intergranular aggregate vary chemically from high- Cr- spinel ($Cr/(Cr+Al)$ at. = 0,81) to common spinel ($Cr/(Cr+Al)$ at. = 0,20).

In general all minerals from this sample are close in composition to the respective minerals from the metasomatic group C from Udachnaya pipe. The only exception is the low Cr_2O_3 concentration in clinopyroxene what is probably explained by later modification.

The compositions of the coexisting olivine and Cr- spinels from the different paragenetic groups including those containing graphite and diamond are shown in figure 4.

The central part of the zoned olivine from the sample 00/177 locates slightly to the left of the field of reactional metasomatites of C group. The intermediate composition drops near the two points of the graphite peridotites, and the magnesian rim on the euhedral crystal is near the points of the ultra-depleted peridotites from Lesotho kimberlites (Carswell *et al.* 1979).

As a whole, the similarity of mineral compositions from the sample 00/177 and metasomatites C from Udachnaya pipe with mineral compositions from graphite and diamond paragenesis doesn't exclude community of processes in their formation. T and P of primary paragenesis in the sample 00/177, calculated using thermobarometer of Finnerty, Boyd (1987), are estimated as 950 °C and 48.5 kb.

Minerals of primary fragmentary paragenesis in the sample 00/93-5 (mantle breccia) are highly magnesian ($mg\#$: Ol - 0,921; Opx - 0,935; Cpx - 0,934; Gnt - 0,817).

Figure 4 - Plot of Fa in olivines (Fa_{ol}) versus $100Cr/(Cr+Al)$ at. in Cr-spinel. (1) - reactionary Phl + Cr-Di + Cr-Sp metasomatic aggregates (group C) in xenoliths from Udachnaya pipe and 200 pipe, Lesotho (Solovjeva *et al.* 1997). (2) - graphite-bearing garnet orthopyroxenite 00/177: Ol_c - center of zoning crystal; Ol_r - thin rim; Ol_i - intermediate composition of Ol grain from this sample. (3) - graphite lherzolites, harzburgites from Udachnaya pipe (Solovjeva *et al.* 1997) and Lesotho pipes (Boyd, Nixon 1975). (4) - diamond-bearing harzburgite-dunites from Udachnaya pipe (Sobolev *et al.* 1984). (5) - combined olivine and chromite inclusions in diamond (Daniels *et al.*, 1991, Gurney *et al.* 1984). (6) - chromite-garnet lherzolites from 200 pipe, Lesotho (Carswell *et al.*, 1979). (8) - ultra-depleted chromite harzburgites and lherzolite from 200 pipe, Lesotho (Carswell *et al.* 1979).

Garnet is Cr-pyropite of lherzolite type (6,8 % Cr_2O_3 ; 6,0 % CaO), and clinopyroxene is Cr-disposide (2,9 % Cr_2O_3) with low $Ca/(Ca+Mg)$ at. (0,476).

Cr-spinel from porphyroclasts is weakly oxidized and has high $Cr/(Cr+Al)$ at. (0,66).

In general, mineral compositions of porphyroclasts correspond to those of garnet lherzolites and partly megacrystalline dunites from Udachnaya pipe (Solovjeva *et al.* 1994, Boyd *et al.* 1997, Sobolev *et al.* 1984).

Practically all minerals of primary paragenesis were subjected to reactional action of fluid or melt, which formed the breccia cement. Small olivine clasts have higher Fe content ($mg\# = 0,882$) than large ones (0,921). Newly formed euhedral olivine crystals are sharply zoned ($mg\# = 0,889$ in the center and 0,929 in the rim). Orthopyroxene porphyroclasts reveal

decrease in $mg\#$ and increase in TiO_2 , CaO, Na_2O contents in the rims.

T and P for conventional primary paragenesis, calculated using the thermometer of Finnerty & Boyd (1987), are estimated as 838 °C and 37 kb.

Minerals from breccia cement are clearly heterogeneous and their chemistry is comparable to "MARID" minerals from Udachnaya pipe, South Africa pipes and cement minerals of "polymict peridotites" from Bultfontein and De Beers pipes, South Africa (Solovjeva *et al.*, 1994; Lawless *et al.* 1979).

Clinopyroxene from breccia cement is low-Al and low-Na diopside with $Ca/(Ca+Mg)$ at. = 0,511.

Chemically heterogeneous phlogopite plates reveal variations in TiO_2 and Cr_2O_3 contents (1,5-4,17 % and 0,37 - 1,09 %). In Figure 3 points of phlogopite from breccia cement reveal direct correlation between Cr_2O_3 and TiO_2 contents and are located within the field of secondary micas, as well as partly within the field of rocks with texturally equilibrated mica. Chemically phlogopite from mantle breccia is close to "MARID" mica (Dawson & Smith 1977, Solovjeva *et al.* 1994).

Rutile from breccia has visible admixture of Cr_2O_3 (1,77 %) and FeO (1,8 %) and its composition is comparable with "MARID" rutile from South Africa kimberlite (Dawson & Smith 1977).

Ilmenite varies chemically in TiO_2 (32,1-53,7%), FeO (25,5-29%), MgO (11,7-13,4%), $Fe^{3+}/(Fe^{3+}+Fe^{2+})$ at = 0,12 - 0,78. Composition heterogeneity is also fixed in Ti-magnetite and monticellite.

Small carbonate grains in breccia cement are represented by calcite and dolomite. Composition heterogeneity of matrix minerals, zoned reactional rims on primary minerals, variation of ferric iron in ilmenite and Ti-magnetite from breccia cement are evidence of nonequilibrium conditions of crystallization, and as seems, of changing oxidizing state.

NATURE OF THE STUDIED SAMPLES

The petrography of the studied samples (00/165, 11/84) and rocks of group A with the texturally equilibrated mica from the Udachnaya pipe displays the common relation of mica with pyroxenites and websterites. This association is evident also when mica forms separate plates, veinlets or phlogopite - clinopyroxene bands in granular garnet and spinel peridotites. The rare deformed sulfide globules may suggest the original magmatic nature of pyroxenites and websterites. The contact between the mica websterite and spinel lherzolite in the sample 11/84 may testify both the premetamorphic intrusion of websterite dyke or sill into lherzolite and the adjoining of different cumulate layers. The shadow xenoliths of pyroxenites within the lherzolite in the sample 00/165 may represent metamorphosed relics of early dyke or crystal cumulates. The peculiarities of the REE distribution in pyroxenites and websterites (with the signs of the primary cumulative genesis) from the Udachnaya pipe are not in the contradiction with the hypothesis of their origin from the komatiite, basalt - komatiite and basalt melts (Solovjeva *et al.* 2000). The appearance of phlogopite, ilmenite and sulfides is supposed due to a premetamorphic metasomatism.

The evolution of the sample 00/177 with metasomatic graphite, phlogopite, sulfides possibly proceeded in two or three stages. The megacrystalline orthopyroxene rock is thought to be

of the original cumulate genesis. Megacrystalline orthopyroxenites with intergranular veinlets of garnet and minor clinopyroxenes are common in the xenolith population of the Udachnaya pipe. The peculiarities of these rocks evidence the recrystallization of exsolved garnet and clinopyroxene from primary homogeneous pyroxene into the intergranular aggregate under the conditions of cooling and high pressure.

The later association of Phl + Graph + Sulf is probably related with the influx of the fluids. The heterogeneity of Ol, Gnt, Phl composition shows the lack of complete equilibration of minerals in the rock and the development of metasomatic association not far before the kimberlite formation. The sharp increase of mg # in the marginal parts of olivine, high Cr content in garnet and spinel and the development of graphite do not provide evidence against the high reducing state of the fluids, as was shown for the reactional metasomatites of group C (Solovejeva *et al.* 1997). Some morphological features of graphite possibly suggest its paramorphic origin after the primary diamond. It is not excluded that some part of the carbon was dissolved in the primary pyroxene and then was exsolved in the period of the general metamorphism. Later during the metasomatic stage the graphite crystals were enlarged being in the equilibrium with the passing reducing fluid. Thus, we can assume that a lighter carbon in graphite C_2 indicates an incomplete equilibrium between the carbon supplied by the fluid (C_f) and a lighter primary carbon of the rock.

The nature of the mantle breccia may be discussed according to the composition of the fragmental material and the cementing fine-grained matrix. The fragmental material in rough estimate of the modal composition refers to the lherzolites or harzburgites. Primary compositions of their minerals relate to garnet lherzolites or megacrystalline dunites from Udachnaya pipe (Sobolev *et al.* 1984, Solovejeva *et al.* 1994). Some textural features, namely the inclusions of well shaped crystals of clinopyroxene and rounded grains of garnet in large olivine porphyroclasts, evidence the presence of

megacrystalline dunites debris in breccia. It is likely that both types of rocks underwent fracturing and brecciation in the mantle and the process of the fragmentation took place at the level of the garnet facies. Unlike mantle breccia from the Udachnaya pipe, the "polymict peridotites" from Bultfontein and De Beers (Lawless *et al.* 1979) contain eclogite and megacryst fragments. P. Lawless *et al.* (1979) consider the "polymict peridotites" to be the conduits remnants of kimberlite melts passed through the lithospheric mantle. The cement of the mantle breccia was possibly created after the crystallization of the high-Ti -K melt containing carbon dioxide and F.

MAIN CONCLUSIONS 1 - Compound samples 00/165 and 11/84 with the contacts between granular peridotites and pyroxenites and containing texturally equilibrated mica reflect the existence of the intruded or cumulate pyroxenite within the ancient craton lithosphere. The origin of phlogopite, ilmenite and sulfides is thought to be due to premetamorphic mantle metasomatism.

2 - Graphite-bearing garnet orthopyroxenite with phlogopite and sulfides (sample 00/177) reveals two major episodes of their evolution. The earlier stage was related to the existence of monomineralic orthopyroxene rock possibly of magmatic nature similar to pyroxenites from the samples 00/165 and 11/84. In the period of general metamorphism the rock underwent recrystallization due to the cooling. The formation of Phl + Graph + Sulf is possibly related to influx of reducing fluids just before kimberlite formation.

3 - Mantle breccia (sample 00/93-5) was formed during the fracturing of the rocks similar to garnet lherzolites of the common type and megacrystalline dunites. The matrix of breccia was formed by crystallization of a high - Ti, K melt like that of protokimberlites.

Acknowledgements The investigations were supported by RFBR (grant N 02-05-64793). To the reviewers of RBG for the suggestions to the manuscript.

References

- Boyd F.R., Nixon P.H. 1975. Origins of the ultramafic nodules from some kimberlites of Northern Lesotho and Monastery mine, South Africa. *Phys. Chem. Earth*, 9: 431-454.
- Boyd F.R., Pokhilenko N.P., Pearson D.G., Mertzman S.A. et al. 1997. Composition of the Siberian cratonic mantle: evidence from Udachnaya peridotite xenoliths. *Contrib. Mineral. Petrol.*, 128: 228-246.
- Carswell D.A. 1975. Primary and secondary phlogopites and clinopyroxenes in garnet lherzolite xenoliths. *Phys. Chem. Earth*, 9: 417-430.
- Carswell et al. 1979. The petrology and geochemistry of ultramafic nodules from pipe 200, Northern Lesotho. The mantle sample: inclusions in kimberlites and other volcanics. AGU Washington D.C.: 127-144.
- Daniels L. R. et al. 1991. Oxygen fugacity constrains on the Southern African lithosphere. *Contrib. Mineral. Petrol.*, 108: 154.
- Dawson J. B., Smith J. V. 1977. The marid (mica- amphibole- rutile- ilmenite- diopside) suite of xenoliths in kimberlite. *Geochim. Cosmochim. Acta*, 41: 309-323.
- Delaney J.S. et al. 1980. Chemistry of micas from kimberlites and xenoliths- II. Primary- and secondary- textured micas from peridotite xenoliths. *Geochim. Cosmochim. Acta*, 44: 857 - 872.
- Finnerty A.A., Boyd F.R. 1987. Thermobarometry for garnet peridotites: basis for determination of thermal and compositional structure of the upper mantle. In: P.H. Nixon, ed., *Mantle xenoliths*. John Wiley and Sons, pp.: 381-402.
- Galimov E. M. 1991. Isotope fractionation related to kimberlite magmatism and diamond formation. *Geochim. Cosmochim. Acta*, 55: 1697-1708.
- Gurney J.J. et al. 1984. Mineral associated with diamonds from the Roberts Victor mine. In: *Kimberlites II: The mantle and crust- mantle relationships*, Servier, pp.: 25-32.
- Lawless P.J. et al. 1979. Polymict peridotites from the Bultfontein and De Beers mines, Kimberley, South Africa. In: *The mantle samples: inclusions in kimberlites and other volcanics*, 2: 145-155.
- Sobolev N. V. et al. 1984. Diamond- bearing peridotite xenoliths in kimberlites and the problem of the origin of diamonds. *Geologiya i Geofizika* (Russian Geology and Geophysics), 12: 63-80.
- Solovejeva L.V. et al. 1994. Kimberlites and Kimberlite- like rocks. The Substance of the upper Mantle beneath ancient Platforms [in Russian]. Novosibirsk: 255.

- Solovjeva L.V. et al. 1997. Mantle metasomatism and melting in mantle- derived xenoliths from the Udachnaya kimberlite; their possible relationship with diamond and kimberlite formation. *Russian geology and geophysics*, 38(1):182-204.
- Solovjeva L.V., Gornova M.A., Lozhkin V.I. 2000. Rare earths in xenoliths of pyroxenites, eclogites and basic granulites from kimberlite pipes Udachnaya

and Obnazhennaya, Yakutia. *Dokladi RAN*, V. 373(4):532 – 535.

Manuscrito A-1300

Recebido em 22 de novembro de 2001

Revisão dos autores em 18 de dezembro de 2001

Revisão aceita em 19 de dezembro de 2001