10th International Kimberlite Conference, Bangalore - 2012

10IKC-89

ISOTOPE HETEROGENEITY FROM OXYGEN IN ROCKS OF LITHOSPHERE MANTLE

Kostrovitsky[1]SI, Gornova[1]MA, Solovyeva[2]LV, Yakovlev[1]DA

[1] *Institute of Geochemistry, Irkutsk, serkost@igc.irk.ru*

[2] *Institute of the Earth's Crust, Irkutsk, solv777@crust.irk.ru*

Early studies (Mattey et al, 1994a,b) clearly recognized that $\delta^{18}O$ values are invariant for each of the minerals composing the rocks of the lithosphere mantle. The conclusion about invariant oxygen (O_2) isotopic composition for minerals of the lithosphere mantle irrespective of paragenesis and facies (spinel -, garnet-, diamond-bearing) is related to the concept of the "mantle range", "mantle value", as an O_2 isotopic characteristic for mantle rocks (Mattey et al, 1994; Taylor et al, 2005). Average values ± a standard deviation for $\delta^{18}O$ were determined for major minerals of the lithosphere mantle - olivine (Ol), garnet (Grt), clinopyroxene (Cpx), orthopyroxene (Opx). If $\delta^{18}O$ values fall outside the limits of the mantle range, they are considered as anomalous. Different hypotheses are proposed to explain values lying outside the mantle range, e.g. the contribution of the oceanic crust to the formation of the lithosphere mantle (Taylor et al, 2005). The main goal of the present study is to obtain an O_2 isotope systematics for high-pressure minerals of different parageneses from mantle xenoliths and kimberlites of the Yakutian province and to consider the possible reasons of variations of $\delta^{18}O$ values in minerals.

Minerals for studies were sampled from kimberlite pipe Udachnaya -Eastern (Daldyn field), which is unique by fresh kimberlites, and from mantle xenoliths. Kimberlites from Komsomolskaya-Magnitnaya pipe (Upper Muna field) were analyzed as well. Oxygen isotopic composition was studied for Ol being the rock-forming mineral of kimberlites that started to crystallize at the mantle depth and terminated crystallizing in pipe conditions when rock matrix was formed, as well as for minerals from low-T^0 granular and high-T^0 deformed peridotites - Ol, Grt, Opx, Cpx, chromespinelid (CrSp) and picroilmenite (Ilm), and for minerals of low-Cr megacryst association. The total number of analyses is 146, including those for minerals: Ol - 61, Grt - 33, Cpx - 17, Opx - 18, Ilm - 9, CrSp-3.

Oxygen isotopic composition was determined at the Analytical Center of Far East Geological Institute, Far East Branch of Russian Academy of Sciences by a laser fluorination (LF) using BrF5 and infra-red continuous Nd-YAG laser (l=1.064 mm, CW, 100W) for heating the sample (Ignatyev, Velivetskaya, 2004). The accuracy of the method (1 σ) is 0.1 ‰ (n =5) for international standards NBS-28, NBS-30. The weight of analyzed garnet monofractions made up 1-2 mg. $\delta^{18}O$ were measured via mass-spectrometer Finnigan MAT 252 with a double system of lap joint. The reproducibility of $\delta^{18}O$ determinations for samples constituted 0.1 ‰. The oxygen isotope data, given by other researchers for peridotites from Udachnaya pipe (Taylor et al, 2005) as a whole well agree with the data obtained by us (Table 3).

Results of studies

Table 1 gives the average $\delta^{18}O$ ± a standard deviation values for mantle minerals of different parageneses. We calculated both Ol from megacrysts and from mantle xenoliths. Tables 2-4 present the oxygen isotopic ($\delta^{18}O$) composition and the main chemical characteristics for Ol, Grt, Opx and Cpx.

Table 1. Average $\delta^{18}O$ values for different mantle minerals.

Mine -ral	Opx (18)	Cpx (17)	Grt (45)	Ol (53)	Ilm (9)	CrSp (3)
δO^{18}, ‰	5,51± 0.27	5,39± 0,21	5,1± 0,24	5,02± 0,16	3,60± 0,35	1,25± 0,95

Table. 2. Average composition of different parageneses olivine.

	Peridotites		Megacrysts		Ol from matrix (8)
	Granular (17)	Deformed (15)	Green (14)	Yellow -brown (7)	
FeO	7,66 ±1,10	9,47± 1,69	7,18± 1,07	13,07± 0,96	
MgO	50,3±0,84	49,40± 1,46	51,2± 0,81	46,41± 1,28	
Mg#	92,2±1,05	90,24± 1,70	92,8± 0,81	86,9± 1,74	88,9-92,5*
$\delta^{18}O$, ‰	5,10±0,14	4,96± 0,1	5,14± 0,14	4,8± 1,21	4,76± 0,07

Ol of the matrix, forming idiomorphic and subidiomorphic phenocrysts with the size ranging from 0,25 up to 2 mm, was studied from kimberlites of Udachnaya-Eastern and

Komsomolskaya-Magnitnaya pipes (Upper Muna field). The forsterite minal concentration in Ol from Udachnaya-Eastern kimberlites varies in the range from 88,9 to 92,5 % (Kostrovitsky, 1986). Variability in the $\delta^{18}O$ of Ol from the matrix ranges in the interval as 4,7-4,9 ‰, averaging 4,76+0,07 ‰.

Ol megacrysts from Udachnaya-Eastern kimberlites form two genetic groups. The first group includes high Mg# Ol of green color (92,5-93,9 Fo minal), belonging to diamond-bearing dunite-harzburgite paragenesis (Sobolev et al, 1984; Pokhilenko et al,1993). The second group of Ol megacrysts of yellow-brown color demonstrates low Mg# (table 2) and belongs to low-Cr megacryst association. $\delta^{18}O$ values in Ol megacrysts of the 1st and 2nd groups vary within the range as 4,9-5,4 and 4,6-5,0 ‰, correspondingly.

$\delta^{18}O$ values in olivines from low-T^0 granular and high-T^0 deformed peridotites vary within 4,8-5,4 and 4,7-5,1 ‰, correspondingly. The latter are characterized by low Mg# (Table 2).

Table 3. Average composition of garnet of different parageneses.

	Granular lherzolites		Deformed lherzolites	Mega-crysts
	(17)	(11) (Taylor et al, 2005)	(12)	(5)
Al_2O_3	20,2±1,94	20,3±1,8	17,4±2,7	19,4±1,0
Cr_2O_3	4,73±2,45	3,7±2,8	5,8±3,3	2,1±1,1
Mg#	81,1±1,69	83,6±4,0	82,0±2,1	79,0±2,4
$\delta^{18}O$, ‰	5,15±0,27	5,2±0,17	5,0±0,27	4,98±0,13

Table 4. Average composition of pyroxene of different parageneses.

	Granular lherzolites		Deformed lherzolites		Mega-cryst
	Cpx (7)	Opx (9)	Cpx (9)	Opx (9)	Cpx (1)
SiO_2	54,81 ±0,63	58,16± 0,34	55,21± 0,79	57,88± 0,55	54,65
Al_2O_3	2,19± 0,56	0,61± 0,23	1,52± 0,52	0,56± 0,1	1,72
Cr_2O_3	1,73± 0,92	0,32± 0,22	1,03± 0,47	0,27± 0,12	0,32
FeO	1,98± 0,55	4,81± 0,53	3,61± 0,73	5,49± 0,77	3,84
MgO	16,43 ±0,71	35,45± 0,94	18,72± 0,96	34,5± 0,82	16,23
CaO	20,62 ±1,2	0,51± 0,42	17,74± 1,31	0,88± 0,21	20,62
Na_2O	1,71± 0,39	0,04± 0,05	1,5± 0,57	0,22± 0,11	1,58
Mg#	93,66 ±1,57	92,91± 0,84	90,17± 1,97	91,83± 1,3	88,28
$\delta^{18}O$, ‰	5,57± 0,18	5,66± 0,21	5,24± 0,09	5,37± 0,26	5,2

A significant difference $\delta^{18}O$ is found when Grt and Prx from different groups of megacrysts and xenoliths are compared. As Tables 3 and 4 demonstrate the low Mg# minerals from megacrysts and deformed peridotites are ^{18}O depleted in comparison with low-T^0 granular peridotites.

Discussion

The decrease in $\delta^{18}O$ values in mineral succession Opx>Cpx>Grt>Ol>Ilm>CrSp (Table 1) completely corresponds to that for mantle minerals, recognized in early studies (Mattey et al, 1994; Zheng, 1997). The oxides demonstrate ^{18}O depletion while silicates are characterized by ^{18}O enrichment. Precise distinctions in $\delta^{18}O$ values for different minerals are due to the isotope fractionation resulting from crystal-chemical features (composition and structure).

Fig. 1-3 show an evident direct correlation between $\delta^{18}O$ values and Mg# of olivine and pyroxenes, a reverse correlation between $\delta^{18}O$ and Cr_2O_3 content and a direct correlation of $\delta^{18}O$ with Al_2O_3 content in garnets.

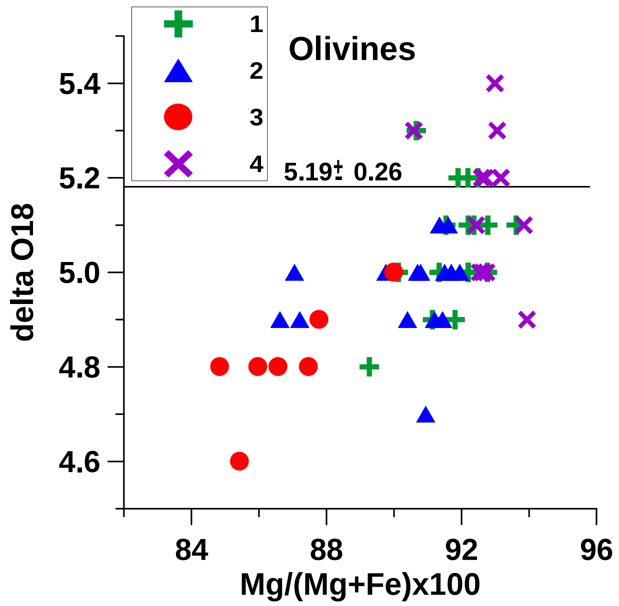


Fig. 1. Diagram Mg/(Mg+Fe)*100 - $\delta^{18}O$ for olivines of different parageneses: 1 – granular lherzolites; 2 –deformed lherzolites; 3 – low-Cr megacrysts; 4 – megacryst dunite-harzburgites. The line 5.19±0.26 correspond to the average value $\delta^{18}O$ of "mantle range" for Ol (Mattey et al, 1994).

The lowest $\delta^{18}O$ values are typical of Ol from the kimberlite groundmass, for Ol megacrysts of low-Cr association and for Ol from deformed peridotites. Though the above olivines belong to different parageneses, the general features of them are high FeO content and accordingly low Mg#. High-Mg# Ol from grained peridotites and megacrysts of dunite-harzburgite paragenesis demonstrate relatively high $\delta^{18}O$ values. Similar ratios are found for pyroxenes (Table 4, Fig. 3). Pyroxenes from deformed lherzolite and low-Cr megacryst association, characterized

by relatively high FeO content (low Mg#), show lower $\delta^{18}O$ values.
The another correlation of $\delta^{18}O$ on the mineral composition is found for Grt. The major factor of its variability is not Mg#, but Al_2O_3 and Cr_2O_3 concentrations in the mineral. The corresponding plots (we used and literature data of Taylor et al, 2005) show a direct correlation between $\delta^{18}O$ values and Al_2O_3 content and a reverse correlation of $\delta^{18}O$ with Cr_2O_3 (Fig. 2).

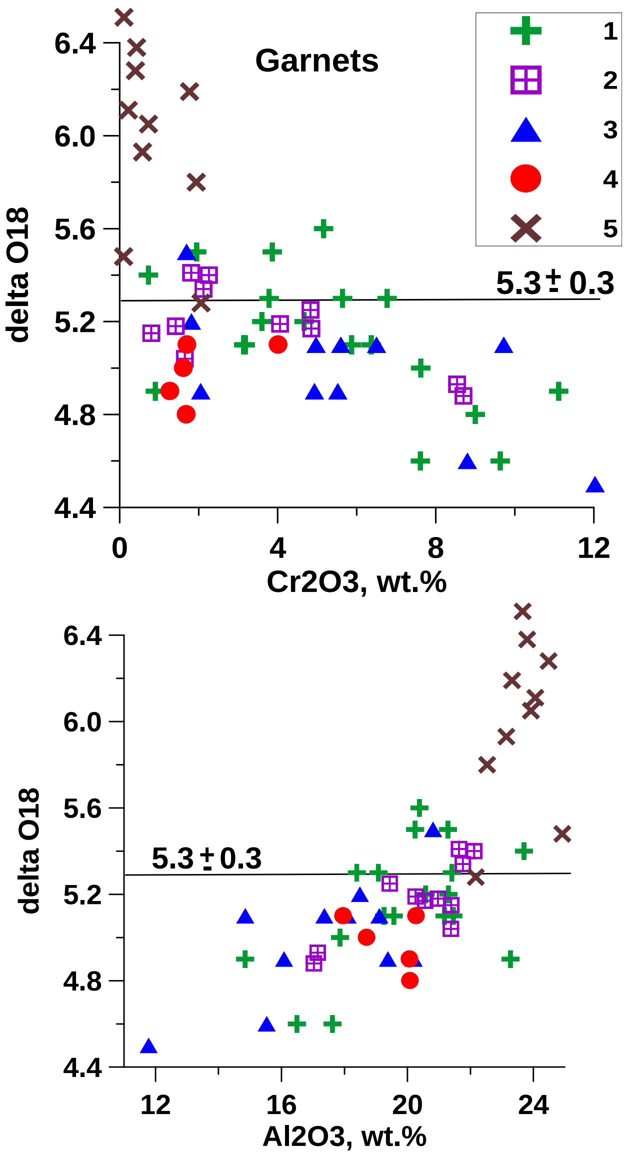
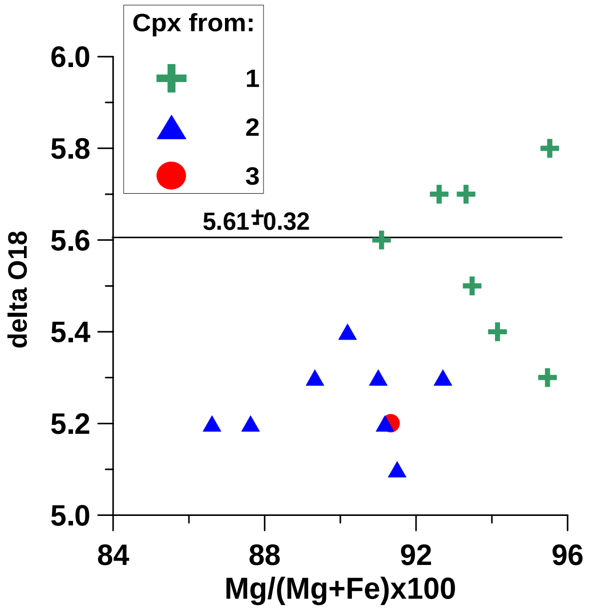


Fig. 2. Diagrams Al_2O_3 - δO^{18}, Cr_2O_3 - $\delta^{18}O$ and Mg/(Mg+Fe)*100 - $\delta^{18}O$ for garnets of different parageneses: 1 – granular lherzolites; 2 - granular lherzolites (by Taylor et al., 2005); 3 – deformed lherzolites; 4 – low-Cr megacrysts; 5 – lherzolites from Obnajennaya pipe (by Taylor et al., 2005). The line 5.3±0.3 correspond to the average value $\delta^{18}O$ of "mantle range" for Grt (Taylor et al, 2005).

These correlations are characteristic both of high-T^0 deformed peridotites, low-Cr megacrysts and low-T^0 grained peridotites. The conclusions about these correlations are confirmed by the data published in the paper by L.Taylor et al. (See Fig. 2). The lowest $\delta^{18}O$ (<5,0 ‰) values are observed for garnets from Udachnaya peridotites with high-Cr content (5-8 % Cr_2O_3), while the highest $\delta^{18}O$ values (≥5,4 ‰) are characteristic of low-Cr garnets (<2,5 % Cr_2O_3), of high-Al garnets (23,6 % Al_2O_3). A reverse correlation between $\delta^{18}O$ and Cr_2O_3 is found in garnet inclusions of Finsch diamonds (Lowry et al, 1999), in garnets from polymict peridotites of the Kaapvaal craton, Republic of South Africa (Zhang et al, 2003).
Thus, we can conclude, that the oxygen isotopic composition is a function of integrated effect on the concentrations of the basic oxides, composing a mineral. Isotope O_2 fractionation is defined by a different isomorphous capacity of heavy O_2 isotope for various oxides. If the contents of light oxides (SiO_2, MgO, Al_2O_3) in the mineral are high, the oxygen isotopic composition is heavy. If the contents of Fe and Cr oxides are high in the garnet, the content of ^{18}O is relatively low.

Oxygen isotope systematics of mantle minerals and the observed correlations cannot be explained only by change in the mineral chemistry. ^{18}O depletion of minerals from the deformed peridotites and low-Cr megacrysts in comparison with minerals of low-T^0 grained peridotites and high-Mg# megacrysts can be considered as result of the influence of ^{18}O depleted astenosphere substance on lithosphere-astenosphere boundary during kimberlite formation. ^{18}O depletion with the depth (from the crust to the lower mantle) is owing to the increase of P-T parameters, to spinel and perovskite textures of minerals at the greater depth and the decrease in the silicate tetrahedron content (Zheng, 1997). This approach logically agrees with the idea about the significant contribution of the deep-seated substance from transition zone and the lower mantle in the astenosphere, brought by the plume uplifted to the lithosphere bottom (Solov'eva et al.., 2008).

This bring up the question: What factor was the predominant in ^{18}O depletion of minerals from deformed lherzolites and megacrysts: 1) higher content Fe in Ol and Cpx, and higher content Cr and lower content Al in Grt (the dependence of $\delta^{18}O$ values from mineral composition); or 2) the influence of the astenosphere? We leave this question still open for debate - as additional studies are required. But it is obvious that the lithosphere mantle is not homogeneous by oxygen isotopic composition. The granular (coarce) and deformed lherzolites are characterized by different $\delta^{18}O$ values.



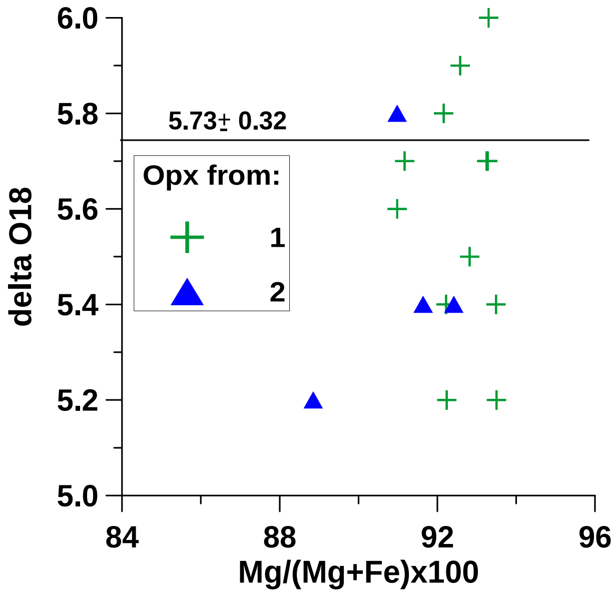


Fig. 3. Diagrams Mg/(Mg+Fe)*100 - $\delta^{18}O$ for clino- and orthopyroxenes of different parageneses: *1* – granular lherzolites; *2* – deformed lherzolites; *3* – low-Cr megacryst. The lines 5.61 and 5.73 correspond to the average values $\delta^{18}O$ of "mantle range" for Cpx and Opx (Mattey et al, 1994).

The studies were supported by the integration projects of the Russian Academy of Sciences № 72 and 24.1 and the project of the Russian Foundation for Basic Research № 10-05-00589.

Reference

Chazot, G. Lowry, D. Menzies, M. and Matthey, D. (1997) Oxygen isotopic composition of hydrous and anhydrous mantle peridotites. Geochim. Cosmochim. Acta, 61, 161-169.

Ignat'ev A.V., Velivetskaya T.A. (2004) Method to extract CO_2 from the micro weight probes for measuring oxygen and carbon isotopes. XVII Symposium on geochemistry of isotopes devoted to the Academician A.P. Vinogradov. Moscow: Abstracts. M.: GEOKHI, 2004. p. 95. (in Russian)

Kostrovitsky S.I. Geochemical features of minerals from kimberlites. (1986) Novosibirsk: Nauka. 263 p. (in Russian)

Lowry D., Mattey D.P., Harris J.W. (1999) Oxygen isotope composition of syngenetic inclusions in diamond from the Finsch Mine, RSA. Geochim Cosmochim Acta 63:1825–1836.

Mattey D., Lowry D., Macpherson, C. and Chazot G. (1994a) Oxygen isotope composition of mantle minerals by laser fluorination analysis; homogeneity in peridotites, heterogeneity in eclogites. Mineralogical Magazine, 58a (L-Z): 573-574.

Mattey, D., D. Lowry and C. Macpherson. (1994b) Oxygen isotope composition of mantle peridotite. Earth Planet. Sci. Lett. 128: 231-241.

Pokhilenko N.P., Sobolev N.V., Boyd F.R., Pearson G.D., Shimizu H. (1993) Megacrystalline pyrope peridotites in the lithosphere of the Siberian platform: mineralogym geochemical features and the problem of the origin. Geology and Geophysics. V. 34. № 1. p. 71-84. (in Russian)

Sobolev N.V., Pokhilenko N.P., Efimova E.S. (1984) Xenoliths of diamond-bearing peridotites in kimberlites and origin of diamonds. Geology and Geophysics. № 25. p. 63–80. (in Russian)

Solov'eva L.V., Lavrent'ev Yu. G., Egorov K.N., Kostrovitsky S.I. (2008) Nature of the astenosphere liquids during kimberlite-forming cycle: geochemistry of garnet and clinopyroxene from deformed peridotites and megacrysts of Udachnaya pipe. Geology and geophysics. V. 49. № 4. p. 281-301. (in Russian)

Taylor L.A., Spetsius Z.V., Wiesli R., Spicuzza M., and Valley J.W. (2005) Oceanic protolites of diamond-bearing perdotites: an evidence of crustal origin exemplified by the Yakutian kimberlites. Geology and Geophysics. V. 46. № 12. p. 1198-1206. (in Russian)

Zhang H.-F., Menzies M. A., Mattey D. (2003) Mixed mantle provenance : diverse garnet compositions in polymict peridotites, Kaapvaal craton, South Africa. Earth and Planetary Science Letters. 216(3). 329-346. (in Russian)

Zheng Y.-F. (1997) Prediction of high-temperature oxygen isotope fractionation factors between mantle minerals. Physics and Chemistry of Minerals, 24, 356-364.