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MANTLE STRUCTURE BENEATH UDACHNAYA PIPE RECONSTRUCTED BY FRESH MANTLE XENOLITHS FROM BROWN BRECCIA

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DATA AND METHODS.

Minerals from >340 400 new fresh xenoliths from Udachnaya pipe brown breccias containing absolutely fresh xenoliths (Kamenetsky et al.,2009; Ionov et al., 2011) were analyzed for major and trace elements. EPMA data for minerals from 110 relatively small peridotite- pyroxenite samples (3-7 cm) were analysed in University of Vienna using Cameca 100SX. Tee high precision analyses of olivines were obtained for 64 associations. The other xenoliths were analysed in IGM, Novosibirsk in mounts and analyses of 27 samples from the same collection were added (Ionov et al., 2011). In addition the published data by (Jagoutz, 1973; Jacob et al., 1974; Snyder et al., 1997; Pokhilenko et al., 1976- 2000; Griffin et al., Boyd et al., 1997; Smith, 1999; Kuligin et al., 1995; Malygina et al., 2000; Pokhilenko et al., 2006; Shatsky et al., 2008; Ionov et al., 2010 etc) including ~1800 associations and xenocrysts were used for the deciphering of the mantle structure and layering starting at depth of 80 kbar.

MINERALOGY OF XENOCRYSTS

GARNETS show high variations in Cr_2O_3 within lherzolite field (Sobolev et al., 1973). Green garnets form wehrlites have the higest Cr_2O_3 and CaO contents (13.8 and 8.0-9.0 wt% respectively (Fig.1). Rare dunites and harzburgites reveal sub calsic garnet compositions such as in diamond inclusions (Logvinova et all .,2005; Sobolev et al.,1987). The garnets from Phl bearing associations often show mainly enrichment in TiO_2 indicating that .

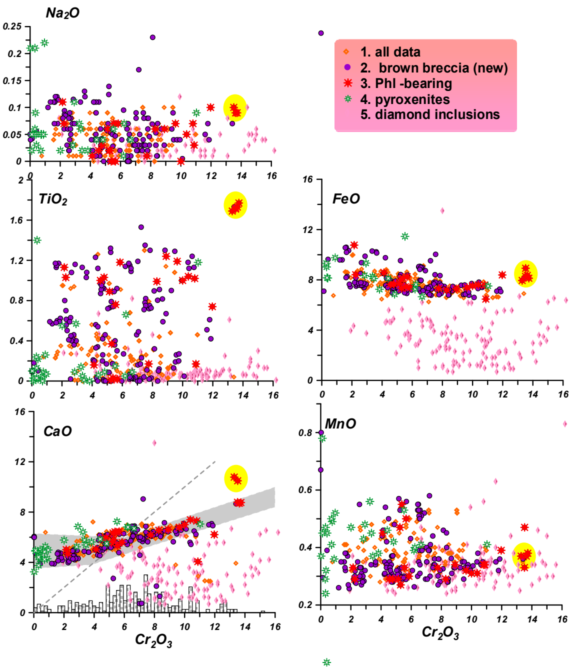

Fig.1. Variations of major element compositions of the garnets from brown kimberlite breccia in comparison with other published data from Udachnaya pipe. 1. Published previous data. 2.new data. 3. Phl bearing associations. 4. Pyroxenites, wehrlite is marked by circle

CR-DIOPSIDES form brown breccia peridotite xenoliths (Fig.2). repeat variations of previous collections but are higher in TiO_2 and Cr_2O_3.

CHROMITES show variations from 10 to 60 % Cr_2O_3, the varieties >40 Cr_2O_3 are enriched in TiO_2 and FeO which is more typical for the pyroxenites and phlogopites (Fig.3) when compared to the published data.

ILMENITES found in carbonite - bearing phlogopie- bearing veins 7-11Wt % MgO in peridotites and Cr-low pyroxenites (Alymova et al., 2004) are close in compositions to the xenocrysts in kimberlites

PHLOGOPITES The compositions of the phlogopites are ranging in FeO from 2 to 6.5% (Fig. 4) whereas FeO in Phl from olivine –Phl breccia ranges from 5 to 8.5%, they are low in Cr_2O_3 but higher in Na_2O (to 1.5%).

HIGH PRECISION DATA FOR OLIVINE

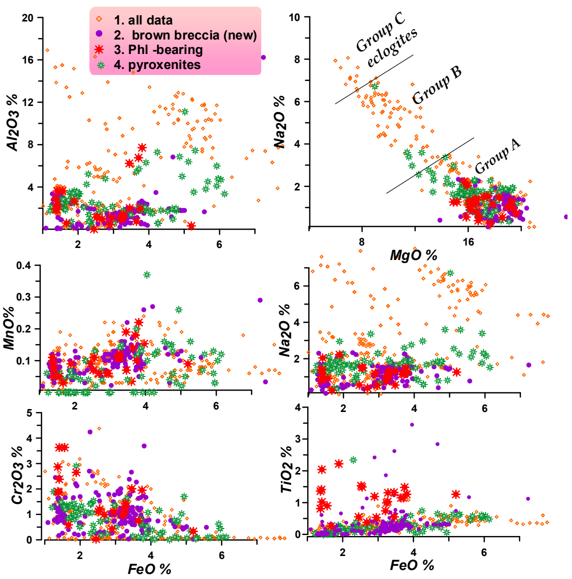

Fig.2. Variations of major element compositions from the clinopyroxenes of brown kimberlite breccia in comparison with other published data from Udachnaya pipe, Eclogite groups after (Dawson, 1980).

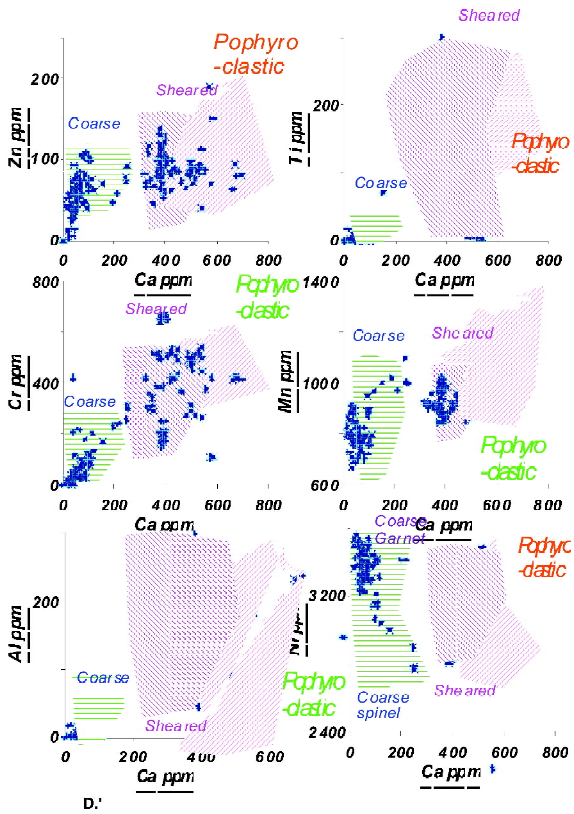

Fig.5. Minor element variations in olivine obtained with the high precision olivine measurements.

The high precision olivine trace element microprobe analyses (HPA) for 64 xenoliths obtained using CAMECA100SX are divided into 3 major groups. Group 1 consisting of porphyroclastc and/or shared peridotites is characterized by high Ca, Ti. Group 2 consists of coarse grained garnet peridotites that have low Ca- and high Ni- olivines. Group 3 are low pressure garnet-spinel peridotites with low Ni-olivines.

THERMOBAROMETRY OF OLIVINE

The Al- and Cr-in-olivine thermometer (De Hoog et al., 2010) provides temperatures comparable to those calculated using orthopyroxene thermometry (Fig. 6b) (De Hoog et al., 2010) especially based on Cr-Al exchange

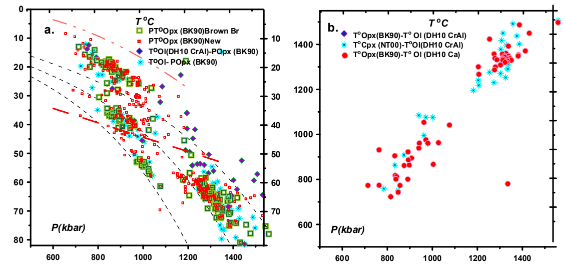

Fig.6. PT conditions for peridotites from the brown kimberlite breccia, ,Udachnaya pipe (new data). a. PT Correlations of the Ol – based T and Px- based pressure. Symbols like in Fig.7. b:. Temperatures calculated using Ol-thermometry are similar to those calculated using Px thermometry.

provide results very similar to pyroxene temperatures. (Fig6. b). Using this thermometry and common Opx barometry the obtain geotherm is nearly the same like as constructed by most effective methods (Brey, Kohler, 1990). De Hoog and colleagues (2010) reported that these thermometric equations in inverse form may be used as barometers. Nevertheless in general they give lower pressures then Opx based method (Brey, Kohler, 1990). Ca-Ol-Cpx barometry for olivine (Kohler, Brey, 1990) also give not regular geotherms when using this equation together with the Ol thermometers. The modification of inversed (De Hoog et al., 2010) equations with the corrections for Mn, Al, Cr and Ti HPA is promising for the good barometric method.

THERMOBAROMETRY AND RECONSTRUCTIONS OF MANTLE SECTION.

The Udachnaya SCLM section (Pokhilenko et al., 2000æ Ashchepkov et al., 2003): 1. The layer (75-60kbar) includes sheared and porhyroclastic peridotites, dunite veins with the Chr, Gar and Ilm and Ilm metasomatites; 2. The layer (60- 55 kbar) - eclogites lens and low -T dunites; 3. (55-45 kbar) low-T° lower layered ultramafic unit 4. (45-40 kbar) pyroxenite lens; 5. (40-30 kbar) low-T° upper garnet peridotite unit. 6. (30-10 kbar) high T° and low-T Sp- Gar and Sp lherzolites and Fe- rich pyroxenites.

Measurements in thin sections of small xenoliths which are commonly represent the disintegrated material close to the melt channels gave more points tracing advective branch from 80 to 40 kbars. Most of them refer to the porphyroclastic or shared peridotites of polybaric nature (Katayama et al., 2009). Colder associations 33 mw/m^2 occurs at least in three intervals from the base of SCLM.

New data for phlogopite bearing associations show that the metasomatism refer to lowermost part of SCLM to pyroxenite layer and to the incline PT path joining the advective PT path which is traced by the PT for secondary Cr – diopsides rising from base to pyroxenite layer. The P – Fe# diagram for the

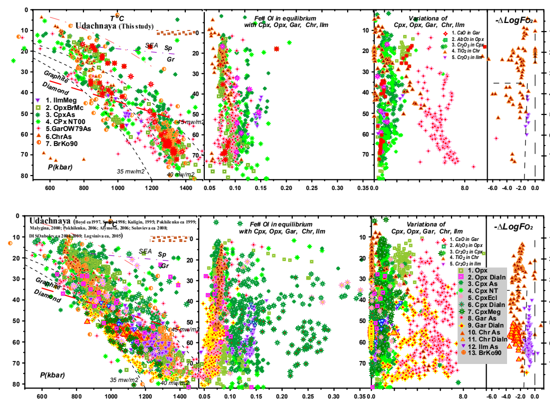

Fig.7. PTXFO$_2$. PT conditions for only new data for brown breccia B PT conditions for the new data for all previous data set of deep seated inclusions from Udachnaya pipe. Signs see legend, methods: (Ashchepkov et al., 2010). NT- (Nimis, Taylor, 2000). BrKo- Brey, Kohler, 1990.

THE DEEP PHLOPITE-OLIVINE BRECCIAS

Two kinds of the deep essentially Phl-Ol magmatic breccias were found: 1) Ol-Phl-Ilm aggregates containing abundant xenocrysts of Ol (7-14% FeO), picroilmenites (6-14% MgO). 2) Ol-Phl-Chr aggregates, where intergranular minerals: Ti-Fe, Cpx, richterite Amph, Ti- Phl and K –fieldspar evidences that final crystallization probably took place near Moho boundary. But original material includes fragments of very deep sheared peridotites. All garnet and pyroxenes were dissolved. Abundant Ol- Chr aggregates varying in compositions with wide range of compositions with increasing Fe, Al, Ti in Chr.

Breccies reflect crystallization of two types of deep seated hydrous protokimberlite which coursed the Phl metasomatism in mantle from base to the SCLM top in vicinity of the magma feeders.

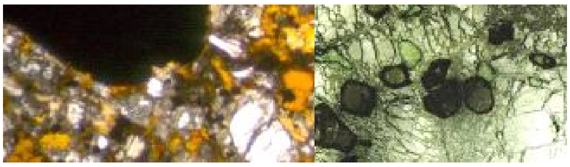

Fig. 8. a) Phl –Ilm –Chr magmatic breccia from Udachnaya pipe; b) xenolith of wehrlite with green garnet (14% Cr_2O_3)

GEOCHEMISTRY

Garnet and clinopyroxene chondrite-normalized trace element abundances from eclogites, garnet- peridotites and pyroxenites are shown in Fig.9 Both, garnet and clinopyroxene TRE- patterns reveal the depleted character of the studied associations. Sigmoidal garnet REE patterns with lower TRE content for peridotitic garnets, indicating metasomatic events (Fig. 9a) are common for sub-Ca compositions. All patters show deep Sr, Ba, Th minima and Zr and Hf dips, elevated U and Nb and Ta (Fig.9). Pyroxenitic garnets show mainly rounded patterns and higher peaks in Nb and Ta. Eclogitic garnets of subductions type are low in TRE level and display jugged spiderdiagram while melt metasomatized reveal smooth patters and high TRE level. The trace elements patterns for the Cpx from the deep seated xenoliths demonstrate highly inclined patterns with the small hump which is shifted to the left part of the REE patterns (Fig.9). The TRE are complex and varying. Clinopyroxenes from peridotites show highly inclined $(Ga/Yb)_n$ REE patterns (<1% melting and high Ga/CPx). The TRE are varying from fertilized close to derived from protokimberlites (Kamenetsky et al., 2009)

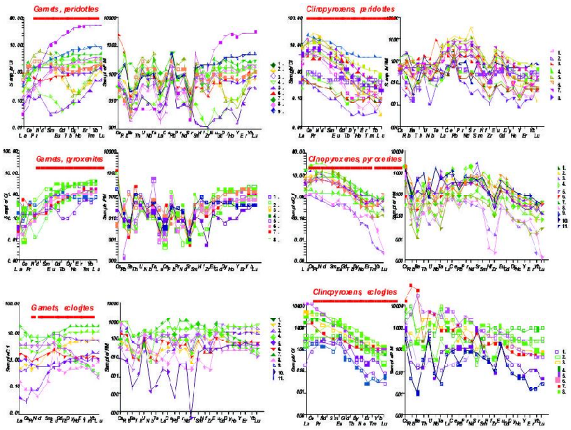

Fig. 9. Trace element patterns for minerals from deep-seated inclusions Udachnaya pipe

like those from Cr - Ti rich green garnets to nearly primitive for Cpx - rich from sheared varieties (Agashev et al., 2010). In depleted peridotites from upper part of SCLM the inclinations of REE and TRE patterns are varying.

The LREE enriched harzburgites related to the fluid-rich melt interactions are intercalated with LREE depleted varieties. Cpx REE patterns from pyroxenites are nearly uniform (~1% melting). Eclogite's Cpx highly differ. The TRE level is lower for those with the signs of the primary subduction origin showing Eu, U , Sr peaks. Those refered to the metasomatic or remelted type (Misra et al., 2004;

Shatsky et al., 2008) show higher TRE level and midly inclined REE patterns, TRE fluctuation in Ta and elevated LILE are marking protokimberlite metasomatism.

The TRE patterns for the phlogopites reveal high inclination in general. The TRE are jugged with the picks in LILE components and Sr, Pb and depression in Th and some HFSE.

DISCUSSION

The detail thermobarometry show that there are high variations of the PT conditions referred to the different lithosphere thickness (Artemieva et al., 2009).

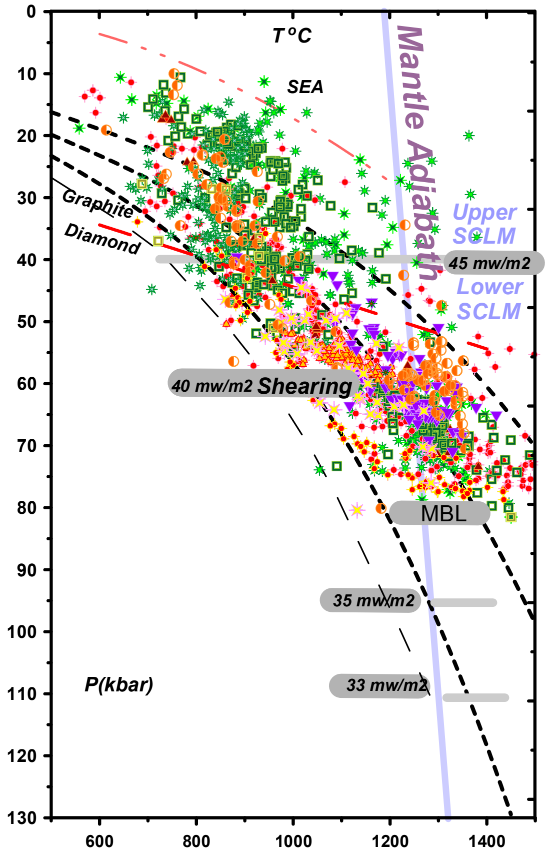

Fig.10. Variations of the geothermal regime according to the decreasing of the lithosphere thickness.

Wide variations of the mineral compositions and position of the geotherms from the SCLM base to 20 kbars show that interactions in several (6) levels of SCLM took place under the influence of 3 major stages of plume melts intrusions including protokimberlites. The deeper level was undergone to the influence of the protokimberlite melts which created magmatic chamber or melt feeder and – vein system within 75 and 55 kabrs created major portion of megacrysts and coursed the deformations of the peridotites due to hydraulic fracturing, submelting and high scale interactions. Existence of relatively easy melted material like eclogites and melt conduits like dunites in SCLM base were probably responsible for the melt concentration and diamond growths.

The upper 55 -40 kbar levels is correspondent mainly to the interactions around the veins which should be formed by the moving of protokimberlites which became essentially carbonatitic in the level near the middle part of SCLM due to the splitting of the primary melts during the differentiation, rising and cooling. Such systems containing abundant carbonates are favorable for the creation of the diamonds (Zedgenizov et al., 2004; Rege et al., 2009) as a result of interactions with the reduced peridotites (Logvinova, Ashchepkov, 2008). Stopping of the pervasive melt percolation pobably occurred near 40 kbar hear the layer of pyroxenites and eclogites.

The large unites in the mantle columns were created by subduction processes and most Fe-rich eclogites should correspond to the upper parts of the subduction slabs.

The layer of the garnet dunites (Pokhilenko et al., 1991) beneath at the SCLM base was created in Archean time probably by subduction related fluids and wad later used by the kimberlite magmas for the melt transfer.

The thermal boundary layer (Artemieva et al., 2009) near 65 kbar corresponds to the temperature minima of the oxidized peridotite solidus at SCLM base (Tappe et al., 2007) due to interaction with lower eclogitic lens. The heterogeneity of the base and abundance of dunites served as melt transfers were responsible for the high degree interaction in 80-50 kbar interval. The chemical boundary for carbonated peridotites near 40 kbars should bring to the melt concentration and creation of the pyroxenite lens. The separate high temperature level appeared in the upper part near the Gar-Sp boundarywere melts werew concentrated also. The 20-30 kbar trap for hydrous melts was responsible was abundant melt percolation on this interval. Possibly most evolved H_2O rich protokimberlite melt portion reached this level as it seen from Ol-Phl breccia. But it also likely that heating within the Sp-Gar facie was close the stage before kimberlites when basalt abundant in this area and as the xenoliths in kimberlites were erupted. Grant RBRF 05-11-00060à 11-05-91060-PICSa

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