Geochemistry of Eclogite Xenoliths from Kimberlite Pipe Udachnaya: Section of Archean Oceanic crust sampled?

A.M. Agashev, L.N. Pokhilenko, N.P.Pokhilenko
V.S. Sobolev Institute of Geology & Mineralogy SB RAS, Novosibirsk 630090, Russia (correspondence: agashev@igm.nsc.ru*

Introduction

Eclogites are important component of lithospheric mantle beneath Archean cratons. They found as xenoliths in all kimberlites worldwide usually comprising minor (1-5%) part, but in some cases can dominate the xenoliths population. As the most of kimberlitic eclogites are Archean in age (Pearson et al, 1995: Jacob 2004) study of their composition is very useful tool to constrain the Archean geodynamics and cratons formation. Among the xenoliths population in kimberlites eclogites more often contain diamonds then other type of mantle rocks and hence could be the main diamond reservoir of the earth. Here we report the new results on eclogites from Siberian Udachnaya kimberlite pipe. A suite of 17 unique big (1 to 20 kg) and fresh eclogite xenoliths including two diamondiferous have been studied for their whole-rock and minerals major and trace elements composition.

Results

Whole rock major elements composition of the Udachnaya eclogite xenoliths suite have a great variability in their MgO contents (9-19 wt%). Based on major elements composition Udachnaya eclogites can be subdivided in two subsets, high magnesian (Mg# 68.8-81.9) and low magnesian (Mg# 56.8-59). High variations also shown by Al_2O_3 (10.17- 18.74 wt %) and Na_2O (0.64-3.09 wt%) concentrations and high Mg# samples tend to contain less of those oxides then low Mg# samples with some exceptions. Two eclogitic groups are clearly different in style of inter-elements correlations. FeO and CaO contents are positively correlate with MgO in low Mg# group of eclogites but negatively in high Mg# group. The same relations present between Al_2O_3 contents of eclogite groups with their Mg#. Compared to present day MORB composition eclogite samples have similar contents of most elements with some depletion in TiO_2 and P_2O_5 and enrichment in MgO and K_2O. Concentrations of TiO_2 are varies in range of 0.2 -1.2 wt % in both groups and do no correlates with their Mg#. Loss of ignition (LOI) values detected in eclogites is in the range of 0.44-1.78 wt% that indicates a little or no secondary alternation experienced by samples at near surface environment. Only one sample has LOI value of 3.58 wt%.

In terms of trace elements composition Udachnaya eclogites are variable enriched over PM in incompatible elements with most pronounced enrichment in LILE elements (Rb, Ba, K, Sr) contents. Concentrations of incompatible HFSE (Nb, Ta, and REE are comparable to present day MORB values. Middle REE and Zr are lower than that of MORB. Heavy REE elements concentration varies from values comparable to present day MORB to significantly lower. Although the two groups of eclogites are overlapped in their HREE contents the high Mg# group has subset of samples with very low concentrations of HREE (Yb n 2.38-1.48 ppm) that outside the range of low Mg# group (6.83-2.72 ppm). Most of the samples show positive Eu anomaly irrespectable of groups (Fig.1). Excess of Eu expressed as Eu# (Eu_n/(Sm_n

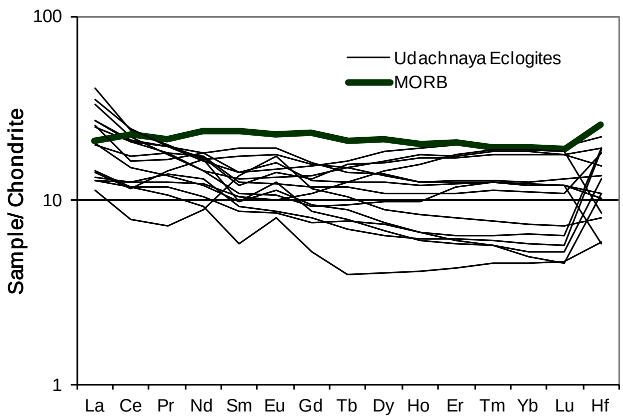


Figure 1. Chondrite normalized REE patterns of Udachnaya eclogites

+Gd_n/2)) positively correlate with Sr concentrations of the rocks. The positive Eu anomaly is positively correlate with Mg# in low Mg group but do not correlate in high Mg group. Most of eclogites of both groups show positive Sr and Nb anomalies and negative Ti anomalies. The most pronounced difference in trace elements pattern between groups is the Zr anomaly which is negative in low Mg group of samples but not evident or positive in high Mg groups. Concentration of the very incompatible elements (Kd mineral/melt close to zero) La,Ce, Nb, Ta, Th and U are positively correlates with P_2O_5 contents in WR composition and between each other. The same feature was documented for deformed peridotite xenoliths from Udachnaya (Agashev et al, 2013).

Discussion and Conclusion

To evaluate the degree of metasomatic enrichment we calculate the WR composition of eclogites from composition of Cpx and Gar and their modes. Calculated WR composition contain only 0-20% of Rb and Ba of measured WR and 1-30% of Nb, Th and U (Fig). Budget of LREE in calculated WR composition are in range of 20-50% as they are compatible in Cpx. Calculated WR composition contains from 60 to 100 % of MREE, Zr and Hf. Negative Zr anomaly is present in lowMg# eclogites reconstructed composition and absent in High Mg# rocks. Positive Sr anomaly is preserved in calculated WR composition of both groups indicating that it is not of metasomatic origin. Approximately 100% of heavy REE, Ni, Co, and Sc budget of WR composition are concentrated in Gar and Cpx. The most of hardly incompatible elements reside in garnet rims. It is unclear when that garnet rims was formed. The nature of metasomatic agent is impossible to evaluate from concentration. Simple substruction of calculated WR composition from measured gives composition that is comparable to measured composition in terms of incompatible elements and significantly different from host kimberlite composition. Therefore simple addition of kimberlite melt is not a suitable explanation of metasomatic enrichment observed in measured WR composition of eclogites.

Major elements composition of eclogites does not significantly change by metasomatic overprint that allow to use measured WR composition to constrain the protholith composition. For comparison of major elements compositions we selects two section of modern oceanic crust particularly IODP site U1309 of Atlantis Massif (Godard et al, 2009) and Hess Deep rift of Pacific Ocean (Gillis et al, 2013). As an example of Archean oceanic crust section we take the well documented and geochemically characterized rocks of Ivisaartog greenstone belt (Polat et al, 2008). In term of MgO-CaO relations Udachnaya eclogites show identical trends to that of modern oceanic crust (Godard et al, 2009; Gillis et al, 2013) from troctolite through gabbroic rocks to basalts (Fig. 2). The same relation is evident in composition of Archean section of oceanic crust in Ivisaartoq greenstone belt (Greenland). However, modern oceanic crust contains less FeO than Udachnaya eclogites and Archean oceanic crust from Greenland. That could be consequence of higher Fe contents of Archean mantle and/or lower redox condition under which Fe was preferably incorporated in silicate minerals but presently it form oxides and oxide gabbro layers. Probably the amount of oxide gabbros is underestimated in average lower oceanic crust composition. The gabbroic suite from Atlantis massif contain to low FeO to be in equilibrium with the mantle (Coogan, 2014).

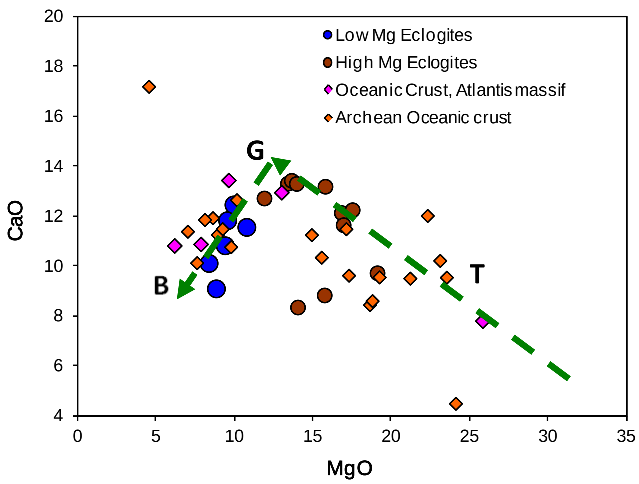
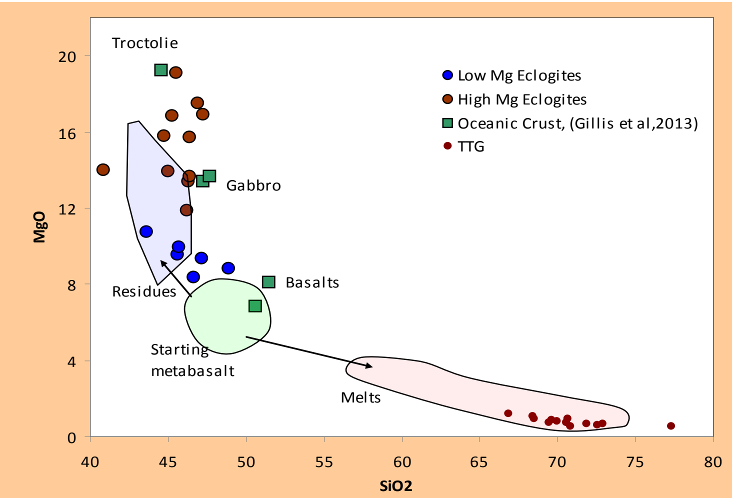


Figure 2. MgO-CaO relations in Udachnaya Eclogites compared to modern and Archean oceanic crust. Line with arrow indicate crystallisation trend (Gillis et al, 2013)

Effect of partial melting:

Mantle eclogite are often considered to be complementary residues to TTG complexes that occurs in archean cratonic areas (Rudnic 1995). This melting process according the experimental data lives SiO_2 poor and MgO rich residues compared to starting material of basaltic composition (Rapp and Watson 1995). To evaluate the effect of partial melting we compare eclogites major elements composition to experimental data of metabasalt partial melting (Rapp and Watson 1995) and composition of present day oceanic crust. The low Mg# eclogites show negative correlations between MgO and SiO_2 that could be expected from partial melting. However high MgO eclogites have a range of MgO contents at nearly constant SiO_2 that comparable to variation of these elements observed in present day lower oceanic crust gabbro-troctolite rocks composition of (Godard 2009). Udachnaya eclogites have range of Sm/Nd ratio from 0.25 to 0.5 (MORB is 0.32) which positive covariates with Nd content that contradict to all geochemical lows. This trend could not be a result of dehydration, melt extraction nor of metasomatic enrichment as all that processes will give positive correlation. This feature is also precludes the origin of eclogites as cumulates because fractional crystallization of basic melt in the mantle will produce positive correlation between Nd and Sm/Nd ratio. Rather this feature could reflect heterogeneity of oceanic crust composition and milling/mixing of different lithologies of oceanic crust especially its lower section that consists of sm scaled layers of different rocks during subduction. Mixing with peridotite component is also possible.



Based on study results following conclusion can be made. WR Major element composition and HREE contents of Udachnaya eclogites indicate the oceanic crustal protholith. Low Mg# eclogites could represent upper oceanic crust. High Mg# eclogites could be a mixture of different rocks composing layered lower oceanic crust. High Mg# eclogites do not experienced significant partial melting during subduction.

Figure 3. Diagram comparing composition of Udachnaya eclogites with oceanic crust section of Gillis et al, 2013) and experimental data on metabasalt melting that produce eclogitic residues (Rapp and Watson 1995).

References

Agashev, A.M., Ionov, D.A., Pokhilenko, N.P., Golovin, A.V., Cherepanova,Yu., Sharygin, I.S., 2013. Metasomatism in the lithospheric mantle roots: constraints from WR and minerals chemical composition of deformed peridotite xenoliths from kimberlite pipe Udachnaya. Lithos 160–161, 201–215.

Gillis, K.M., Snow, J.E., Klaus, A., Abe, N., et al., 2013. Primitive layered gabbros from fast spreading lower oceanic crust. Nature 505, 204–207

Jacob DE (2004) Nature and origin of eclogite xenoliths from kimberlites. Lithos 77:295–316

Godard M, Awaji S, Hansen H, et al. Hellebrand E., Brunelli D., Johnson K., Yamasaki T., Maeda J., Abratis M., Christie D., Kato Y., Mariet C., Rosner M. (2009) Geochemistry of a long in-situ section of intrusive slow-spread oceanic lithosphere: Results from IODP Site U1309 (Atlantis Massif, 30°N Mid-Atlantic Ridge). Earth and Planetary Science Letters 279: 110–122.

Pearson, D.G., Snyder, G.A., Shirey, S.B., Taylor, L.A., Carlson, R.W., Sobolev, N.V., 1995. Archaean Re–Os age for Siberian eclogites and constraints on Archaean tectonics. Nature 374, 711 – 713.

Polat, A., Frei, R., Appel, P.W.U., Dilek, Y., Fryer, B., Ordóñez-Calderón, J.C., Yang, Z., 2008. The origin and compositions of Mesoarchean oceanic crust: evidence from the 3075 Ma Ivisaartoq greenstone belt, SW Greenland. Lithos 100, 293–321.

Rudnick R (1995) Making continental crust. Nature 378:571–577

Rapp RP, Watson EB (1995) Dehydration melting of metabasalt at 8-32 kbar: implication for continental growth and crust-mantle recycling. J Petrol 36:891–93