CLINOPYROXENE GEOTHERMS FOR THE MANTLE COLUMNS BENEATH KIMBERLITE PIPES FROM SIBERIAN CRATON

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INTRODUCTION

Thermal structure of mantle beneath kimberlite pipes under Siberian craton is not clear in detail. Precision of the garnet thermobarometry used by Griffin and colleagues (1996, 2002) marked general tendencies of mantle construction. Previous thermobarometric study gave smooth geotherm (Boyd et al, 1997). Lack of fresh xenoliths in some pipes restricts the detail PT reconstruction. Orthopyroxene thermobarometry (Brey, Kohler, 1990 – McGregor, 1974) produce the best geotherms (Kopylova et al, 1999) but do not allow PT estimates for eclogites as well as Cr-Cpx thermobarometry (Nimis, Taylor, 2000).

We used pyroxene barometer Jd-Di (Ashchepkov, 2002) especially compiled to produce the geotherm comparable with and Cr-Cpx (Nimis, Taylor, 2000) to determine thermal conditions and mantle structure beneath kimberlite pipes from Siberian craton.

LAYERING IN THE MANTLE

PALEOZOIC STAGE

Udachnaya

Large middle Paleozoic pipes Udachnaya (Pokhilenko, 1977; Boyd et al, 1997), Yubileynaya, Mir (Spetsius, 2001; Roden, Lasko, 1995; Beard et al, 2000) reveal distinct layering but varying compositions (Fig.1). Comparison of the TP estimates based on Opx and Cpx methods allow to reconstruct the structure for the most well studied pipe Udachnaya (Pokhilenko et al., 1991, 2000, Boyd et al., 1997; Kuligin et al., 2000, Malygina, 2002, dissertation) Recalculated using OPx (Brey,

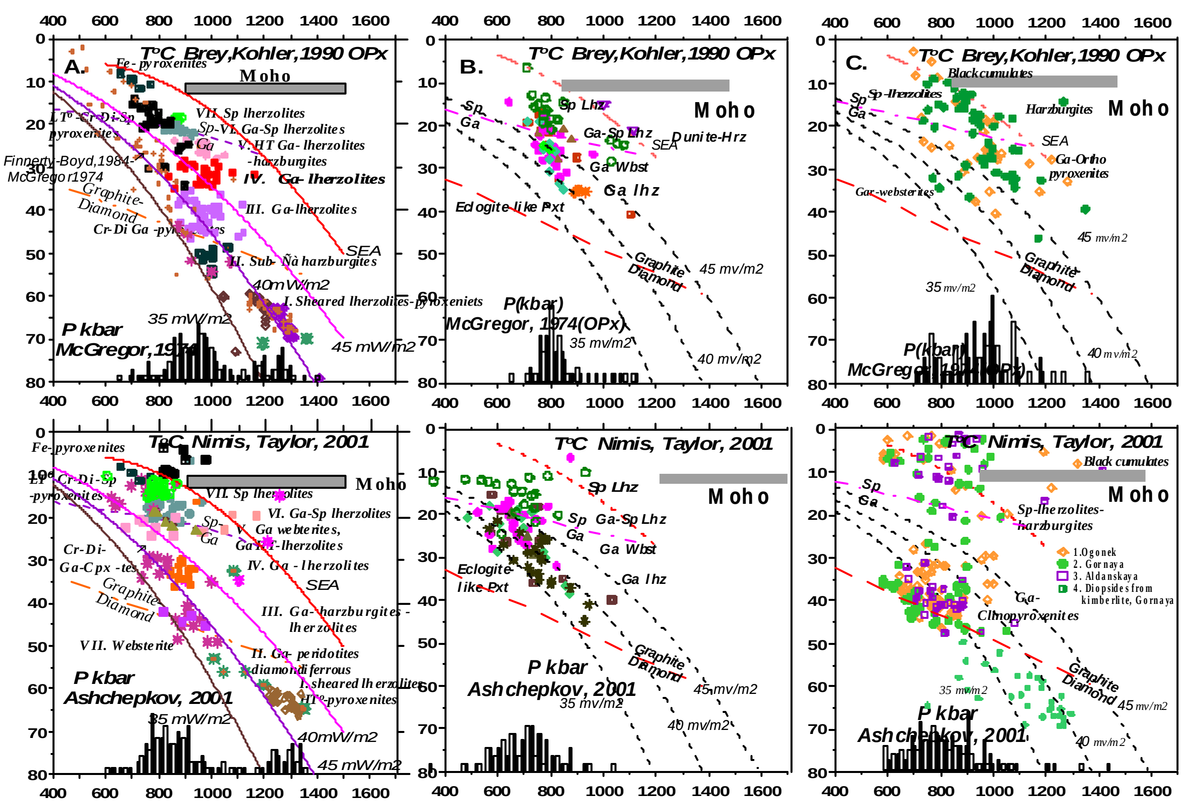

Figure 1: Reconstructed with Opx and Cpx thermobarometry mantle sections beneath: A:.Udachnaya pipe; B. Obnazhennaya pipe; Aldan (Chompolo area) kimberlite pipes.

Kohler, 1990-McGregor, 1974) and Cpx (Nimis, Taylor- Ashchepkov, 2001) thermobarometry all data of xenoliths reveal complex mantle layering (Fig1.A). The HT layer (I) (70-60 kbar) with two PT trends for sheared fine-grained peridotites gives the inflection of geotherm to 40-42mW/m^2. (II) (60-45kbar) – coarse-grained cold (diamondiferous) garnet peridotites– close to 35mW/m^2 conductive geotherm. 'Deep' Ga-lherzolites (III) (45 to 35 kbar) deviates to 38-40 mW/m2 thermal gradients. (IV) (35-27 kbar) common Ga-lherzolites are dispersed from 35 to 50 (average 45) mW/m^2. (V) – hot Ga lherzolites (27-20 kbar) are slightly above conductive geotherm 50mW/m^2 as well as Ga-Sp lherzolites group (VI) (23-20kbar). (VII) Sp-lherzolites are rare. HT-eclogites occur within thermally excited layer (I). Subduction eclogites locate at the bottoms of layers II- III. Ga - Cr-Di websterites occur in deep zones rarely but trace boundaries of Ga- and Ga-Sp lherzolites (20-23kbar), the Ga -Sp transition (~20kbar) and are highly distributed above. Fe- Ga-pyroxenites underlie the Moho boundary. Cr# in spinel, Cr and Ca in garnet demonstrate good correlation with estimated pressure for the saturated compositions. ÄQFM LogFO_2 increases upward gradually (–3 - –0,5) with higher values for porhyroclastic lherzolites and sheared varieties. The heating upper 30kbar are likely correspondent to plume impact in Middle Paleozoic producing the melting, decomposition of garnet, melt migration, creation of pyroxenites in mantle and a dyke swamp at the surface.

Yubilenaya

In mantle section beneath Yubileynaya peridotites and Cr-Di pyroxenites and Amph- Phl metasomatites with Na-Cr rich compositions prevail. Cpx geotherm reveal divide at 35 kbars. Three lherzolitic units below this boundary correspond to 40mv/m^2 geotherm at the upper part and are close to 35 mv/m^2 at the lower part (Fig.2.b). Upper geotherm part is more dispersed irregularly deviating to LT conditions. The inflection to hot 'asthenospheric' branch to 1350^{o}C was found in the 55-65 kbar cold branch is also traced by several points. Sequence upper 35 kbars is represented by Ca-Ti-enriched peridotites- pyroxenites judging from garnet and CPx compositions. The middle horizon is represented by highly alkaline clinopyroxenes associated with abundant phlogopite and amphibole. Lower unites are represented by NaCr - rich CPx (3-4% each) and Ca-Fe enriched garnets. Sub- Ca garnets reveal presence of harzburgites in each three units and relic unmetasomitised lherzolite fragments rare occurring in CPx concentrate. Amphiboles in upper part (< 35 kbar) belonging to pargasites are Ca-rich while in lower part belong to richterite-kataforite groups The Na-Cr content in pyroxene rises with pressure according to both Jd-Di and Cr in Cpx barometry.

Zarnitsa

Sepentinizated peridotites from this pipe restricted PT estimates. Both clinopyroxene and orthopyroxene thermbarometry display three units. Lower horizon beneath 55-60 kbar is heated. (Fig.2.a) Uooer interval to 40kbar is missed and probably is represented by dunite- harzburgites and minor eclogites. The horizon near 40kbar is represented by the moderately depleted in incompatible pyroxene compositions and probably corresponds to the depleted lherzolites. Upper part of the section is traced by several points. Judjing from the garnet composition the construction of Zarnitsa mantle column should be layered and close to those from the nearest pipes (Pokhilenko , Kostrovitsky , unpublished).

Irelyahskaya and Dolgozhdannaya

Closely located to Udachnaya Irelyahskaya and Dolgozhdannaya pipes contain more clinopyroxene-rich layers at the 40-65kbar interval of mantle column and do not carry abundant shallow mantle peridotites. The new variant of Na-Al CPx (Ashchepkov, 2003) barometry display more irregulary heated and more shallow part of the geotherm. (Fig.2.e)

Mir

Combining data from literature (Spetsius, 2001; Beard et al; 2000; Roden, Las'ko, 1995 and unpublished data) general structure of Mir pipe represent the marble eclogite – primitive metasomatic lherzolites layers. For Mir the geotherm is constructed at the shallow depth by eclogites – pyroxenite mixture with lherzolites and Phl-peridotites in the middle part 30-50 kbar mixed with Na-rich pyroxenites as well as in the other pipes and dunite – harzburgites constituting the deeper part of section. The Opx- Garnet-Ilmenite intergrowths correspond to 60kbar while the megacrystalline Ga -Ilm (Cr- bearing assemblages) are close to 40 kbar. (Fig.2.c)

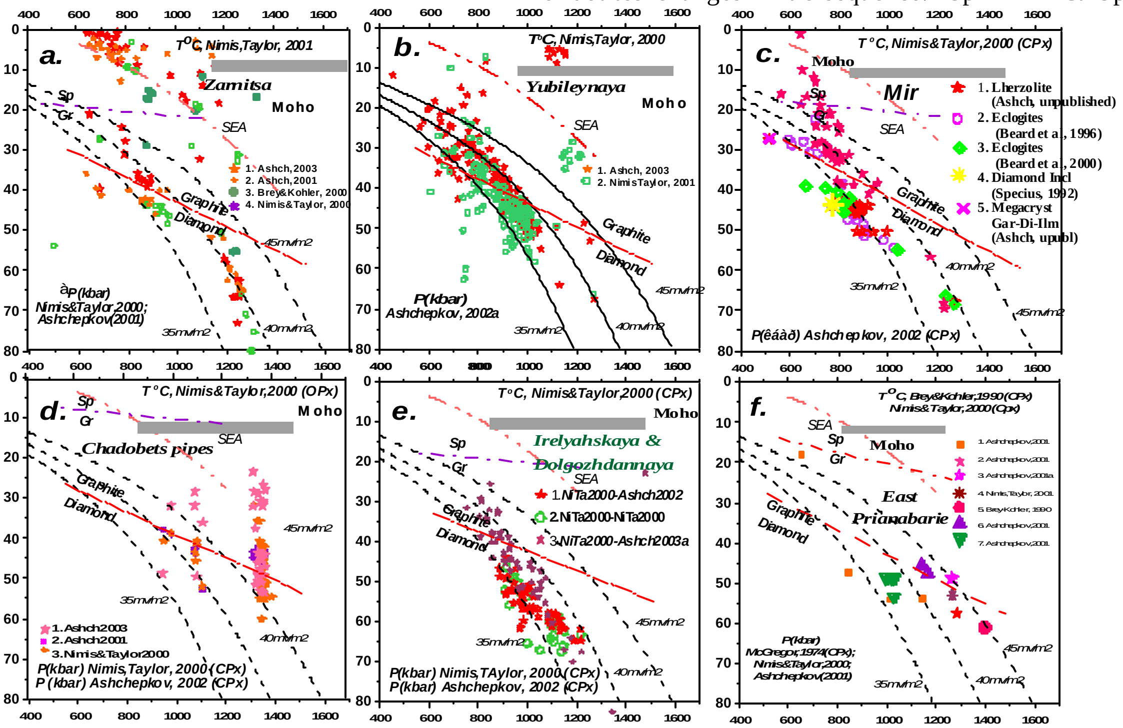

Figure 2: Reconstructed with Opx and Cpx thermobarometry mantle sections between: different pipes from Siberian craton

Summary

Thus general regularities for Paleozoic pipes are: Fe-enriched lherzolite – pyroxenite horizons upper 35 kbar, metasomatic and Cr- diopside anatexic websterites near 40 kbar increasing the degree of depletion with the depth in general to 60kbar. Deformed peridotites (slightly Fe- enriched) associated with hot eclogites (Ga-websterites) typical for 60 -70 kbar interval everywhere..

MESOZOIC STAGE

Mesozoic kimberlite volcanism take place mainly at the peripheral regions pof Siberian platfor, in Prianabarie, Aldan shield (Chompolo area), and Chadobets uprise (Mcrtychan, unpublished) All kimberlite pipes in studied regions have mantle roots starting from 40kbar or tracing diamond – graphite stability line.

Obnazhennaya

Most well studied Obnazhennaya pipe (Ovchinnikov, 1991, dissertation) represent the column without sharp stratification. (Fig.1.b). Amount of pyroxenites and their Na-Al- Cr content increase to the depth. Peridotites changes in the sequence: Sp lhz – Ga-Sp lhz, Ga-Ol webs, Ga- lherzolites. Eclogites trace the low temperature branch the ilmenite bearing Fe-depleted peridotites close hot branch.

Aldan

Post Permian-Jurassic plume pipes in Chompolo field has irregular heated starting from 40 kbar mantle columns. Cold branch is represented by Cr-diopside pyroxenites. In shallow level the geotherm is splitting to SEA type branch and cold branch crossing conductive geotherms. Heating is associated with high Fe-Ti–Al enrichment probably related to the plum melt interaction. Cold branch corresponds to very mg-rich pyroxenes high in Na-Cr (to 4 %). Lower part is constructed from depleted Fe- enriched dunites. (Fig.1.C)

Prianabarie

Mantle peridotites here are highly depleted. All the spinel facie harzburgites are serpentinized probably in mantle. Eclogites and transitional pyroxenites occurs in the 35-40 kbar interval. Lower part is very irregular heated and is represented by coarse grained dunites with the nests of garnets – two pyroxenes correspondent to the depth 60kbar. The Fe - enriched Ilm glimmerites are common in dunites. (Fig.2.f)

Chadobets uprise

Here garnets peridotites were found in newly discovered pipes (Mcrtychan et al, unpublished) In Chadobets upwelling the kimberlites carry pyroxenes from the unusually heated to 1350oC peridotites. (Fig.2.d) The more cold rocks trace the graphite – diamond boundary supposing irregular heating of mantle column. Here the Fe- metasomatism is not found like it is typical for Chompolo field in Aldan.

COMPARISION MINERAL DATA

GARNETS

Comparison with the Cr_2O_3-CaO% diagram (Sobolev, 1977) where the Cr – axe, in general corresponding to the depth, shows very well agreement with the data obtained with the mineral thermobarometry. Amount of the groups for garnets in Yubileinaya, Udachnaya, Zarnitsa and the gaps between the intervals agree well with those on the in PT diagrams. The enrichment in Fe-Ti and trace element components (Griffin et al., 1999) helps to reconstruct the litthology of mantle peridotite layers. The divergence of the CaO content of the garnets with the decreasing pressure - reflect the marble cake – lherzolite – dunite – pyroxenites – eclogite layering becaming more sharp with the depth. The common inflection in the 4% Cr_2O_3 in the Sobolev's diagram reflect the changes in the mantle stratigraphy and presence of the metasomatic anatexic associations. In general this coincides with the depth of dehydration of peridotite in subducted mantle wedges (van Keken et al., 2002).

SPINELS

Spinel groups in general repeat the regularities for the garnets in amount. But the histogram peaks for the Cr-rich varieties is much higher due to the wider occurrence of spinels in dunites. Most Fe-rich and Ti rich associations occurs mainly among Cr- rich varieties and an opposite in the low -Cr ones.

ILMENITES

In all studied pipes amount of ilmenites groups also coincides with the determined amount of the mantle horizons. Ilmenite trends correspond to the fractionation and AFC lines (Moor, 1992; Neal 1995). Thus continuous trends relflect the rising of the protokimberlite (sometimes carbonatite) magma forming the feeding system in the pre- eruption stages. The Cr- rich associations corrsponds to the metasomatic peridotites (Gregory et al, 2002)

SPATIAL REGULIARITIES

The regularities revealed by Griffin et al (1999) with the submerging of the eclogite mantle layers from the NE to the central part of Siberian craton in general found the agreement with the pyroxene thermobarometry but later is more detail. Close located pipes sometimes have varying mantle section possibly due to the inclined or sub- vertical positions of eclogite and other bends. The difference in composition of mantle column in Alakit and Daldyn kimberlite fields corresponds to the variation between the high scale K-Na (LILE, Th, U, Ba) metasomatism (continental crust subduction related) and depleted mantle more restricted Na metasomatism related to oceanic crust subduction (U, Pb, Sr, Na). Sometimes type of metasometism may changes in the mantle column. Lower depleted horizons are subjected to the high scale LILE eriched malt-luid percalation with the chromatographic minimas for the minerals.

Marginal parts of craton are in general more depleted but contain thick anatexic and other pyroxenite layers. Developing in time reveals thinning and heating of the mantle columns (Pokhilenko et al, 2002; O'Reilly et al, 2001; and this paper).

CONCLUSIONS

Pyroxene thermobaromatry agrees very well with the data for the mantle layering obtained by the garnet thermobarometry (Ryan, 1996) poly phase mineral thermobarometry (Brey , Kohler, 1990; Nickel- Green, 1985 etc.) and give the clues for the detail reconstruction even using only concentrate in highly serpentinized pipes. Supported by RFBR grants 99-05-65688, 00-05-65288; 01-05-65170; 02-05-64248; 03-05-64146.

REFERENCES

Ashchepkov, I., Vladykin, N., Ovchinnikov, Yu., Anoshin, G., Gerasimov, P., Saprykin, A. 2000. Thermal Gradient, Mantle Layering and Geochemistry beneath Aldan Shield According to the Kimberlitic Deep Seated Disintegrated Inclusions. J.Confer. Abstr.,.5/2., pp.162-163

Ashchepkov, I.V., 2002. An Empirical Clinopyroxene Thermobarometer for Mantle Rocks Based on the Jadeite-Diopside Exchange. Trans. (Doklady) RAS (ESS), 382.(1), pp.78-82.

Ashchepkov, I.V., Vladykin, N.V., Saprykin, A.I., Khmelnikova, O.S., 2001. Composition and thermal structure of the mantle in peripheral parts of the ancient shields within Siberian craton. Revista Brasileira de Geociencias, 31(4), pp. 527-636

Beard, A.D., Downes, H., Hegner, E., Sablukov, S.M. 2000.Geochemistry and mineralogy of kimberlites from the Arkhangelsk Region, NW Russia: evidence for transitional kimberlite magma types. Lithos. 51 pp. 47–73.

Boyd, F.R., Pokhilenko, N.P., Pearson, D.G., Mertzman, S.A., Sobolev, N.V., Finger, L.W., 1997. Composition of the Siberian cratonic mantle: evidence from Udachnaya peridotites xenoliths. Contrib. Mineral. Petrol., 128, pp.228–246.

Brey, G.P., Kohler, T., 1990 Geothermobarometry in four phase lherzolites II: new thermo-barometers and practical assessment of using thermobarometers. J.Petrol., 31, pp.1353-1378

Gregoire M., Bell, D.R.; Le Roex, A.P. 2002. Trace element geochemistry of phlogopite-rich mafic mantle xenoliths: their classification and their relationship to phlogopite-bearing peridotites and kimberlites revisited Contrib Mineral Petrol. 142(5) pp. 603-625.

Griffin, W.L., Ryan, C.G., Kaminsky, F.V., O'Reilly, S.Y., Natapov, L.M., Win, T.T., Kinny, P.D., Ilupin, I.P. 1999. The Siberian lithosphere traverse: mantle terranes and the assembly of the Siberian Craton. Tectonophysics, 310, pp. 1–35.

Kopylova, M.G., Russell, J.K., Cookenboo H. 1999. Petrology of peridotite and pyroxenite xenoliths from the Jericho kimberlite: Implications for the thermal state of the mantle beneath the Slave craton, northern Canada. J. Petrol. 40(1). pp. 79-104.

Kuligin, S.S., Pokhilenko, N.P. 1998 Mineralogy of xenoliths of garnet pyroxenites from kimberlite pipes of Siberian platform. Extended Abstracts 7IKC. Cape Town. pp.480- 482.

MacGregor, I.D. 1974. The system MgO–Al2O3–SiO2: solubility of Al2O3 in enstatite for spinel and garnet–spinel compositions. Am. Mineral. 59:110–19.

Moor, R.O., Griffin, W.L. Gurney et al. 1992 Trace element geochemistry of ilmenites megacrysts from the Monastery kimberlite, South Africa. Lithos. 29, pp.1-18.

Nimis, P., Taylor, W. 2000. Single clinopyroxene thermobarometry for garnet peridotites. Part I. Calibration and testing of a Cr-in-Cpx barometer and an enstatite-in-Cpx thermometer. Contrib. Mineral. Petrol. 139(5), pp. 541-554.

Nixon, P.H., Boyd, F.R. 1973. Petrogenesis of the granular and sheared ultrabasic nodule suite in kimberlite. / Ed.: Nixon, P.H. Lesotho Kimberlites. Cape and Transvaal, Cape Town. pp. 48–56.

O'Reilly, S.Y., Griffin, W.L., Djomani, P., Y.H., Morgan, P. 2001 Are Lithosphere Forever Track-ing Changes in Subcontinental Lithospheric Mantle Through Time. GSA Today 11/4: 4-9.

Pearson, D.G. 1999. The age of continental roots. Lithos .48:171–194.

Pokh1lenko, N. P., Sobolev, N.V., Kuligin, S. S., Shimizu, N. 2000. Peculiarities of distribution of pyroxenite paragenesis garnets in Yakutian kimberlites and some aspects of the evolution of the Siberian craton lithospheric mantle. Proceedings of the VII International Kimberlite Conference. The P.H. Nixon volume. Pp. 690-707.

Pokhilenko, N.P., Pearson, D.G., Boyd, F.R., Sobolev N.V.1991. Megacrystalline dunites: sources of Siberian diamonds. Carnegie Inst. Wash. Yearb. 90: 11-18

Roden, M.F., Laz'ko, E.E., Ponomarenko A.I., Serenko V.P.Mineralogy of peridotite xenoliths from the Mir kimberlite, Yakutia, Russia . 5 IKC Axetended Abstracts. Novosibirsk, 1995. pp. 462-464

Ryan, C.G., Griffin, W.L., Pearson, N.J., 1996. Garnet geotherms: Pressure-temperature data from Cr-pyrope garnet xenocrysts in volcanic rocks. J. Geophys. Res. 101, pp. 5611-5625.

Spetsius, Z.V. 2002. A xenolith of high-temperature diamondiferous peridotites from the Udachnaya kimberlite pipe. Dokl (Transact) RAN (ESS). v.379 pp. 550-552.

van Keken, P. E. , Kiefer, B., Peacock, S.M. 2002. High-resolution models of subduction zones: Implications for mineral dehydration reactions and the transport of water into the deep mantle. Geochemistry, Geophysics, Geochemistry v. 3, N 10

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