

KIMBERLITES OF THE NAKYN FIELD, SIBERIA, AND THE SNAP LAKE/KING LAKE DYKE SYSTEM, SLAVE CRATON, CANADA: A NEW VARIETY OF KIMBERLITE WITH A PROPOSED ULTRADEEP ORIGIN

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INTRODUCTION

Diamondiferous kimberlites of Siberia's Nakyn Field (NF), specifically the Nyurbinskaya and Botuobinskaya pipes, and those of the Snap Lake/King Lake (SL/KL) kimberlite dyke system, Slave Craton, Canada, are important geological discoveries of the late 20th century. The rocks from both localities have specific mineralogical, geochemical and petrological features separating them from known kimberlites, as well as features linking them to those of Groups I & II kimberlites. Data from ongoing studies of the NF and SL/KL kimberlites indicates a proposed ultradeep source of these kimberlites compared to other known kimberlites. These rocks provide a unique opportunity to obtain new information on the mantle structure, composition and magma generation process.

METHODS AND RESULTS

Major element compositions of the diamond inclusions and diamond indicator minerals have been analyzed using CAMEBAX-Micro, Cameca, electron microprobe at the Analytical Center of the UIGGM SB RAS, Novosibirsk, Russia. Sr and Nd isotope compositions of the kimberlites were measured at the Division of Earth and Planetary Science, Graduate School of Science, Hokkaido University, Japan using a Finnigan MAT 262 mass spectrometer equipped with seven collectors and operating in static mode (Orihashi *et al.* 1998). Trace elements were determined by ICPMS at Niigata University, Japan, using state-of-the-art procedures as described in Eggins *et al.* (1997). A multi-elemental internal standard was added to each sample, which allowed the monitoring and correction of the complex mass-dependent variation in instrument sensitivity.

The results of ongoing mineralogical and geochemical studies of NF and SL/KL rocks are briefly summarized here, and their important characteristic features provided. Features common to the Nakyn and SL/KL

kimberlites include: 1) their micaceous character and relatively low K₂O/TiO₂ ratios (Fig.1); 2) a wide range of CaO contents (*e.g.* 0.6-26.5 wt.% for SL/KL kimberlites) related to wide variations of carbonatite component; 3) very trace amounts of magnesian ilmenite and perovskite; 4) low total content of diamond indicator minerals (Cr-pyropes and chromites) (*e.g.* < 0.5 kg/tonne); 5) a very wide range of Cr₂O₃ content in pyropes (up to 17 wt.% for SL/KL and up to 15 wt.% for Nakyn kimberlites) Pokhilenko *et al.* (2000); 6) an abnormally high proportion of high-Cr (> 62 wt.% Cr₂O₃)- low Ti (< 0.7 wt.% TiO₂) chromites (up to 27 and 42 % respectively); 7) a high diamond grade with a high proportion of octahedral and coated diamonds; 8) undifferentiated composition of Nd isotopes that have a nearly chondritic value at the time of kimberlite emplacement (Fig. 2).

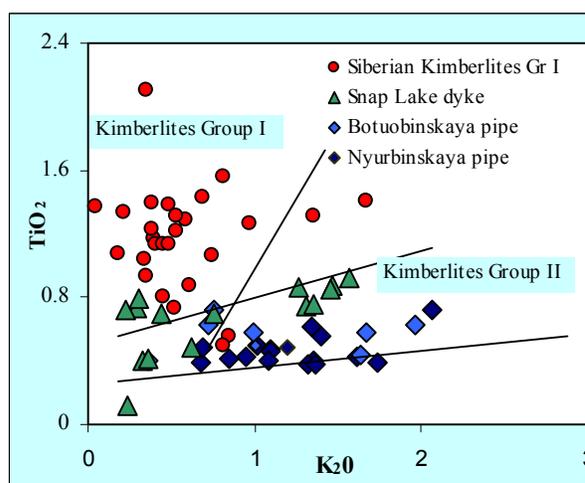


Figure 1. TiO₂- K₂O relationship in the NF and SL/KL kimberlites in comparison with the Siberian Group I and South African Groups I&II kimberlites. The fields of Groups I&II kimberlites are after Smith *et al.* (1985).

Geochemical features similar to those of Group I kimberlites for NF kimberlites include: 1) low La/Nb ratio (0.58), and 2) Nd isotope compositions (Fig. 2). For SL/KL kimberlites they include: 1) trace element

distribution pattern; 2) Sr and Nd isotope compositions; and 3) Nb/Zr (>1) and La/Nb ratios (<1).

Geochemical features similar to those of Group II kimberlites for NF kimberlites are: 1) the pattern of trace element distribution (Fig.3), and 2) Nb/Zr (~0.4) and TiO₂/K₂O (~0.43) ratios (Fig.1). For the SL/KL kimberlites they include: 1) TiO₂/K₂O ratios (0.37-2.6) (Fig. 1), and 2) Ba, Th and LREE abundances (Fig. 3).

Geochemical features intermediate between those of Group I and II kimberlites for NF kimberlites include Ba/Nb (0.95) and Ni/MgO (45.2) ratios. For the SL/KL kimberlites they include: 1) distribution of the most incompatible elements (Pb, Rb, La, Ce) (Fig. 3), and 2) some TiO₂/K₂O ratios.

The distinctive feature separating the NF and SL/KL kimberlites is the incompatible element concentration. NF rocks contain less of them than any known kimberlites (Agashev *et al.*, 2001), whereas the SL/KL dyke system rocks are enriched in these elements (Fig. 3), more than kimberlites of Group I and comparable to kimberlites of Group II.

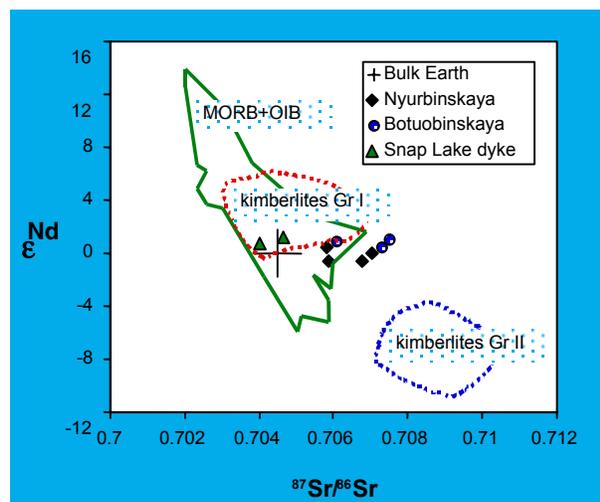


Figure 2. Sr and Nd isotope composition of NF (Nyurbinskaya and Botuobinskaya pipes) and SL kimberlites calculated back to the time of emplacement- t . The fields of MORB and OIB (Hofmann, 1997) and groups I&II kimberlites (Smith *et al.*, 1983) are shown. $t = 364$ Ma for NF and 535 Ma for SL/KL kimberlites.

DISCUSSION

The existence of very thick lithosphere beneath the SL/KL area at emplacement age, is supported by the presence of majorite-bearing (up to 17 mol %) high-Mg, high-Cr subcalcic pyropes as SL/KL diamond inclusions (Pokhilenko *et al.*, 2001). These majorite-bearing pyropes are most probably related to depleted, ultramafic rocks (harzburgites) of the lithospheric

mantle (Pokhilenko *et al.*, this volume). Although, the data on the inclusions in diamonds is not yet available for the NF kimberlites, the similarity of the composition of the diamond indicator minerals between the NF and SL/KL rocks suggests similarity in depth and composition of the lithospheric mantle sampled by these kimberlites.

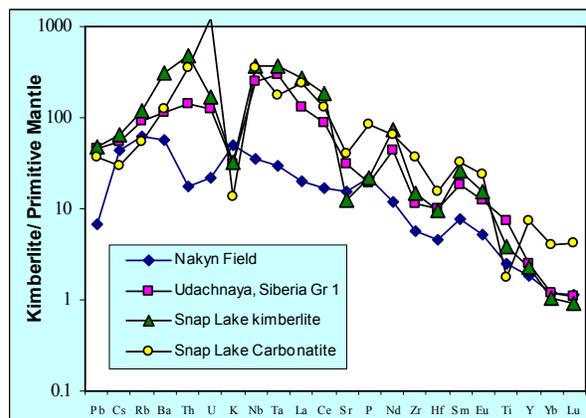


Figure 3. Primitive mantle normalized trace elements patterns of NF kimberlites and SL/KL dyke kimberlites and carbonatites. Composition of Udachnaya kimberlites is from Agashev (2002a). Primitive mantle composition used for normalization is from McDonough and Sun (1995).

The geochemical signatures of rocks from both localities provides additional evidence for deep source regions. In the NF kimberlites, this deep source can be traced from the inter-element ratios. The calculation of partial melting in terms of Sm/Nd and Lu/Hf ratios indicates NF kimberlites can be generated by 0.5% partial melting of a source with primitive mantle composition (Agashev, 2002a), whereas all other kimberlites require significantly incompatible-element enriched source compositions. Another important feature of NF kimberlites is their superchondritic Nb/Ta ratios (21-24). These ratios can be inherited from the “missing reservoir” of Barth *et al.* (2000), which is located at the core-mantle boundary (Rudnick *et al.*, 2000) and carried upwards to the lithospheric roots by mantle plume (Agashev *et al.*, 2002b).

The chemical composition of SL/KL rocks ranges from magnesiocarbonatites (with SiO₂ contents of ~3 wt%), to carbonatitic kimberlites, through to typical kimberlites. The composition of carbonatites and kimberlites is in excellent agreement with that of melts obtained in carbonated lherzolite melting experiments that were done at 6 Gpa (Dalton and Presnall, 1998). Distribution characteristics of HREE, Y, Zr and Rb, K, Ba between the SL/KL carbonatites and kimberlites suggests that they were produced by primary partial melting of slightly carbonated depleted lherzolites. This melting process occurred at depths exceeding 300 km,

as indicated by the composition of majorite garnet inclusions in SL/KL diamonds. At a partial melting level of about 0.3-0.6% the liquid was mainly magnesio-carbonatitic, and at levels of 1% and more the liquid was kimberlitic in composition. In the SL/KL rocks the superchondritic Nb/Ta ratios can be explained by fractionation during partial melting in the mantle.

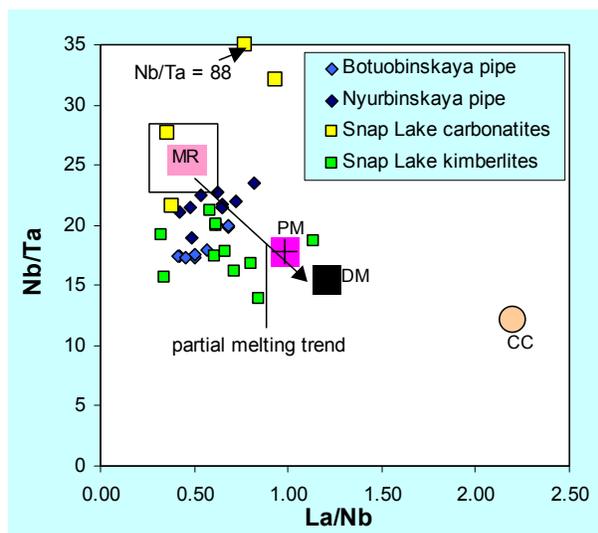


Figure 4. La/Nb vs. Nb/Ta ratio diagram for Nakyn field kimberlites and for Snap Lake dyke (Canada) rocks. PM (Primitive mantle), DM (Depleted mantle) and CC (Continental crust) compositions are shown for comparison. MR is "Missing Reservoir" after Barth *et al.* (2000). Partial melting trend is shown by line with the arrow.

Both the Nb/Ta ratios and the Zr/Hf ratios are significantly superchondritic in carbonatites and display a negative correlation with SiO₂ contents. The Nb/Ta ratio in carbonatites ranges from slightly superchondritic (Nb/Ta=22 and SiO₂=17 wt%) to superchondritic (Nb/Ta=81 and SiO₂=3.7 wt%), whereas Nb/Ta ratio in kimberlites scatters around the chondritic value of 18.

CONCLUSIONS

The geochemical and mineralogical features of both the Nakyn kimberlites and the SL/KL kimberlite-carbonatite association require a specific source located at depths of ~300 km within the lithospheric mantle, much deeper than source depths postulated for known Siberian and South African kimberlites. These results indicate that the Nakyn and SL/KL kimberlite suites were sourced in, and sampled en-route, similar deep-seated levels of lithospheric mantle as shown by their diamond indicator minerals. However, geochemical data indicate that the source of the SL/KL kimberlites was pre-enriched in incompatible elements directly before the kimberlite formation. For NF rocks, this pre-enrichment stage was missed.

REFERENCES

- Agashev A.M., Watanabe T., Budaev D.A., Pokhilenko N.P., Fomin A.S., Maehara K., and Maeda J., 2001. Geochemistry of Nakyn field kimberlites Siberia: evidence for a unique source composition. *Geology*. 3, 267-270.
- Agashev A.M., 2002a. Rb-Sr and Sm-Nd isotope systematic and trace elements geochemistry of Siberian kimberlites. Ph.D. Thesis, Hokkaido Univ. Sapporo, Japan.
- Agashev A.M., Pokhilenko N.P., Takazawa E., Watanabe T., McDonald J.A., Sobolev N.V., Vavilov M.A., and Fomin A.S., 2002b. Do superchondritic Nb/Ta ratios in kimberlites tell the lower mantle plume signature? Extended Abstract on the 2nd International Superplume Workshop, Tokyo, Japan.
- Barth M.G., McDonough W.F. and Rudnick R.L., 2000. Tracing the budget of Nb and Ta in the continental crust. *Chem. Geology*. 165, 197-213.
- Dalton J.A. and Presnall D.C., 1998. The continuum of primary Carbonatitic-kimberlitic melt compositions in equilibrium with lherzolite: Data from the system CaO-MgO-Al₂O₃-SiO₂-CO₂ at 6GPa. *J. of Petrology*. 39, 1953-1964.
- Hofmann, A.W., 1997. Mantle geochemistry: the message from oceanic volcanism: *Nature*, v. 385, p. 219-229.
- Eggins, S.M., Woodhead, J.D., Kinsley, L.P.J., Mortimer, G.E., Sylvester, P., McCulloch, M.T., Hergt, J.M. and Handler, M.R., 1997. A simple method for the precise determination of ≥ 40 trace elements in geological samples by ICPMS using enriched isotope internal standardisation: *Chemical Geology*. 134, 311-326.
- McDonough, W.F., and Sun, S.-s., 1995. The composition of the Earth: *Chemical Geology*. 120, 223-253.
- Pokhilenko N.P., Sobolev N.V., Cherny S.D., Mitukhin S.I. and Yanygin Yu.T., 2000. Pyropes and Cromites from Nakyn field (Yakytia) and Snap Lake region (Canada) kimberlites: Evidences for anomalous lithosphere compositions. Reports of RAS. 372, 356-360
- Pokhilenko N.P., McDonald J.A., Hall A.E., and Sobolev N.V., 2001. Abnormally thick Cambrian lithosphere of the Southeast Slave Craton: evidence from crystalline inclusions in diamonds and pyrope compositions in Snap lake kimberlites. Extended Abstracts volume of the Slave-Kaapvaal Workshop "A tale of two cratons". Merrickville, Ontario, Canada, Non-paginated.
- Pokhilenko N.P., McDonald J.A., Sobolev N.V., Reutsky V.N., Hall A.E., Logvinova A.M., Reimers L.F., 2003. Crystalline inclusions and C isotope ratios in diamonds from the Snap Lake/King Lake kimberlite dyke system: evidence for ultradeep and enriched lithospheric mantle. This volume.
- Orihashi, Y., Maeda, J., Tanaka, R., and Zeniya, R., 1998. Application test of Sr and Nd isotopic standards for seven GSJ rocks reference samples; JA-1, JB-1a, JB-2, JB-3, Jgb-1, JG-1a and JR-1: *Geochemical Journal*. 32, 205-211.
- Rudnick R.L., Barth M., Horn I and McDonough W.F., 2000. Rutile-bearing refractory eclogites: Missing link between continents and depleted mantle. *Science*. 287, 278-281.
- Smith, C.B., 1983. Pb, Sr and Nd isotopic evidence for

sources of southern African Cretaceous kimberlites:
Nature. 304, 51-54.

Smith, C.B., Gurney, J.J., Skinner, E.M.W., Clement, C.R.,
and Ebrachim, N., 1985. Geochemical character of
southern African kimberlites: A new approach based
on isotopic constraints: Transactions Geological
Society South Africa. 88, 267-280.

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