

## Sr and Nd Isotopic Compositions of Kimberlites and Associated Rocks of the Siberian Craton

A. V. Lapin<sup>a</sup>, A. V. Tolstov<sup>b</sup>, and A. V. Antonov<sup>c</sup>

Presented by L.N. Kogarko June 1, 2006

Received June 1, 2006

DOI: 10.1134/S1028334X07040150

Recent revision of the classification of kimberlite rocks and associated rocks made it possible to propose a modern classification that includes two natural formation series (hereafter, series) with different features. The first series includes traditional rock associations of platform alkali ultramafic magmatism: diamondiferous kimberlites, picrite–alnoite rocks associated with rare-metal carbonatite complexes (alpicrites), and a large group of alkali picrites (kimpicrites) that occupy an intermediate position between the two series and lack any distinct metallogenic specifics. The second series includes diamondiferous olivine lamproites, orangeites, and majhgawanites [1].

In the proposed classification, the term “kimberlite” (sensu stricto) refers to rocks with diamond and minerals of the diamond assemblage. Based on this classification, diamondiferous kimberlites are combined with nondiamondiferous and weakly diamondiferous kimpicrites, as well as alpicrites associated with rare-metal carbonatite complexes, in a single natural series, as opposed to the diamondiferous rocks of another series (olivine lamproites–majhgawanites).

However, we have only limited geochemical and isotope data on rocks of these series, except for the kimberlites and lamproites, which hampers interpretation of genetic relations both within series and between rocks of different series. In particular, data on the Sr and Nd isotopic compositions of kimpicrites and alpicrites are nearly absent. Given this fact, we report new Sr and Nd isotope data on the classical alpicrite occurrences of the Siberian Craton, which include phlogopite

picrite dikes of the Arbarastakh carbonatite massif (Aldan Shield), as well as dikes and pipes of alnoites and picrites of the Chadobets Complex (southwestern Siberian Craton) and the Tomtor Massif or Udzha Uplift (table). For the sake of comparison, the table also presents original Sr and Nd isotope data on kimberlites from the Yubileynaya, Aikhal, Udachnaya, Komsomol'skaya, Mir, Internatsional'naya, Botuoba, and Nyurba pipes. Isotope diagrams plotted on this basis were supplemented with literature data [2, 3]. In the diagrams, kimpicrites are represented by recent data on typical occurrences of these rocks in the northern Siberian Craton (eastern Anabar Shield) [3].

The Rb–Sr and Sm–Nd measurements were conducted by the isotope dilution method at the Center of Isotope Research, Karpinskii All-Russia Research Institute of Geology. The Sr and Nd isotopic compositions of alpicrites, kimpicrites, and kimberlites of the Siberian Craton are shown in the  $^{87}\text{Sr}/^{86}\text{Sr}-\epsilon_{\text{Nd}}$  diagram (figure). Analysis of the data presented in the table and figure suggests the following conclusions.

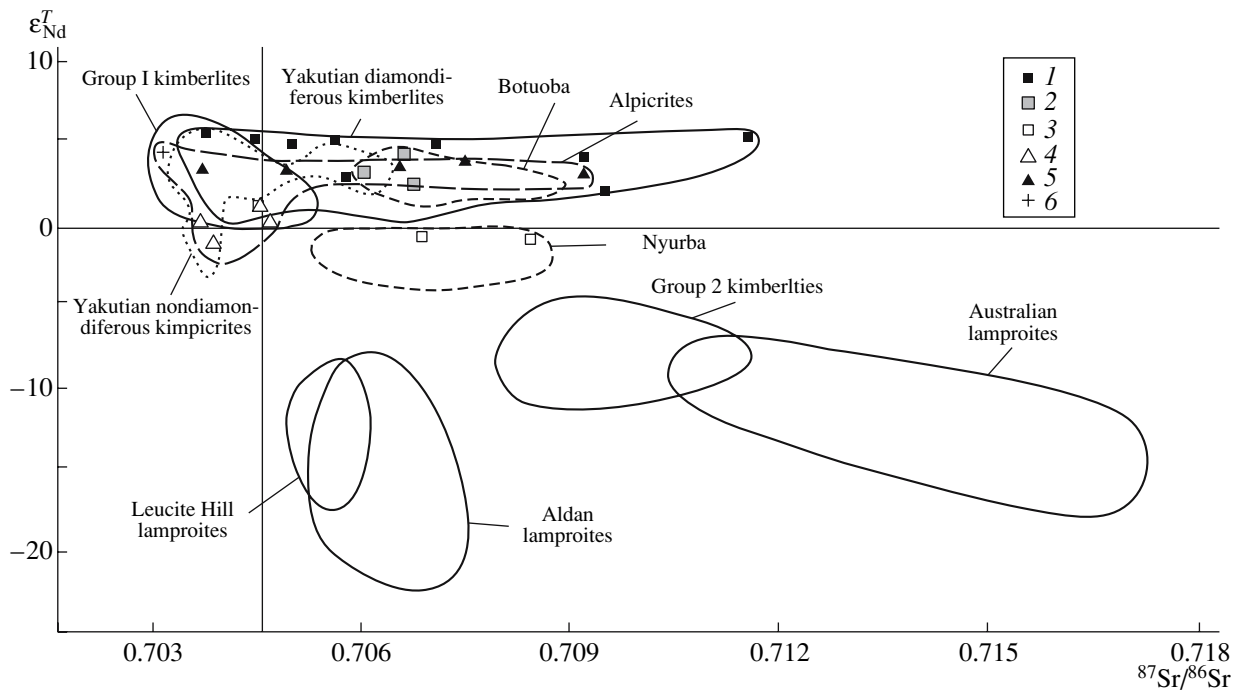
All the rocks of the kimberlite–alpicrite series are significantly overlapped with Group 1 kimberlites, which are mainly plotted in quadrant II of the diagram. Hence, at least some of these rocks were derived from the weakly depleted sublithospheric mantle. At the same time, unlike Group 1 kimberlites, the Sr and Nd isotope ratios in all groups form fairly large fields extending from quadrant II to quadrant I with higher  $^{87}\text{Sr}/^{86}\text{Sr}$  values at comparatively constant positive  $\epsilon_{\text{Nd}}$  values. Similar variations in isotope ratios are unusual and deserve special attention.

All rocks of the kimberlite–kimpicrite–alpicrite metallogenic series of the Siberian Craton have similar Sr and Nd isotope characteristics, which is expressed in significant overlapping of fields of these rocks up to the point of their complete coincidence in the  $^{87}\text{Sr}/^{86}\text{Sr}-\epsilon_{\text{Nd}}$  diagram. This fact indicates the principle similarity of not only their mantle sources (the weakly depleted sublithospheric mantle is among such sources), but also

<sup>a</sup> Institute of Mineralogy, Geochemistry, and Crystal Chemistry of Rare Elements, ul. Veresaeva 15, Moscow, 121327 Russia; e-mail: lapin@imgre.ru

<sup>b</sup> Botuoba Geoexploration Expedition, ALROSA Joint-Stock Company, ul. Lenina 44b, Mirnyi, Yakutia, 678170 Russia

<sup>c</sup> Center of Isotopic Research, Karpinskii All-Russia Research Institute of Geology, Srednii pr. 74, St. Petersburg, 199106 Russia



Sr and Nd isotopic compositions of kimberlites, kimpicrites, and alpicrites of the Siberian Craton. The fields of isotopic compositions of kimberlites of the Botuoba and Nyurba pipes are outlined separately. The contours of the fields of kimberlites and kimpicrites were drawn using original (table) and published data [2, 3]. The fields of Group I and Group 2 kimberlites, as well as lamproites of Australia, the United States, and Aldan, are plotted according to data from [4–7]. (1) Kimberlites in traditional diamondiferous areas of Yakutia; (2, 3) kimberlites of the Botuoba and Nyurba pipes, respectively; (4–6) alpicrites of the Tomtor Massif, Chadobets Uplift, and Arbarastakh Massif, respectively.

processes that defined variations in the isotope parameters of these rocks.

The obtained results and previously noted similarity in isotopic compositions of the kimberlites and carbonatites confirm the possible genetic difference between two series of deep-seated alkali ultramafic rocks. The first series includes the traditional platformal rock associations (kimberlites, alpicrites, carbonatites, and intermediate kimpicrites) described above. Data points of rocks of the second series (olivine lamproites, orangeites, and majhgawanites) make up a cluster separated from the field of the kimberlite–carbonatite series in the  $^{87}\text{Sr}/^{86}\text{Sr}$ – $\epsilon_{\text{Nd}}$  diagram (figure). The isotopic parameters of the field of rocks of the second series suggest their derivation from both the primitive substrate and EM1- and EM2-type sources.

Significant variations in Sr isotope ratios of kimberlites, kimpicrites, and alpicrites of the Siberian Craton are expressed in the distinct extension of the Sr and Nd isotope fields along the  $^{87}\text{Sr}/^{86}\text{Sr}$  axis, passing from negative to positive  $\epsilon_{\text{Sr}}$  values at the relatively stable parameter  $\epsilon_{\text{Nd}}$ . This could result from isotope mixing of different sources, e.g., the depleted sublithospheric mantle and the lithospheric EM2 source with upper crustal isotopic parameters. This assumption is supported by the correlation of the chemical composition

of kimberlites with the composition of host rocks in many provinces [8].

In particular, kimberlites of the Central Yakutian subprovince contain abundant carbonate xenoliths. Therefore, their chemical composition is distinguished from that of kimberlites of other provinces by higher concentrations of CaO and  $\text{CO}_2$  and lower contents of silicate components (primarily,  $\text{SiO}_2$  and MgO). Host rocks in the Arkhangelsk province are dominated by weakly metamorphosed clayey–quartzose sedimentary rocks. Correspondingly, the kimberlites of this province are enriched in  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ , which derived from the host rocks, and depleted in carbonates. The kimberlites of the Arkhangelsk province are characterized by specific secondary alterations, which are expressed in saponitization instead of the traditional serpentinization and carbonatization. This fact testifies that exchange between kimberlites and xenogenic material of the host rocks occurred presumably at the postmagmatic stage.

These features of kimberlites convincingly argue for the introduction of different portions of Sr from host rocks of the continental crust. This is also consistent with the fact that the isotope composition of South African kimberlites (Group I), which are generally less contaminated by xenogenic material and less subjected to crustal contamination, occupies a relatively compact

Sr and Nd isotopic compositions of kimberlites and alpicrites of the Siberian Craton

Rock	Pipe, area	Age	[Sm]	[Nd]	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	$\epsilon_{\text{Nd}}$	[Rb]	[Sr]	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	$(^{87}\text{Sr}/^{86}\text{Sr})_t$
			ppm					ppm				
Picrite	Chadobets	240	32.83	174.80	0.1136	0.51269	3.56	33.85	1003	0.0975	0.704024	0.703691
Alnoite	The same	240	25.91	156.80	0.0999	0.512671	3.61	87.61	1567	0.1616	0.707089	0.706537
The same	"	240	12.89	67.68	0.1152	0.512677	3.26	99.04	1293	0.2214	0.709975	0.709219
Picrite	"	240	27.25	153.30	0.1074	0.512673	3.42	55.29	655.4	0.2438	0.705714	0.704882
The same	"	240	15.37	89.19	0.1042	0.512691	3.87	67.88	967.7	0.2027	0.708183	0.707491
"	Tomtor	400	29.31	163.30	0.1085	0.512349	-1.13	94.29	2048	0.133	0.704629	0.703871
Alnoite	The same	400	13.34	77.28	0.1044	0.512411	0.29	88.55	2717	0.0942	0.705216	0.704679
Picrite	"	400	17.96	117	0.0928	0.512378	0.24	99.52	4707	0.0611	0.703966	0.703618
Alnoite	"	400	27.35	162.2	0.1019	0.512454	1.26	70.9	4244	0.0483	0.704803	0.704528
Picrite	Arbarastakh	630	43.09	191.9	0.1357	0.512605	4.28	39.57	2198	0.052	0.703593	0.703126
Kimberlite	Yubileinaya	360	4.457	33.43	0.0806	0.512627	5.13	8.034	82.89	0.2801	0.712984	0.711548
The same	Aikhail	360	5.418	33.99	0.0964	0.512544	2.78	45.13	835.4	0.1561	0.70657	0.705770
"	Internatsional'naya	360	9.872	68.38	0.0873	0.512664	5.54	12.52	688.4	0.0526	0.704033	0.703763
"	The same	360	6.554	46.46	0.0853	0.51262	4.78	37.67	1918	0.0568	0.707318	0.707027
"	Mir	360	4.959	33.89	0.0885	0.512645	5.12	17.57	400.8	0.1267	0.705099	0.704450
"	The same	360	5.38	36.98	0.0879	0.512626	4.77	16.17	284.5	0.1642	0.705817	0.704975
"	Udachnaya	360	6.60	50.17	0.0795	0.512466	2.04	41.01	585.6	0.2024	0.71052	0.709483
"	The same	360	4.26	29.53	0.0871	0.512581	3.93	21.13	437.6	0.1396	0.709881	0.709166
"	Komsomol'skaya	358	3.907	28.38	0.0832	0.512635	5.14	18.23	350.3	0.1505	0.706362	0.705595
"	Nyurba	364	2.593	12.63	0.1241	0.512421	-0.86	14.41	98.48	0.4229	0.70905	0.706858
"	The same	364	2.351	12.18	0.1167	0.5124	-0.92	12.34	353.2	0.101	0.708951	0.708428
"	Botuoba	364	4.62	21.39	0.1306	0.512698	4.25	37.08	621.2	0.1725	0.707487	0.706593
"	The same	364	3.768	17.97	0.1267	0.512593	2.38	33.89	417.1	0.2348	0.707955	0.706738
"	"	364	3.437	16.31	0.1274	0.512636	3.19	43.6	347.2	0.3629	0.707912	0.706031

Note: Rb, Sr, Sm, and Nd isotopic compositions were analyzed on a nine-collector Triton mass spectrometer in a static regime. Sr isotope fractionation was corrected by normalizing measured values to  $^{88}\text{Sr}/^{86}\text{Sr} = 8.37521$  and the normalized values were adjusted to  $^{88}\text{Sr}/^{86}\text{Sr} = 0.71025$  in the international NBS-987 standard. Nd isotope fractionation was corrected by normalizing to the  $^{148}\text{Nd}/^{144}\text{Nd} = 0.241578$  and given relative to  $^{143}\text{Nd}/^{144}\text{Nd} = 0.511860$  in the international La Jolla isotope standard.

field (figure) with no trend subparallel to the  $^{87}\text{Sr}/^{86}\text{Sr}$  axis. This field corresponds to isotope characteristics of the depleted asthenospheric mantle.

This interpretation of Sr and Nd isotopic compositions in kimberlites is apparently consistent with their contamination with the crustal material. However, calculations show that this model cannot explain the Sr isotope variations in kimberlites [2].

Alternatively, the Sr and Nd isotope variations in kimberlites can be explained by heterogeneous mantle sources, which were formed by inflow of deep-seated material with high Rb/Sr and low Sm/N ratios. According to Zindler et al. [9], the partial melting of the isotopically heterogeneous mantle could produce liquids with variable  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios owing to the variable contents of deep-seated enriched material in the source.

A more likely explanation is that both these factors—isotope mixing during crustal contamination of kimberlites and isotope heterogeneity of the mantle caused by irregular inflow of enriched material during repeated processes of deep-seated metasomatism—participated in the formation of the isotopic composition of kimberlites.

We have obtained new data that allow us to compare the Sr and Nd isotopic compositions of geochemically anomalous kimberlites in the recently discovered Nakyn field with the respective isotopic compositions of rocks from traditional diamondiferous areas in Yakutia. The data points of rocks of the Botuoba Pipe located in the main field of diamondiferous kimberlites of Yakutia are slightly shifted toward the higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios. The Nyurba kimberlite field is additionally shifted along the  $\epsilon_{\text{Nd}}$  axis toward negative values. It should be noted that such a shift is typical of geochemically anomalous kimberlites of the Zolotitsa field of the Arkhangelsk province and kimberlites of the Slave province in Canada. These facts probably support the assumption that the geochemically anomalous kimberlites are related to the deepest sources located in the transitional mantle zone (more than 300 km deep) in the segments with a greater thickness of the lithosphere [10].

The similarity in Sr and Nd isotope characteristics of kimberlites, kimpicrites, and alpicrites of the Siberian Craton emphasizes the genetic relation of these formation-minerogenic types of magmatic rocks and

the principle similarity of their mantle sources. Correspondingly, specific features of the rocks described above confirm their affiliation to a common natural series [1]. This conclusion does not contradict other concepts, according to which the formation-metallogenic diversity of magmatic rocks could primarily be related to different depths of magma generation. The depth discrepancy provoked systematic changes in protolith composition and different degrees of the permeability of sublithospheric blocks for deep-seated solutions and melts. The latter parameter, in turn, is correlated with heat flow and the geothermal gradient [11]. Processes discussed above were responsible for differences in the degree of partial melting of the mantle; the composition, volume, and energetic resource of magmatic melts; and the mode of their subsequent evolution in the course of ascent to the surface.

## REFERENCES

1. A. V. Lapin, A. V. Tolstov, and D. V. Lisitsyn, *Kimberlites and Related Rocks* (IMGRE, Moscow, 2004) [in Russian].
2. A. M. Agashev, Y. Orihashi, T. Watanabe, et al., *Geol. Geofiz.* **41**, 90 (2000).
3. T. Morikiyo, S. I. Kostrovitsky, M. K. Weerakoons, et al., *Proceedings of 8th Int. Kimberl. Conf. Ottawa, Canada, 2003* (Ottawa, 2003).
4. C. B. Smith, *Nature* **304**, 51 (1983).
5. R. H. Mitchell and S. C. Bergman, *Petrology of Lamproites* (Plenum, New York, 1991).
6. R. H. Mitchell, C. B. Smith, and N. V. Vladykin, *Lithos* **32**, 243 (1994).
7. K. J. Fraser, C. J. Hawkesworth, A. J. Erlank, et al., *Earth Planet. Sci. Lett.* **76**, 57 (1995).
8. A. D. Khar'kiv, V. V. Zuenko, N. N. Zinchuk, et al., *Petrochemistry of Kimberlites* (Moscow, 1991) [in Russian].
9. A. Zindler, S. R. Hart, F. A. Frey, and S. P. Jacobsson, *Earth. Planet. Sci. Lett.* **45**, 249 (1979).
10. N. P. Pokhilenko, A. M. Agashev, M. A. Vavilov, and N. V. Sobolev, in *Proceedings of the All-Russia Petrographic Conference "Petrography of the 21st Century* (Apatity, 2005), Vol. 2. *Origin of Magmatic Rocks*, pp. 199–201 [in Russian].
11. A. V. Lapin, *Izv. Akad. Nauk SSSR, Ser. Geol.*, No. 12, 36 (1986).