ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 413A, No. 3, pp. 469–473. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © A.M. Sazonov, V.V. Vrublevsky, I.F. Gertner, A.V. Fedorova, V.V. Gavrilenko, E.A. Zvyagina, S.I. Leont'ev, 2007, published in Doklady Akademii Nauk, 2007, Vol. 413, No. 6, pp. 798–802.

GEOCHEMISTRY

The Transangara Alkaline Pluton, Yenisei Range: Rb–Sr and Sm–Nd Isotope Ages and Sources of Feldspathoid Magmas in Late Precambrian

A. M. Sazonov[a], V. V. Vrublevsky[b], I. F. Gertner[b], A. V. Fedorova[a], V. V. Gavrilenko[c], E. A. Zvyagina[a], and S. I. Leont'ev[a]

Presented by Academician L.N. Kogarko April 25, 2006

Received June 1, 2006

DOI: 10.1134/S1028334X07030336

According to the existing geodynamic models, the Precambrian fold-thrust belt of the Yenisei Range was formed by the successive accretion of several terranes to the western margin of the Siberian Craton in the Neoproterozoic [1]. The main collisional events at 880–860 and 760–720 Ma B.P. were presumably accompanied by the emplacement of the Teisk, Tatar–Ayakhta, and Glushikha granitoid complexes located, respectively, in the central and western part of the Transangara region. This was followed by the amalgamation of an island-arc complex and obduction of the ophiolites of the Yenisei Range at the Riphean–Vendian boundary (700–630 B.P.). Noteworthy is the fact that this stage is close to the manifestation of small-scale spatially associated rift-type alkaline and carbonatite magmatism in the southern Yenisei Range (660–675 Ma B.P.). This event is reflected in the Middle Tatar ijolite–foyaite and Penchenga fenite–carbonatite complexes [2, 3]. The appearance of local magma-permeable zones, which controlled the emplacement of rock complexes mentioned above, could be related to the evolution of late collisional strike-slip deformations within the sufficiently consolidated continental crust [4]. According to other concepts [5], the Late Riphean–Vendian alkaline magmatism at the margin of the Siberian paleocontinent was stimulated by superplume activity, which provoked riftogenic breakup of Laurasia and opening of the Paleoasian Ocean. Newly obtained isotope–geochronological and geochemical data on the rocks and minerals of the Transangara alkali massif, a member of the Middle Tatar intrusive complex, allowed us to specify the age and formation sequence, assess the duration of rifting, and unravel the sources of feldspathoid magmas at the Late Precambrian stage of the geological evolution of this region.

The Transangara ijolite–foyaite pluton located in the southwestern part of the Central Angara terrane is the largest body among four alkaline massifs in the Tatarka River basin, the right tributary of the Angara River (Fig. 1). The stock-shaped pluton is hosted in the Upper Riphean marblized limestones and shales. The host rocks are fenitized in a narrow (200–500 m) contact zone. The massif is mainly composed of leucocratic aegirine foyaite, with vein facies developed as alkali syenite pegmatites in the framework rocks. Feldspathic ijolites of the second intrusive phase are significantly less developed. They form a subhorizontal sheet (2×3.4 km) up to 300 m thick in the central part of the pluton and a few small veins among foyaites in its eastern flank. The contacts between ijolites and nepheline syenites suggest injection relationships. The formation of foidolites is completed by the emplacement of veined foyaite–pegmatites within the massif. The northeastern inner contact of the pluton is complicated by a zone of muscovite syenites, which differ from foyaites in higher silica content and lower alkalinity. All primary magmatic rocks were variably microclinized and repeatedly albitized. Based on Nd–Sr–O–C isotopic compositions, silicate–carbonate veins are classed with mantle carbonatites [6].

The nepheline-bearing rocks of the Transangara Pluton are marked by lower silica content (SiO_2 47–56 wt %) and enrichment in alumina (Al_2O_3 ~18–22 wt %) and alkali metals ($Na_2O + K_2O$ ~11–14 wt %; Na_2O/K_2O ~1.2–2.2). More melanocratic ijolites are characterized by an increase in femic components, Co, and P. Contents of siderophile Cr, Ni, and V (up to 10–16 ppm) in them are

[a] Krasnoyarsk State University of Nonferrous Metals and Gold, pr. Gazety Krasnoyarskii Rabochii 95, Krasnoyarsk, 660025 Russia
[b] Tomsk State University, pr. Lenina 36, Tomsk, 634050 Russia; e-mail: labspm@ggf.tsu.ru
[c] St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199164 Russia

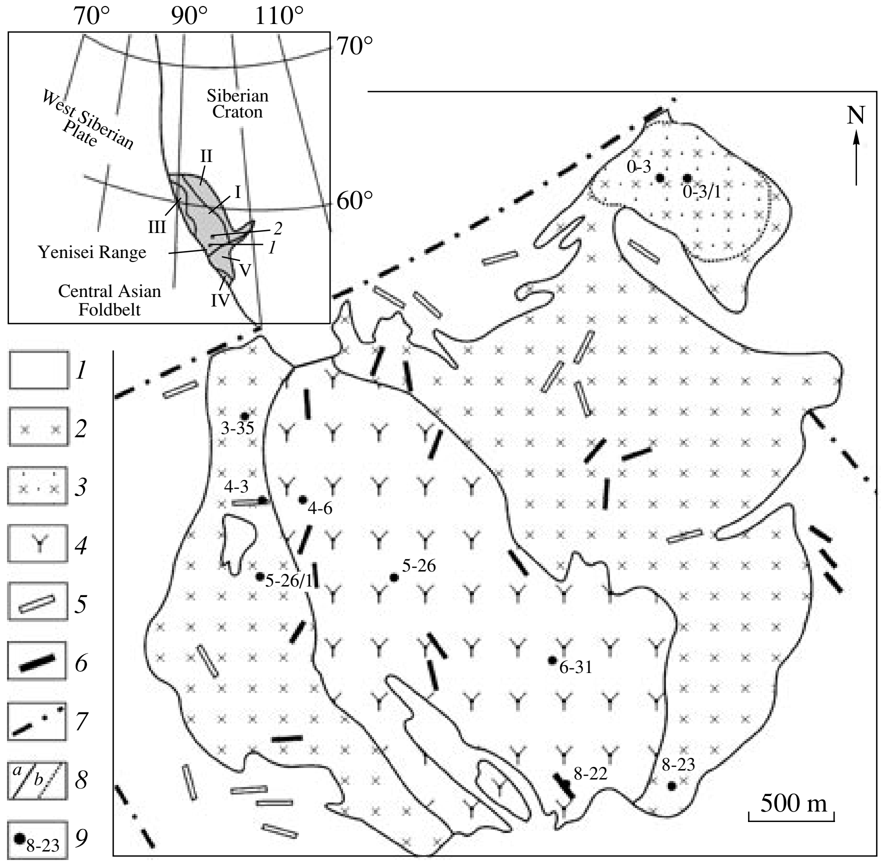

Fig. 1. Geological scheme of the Transangara Pluton (based on materials of the Angara Geoexploration Expedition and [2]). (*1*) Late Riphean terrigenous–carbonate rocks (Sukhoi Khrebet and Gorevskaya formations); (*2–6*) Middle Tatar Complex: (*2*) foyaites, (*3*) muscovite syenites, (*4*) feldspathic ijolites, (*5*) alkali syenite–pegmatites, (*6*) foyaite–pegmatites; (*7*) faults; (*8*) geological boundaries: (*a*) geological bodies, (*b*) facies; (*9*) locality and number of samples. Inset shows the geographical position of alkali and carbonatite complexes of the Yenisei Range: (*1*) Middle Tatar ijolite–foyaite, (*2*) Penchenga fenite–carbonatite. Structural subdivision of the region is given according to [1]. (I–V) Terranes: (I) Central Angara, (II) Eastern Angara, (III) Isakov, (IV) Predivinski, (V) Angara–Kan.

similar to those in foyaites. At the same time, the HFSE and LILE concentrations determined by the ICP-MS method at the Institute of Mineralogy, Geochemistry, and Crystal Chemistry of Rare Elements, Moscow (D.Z. Zhuravlev, analyst) are approximately 2–4 times higher (Zr 681–839, Hf 11–15, Nb 214–241, Ta 7–9, Th 14–24, Y 37–51, Sr 1472–3005, Ba 852–2170 ppm) than in nepheline syenites. In addition, the REE content is almost seven times higher (357–672 ppm, La/Yb ~ 22–53). These facts indicate either the different nature of magmatic sources, or different degrees of the mixing of their materials. In general, the spidergrams and trace element ratios (Ba/Nb ~4–9, Ba/La ~9–12, La/Nb ~0.5–0.8, Rb/Nb ~0.6–0.9) in ijolites approximate those in a within-plate OIB source, the present-day composition of which is determined by the interaction of HIMU and EMI mantle reservoirs [7, 8]. In addition, the crustal component was probably involved in the formation of foyaites (Rb/Nb ~2.5–4.6, Ba/La ~16.5–20.6). The influence of these sources on magma genesis is also appreciably reflected in the Nd–Sr isotopic composition of the rocks of the Transangara Massif. It is worth mentioning that late- and postmagmatic alterations in the massif led to the formation of zones with diverse rare-metal (Zr, Nb, Th, Li, REE) and scattered gold–PGE mineralization.

The Nd and Sr isotopic composition in alkali rocks was determined on a TRITON-TI multichannel mass spectrometer at the Institute of Precambrian Geology and Geochronology, St. Petersburg (V.V. Belyatskii, analyst) in a static regime using the conventional technique (table). The isochron parameters and absolute age were calculated with the ISOPLOT-2 program using the York procedure [9]. Previous K–Ar datings [2] suggested that the nepheline syenites (~660 Ma) are younger than the ijolites (675 ± 27 Ma). However, the data obtained suggest a different scenario of the crystallization sequence and duration for the Transangara Massif. The Rb–Sr mineral isochron (I_{Sr} = 0.702715, MSWD = 1.48) based on aegirine, albite, fluorite, and whole-rock foyaite (sample 3-35) defines an age of 678 ± 7.9 Ma, thus characterizing them as products of the earliest intrusive phase of the massif. The six-point isochron, including whole-rock compositions of

Nd and Sr isotopic compositions of rocks of the Transangara Massif

Sample no., rock	Material	Sm, ppm	Nd, ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$(^{143}Nd/^{144}Nd)_T$	$\varepsilon_{Nd}(T)$	$T(Nd)_{DM}$
3-35, F	Wr	2.347	14.23	0.09968	0.512460 ± 3	0.512017	+4.98	922
	Ab	0.130	0.918	0.08548	0.512410 ± 10	0.512030	+5.24	
	Aeg	3.120	20.49	0.09201	0.512437 ± 17	0.512028	+5.20	
	Fl	2.816	19.73	0.11226	0.512529 ± 6	0.512030	+5.24	
8-23, F	Wr	0.744	5.133	0.08759	0.512413 ± 3	0.512024	+5.12	890
5-26/1, F	"	2.869	19.52	0.08887	0.512395 ± 6	0.512000	+4.65	922
4-3, SP	"	18.32	88.31	0.12537	0.512586 ± 14	0.512029	+5.22	973
5-26, I	"	11.15	60.68	0.11108	0.512529 ± 7	0.512085	+4.61	922
4-6, I	"	6.705	35.45	0.11435	0.512511 ± 3	0.512054	+4.01	980
6-31, I	"	15.42	122.9	0.07585	0.512369 ± 4	0.512066	+4.24	864
8-22, FP	"	129.6	663.0	0.11816	0.512496 ± 2	0.512023	+3.40	1043
0-3, S	"	2.890	16.13	0.10828	0.512453 ± 5	0.512009	+3.50	1007
0-3/1, S	"	1.898	9.171	0.12507	0.512470 ± 4	0.511957	+2.48	1168
Sample no., rock	**Material**	**Rb, ppm**	**Sr, ppm**	**$^{87}Rb/^{86}Sr$**	**$^{87}Sr/^{86}Sr$**	**$(^{87}Sr/^{86}Sr)_T$**	**$\varepsilon_{Sr}(T)$**	
3-35, F	Wr	275.8	808.4	0.98747	0.712392 ± 16	0.702837	–12.41	
	Ab	322.0	414.5	2.25122	0.724387 ± 8	0.702602	–15.75	
	Aeg	30.49	1444	0.06105	0.703288 ± 5	0.702697	–14.40	
	Fl	9.362	9401	0.00288	0.702715 ± 17	0.702687	–14.54	
8-23, F	Wr	447.5	392.1	3.31095	0.734498 ± 13	0.702459	–17.78	
5-26/1, F	»	235.9	1349	0.50594	0.707568 ± 10	0.702672	–14.75	
4-3, SP	»	13.78	119.1	0.33467	0.705995 ± 20	0.702757	–13.54	
5-26, I	»	247.7	1530	0.46846	0.706531 ± 12	0.702453	–18.86	
	Aeg	78.47	1561	0.14543	0.703908 ± 31	0.702642	–16.17	
	Bi	1112	365.9	8.85386	0.779708 ± 7	0.702628	–16.37	
4-6, I	Wr	203.2	2024	0.29046	0.705140 ± 7	0.702611	–16.61	
6-31, I	"	166.3	3193	0.15065	0.703988 ± 13	0.702677	–15.67	
8-22, FP	"	192.1	2952	0.18827	0.704517 ± 6	0.702878	–12.82	
0-3, S	"	302.3	99.01	8.90370	0.786894 ± 8	0.706860	+44.09	
	Mu	950.7	12.55	271.2873	3.134361 ± 108			
0-3/1, S	Wr	252.4	87.51	8.40708	0.781558 ± 13	0.705988	+31.70	
	Mu	966.1	7.699	534.2398	5.527493 ± 60			

Note: (F) Foyaite, (I) feldspathic ijolite and uvite, (S) muscovite syenite, (SP) syenite pegmatite, (FP) foyaite pegmatite, (Wr) whole-rock composition, (Aeg) aegirine, (Ab) albite, (Bi) biotite, (Mu) muscovite, (Fl) fluorite. Element contents were measured accurate to 0.5 rel %. The measurement errors (2σ) are no more than 0.5 rel % for $^{147}Sm/^{144}Nd$ and $^{87}Rb/^{86}Sr$ ratios,0.005 rel % for $^{143}Nd/^{144}Nd$, and 0.05 rel % for $^{87}Sr/^{86}Sr$. Replicate measurements yielded the following values: $^{143}Nd/^{144}Nd = 0.511839 \pm 7$ for the La Jolla standard ($N = 13$, normalized to $^{146}Nd/^{144}Nd = 0.7219$); $^{87}Sr/^{86}Sr = 0.710283 \pm 21$ for the SRM-987 standard ($N = 9$, normalized to $^{88}Sr/^{86}Sr = 8.37251$). Initial isotope ratios and values of $\varepsilon_{Nd}(T)$ and $\varepsilon_{Sr}(T)$ were calculated using present-day values for CHUR ($^{143}Nd/^{144}Nd = 0.512638$; $^{147}Sm/^{144}Nd = 0.1967$) and UR ($^{87}Sr/^{86}Sr = 0.7045$; $^{87}Rb/^{86}Sr = 0.0827$). Model ages $T(Nd)_{DM}$ (Ma) were calculated using present-day values for depleted mantle $^{143}Nd/^{144}Nd = 0.51315$; $^{147}Sm/^{144}Nd = 0.2137$.

foyaites (samples 5-26/1 and 8-23) and alkali syenite–pegmatite (vein facies of foyaites, sample 4-3), yields a more reliable isochron (MSWD = 0.94) with the slope corresponding to 675 ± 5.8 Ma ($I_{Sr} = 0.70273$, Fig. 2). Close datings ($T = 680 \pm 61$ Ma, MSWD = 0.04, $\varepsilon_{Nd} = +5.3$; $T = 678 \pm 72$ Ma, MSWD = 1.5, $\varepsilon_{Nd} = +5.2$) were obtained by the Sm–Nd method in the same samples (Fig. 2). The foidolite phase is much younger. This fact evidently indicates a polychronous character of the Transangara Pluton. Aegirine, biotite, and whole-rock

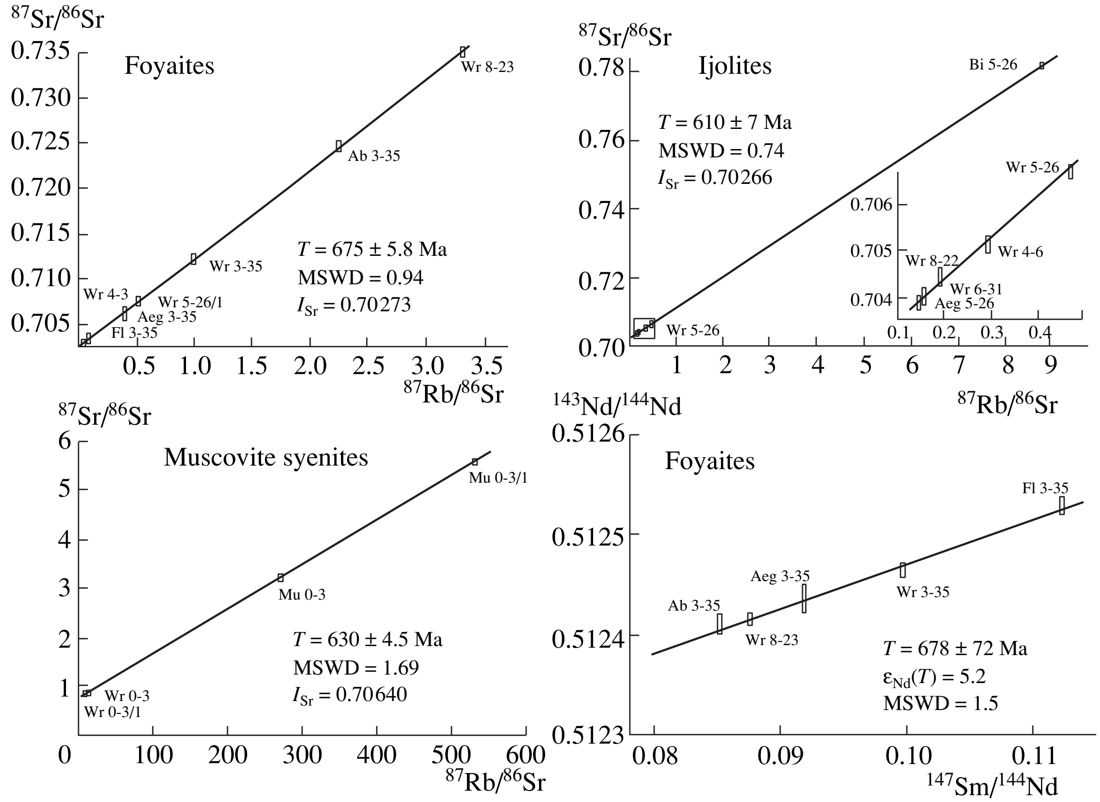

Fig. 2. Rb–Sr and Sm–Nd isochrons for rocks and minerals of the Transangara Massif. Numbers in the diagram correspond to those in the table.

ijolite (sample 5-26) define a Rb–Sr isochron with an age of 611 ± 7.2 Ma (I_{Sr} = 0.702548, MSWD = 0.59). The five-point isochron, including whole rock foidolites and foyaite–pegmatite, defines a similar age (T = 610 ± 7 Ma, MSWD = 0.74, I_{Sr} = 0.702656, Fig. 2).

Despite the significant difference in age, the alkali rocks of the Transangara Massif have similar isotope composition. The ε_{Nd} values in the nepheline syenites ($\varepsilon_{Nd}(T)$ from + 4.7 to + 5.2; ε_{Sr} from –12.4 to –17.8) and ijolites (ε_{Nd}(T) from + 4.0 to + 4.6; $\varepsilon_{Sr}(T)$ from –15.7 to –18.9) testify to similarity of feldspathoid magma sources, which were either modestly depleted HIMU-component or the mixing product of the more depleted PREMA or E-MORB mantle with enriched EMI reservoir (Fig. 3). Similar values are typical of carbonate veins of the massif (ε_{Nd}(T) approximately + 5.5, $\varepsilon_{Sr}(T)$ approximately –18.5, Fig. 3). The observed isotope relations can be attributed to plume–lithosphere interaction, which usually initiates riftogenic alkali and carbonatite magmatism. The material with such characteristics was presumably one of the components of mantle alkali–dolomitic magma, whose evolution led to the almost coeval (~672 Ma) formation of the Penchenga fenite–carbonatite complex ($\varepsilon_{Nd}(T)$ from + 5.1 to + 5.5, $\varepsilon_{Sr}(T)$ from –19.4 to –20.4, T(Nd)DM ~0.91 Ga, Fig. 3) in the Central Angara terrane [3]. In our opinion, the same stage of the plume activity (~600–700 Ma) also produced alkaline magmatic centers in the Transangara region with the formation of the Chapa alkali picritic–lamproite, Zakhrebetnyi gabbro–nepheline–syenite, and Chivida trachybasalt complexes [10]. Furthermore, the relatively simultaneous Neoproterozoic (630–725 Ma) riftogenic association of alkali–ultrabasic rocks and carbonatites of the East Sayan province is similar to the Transangara Massif in terms of the Nd–Sr isotopic composition (Fig. 3) and model ages ($T(\mathrm{Nd})_{DM}$ ~ 0.83–0.96 Ga) [6, 11]. These data testify indirectly to a common source for the rocks mentioned above. The observed compositional variations could be caused by different degrees of the mixing of DM and EMI components.

According to plate tectonics, the significantly younger (~610 Ma) age of the ijolites of the Transangara Pluton, their enrichment in trace elements, close spatial relationships, and isotope similarity with foyaites can be attributed to the repeated partial melting of lithospheric mantle, which was already eroded and metasomatically reworked by the initial plume [12]. Despite the fluid mass transfer and enrichment in trace elements, the isotope systems of the lithospheric protolith did not have enough time to reach new isotope equilibrium at the moment of foidolite magma generation. It should be also noted that muscovite syenites, which were formed at 630 ± 4.5 Ma (Rb–Sr isochron based on two whole-rock samples and two muscovites, I_{Sr} = 0.70640, MSWD = 1.69, Fig. 2) at the northeastern

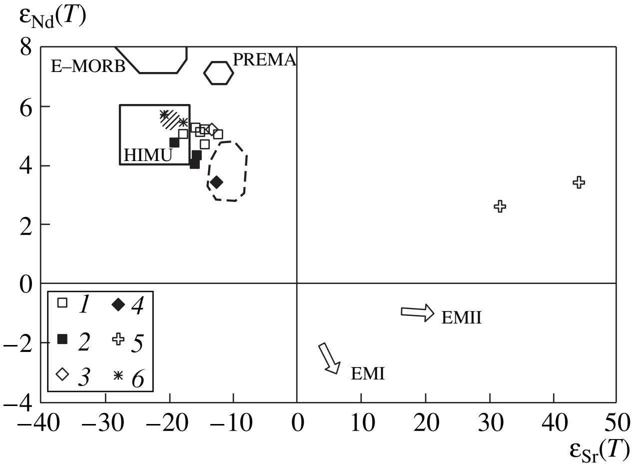

Fig. 3. Nd–Sr isotopic composition of alkali rocks and carbonatites of the Yenisei Range and eastern Sayan. (*1*) Foyaites, (*2*) ijolites, (*3*) alkali syenite–pegmatite, (*4*) foyaite–pegmatite, (*5*) muscovite syenites, (*6*) carbonatites. Shaded area includes carbonatites of the Penchenga Complex of the Yenisei Range. Dashed line outlines the compositional field of the rocks of the carbonatite-bearing alkali ultramafic massifs of the Urik Graben, eastern Sayan (Zima Complex) [6, 11]. E-MORB, PREMA, HIMU, EMI, and EMII reservoirs are shown in accordance with their isotope parameters in [7].

inner contact of the massif, presumably do not represent an independent intrusive phase. Given their radiogenic Sr isotopic composition and relatively old model age $T(\mathrm{Nd})_{DM}$ (table, Fig. 3), these rocks represent the products of hydrothermal–metasomatic muscovitization of foyaites under the action of heterogeneous fluid with a crustal component.

Thus, the Transangara alkali massif is a Late Precambrian polychronous (~680–610 Ma) pluton, which was formed at the margin of the Siberian Craton in a setting of rifting and pulsed intrusions of mantle feldspathoid magmas. The isotope–geochemical characteristics indicate that their sources corresponded to DM materials of the HIMU, PREMA, or E-MORB type variably mixed with EMI. Similar Nd–Sr isotopic compositions, timings, and model ages of the alkali rocks and carbonatites of the Yenisei Range and eastern Sayan suggest similar geodynamic settings and close spatial relationships of Late Riphean–Vendian magmatism in these regions.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project nos. 04-05-64331, 07-05-00480.

REFERENCES

1. V. A. Vernikovsky, A. E. Vernikovskaya, A. B. Kotov, et al., Tectonophysics **375**, 147 (2003).
2. E. V. Sveshnikova, E. I. Semenov, and A. M. Khomyakov, *The Transangara Alkali Massif and Its Rocks and Minerals* (Nauka, Moscow, 1976) [in Russian].
3. V. V. Vrublevsky, B. G. Pokrovsky, D. Z. Zhuravlev, and G. N. Anoshin, J. Petrol. **11**, 130 (2003) [Petrologiya **11**, 145 (2003)].
4. V. V. Vrublevsky, Doctoral Dissertation in Geology and Mineralogy (Novosibirsk, 2003).
5. V. V. Yarmolyuk, V. I. Kovalenko, E. B. Sal'nikova, et al., Dokl. Earth Sci. **404**, 986 (2005) [Dokl Akad. Nauk **404**, 400 (2005)].
6. T. Morykiyo, T. Miyazaki, H. Kagami, et al., in *Proc. Int. Workshop on Alkaline Magmatism and Problems of Mantle Sources, Irkutsk, Russia, 2001* (Irkutsk, 2001), pp. 69–84.
7. A. Zindler and S. R. Hart, Ann. Rev. Earth Planet. Sci. **14**, 493 (1986).
8. N. I. Filatova, J. Petrol. **10**, 362 (2002) [Petrologiya **10**, 411 (2002)].
9. D. York. Can. J. Phys. **44**, 1079 (1966).
10. T. Ya. Kornev, L. K. Kachevsky, A. D. Nozhkin, et al., in *Regional Correlation Schemes of Magmatic and Metamorphic Complexes in the Altai–Sayan Fold Zone* (SNIIGGiMS, Novosibirsk, 1999), p. 17–46 [in Russian].
11. E. A. Chernysheva and T. Morykiyo, Dokl. Earth Sci. **369A**, 1291 (1999) [Dokl. Akad. Nauk **369**, 381 (1999)].
12. V. V. Vrublevsky, I. F. Gertner, A. G. Vladimirov, et al., Dokl. Earth Sci. **398**, 990 (2004) [Dokl. Akad. Nauk **398**, 374 (2004)].