ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 411, No. 8, pp. 1277–1283. © Pleiades Publishing, Inc., 2006.
Original Russian Text © S.N. Rudnev, D.I. Matukov, S. A. Sergeev, P.A. Serov, 2006, published in Doklady Akademii Nauk, 2006, Vol. 410, No. 6, pp. 809–815.

GEOCHEMISTRY

Late Riphean Plagiogranites of Kuznetskii Alatau: Composition, Age, and Sources

S. N. Rudnev[a], D. I. Matukov[b], S. A. Sergeev[b], and P. A. Serov[c]

Presented by Academician N.L. Dobretsov December 16, 2005

Received January 17, 2006

DOI: 10.1134/S1028334X06080265

The geological–petrographic, petrogeochemical, geochronological, and isotopic–geochemical data obtained during recent decades in Kuznetskii Alatau and Gornaya Shoria on igneous rocks confined to Early Caledonian structures of the western Altai–Sayan mobile belt, as well as the analysis of stratigraphic materials, show that these regions are characterized by an intricate tectonic structure and development of igneous rocks ranging in age from the Late Precambrian to Early Mesozoic (Fig. 1) [1, 2]. Intrusive rocks of these regions have been studied in detail for over 70 years beginning with classical works by N.A. Eliseev, V.A. Kuznetsov, G.V. Pinus, A.F. Belousov, and other prominent geologists. Nevertheless, many problems of the geological structure and age of igneous rocks remain debatable thus far.

Recently, it has been established that Late Riphean–Early Vendian(?) and Late Vendian–Early Cambrian ophiolitic associations, which extend as belts along the Kuznetskii Alatau deep fault, are the oldest igneous rocks in Kuznetskii Alatau and Gornaya Shoria (Fig. 1). The Late Riphean–Early Vendian(?) association was discovered and thoroughly described in the Tom and Tashelga blocks of Gornaya Shoria (Konzhin and Tersin complexes). This association is represented by rare isolated outcrops of tectonic sheets composed of metamorphosed ultramafics, metabasalts, amphibolites, gabbro, siliciliths, and marbles. Metabasalts of the Konzhin Complex are dated by the Sm–Nd isochron method (bulk rock, amphibole, and plagioclase) back to 694 ± 43 Ma [1]. The Late Vendian–Early Cambrian association is largely composed of basaltoids (Ust'-Anzas and Koltas volcanic complexes) and is closely associated with mafic–ultramafic sheets [3–7]. Based on the U–Pb zircon dating of plagiorhyolites and subvolcanic plagiogranites of the Koltas complex, the age of this association is estimated at 544 ± 8 Ma [1].

The Cambrian–Ordovician stage in Kuznetsk Alatau and Gornaya Shoria is marked by the formation of most intrusive rocks. It comprises four peaks of magmatic activity (530 ± 5, 495 ± 5, 475 ± 5, and 450 ± 5 Ma) [9], each characterized by the formation of granitoid and gabbro–granite associations making up large polychronous plutons (Fig. 1). The plutons are largely composed of granitoid associations of different petrochemical (tholeiitic, calc-alkaline, subalkaline, and alkaline) types with anomalously high positive values of the Nd isotope: $\varepsilon_{Nd}(T)$ = +2.5…+8.9 (T_{Nd}(DM-2st) = 0.9–0.6 Ga). These rocks formed in different geodynamic settings (island arc, accretionary–collisional, and collisional) [1, 8–10].

This paper presents new data indicating that, in addition to the Cambrian–Ordovician granitoid associations, an older (Late Riphean) granitoid association is developed in the region. In terms of the isotopic–geochemical parameters, the Late Riphean association significantly differs from the Cambrian–Ordovician variety and implies the presence of fragments of old continental blocks in Early Caledonian structures of the western segment of the Altai–Sayan mobile belt. This granitoid association is defined in the Kundusuyul polychronous pluton located in the Kiya segment of the Martaiga Uplift in Kuznetskii Alatau (Fig. 1). Lithological description of this pluton is given below.

The elongated Kundusuyul pluton is confined to the Kundat fault system and extends in the meridional direction parallel to the strike of its host Middle–Upper Riphean rocks: limestones, marbles, carbonaceous–

[a] *Institute of Geology and Mineralogy, Siberian Division, Russian Academy of Sciences, ul. akademika Koptyuga 3, Novosibirsk, 630090 Russia; e-mail: rudnev@iggm.nsc.ru*

[b] *Karpinsky All-Russia Geological Institute, Srednii pr. 74, St. Petersburg, 199026 Russia*

[c] *Geological Institute, Kola Scientific Center, Russian Academy of Sciences, ul. Fersmana 14, Apatity, 184209 Russia*

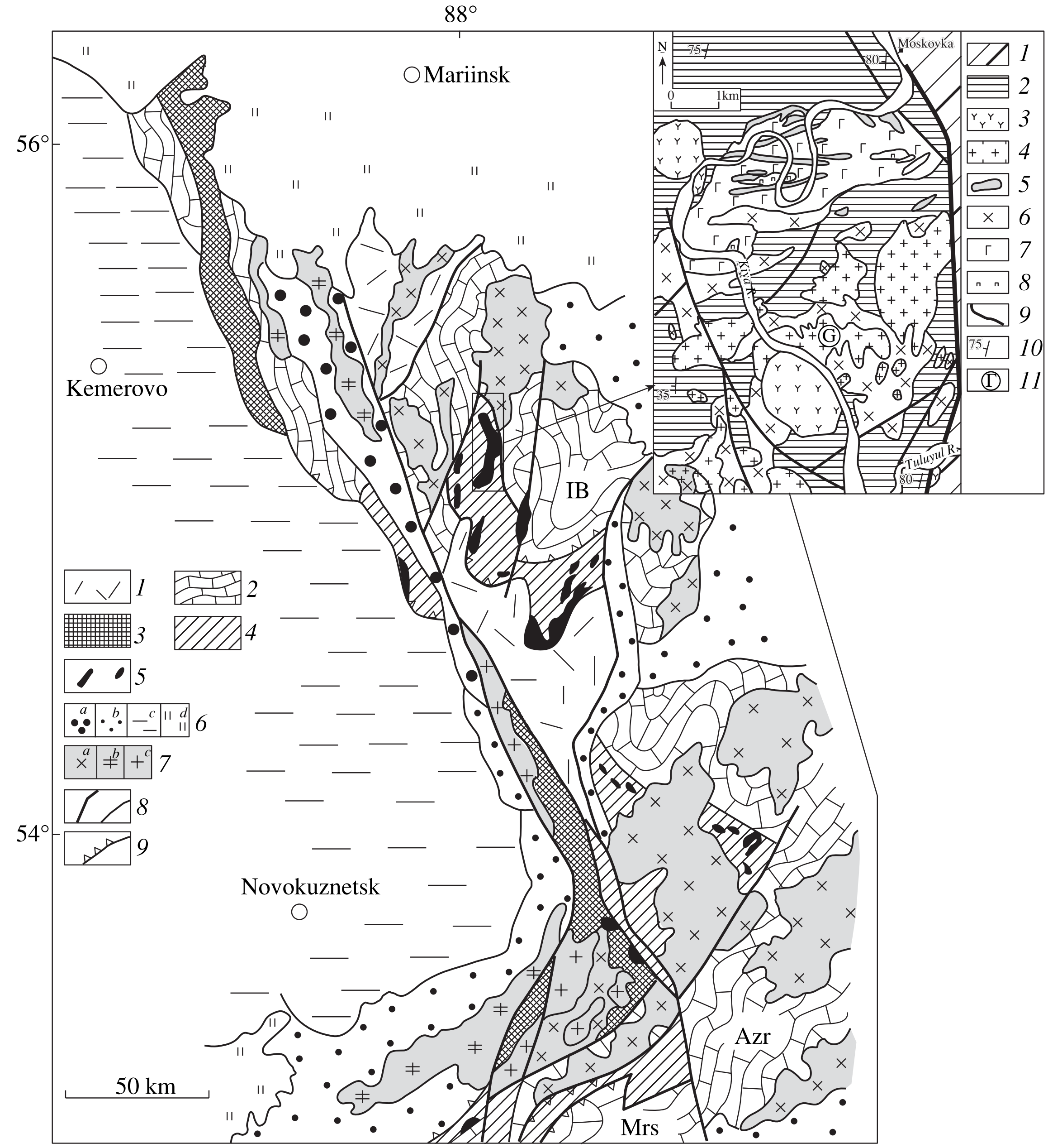

Fig. 1. Tectonic sketch map of the distribution of ophiolitic and granitoid associations in Kuznetskii Alatau and Gornaya Shoria (modified after the data from [2, 6]).

(*1*) Island-arc terranes ($V{-}Є_1$); (*2*) terranes corresponding to intraoceanic rises with the Riphean–Cambrian terrigenous–carbonate cover: (Mrs) Mras, (Azr) Azyrtal, (IB) Iyus–Batenev; (*3*) ophiolites related to the evolution of the mid-oceanic hot spot of the Iceland type ($R_3{-}V_1$(?)); (*4*) ophiolites of the back-arc basin related to the development of the Salair and North Sayan island arcs (or segments of a single arc) ($V_2{-}Є_1^1$); (*5*) undivided restite ultramafics representing constituents of different-age ophiolitic associations; (*6*) overlying geological structures (troughs, depressions, and grabens) mostly filled with (*a*) Cambrian–Ordovician, (*b*) Devonian, (*c*) Upper Paleozoic coaliferous, and (*d*) Mesozoic–Cenozoic sediments; (*7*) granite and gabbro–granite plutons: (*a*) Early Paleozoic, (*b*) Middle Paleozoic, (*c*) Late Paleozoic–Early Mesozoic; (*8*) faults and other geological boundaries; (*9*) overthrusts. The box shows the position of the Kundusuyul polychronous pluton. The inset demonstrates the schematic geological structure of the northern Kundusuyul polychronous pluton (modified after the data of S.M. Baranov, V.S. Dubskii, and others, Zapsibgeols'emka Federal Geological Management (Novokuznetsk). (*1*) Carbonate–terrigenous–volcanogenic rocks ($V{-}Є_1$); (*2*) dolomites, limestones, schists, and metavolcanics ($R_{2–3}$); (*3*) granosyenites of the Chebulin alkaline granite complex ($D_{1–2}$); (*4*) tonalites and plagiogranites (R_3); (*5, 6*) Kundusuyul gabbro–dolerite complex (R_3?): (*5*) doleritic dikes, (*6*) undivided gabbro and diorites; (*7, 8*) Moskovka peridotite–pyroxene–gabbro complex (R_3?):(*7*) gabbroids, (*8*) undivided peridotites and pyroxenites; (*9*) tectonic dislocations; (*10*) strike and dip; (*11*) location of the examined Gremyach'e Massif.

clayey–siliceous schists, quartzites, dolomites, and basic and intermediate volcanics [11]. The pluton comprises three igneous complexes (from older to younger): the Moskovka peridotite–pyroxenite–gabbro and Kundusuyul gabbro–diorite–dolerite complexes of the ophiolitic association and the plagiogranite complex. Previously, it was assumed that these complexes belong to a single ophiolitic association correlative with the Middle Tersin (V_2–$Є_1^1$) ophiolitic association [2–6]. The data discussed below indicate, however, that judging from their composition, age, and isotopic–geochemical characteristics, plagiogranites cannot be affiliated with this ophiolitic association and they formed in different geological settings.

The rocks of the plagiogranite association in the Kundusuyul pluton form the Gremyach'e and other small massifs (Fig. 1, inset) located along the right and left banks of the Kiya River. The rock massifs constitute approximately 25–30% of the pluton area. They intrude into the host Middle–Upper Riphean rocks and Kundusuyul igneous gabbro–dolerite complex [11]. The plagiogranite association is represented by plagiogranites and tonalites. Its petrochemical and mineralogical compositions, age, and isotopic–geochemical characteristics are exemplified by the Gremyach'e Massif.

The massif, approximately 5 km^2 in size and located in the central part of the Kundusuyul pluton, is characterized by irregular configuration and extends in the near-latitudinal direction (Fig. 1, inset). It is largely composed of plagiogranites and leucoplagiogranites (90% of the distribution area) developed in the central part of the massif and, to a lesser extent, of tonalites confined to its peripheral parts. The plagiogranites are medium-grained, mostly cataclastic and foliated rocks. They are characterized by a cataclastic texture with elements of blastomylonitic or granuloblastic and gneissic structures. The major minerals are quartz (30–35%), albite (55–60%), orthoclase (5%), biotite, and amphibole (1–3%). Accessory minerals are represented by apatite, zircon, sphene, magnetite, and pyrite. In terms of their petrochemical composition, plagiogranites belong to the sodic calc-alkaline series (Table 1). In the Ab–An–Or diagram, they fall into the field of tonalite–trondhjemite rocks. Unlike plagiogranites of the tholeiitic series that are constituents of ophiolitic complexes, they are characterized by higher contents of K_2O (0.85–2.6 wt %); $Na_2O + K_2O$ (5.7–9.1 wt %); Al_2O_3 (14.3–15.7 wt %); Rb (18–53 ppm); Sr (300–367 ppm); Th (2.9–4.4 ppm); Hf (1.9–3.2 ppm); Zr (51–122 ppm); and, particularly, Ba (up to 1230 ppm). The curves illustrating the REE distribution spectra indicate a sharp prevalence of LREEs over HREEs (total REE content 53–60 ppm, $(La/Yb)_N$ = 16.9–21.4) and the absence of a Eu anomaly or an insignificant value for it in rare cases ($(Eu/Eu^*)_N$ = 0.92–1.2) (Fig 2). Multielement spectra of plagiogranites show distinct negative Nb and Ti anomalies, which are typical of rocks of the tonalite–trondhjemite–granodiorite complexes. In terms of the contents of Yb (0.4–0.6 ppm), Al_2O_3 (14.2–15.4 wt %), Eu and Sr, as well as in the La/Yb and Sr/Y values, the rocks of this association are similar to those from the high-alumina tonalite–trondhjemite complexes, which are presumably formed at $P > 10$–12 kbar in equilibrium with the garnet-bearing restite, i.e., at depths exceeding 35 km. The formation of such melts at the corresponding depth can result either from the melting of an oceanic plate, which subducted into a zone with an elevated geothermal gradient, or from the melting of metabasite (or plagiogneiss) substrates at the base of the thickened crust during collision.

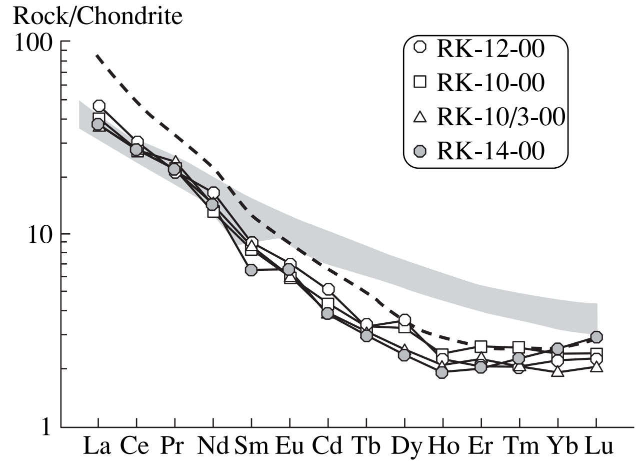

Fig. 2. The REE distribution spectra in plagiogranites of the Gremyach'e Massif. Sample numbers in the diagrams are as in Table 1. Samples were normalized to chondrites. The shaded field corresponds to the composition of tonalities and plagiogranites of the Sumsunur Complex of the eastern Sayan region [14]; the dashed line, to the average composition of Archean high-alumina tonalite–trondhjemite–granodiorite associations.

In order to determine the age of plagiogranites, the zircon monofraction sampled from the central part of the Gremyach'e Massif (sample RK-10-00) was studied. Zircons from this sample are represented by yellow euhedral, transparent to semitransparent, long prismatic (K_{elong} = 3.0–5.0) crystals. Their study by the optical and cathodoluminescence methods revealed finely zoned patterns and lack of relicts of "old" nuclei (Fig. 3). The morphological features of zircons indicate their magmatic origin. The SHRIMP-II U–Pb analysis of single zircon grains was carried out at the Center of Isotopic Studies of the Karpinskii All-Russia Research Institute of Geology (St. Petersburg) (Table 2). The age of zircon crystallization is estimated at 875.9 ± 6.2 Ma (Fig. 4). Taking into consideration the magmatic origin of zircons, this date can be considered as the crystallization age of the Gremyach'e plagiogranite. It should be noted that this is the first date obtained for Kuznetskii Alatau. It indicates that Early Paleozoic plagiogranites, which are widespread in this region, also host their Late Riphean varieties [9, 13].

Table 1. Contents of petrogenic (wt %) and rare (ppm) elements in representative plagiogranite samples from the Gremyach'e Massif

Component	RK-12-00	RK-10-00	RK-14-00	RK-10/3-00
SiO_2	71.35	72.34	73.25	73.60
TiO_2	0.20	0.14	0.19	0.12
Al_2O_3	14.76	15.09	15.08	14.23
Fe_2O_{3tot}	3.10	1.72	2.07	1.71
MnO	0.05	0.04	0.03	0.03
MgO	0.43	0.78	0.48	0.23
CaO	1.60	1.28	1.83	1.26
Na_2O	5.35	4.74	4.89	4.76
K_2O	1.80	2.69	0.85	2.61
L.O.I.	0.48	0.76	0.58	0.51
P_2O_5	0.07	0.03	0.06	0.05
Total	99.19	99.58	99.28	99.11
Rb	33	53	18	52
Sr	343	301	367	367
Y	6.40	5.52	5.10	4.52
Zr	91	51	122	100
Nb	n.d.	1.94	6.99	n.d.
Ba	921	1118	243	1232
La	15.22	13.01	12.60	12.11
Ce	25.78	23.51	24.28	23.57
Pr	2.74	2.81	2.88	3.04
Nd	10.15	8.11	8.95	8.89
Sm	1.81	1.71	1.34	1.75
Eu	0.53	0.45	0.51	0.46
Gd	1.40	1.17	1.08	1.06
Tb	0.16	0.16	0.15	0.15
Dy	1.20	1.11	0.82	0.85
Ho	0.17	0.18	0.15	0.16
Er	0.46	0.58	0.46	0.50
Tm	0.09	0.09	0.08	0.13
Yb	0.48	0.52	0.57	0.42
Lu	0.12	0.08	0.10	0.07
Hf	2.63	1.86	2.93	3.17
Ta	n.d.	n.d.	0.36	n.d.
Th	2.92	4.42	3.90	3.87
U	0.57	0.69	0.46	0.32

Note: Contents of petrogenic elements were determined by the X-ray fluorescence method using the SRM-25 equipment at the United Institute of Geology, Geophysics, and Mineralogy (Novosibirsk; A.D. Kireev and N.M. Glukhova, analysts). The concentrations of the trace and rare earth elements were measured by the ICP-MS method: analyses with the VG Plasmquad PQ-2 equipment were carried out at the Collective Analytical Center of the Irkutsk Scientific Center, Siberian Division, Russian Academy of Sciences (Irkutsk; S.V. Panteeva and V.V. Markov, analysts); analyses with the ELEMENT Finnigan Mat equipment (Germany), at the Analytical Center of the Institute of Geology, Geophysics, and Mineralogy (Novosibirsk; I.V. Nikolaeva and S.V. Palesskii, analysts). (n.d.) Not detected. Samples from the collection of S.N. Rudnev.

The Nd isotope study of plagiogranites from the Gremyach'e Massif (sample RK-10-00) revealed that they are characterized by a negative $\varepsilon_{Nd}(T)$ value (–7.8) at $^{147}Sm/^{144}Nd = 0.101403$ and their model age corresponds to the Early Proterozoic (T_{Nd}(DM-2st) = 2.2 Ga). Granitoids with such isotopic parameters have been noted in Kuznetskii Alatau for the first time. With account for geochemical and isotopic data, we can postulate that high-alumina plagiogranites of the Gremyach'e Massif formed at the base of the thickened crust from the source with a long crustal history. Plagiogranites and tonalites from the Sumsunur Complex in the eastern Sayan region can serve as their analogue in adjacent regions. The rocks of the Sumsunur Complex are approximately 800 Ma old and are characterized by the following parameters: $\varepsilon_{Nd}(T) = -13.1$ and T_{Nd}(DM-2st) = 2.57 Ga [14]. Their formation could be related to melting of Archean tonalite–gneisses of the Gargan block (2.66 Ga [15]). Rocks of this block and relevant plagiogranites of the Sumsunur Complex are well exposed. However, no outcrops of Upper Archean or Lower Proterozoic rocks have been established so far at the present-day erosional surface of Kuznetskii Alatau, because they are likely overlain (or overthrusted) by younger strata. The only present-day evidence for development of Lower Precambrian crystalline rocks in structures of Kuznetskii Alatau are the Nd isotope data obtained for Late Riphean plagiogranites of the Gremyach'e Massif. Thus, in terms of the isotopic characteristics that reflect the source, the rocks of the massif are sharply different from Early Paleozoic igneous rocks in Early Caledonian structures of the western Altai–Sayan mobile belt. As was mentioned, the latter are characterized by positive $\varepsilon_{Nd}(T)$ values (from +2.5 to +8.9) and Nd model ages ranging from 0.6 to 0.9 Ga, suggesting their formation mainly due to the melting of the juvenile Late Riphean crust [1, 8, 10].

Thus, the data obtained allow the following inferences.

(1) Based on the U–Pb zircon dating of plagiogranites of the Gremyach'e Massif (875.9 ± 6.2 Ma), we have discovered Late Riphean plagiogranites in Kuznetskii Alatau.

(2) The petrogeochemical data obtained for plagiogranites of the Gremyach'e Massif indicate that they belong to the high-alumina type formed at $P > 10$ kbar in equilibrium with the garnet-bearing restite, suggesting their formation independently from ophiolites.

(3) The plagiogranites from the Gremyach'e Massif are characterized by a negative $\varepsilon_{Nd}(T)$ value (–7.8) and Early Proterozoic Nd model age value (ε_{Nd}(DM-2st) = 2.20 Ga). The isotope data point to formation of plagiogranites from a source with a long crustal history and, consequently, suggest the existence of fragments of the Early Precambrian continental crust at the base of the Kuznetskii Alatau collisional structure. These data are of regional significance, since previous geochronological and isotopic–geochemical studies in the Tomsk

Table 2. Results of U–P isotopic studies of single zircon grains from plagiogranites of the Gremyach'e Massif (SHRIMP-II)

Sample, point	$^{206}Pb_c$, %	U, ppm	Th, ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	Age according to isotopic ratios		Discordance, %	$^{238}U/^{206}Pb^*$	±%	$^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	Correlation coefficient
						$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$										
RK 10-1-1	0.86	119	88	0.77	14.7	862.0 ± 11	924 ± 100	7	6.991	1.4	0.0698	5.1	1.378	5.2	0.1430	1.4	0.259
RK 10-2-1	0.00	342	254	0.77	42	861.1 ± 6.5	894 ± 34	4	6.997	0.8	0.0689	1.7	1.357	1.8	0.1429	0.8	0.435
RK 10-3-1	0.22	488	14	0.03	61.8	883.9 ± 6.1	921 ± 39	4	6.804	0.74	0.0697	1.9	1.413	2.1	0.1470	0.74	0.359
RK 10-4-1	0.05	204	112	0.57	25.7	883.5 ± 8.1	859 ± 54	–3	6.808	0.99	0.0677	2.6	1.371	2.8	0.1469	0.99	0.352
RK 10-5-1	0.40	174	113	0.67	21.7	873.4 ± 8.7	822 ± 68	–6	6.892	1.1	0.0665	3.3	1.330	3.4	0.1451	1.1	0.308
RK 10-6-1	–	119	81	0.71	15.1	885.5 ± 9.9	868 ± 49	–2	6.792	1.2	0.0680	2.3	1.380	2.6	0.1472	1.2	0.453
RK 10-7-1	0.37	76	70	0.95	9.63	884.0 ± 13	888 ± 160	0	6.810	1.6	0.0686	7.7	1.390	7.9	0.1469	1.6	0.202

Note: Accessory zircons were extracted in line with the standard technique using heavy liquids. The SHRIMP-II ionic microprobe analyses of single zircon grains were performed at the Center of Isotopic Studies of the Karpinskii All-Russia Research Institute of Geology (St. Petersburg). Manually picked zircon grains were implanted into epoxide resin together with zircon standards TEMORA and 91500. Subsequently, zircon grains were polished up to their half thickness. Optical (the transmitted and reflected light versions) and cathodoluminescence images reflecting the internal structure and zoned patterns of zircons were used to select areas (points) for dating grains at the surface of the polished section. The cathodoluminescence images were obtained on a scanning electron microscope (analytical conditions: working distance 25–28 mm, accelerating voltage 20 kV, and beam current on the Faraday cup 4–6 nA). U–Pb ratios were measured with the SHRIMP-II ion microprobe in line with the standard technique (analytical conditions: intensity of the primary beam of molecular negatively charged oxygen ions 4 nA, crater diameter 18 μm). The obtained data were processed using the SQUID software. The U–Pb ratios were normalized to the value of 0.0668 attributed to the zircon standard TEMORA. Errors of single analyses (ratios and ages) are given at the 1σ level; errors of calculated concordant ages and intercepts with the concordia, at the 2σ level. Plots with concordia have been constructed using the ISOPLOT/EX software. (Pb_c, Pb^*) common and radiogenic lead, respectively. Correction for common lead is introduced according to the measured ^{204}Pb.

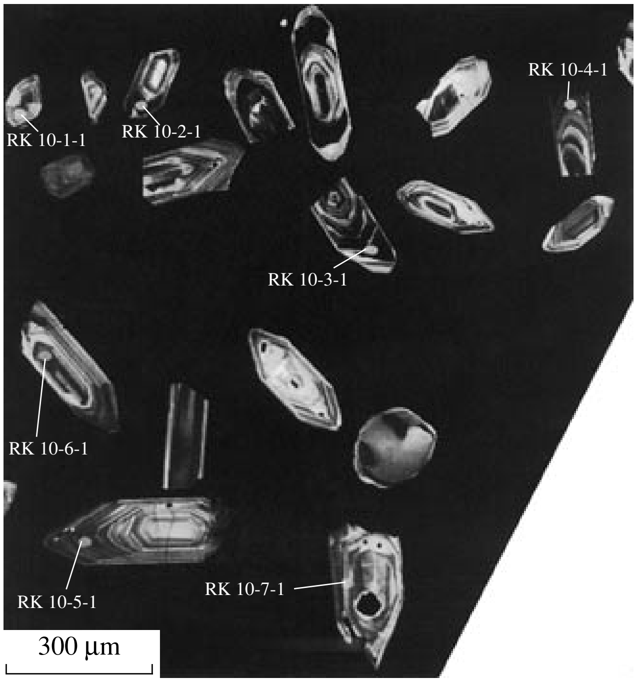

Fig. 3. Morphology of zircon crystals from plagiogranites of the Gremyach'e Massif and their internal structure revealed by the cathodoluminescence method (sample RK-10-00). Ellipses show the points subjected to isotopic studies. Point numbers are as in Table 2.

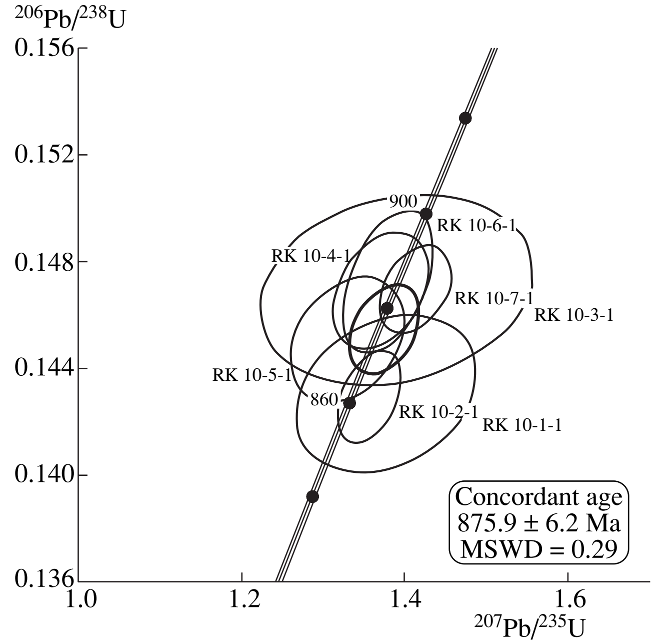

Fig. 4. The U–Pb isotopic diagram with concordia plotted for zircons from plagiogranites of the Gremyach'e Massif (sample RK-10-00). For the results of analyses, see Table 2.

block in Gornaya Shoria revealed no Early Precambrian crystalline basement in this region [1].The new data make it necessary to carry out further additional geochronological and isotopic–geochemical observations in the Kuznetskii Alatau and adjacent regions to determine the lateral distribution of this old continental block and to define whether or not similar rocks are present in the western part of the Altai–Sayan mobile belt.

ACKNOWLEDGMENTS

We thank A.G. Vladimirov, A.D. Nozhkin, O.M. Turkina, A.E. Izokh, N.N. Kruk, G.A. Babin, and T.B. Bayanova for fruitful discussions and valuable remarks during preparation of the manuscript for publication and A.D. Kireev, N.M. Glukhova, I.V. Nikolaeva, S.V. Palesskii, V.V. Markova, and S.V. Panteeva for their help in analytical studies.

This work was supported by the Russian Foundation for Basic Research (project no. 06-05-64767) and the Presidium of the Siberian Division of the Russian Academy of Sciences (integration project no. 10.7.2).

REFERENCES

1. A. G. Vladimirov, A.P. Ponomareva, S.A. Kargopolov, et al., Stratigr. Geol. Correlation **7**, 437 (1999) [Stratigr. Geol. Korrelyatsiya **7** (5), 28 (1999)].
2. S.P. Shokal'ski, G.A. Babin, A.G. Vladimirov, et al., *Correlation of Igneous and Metamorphic Complexes in the Western Altai–Sayan Mobile Belt* (SO RAN, Novosibirsk, 2000) [in Russian].
3. G.V. Pinus, V.A. Kuznetsov, and I.M. Volokhov, *Ultramafics of the Western Altai–Sayan Mobile Belt* (SO RAN, Novosibirsk, 1958) [in Russian].
4. A.I. Goncharenko, P.P. Kuznetsov, V.A. Simonov, et al., *Ophiolitic Association of Kuznetskii Alatau* (Nauka, Novosibirsk, 1982) [in Russian].
5. V. V. Velinskii, D. P. Nikolaev, O. L. Bannikov, et al., Geol. Geofiz., No. 8, 31 (1985).
6. A. V. Plotnikov, S. I. Stupakov, G. A. Babin, et al., Dokl. Earth Sci. **370**, 608 (2000) [Dokl. Akad. Nauk **370**, 80 (2000)].
7. N. L. Dobretsov, V. A. Simonov, M. M. Buslov, and A. V. Kotlyarov, Geol. Geofiz. **46**, 952 (2005).
8. S. N. Rudnev, A. G. Vladimirov, V. A. Ponomarchuk, et al., Dokl. Earth Sci. **396**, 492 (2004) [Dokl. Akad. Nauk **396**, 369 (2004)].
9. S. N. Rudnev, N. N. Kruk, and M. L. Kubiida, in *Materials of the Meeting: Geodynamic Evolution of the Lithosphere beneath the Central Asian Mobile Belt (from Ocean to Continent)* (IZK SO RAN, Irkutsk, 2005), Vol. 2, pp. 81–84 [in Russian].

10. N. N. Kruk, S. N. Rudnev, A. G. Vladimirov, et al., Dokl. Earth Sci. **369A**, 1387 (1999) [Dokl. Akad. Nauk **369**, 395 (1999)].

11. L. V. Alabin, Geol. Geofiz., No. 4, 81 (1966).

12. O. M. Turkina, Geochem. Int. **38**, 640 (2000) [Geokhimiya **38**, 704 (2000)]

13. S. N. Rudnev, A. G. Vladimirov, G. A. Babin, et al., in *Materials of the 38th Tectonic Meeting: Tectonics of the Crust and Mantle* (GEOS, Moscow, 2005), Vol. 2, pp. 152–155 [in Russian].

14. A. B. Kuz'michev, *Tectonic History of the Tuva–Mongol Massif: Early Baikalian, Late Baikalian, and Early Caledonian Stages* (Probel-2000, Moscow, 2004) [in Russian].

15. V. P. Kovach, D. I. Matukov, N. G. Berezhnaya, et al., in *Materials of the Meeting: Geodynamic Evolution of the Lithosphere beneath the Central Asian Mobile Belt (from Ocean to Continent)* (IZK SO RAN, Irkutsk, 2005), Vol. 1, pp. 125–128 [in Russian].