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GEOLOGY

Age of the Stanovoy Complex of East Siberia: Evidence from SHRIMP II Ion Microprobe Data

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Gniesses, crystalline schists, migmatites, and granite gneisses of the Stanovoy Complex compose much of the Dzhugdzhur–Stanovoy Foldbelt (DSFB), which is separated from the Aldan Shield by the Stanovoy collisional suture and extends from the Nyukzhi River in the west to the Sea of Okhotsk in the east. In the south, it is bounded by the Mongolia–Okhotsk belt [1]. The Stanovoy Complex is traditionally attributed to the Late Archean without any isotope–geochronological evidence. However, recently we have obtained a great amount of convincing data indicating that not only allochthonous granitoids, which are widespread in the study region and were previously regarded as Early Proterozoic formations [2], but also large massifs of late Stanovoy granites, are of Mesozoic age (138–142 Ma) [3, 4]. The Archean date (2835 Ma) was only obtained for the Stanovoy granites from the Dambukin block (central DSFB) metamorphosed under granulite facies at about 2700 Ma [5].

This work is focused on the amphibolite-grade gneisses, crystalline schists, migmatites, and granite gneisses of the Elgakan Group of the Stanovoy Complex (Stanovoy block, western DSFB). This group is mainly composed of calc-alkaline basic and intermediate rocks [6], which experienced intense granitization that produced tonalite–trondhjemite–granodiorite nebulites (Lc_1). These processes were identified as magmatic replacement with undoubted melting of the metasomatically reworked material [6, 7]. Syndeformational partial melting also took place later and produced at least three generations of granite leucosomes ($Lc_{2–4}$). An important stage in the tectonic evolution of the region [6] was the formation of thrust–nappe structures involving all rock complexes. These deformations gave rise to new generations of granite veins (Lc_5), which correlate with the Late Stanovoy Complex and compose its deep-seated autochthonous part.

Zircon age was determined on a high-resolution SHRIMP-II ion microprobe at the Center of Isotopic Research, Karpinskii All-Russia Research Institute of Geology. The datings were carried out on samples of Stanovoy granite gneiss (Lc_1) containing relict bands of biotite–amphibole schists, amphibolites, and granites Lc_5.

Based on morphology, structure, and previous age estimates, zircons from the Stanovoy granite gneisses are subdivided into the following four types, which represent populations of different ages (from old to young).

(I) Light pink euhedral prismatic crystals 150–200 μm in size (elongation coefficient, K_{el} = 2–3). Their cathodoluminescence (CL) image shows cores with thin rhythmic zoning and light-colored shells 5 to 40 μm in thickness (Figs. 1a–1d). Thin zoned cores contain 289–2307 ppm U and 25–766 ppm Th (Th/U ratio 0.03–0.68). Such wide variations are related to intense alterations of the zircon crystals. The point with the relict primary near-concordant isotope ratios (Fig. 1a) has 379 ppm U and 98 ppm Th (Th/U 0.26). Figure 1b shows two- and occasional three-layered shells indicating multiple growth of the zircon crystal.

(II) Dull brownish prismatic and rounded crystals. The CL image demonstrates black metamict cores and light-colored shells of variable thickness (Figs. 1f, 1g), reflecting different grades of metasomatic alteration of grains of type I, up to the point of their disappearance in some places. The cores have a heterogeneous block structure. They show wide compositional variations (U 227–2515 ppm, Th 18–301 ppm Th, Th/U 0.02–0.35). Intense U and Th enrichment is presumably related to the metasomatic granitization. The data point with near-concordia age contains 1230 ppm U and 79 ppm Th (Th/U 0.06).

(III) Colorless slightly elongated and equant rounded grains (Figs. 1e, 1f). The CL image typically exhibits thin rhythmic zoning. Spotted and sectorial

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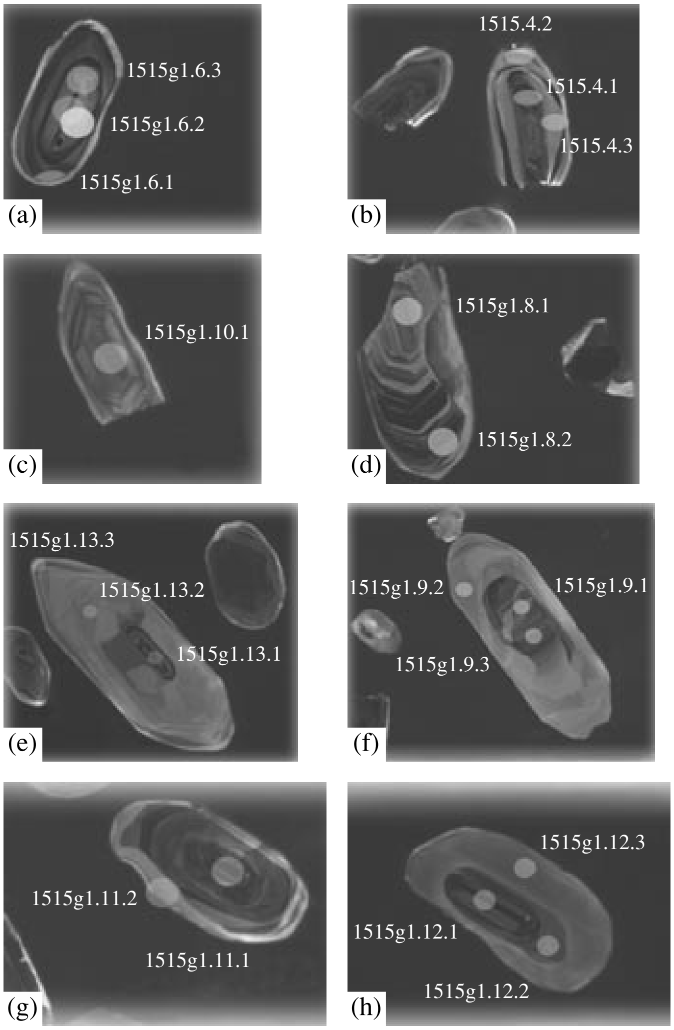

Fig. 1. Cathodoluminescence image of zircons from granite gneiss 1515g. Spot analysis numbers are as in the table.

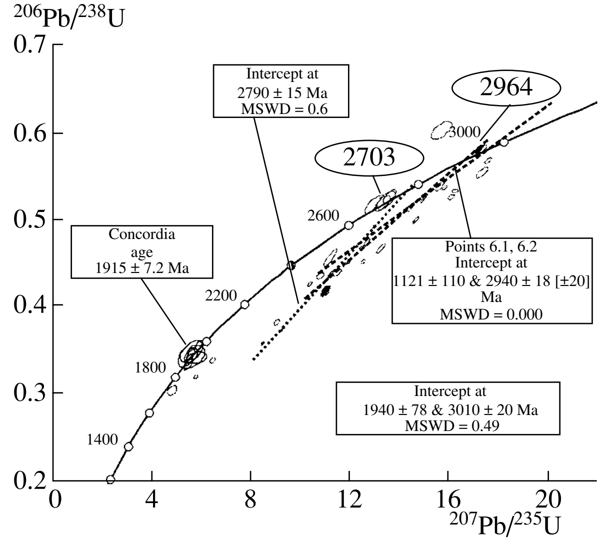

Fig. 2. Concordia diagram for zircons from the Stanovoy granite gneiss. Calculated concordia or intercept ages are shown in boxes. Concordant single grain values are shown by bold type in ovals.

zoning is rare in this sample. The crystal size is 70–400 μm (K_{el} = 2–3). The composition of this zircon sample (29–61 ppm U, 63–139 Th, and extremely high Th/U ratio 1.66–2.28) indicates its formation during high-temperature metamorphism [8].

(IV) Colorless prismatic crystals identical to zircon III in morphology and CL image. They grow around zircons I–III (Figs. 1b, 1e, 1f–1h) and predominate in the zircon monofraction. The crystal size is 150–400 μm (K_{el} = 2–3). They contain 7–431 ppm U and 0–12 ppm Th. The Th/U ratio is extremely low (0.0–0.06). Such a geochemistry is typical of metamorphic zircons.

The rhythmically zoned cores of type I contain devitrified and possibly glassy melt inclusions, whereas rims and individual grains of types II–IV contain only fluid inclusions.

The rhythmically zoned zircons of type I mainly define discordant isotope ratios, which cannot be approximated with sufficient accuracy (Fig. 2). This is consistent with the polymetamorphic evolution of the studied complex. Let us consider the near-concordia points. The age obtained for the core with minimum discordance (3%) is 2964 ± 22 Ma (Fig. 2). The discordia defined by variably altered zircons from points 1.6.2, 1.12.1, and 4.1 with maximum $^{207}Pb/^{206}Pb$ age defines an upper intercept at 3010 ± 20 Ma. This age presumably corresponds to the protolith age.

The next group of near-concordia points in Fig. 2 consists of zircons II and III. The discordia defined by zircons II yields an age of 2790 ± 15 Ma. The isotope ratios for zircon III corresponding to minimum discordance (2%) define an age of 2703 ± 20 Ma, which is taken as the rock age. Although the error can be underestimated during such calculations, the obtained dates can be used for correlation of geological events. This value can be interpreted as the age of metamorphism of granitization.

The third group of the points clustered near concordia is ascribed to zircons IV. Their six points define a concordia age of 1915 ± 7 Ma (discordance ±1%, table). In the given case, data points show a wide scatter along concordia, which could strongly underestimate the error. Judging from zircon features, this dating marks the metamorphic event related to migmatization $Lc_{2–4}$.

Isotope–geochronological study of granite Lc_5 correlated with late Stanovoy granites will be the object of special discussion. Let us note only that the calculated concordia age of zircon in them is 139 ± 4 Ma.

Summing up, the protolith datings of 2964 and 3010 Ma are the oldest ages in the DSFB, which approach the model Nd age obtained for the Stanovoy granites and charnockites of the Dambukin block with the age of the igneous protolith equal to 2833 ± 15 and

Analytical data on zircons from granite gneisses (sample 1515e/1)

Data points	Zircon type	Concentrations						Age, Ma		D, %	Isotope ratios					
		$^{206}Pb_c$, %	U, ppm	Th, ppm	Th/U	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	(1) $^{206}Pb/^{238}U$	(1) $^{207}Pb/^{206}Pb$		(1) $^{207}Pb^*/^{206}Pb^*$	± %	(1) $^{207}Pb^*/^{235}U$	± %	(1) $^{206}Pb^*/^{238}U$	± %
1.1	II	0.06	437	22	0.05	0.05	166	2364 ± 12	2712 ± 18	15	0.1866	1.10	11.40	1.20	0.4431	0.62
2.1	III	0.00	29	63	2.17	2.21	13.2	2703 ± 27	2650 ± 16	–2	0.1796	0.95	12.90	1.60	0.5209	1.20
3.1	I	0.01	846	194	0.23	0.24	366	2629 ± 12	2912 ± 4	11	0.2108	0.24	14.64	0.59	0.5035	0.54
4.1	I	0.01	1075	517	0.48	0.50	487	2730 ± 12	2874 ± 3	5	0.2059	0.21	14.97	0.56	0.5273	0.52
4.2	IV	0.06	208	12	0.06	0.06	61.1	1897 ± 11	2173 ± 19	15	0.1357	1.10	6.40	1.30	0.3420	0.66
4.3	II	0.04	184	57	0.31	0.32	85.9	2791 ± 15	2899 ± 6	4	0.2092	0.40	15.63	0.79	0.5418	0.68
5.1	III	0.21	56	98	1.66	1.79	29.4	3054 ± 27	2725 ± 23	– 11	0.1880	1.40	15.71	1.80	0.6060	1.10
6.1	II	–	2515	260	0.10	0.11	952	2354 ± 10	2688 ± 7	14	0.1839	0.40	11.18	0.65	0.4408	0.51
7.1	IV	0.69	39	2	0.05	0.04	10.3	1728 ± 18	1844 ± 42	7	0.1127	2.30	4.78	2.60	0.3074	1.20
7.2	II	0.38	752	90	0.12	0.12	245	2068 ± 10	2625 ± 6	27	0.1771	0.34	9.23	0.64	0.3783	0.55
8.1	II	–	429	37	0.09	0.09	169	2440 ± 30	2620 ± 11	7	0.1764	0.69	11.19	1.60	0.4601	1.50
9.1	IV	0.30	18	0	0	0.01	5.4	1923 ± 26	1904 ± 42	–1	0.1166	2.30	5.59	2.80	0.3476	1.50
10.1	IV	0.15	38	0	0	0.01	11.1	1876 ± 20	1903 ± 32	1	0.1165	1.80	5.43	2.10	0.3377	1.20
11.1	IV	0.06	31	0	0	0.00	9.1	1900 ± 21	1889 ± 27	–1	0.1156	1.50	5.46	2.00	0.3427	1.30
12.1	III	0.07	50	114	2.28	2.36	22.8	2743 ± 22	2706 ± 13	–1	0.1859	0.79	13.59	1.30	0.5304	0.98
13.1	IV	1.65	7	0	0	0.01	2.12	1917 ± 42	1900 ± 100	–1	0.1163	5.80	5.55	6.30	0.3464	2.50
14.1	II	0.01	845	222	0.26	0.27	347	2518 ± 11	2762 ± 6	10	0.1923	0.39	12.67	0.67	0.4779	0.54
15.1	IV	0.15	16	1	0.06	0.03	4.92	1922 ± 28	1889 ± 50	–2	0.1156	2.80	5.54	3.30	0.3474	1.70
1.1.1	I	0.06	516	111	0.22	0.22	209	2490 ± 9	2759 ± 7	10	0.1920	0.44	12.48	0.61	0.4715	0.43
1.2.1	I	0.02	526	356	0.68	0.70	213	2486 ± 16	2857 ± 7	13	0.2039	0.44	13.23	0.90	0.4706	0.78
1.3.1	I	0.01	2307	766	0.33	0.34	1070	2784 ± 7	2923 ± 5	5	0.2124	0.29	15.82	0.43	0.5403	0.32
1.4.1	I	0.02	988	204	0.21	0.21	450	2740 ± 8	2982 ± 7	8	0.2203	0.44	16.09	0.57	0.5297	0.37
1.5.1	II	0.01	1096	18	0.02	0.02	340	1989 ± 6	2552 ± 8	22	0.1694	0.47	8.44	0.60	0.3614	0.38
1.6.1	I	0.02	379	98	0.26	0.27	190	2964 ± 13	2945 ± 7	–1	0.2152	0.42	17.32	0.68	0.5838	0.54
1.7.1	II	0.09	370	36	0.10	0.10	123	2104 ± 11	2552 ± 11	18	0.1694	0.64	9.02	0.88	0.3859	0.61
1.6.2	I	0.01	718	239	0.33	0.34	352	2914 ± 10	3000 ± 5	3	0.2227	0.34	17.55	0.54	0.5716	0.41
1.6.3	II	0.10	227	41	0.18	0.19	81.9	2261 ± 14	2735 ± 12	17	0.1892	0.73	10.96	1.00	0.4201	0.73
1.8.1	I	0.00	289	25	0.09	0.09	139	2858 ± 17	3017 ± 9	5	0.2251	0.58	17.32	0.94	0.5579	0.75
1.8.2	I	0.03	1031	35	0.03	0.03	404	2420 ± 7	2819 ± 5	14	0.1991	0.32	12.51	0.48	0.4555	0.35
1.9.1	IV	0.00	431	11	0.03	0.03	120	1804 ± 7	2080 ± 11	13	0.1287	0.64	5.73	0.79	0.3230	0.47
1.9.2	III	0.04	45	97	2.16	2.20	20.5	2723 ± 29	2703 ± 22	–1	0.1856	1.40	13.45	1.90	0.5257	1.30
1.9.3	II	0.02	569	67	0.12	0.12	210	2306 ± 8	2603 ± 7	11	0.1746	0.44	10.36	0.59	0.4302	0.40
1.10.1	I	0.00	336	145	0.43	0.45	149	2689 ± 13	2842 ± 8	5	0.2019	0.52	14.41	0.77	0.5176	0.57
1.11.1	II	0.01	1230	79	0.06	0.07	523	2594 ± 7	2741 ± 4	5	0.1899	0.25	12.97	0.40	0.4954	0.31
1.11.2	IV	1.60	79	3	0.04	0.04	23.8	1912 ± 21	1977 ± 79	3	0.1214	4.40	5.78	4.60	0.3453	1.20
1.12.1	I	–	1584	419	0.26	0.27	730	2768 ± 5	2976 ± 7	7	0.2194	0.47	16.23	0.52	0.5363	0.24
1.12.2	III	0.02	382	133	0.35	0.36	144	2348 ± 10	2634 ± 14	11	0.1780	0.84	10.78	0.99	0.4393	0.53
1.12.3	IV	0.00	15	0	0	0.01	4.56	1946 ± 41	1872 ± 85	–4	0.1145	4.70	5.56	5.30	0.3524	2.40
1.13.1	II	0.00	959	301	0.31	0.32	375	2417 ± 6	2742 ± 5	12	0.1900	0.30	11.92	0.43	0.4549	0.30
1.13.2	III	0.03	61	139	2.28	2.35	27.4	2709 ± 25	2696 ± 19	–1	0.1847	1.20	13.30	1.60	0.5224	1.10
1.13.3	IV	0.25	170	10	0.06	0.06	52.6	1974 ± 21	1931 ± 21	–2	0.1183	1.20	5.85	1.70	0.3583	1.20

Note: Errors are given at 1σ level. (Pb_c, Pb*) Common and radiogenic lead, respectively. Standard was calibrated with an error of no more than 0.38%. (1) Common lead was corrected using measured ^{204}Pb. (D) Discordance coefficient, 100((1 – ($^{206}Pb/^{238}U$ age)/($^{207}Pb/^{206}Pb$ age)).

2828 ± 34 Ma, respectively [5]. The high-temperature regional metamorphism, migmatization, and granitization of the Elgakan Group with an age of 2703 ± 20 Ma is correlated with known metamorphic events, which spanned the entire DSFB and Stanovoy suture area with granulite-facies metamorphism: 2648 ± 3 Ma in the Dambukin block [5], 2707 ± 7 in the Kurulta block [9], and 2658 Ma in the Larba (Elgakan) block [1]. These facts confirm the previous conclusion [1] about Archean metamorphic zoning and lateral transition from amphibolite to granulite facies, which were tectonically disturbed later.

The data obtained showed that the Elgakan Group experienced Early Proterozoic metamorphism 1915 ± 7 Ma ago. Despite some uncertainty concerning this age, the event mentioned above is quite consistent with widespread high-grade, often high-pressure metamorphism estimated at 1955 ± 35 Ma in the Sutam block [10], 1849 ± 15 Ma in the Kurulta block [9], 1896 ± 15 Ma in the Dambukin block, and 1950 ± 60 Ma in the Mogocha block [11]. This event is related to collisional zones, which were formed by accretion of fragments of the Archean crust to the southern (in present-day coordinates) margin of the Siberian Craton.

The age of 139 ± 4 Ma established for late granites is quite consistent with the age of previously dated late Stanovoy granites [4]. This fact confirms the validity of the previous correlation and conclusion about Cretaceous metamorphism and migmatization of the Stanovoy Complex [12].

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