ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 416, No. 7, pp. 1070–1075. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © A.A. Krasnobaev, V.I. Kozlov, V. N. Puchkov, A.N. Larionov, A.G. Nekhorosheva, N.G. Berezhnaya, 2007, published in Doklady Akademii Nauk, 2007, Vol. 416, No. 2, pp. 241–246.

GEOCHEMISTRY

The Polygenous–Polychronous Nature of Zircons and the Problem of the Age of the Barangulov Gabbro–Granite Complex

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Received April 17, 2007

DOI: 10.1134/S1028334X07070203

The first precision U–Pb (SIMS SHRIMP II) zircon datings of gabbros (728 ± 8 Ma) and granites (723 ± 10 Ma) have been reported for the Barangulov gabbro–granite complex located in the northern Uraltau zone of the southern Urals. The temporal evolution of the magma chamber has been traced based on zircons. The available data suggest that gabbros and granites of the study region are dated at 725 ± 5 Ma. Based on these data, metasedimentary rocks of the Mazarin and Arvyak formations, which host the Barangulov gabbro–granite complex, are older than 725 Ma. This estimate supports the correlation of metamorphic rocks of the Mazarin and Arvyak formations of the northern Uraltau zone with rocks of the Karatau Group in Riphean type sections of the Bashkirian anticlinorium, southern Urals.

The Barangulov Complex (BC) of the closely interrelated gabbro and granitoid bodies (from 0.5 × 1 to 4 × 7 km^2 in size) is located on the western slope of the southern Urals 13 km east of the Settlement of Tirlyan and 25 km northeast of the town of Beloretsk. Igneous rocks in this region are confined to a NE-striking zone 12–15 km long and 0.5–1 to 5 km wide (Fig. 1). According to [1, 2], the Barangulov Complex is mainly composed of granites characterized by intrusive contacts with the gabbro bodies. The granites often make up numerous dikes, schlieren, and veinlets in the gabbro bodies. Differently reworked mafic clasts are developed in the granites near the contact zone. The absence of gradual transitions between the gabbros and granites suggest their affiliation to different pulses of magmatism. Final manifestations of the pulses are recorded by aplite, granite porphyry, and diabase dikes. Virtually all rocks of the BC underwent postmagmatic alterations, crushing, and foliation. According to [1–5], the available geochronological estimates of the BC age vary from the Upper Proterozoic to the Middle Paleozoic: 340–400 Ma based on K–Ar dating; 660 ± 15 Ma [4] based on the single U–Pb zircon dating without isotope analysis of Pb; and 1.8 Ga based on Pb–Pb mass-spectrometric analysis [5]. Intrusive contacts of the gabbros and granites with metasedimentary rocks of the Upper Riphean Mazarin and Arvyak formations have reliably been established at upper reaches of the Vishnevyi Dol and Ryastok rivers and in the Mt. Galishinskii Kamen area [1, 2]. This fact has principle significance for the BC timing.

Zircons. Under the optical microscope, the studied zircons are observed as sufficiently homogeneous pale pink crystals with high idiomorphism and elongation varying from 1.5–2 to 6–7. They are characterized by the presence of primary inclusions (Fig. 2, crystals *1–5*). Long-prismatic crystals (type I) are highly sterile (homogeneous) due to the virtual absence of inclusions (Fig. 2, crystal *2*). Transition to the short-prismatic variety (type II) is accompanied by a drastic increase in the amount of inclusions ranging from rare acicular crystals (probably rutile or apatite) and rock-forming minerals to large irregular fluid or melt inclusions. These differences are caused by evolution of the primary gabbro melt: at early stages, the gabbro melt represents a homogeneous system with temperature parameters allowing the formation of only the highest temperature solid phase (zircon of type I). Cooling of the melt promotes the formation of crystals of late zircon II nuclei of accessory and rock-forming minerals and melt

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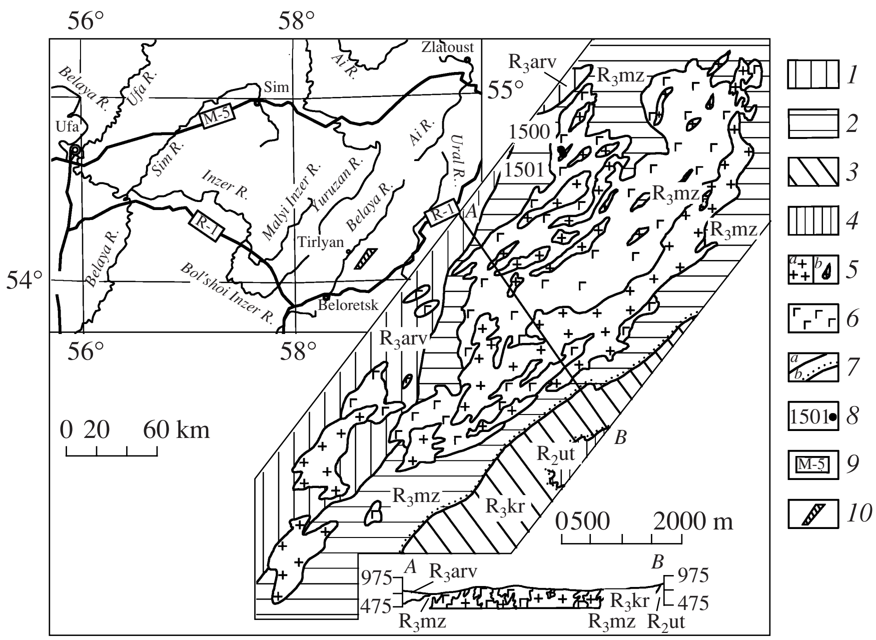

Fig. 1. Schematic geological structure of the Barangulov gabbro–granite complex, southern Urals. Compiled by V.I. Kozlov based on [1, 2]. (*1–3*) Upper Riphean formations: (*1*) Arvyak (R_3arv); (*2*) Mazarin (R_3mz); (*3*) Kurtash (R_3kr); (*4*) Middle Riphean Utkal Formation (R_2ut); (*5*) granites: (*a*) large bodies, (*b*) dikes; (*6*) gabbro; (*7*) geological boundaries: (*a*) intrusive and normal conformable, (*b*) unconformable; (*8*) sites sampled for the zircon age determination and their numbers; (*9*) highways: (M-5) federal Moscow–Vladivostok, (R-1) republic Ufa–Beloretsk–Uchaly; (*10*) location of the Barangulov Complex.

microinclusions making an alien phase in the zircon crystals. This fact indicates initiation of the irreversible process of melt crystallization, i.e., the formation of gabbro).

In terms of the shape, transparency, color, and type of inclusions, the granite-hosted zircons are similar to late varieties (type II) in the gabbro (Fig. 2, crystals *6–12*). They are characterized by the distribution of inclusions along growth zones (Fig. 2, crystal *7*) and the partial entrapment of solid-phase inclusions in some places (crystal *9*). Some crystals show distinct signs of crushing and metasomatic alteration (crystals *10–12*). These data suggest the presence of genetic and hereditary relations between the gabbro and granite melts.

Differences between gabbro-hosted zircons are confirmed by their cathodoluminescence (CL) patterns. Zircons of type I (Fig. 2, crystals *13–15*) are characterized by homogeneity and fine linear zonality; zircons of type II, by an intricate morphology combined in some cases with sectorial pattern (crystals *16–18*). Distinct melt inclusions are confined to the marginal and central parts of crystals (crystals *19* and *20*). One can also see patchy metasomatically altered zones crosscutting primary growth zones (crystal *20*). Separate growth zones and even successive generations are more distinct and contrasting in the granite-hosted zircons (crystals *21–26*) with CL patterns similar to those of the gabbro-hosted zircons of type II. Crystals with different zircon generations show signs of dissolution and alteration of older generations preserved as relicts in some places (crystal *26*).

According to geochemical data (table, Fig. 3), the gabbro-hosted zircon I is distinguished from other varieties by higher ^{232}Th/^{238}U values (0.90–1.00), while the granite- and type II gabbro-hosted zircons are rather similar (0.51–0.86 and 0.53–0.87, respectively). In Fig. 3, data points of the gabbro-hosted zircons make up a compact cluster that intersects the field of the granite-hosted zircons (crystal 4.1 located at the upper corner is an exception). Moreover, one can see two trends (*A* and *B*) that reflect the possible scenarios of the gabbro–granite relationship: compositional legacy from basic to acid rocks (trend *B*, partially *A*); autonomous evolution of a part of granitoids (trend *A*, $U < 220$ ppm); and existence of two pulses of magmatism responsible for the two-stage evolution of BC rocks.

Geochronology. All analyses were carried out with a SHRIMP II ion microprobe at the Central Research Center of the Karpinskii All-Russia Research Institute of Geology (Petersburg) according to the routine procedure [6]. The age parameters of zircons (table; Figs. 2, 4) indicate their temporal evolution and supplement the characteristics based on petrology and mineralogy. Three crystals of type I (table, sample 1500, analyses 2.1, 3.1, and 4.1; Figs. 2, 4a) make up a sufficiently homogeneous cluster with an age estimated at 733 ± 14 Ma. The ignored crystal (analysis 1.1) with the minimal U content can be slightly older (up to 751 ± 14 Ma based on the ^{206}Pb/^{238}U ratio). For the remaining crys-

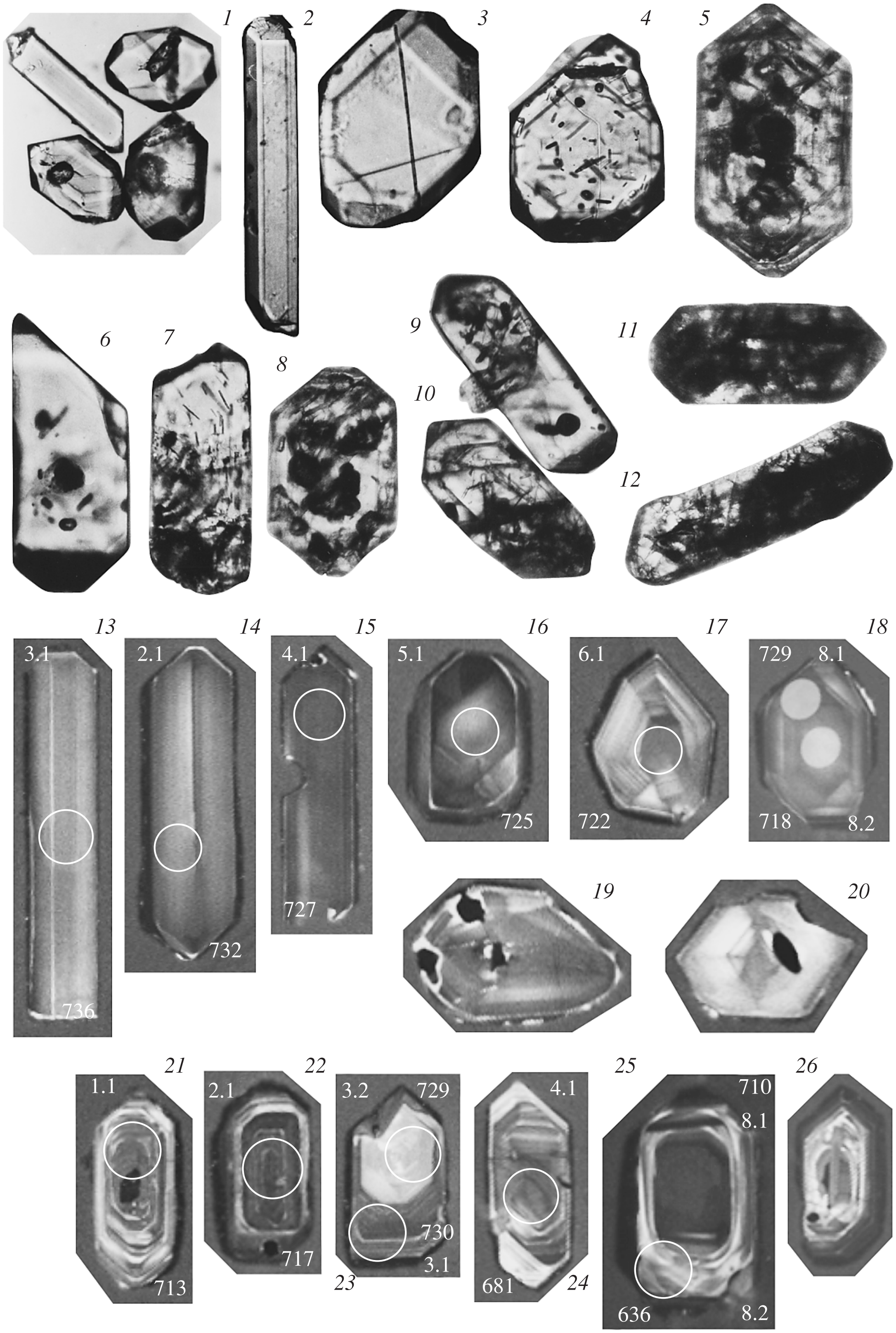

Fig. 2. Structure of zircons of the Barangulov Complex from the gabbros (*1–5, 13–20*) and granites (*6–12, 21–26*) based on optical (*1–12*) and cathodoluminescence (*13–26*) investigations. Circles indicate craters of analysis (up to 30 μm); double figures (2.1, 3.1, and others) indicate crystal and analysis numbers (see table); three-digit figures (732, 736, and others) designate age (Ma) based on $^{206}Pb/^{238}U$ data.

U–Pb age of zircons from the gabbros (K-1500) and granites (K-1501) of the Barangulov Complex

Crystal, analysis	$^{206}Pb_c$, %	U	Th	$^{232}Th/^{238}U$	^{206}Pb, ppm	Age, Ma		D, %	Isotope ratio			Rho
		ppm				$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$		$^{207}Pb^*/^{206}Pb^*$ (±%)	$^{207}Pb^*/^{235}U$ (±%)	$^{207}Pb^*/^{238}U$ (±%)	
Sample 1500												
1.1	0.26	231	204	0.91	24.6	751 ± 14	789 ± 79	5	0.0655 (3.8)	1.115 (4.2)	0.1236 (2)	0.460
2.1	0.40	270	235	0.90	28.0	732 ± 13	733 ± 65	0	0.0637 (3.1)	1.052 (3.6)	0.1203 (1.9)	0.531
3.1	0.50	294	285	1.00	30.7	736 ± 13	673 ± 76	–9	0.062 (3.6)	1.034 (4)	0.121 (1.9)	0.478
4.1	0.11	529	513	1.00	54.2	727 ± 13	759 ± 37	4	0.0645 (1.8)	1.062 (2.6)	0.1193 (1.9)	0.731
5.1	0.29	277	216	0.81	28.4	725 ± 13	751 ± 62	4	0.0643 (2.9)	1.055 (3.5)	0.1191 (1.9)	0.548
6.1	0.18	334	213	0.66	34.1	722 ± 13	688 ± 42	–5	0.0624 (2)	1.02 (2.7)	0.1186 (1.9)	0.697
7.1	0.28	296	151	0.23	30.6	729 ± 13	741 ± 45	2	0.064 (2.1)	1.057 (2.9)	0.1198 (1.9)	0.673
8.1	0.21	288	175	0.63	29.7	729 ± 13	729 ± 52	0	0.0636 (2.4)	1.051 (3.1)	0.1198 (1.9)	0.618
8.2	0.24	242	205	0.87	24.6	718 ± 13	762 ± 68	6	0.0646 (3.2)	1.05 (3.8)	0.1178 (2)	0.518
9.1	0.52	233	189	0.84	24.2	731 ± 14	698 ± 110	–4	0.0627 (5.3)	1.038 (5.6)	0.12 (2)	0.350
Sample 1501												
1.1	0.09	346	188	0.56	34.8	713 ± 13	715 ± 34	0	0.0632 (1.6)	1.018 (2.5)	0.1169 (1.9)	0.770
2.1	0.89	469	301	0.66	47.8	717 ± 13	588 ± 63	–18	0.0596 (2.9)	0.966 (3.5)	0.1177 (1.9)	0.547
3.1	0.20	382	190	0.51	39.4	730 ± 13	696 ± 53	–5	0.0627 (2.5)	1.036 (3.2)	0.1199 (1.9)	0.605
3.2	0.51	142	91	0.66	14.7	729 ± 13	658 ± 130	–10	0.0615 (6)	1.016 (6.4)	0.1197 (2.2)	0.339
4.1	0.57	456	258	0.58	43.9	681 ± 13	701 ± 66	3	0.0628 (3.1)	0.964 (3.6)	0.1114 (1.9)	0.528
5.1	0.16	135	94	0.72	14.0	735 ± 14	867 ± 77	18	0.068 (3.7)	1.132 (4.2)	0.1208 (2)	0.476
6.1	0.61	217	154	0.73	22.2	721 ± 13	683 ± 84	–5	0.0623 (3.9)	1.016 (4.4)	0.1184 (2)	0.446
7.1	1.32	106	64	0.62	10.9	719 ± 14	502 ± 140	–30	0.0573 (6.6)	0.931 (6.9)	0.1179 (2.1)	0.303
8.1	0.23	391	327	0.86	39.2	710 ± 13	714 ± 45	1	0.0632 (2.1)	1.014 (2.8)	0.1164 (1.9)	0.665
8.2	5.10	555	387	0.72	52.2	636 ± 14	564 ± 430	–11	0.059 (20)	0.84 (20)	0.1036 (2.3)	0.114

Note: Errors are quoted at the 2σ level. (Pb_c, Pb^*) Common and radiogenic Pb, respectively. Error of the standard calibration is 0.65%. Correction for common Pb is based on ^{204}Pb. (*D*) Discordance; (*Rho*) correlation coefficient

tals, which represent type II, the most probable age is estimated at 728 ± 8 Ma (Figs. 2, 4b; table, sample 1500, analyses 5.1–9.1). This group also accommodates partly altered individuals, which include coexisting zones (generations) with virtually concordant age values (729 Ma, table, sample 1500, analysis 8.1) and altered zones (718 Ma based on the $^{206/238}U$ dating, analysis 8.2). Taking into consideration analytical errors, the age parameters of both gabbro-hosted zircon types are virtually similar and close to the integral dating based on all crystals: 729 ± 8.2 Ma (2σ, MSWD = 0.03). This value is naturally closer to the estimate based on the most abundant zircon II. Taking into consideration the existence of different zircon types, age estimates for which are smoothed away in the course of joint calculations, we can assume that evolution of the gabbro melt in the BC field was accompanied by the manifestation of two stages of zircon formation. The first stage was marked by the formation of zircon I (733 ± 14 Ma). The second stage (728 ± 8 Ma) was characterized by the large-scale formation of younger zircons and all rock-forming minerals. This stage also corresponds to the timing of the gabbro massif formation. Thus, the duration of the gabbro melt evolution can reach 5 Ma.

Zircons in granites of the BC are polychronous minerals: some zircon crystals retained the starting age parameters, whereas other crystals underwent alterations and lost the status of closed age systems. Based on the $^{206}U/^{238}U$ ratio and discordance values (0–30),

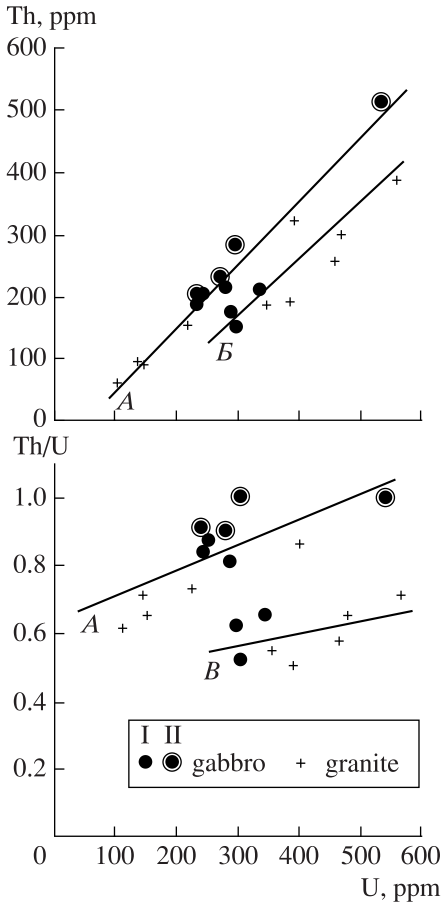

Fig. 3. Geochemical evolution of zircons from the gabbros (types I and II) and granites of the Barangulov Complex. (*A*, *B*) Evolution trends.

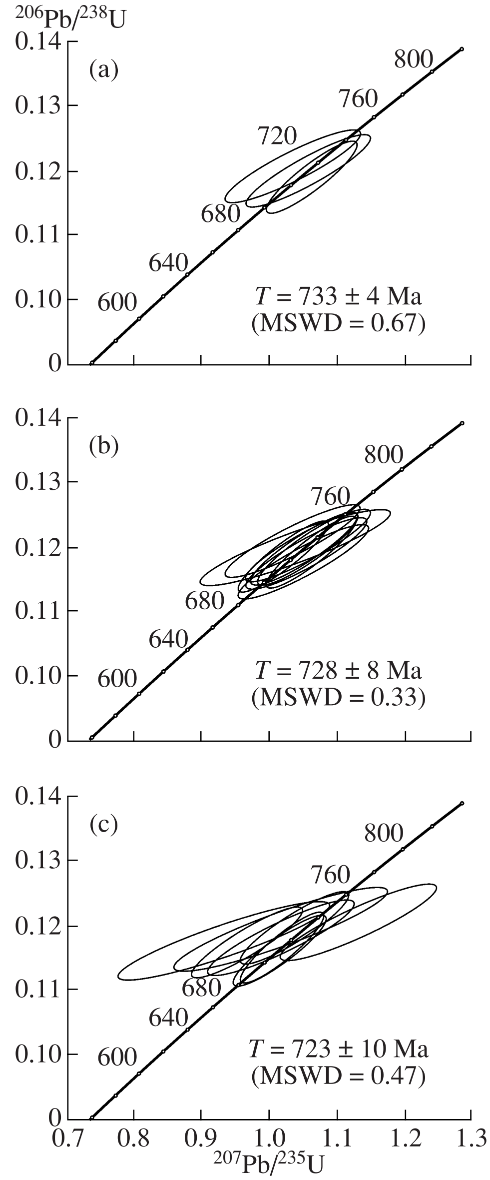

Fig. 4. U–Pb age of zircons from different rocks of the Barangulov Complex. (*a*, *b*) Zircon from gabbro (types I and II, respectively); (c) zircon from granite. Error ellipse size is given at the 2σ level.

age estimates of the zircons range from 735 to 681 Ma (table). Moreover, estimates within a single crystal can vary from the virtually concordant value (710 ± 13 Ma) to the altered value of 636 ± 14 Ma (table, sample 1501, analyses 8.1 and 8.2). In general, datings of the granite-hosted zircons suggest their hereditary nature relative to the gabbro-hosted zircons and the slightly younger generation of some crystals (Fig. 2, crystals *22–25*). The age of granitoid-hosted zircons and granites is estimated at 723 ± 10 Ma (Fig. 4c), except for analyses 8.2 and 4.1 (table, sample 1501) that are appreciably rejuvenated relative to other individuals. However, processes of the formation and transformation of zircons continued for at least 7 to 8 Ma. This is suggested by the presence of some concordant datings (table, sample 1501, analyses 1.1 and 8.1) and dating of the late zircon generation (analysis 8.2). As in the gabbro-hosted zircons, the integral zircon dating (i.e., without the anomalous analysis 8.2) yields 714.8 ± 8.7 Ma (2σ, MSWD = 0.80), which is closer to the timing of postmagmatic and metasomatic processes.

Based on all the data discussed above, the main stages of gabbro and granite formation are separated by an approximately 5-Ma-long interval, which is comparable with the duration of the evolution and fractionation of their parental melts.

Irrespective of interpretations of the isotope data discussed above, the dating of 725 ± 5 Ma should be considered the most realistic estimate for the gabbros and granites. It should be emphasized that both basic and acid rocks of the BC are assigned to a single system of long-term geological–petrological evolution with Upper Riphean metasedimentary rocks of the Mazarin and Arvyak formations as the host rocks. Hence, the latter rocks should be older than 725 Ma.

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