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GEOCHEMISTRY

A Local Source of Detritus for Rocks of the Ai Formation (Basal Level of the Lower Riphean Stratotype, Bashkir Uplift, Southern Urals): Evidence from U–Pb (LA-ICP-MS) Dating of Detrital Zircons

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Abstract—The results of U–Pb dating of detrital zircons separated from rocks of the Ai Formation are presented. A provenance-signal of a local source with an age of about 2.07 Ga has been documented, and the effect of the Ordovician magmatic episode on the sedimentary sequence has been revealed.

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The Bashkirian meganticlinorium (BMA), which is made up of Precambrian rocks, is exposed in the western part of the southern Ural nappe-and-fold belt (Fig. 1a) [8]. Its inner structure is complicated by the Zyuratkul Fault (Fig. 1b). The Bashkir Uplift (BU) [4], made up of Upper Precambrian sequences, is developed to the west of the fault, in the western part of the BMA. Their sections are taken as the summary Riphean stratotype: the Burzyan, Yurmata, and Karatau groups [8, 12] are the stratotypes of, respectively, the Lower, Middle, and Upper Riphean [7]. The Lower Riphean Burzyan Group is most completely represented in the northern **BU**. The Lower Burzyan Ai Formation with unconformity and conglomerates at the base [1, 2] is developed in the southern termination and on the western limb of the Taratash anticline with an Early Precambrian [8, 13, 14] Taratash granite-metamorphic complex at the core (Fig. 1).

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This paper reports new U–Pb data on detrital zircons (***dZr***) from a sandy matrix of conglomerates (sample P-127) and quartz sandstone (sample P-127-1) from the development field of the lower Ai Formation. The samples were taken on the western limb of the Taratash anticlinorium, at a point with the coordinates 55°43.440′ N, 059°50.065′ E, located on the right bank of the Ushat River (Fig. 1c). Eastward of the sampling location (downstream along the Ushat River) above the unexposed area, the stratigraphically and structurally higher terrigenous rocks contain magmatic rocks (sample K2218, Fig. 1c), which have an Ordovician age according to U–Pb zircon dating [3, 9]. In this relation, it is required to verify whether the host rocks ascribed to the Lower Riphean Ai Formation are Paleozoic in age. New data presented in this paper are compared with datings of ***dZr*** from the rocks of the Ai Formation from other sites (sample M08-16-1 in Fig. 1a, sample K13-206 in Fig. 1b) [6, 10, 11].

Dating of ***dZr*** from samples P-127 and P-127-1 was carried out at the Geochronological Research and Education Center of Kazan Federal University. Zircons were mounted on tape without polishing. An NWR213 Laser was coupled with TwoVol2 cell. A helium jet flow (500 mL/min) transported the ablated sample from the sample cell, while an argon jet flow (952 mL/min) transported it further to the spectrometer burner. Helium was also mixed with a small amount of N_2 (6 mL/min) to increase the signal recorded by the mass spectrometer. The isotope ratios were measured on a Neptune Plus (Thermo Scientific, Germany) double-focused multicollector mass spectrometer equipped with a jet interface. Laser ablation measurements were performed in the automated

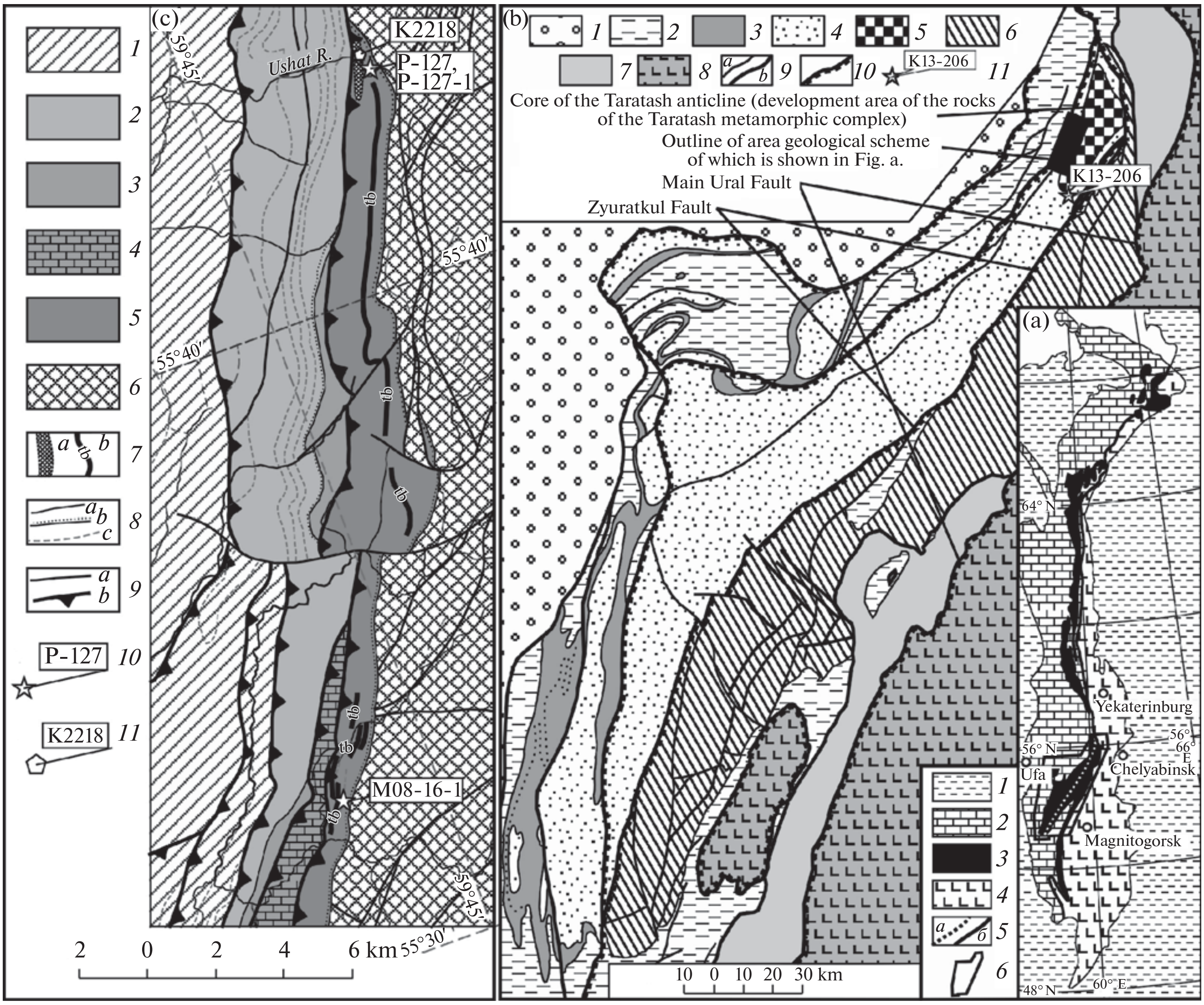

Fig. 1a. Schematic structural–tectonic zoning of the Ural fold-and-nappe belt. (*1*) Mesozoic–Cenozoic cover of the East European platform, Pechora, Caspian, and West Siberian plates and Turgai trough; (*2–3*) Western Ural megazone: (*2*) mainly sedimentary Ordovician–Middle Paleozoic sequences, (*3*) Ordovician complexes: Protouralides–Timanides of the zone of Central Uralian uplifts (mainly Late Precambrian (meta)sedimentary complexes in the south and (meta) volcanogenic–sedimentary complexes, granitoids, and rare ophiolites in the north); (*4*) East Uralian megazone (eastern Uralian Uralides: Ordovician, Silurian, Devonian, and Carboniferous mainly volcanogenic–sedimentary complexes); (*5*) Zyuratkul Fault (*a*), Main Ural Fault (*b*). (*6*) Outline of geological scheme (b). (b) Geological scheme of the Bashkirian Meganticlinorium (BMA) and conjugate structural units (modified after [11]). (*1*) Late Paleozoic complexes filling the trough; (*2–6*) Precambrian and Paleozoic complexes of the Western Ural megazone; (*2*) faunally characterized Paleozoic sequences, (*3–4*) Lower Paleozoic and Precambrian complexes of the Bashkir Uplift (BU): (*3*) Upper Vendian–Cambrian Asha Group; (*4*) Riphean stratotype: undivided deposits of the Upper (Karatau Group), Middle (Yurmata), and Lower (Burzyan Group); (*5*) Early Precambrian metamorphic complexes and granitoids (Taratash Complex); (*6*) unevenly metamorphosed Upper Precambrian Complexes of the eastern flank of the BMA (Taganai–Beloretsk tectonic unit after [4]); (*7*) unevenly metamorphosed Paleozoic and Late Precambrian complexes of the Uraltau zone (in the south) and Ufalei Zone (in the north); (*8*) Early and Middle Paleozoic complexes of the East Uralian megazone and marginal allochthons (Krakin and Tirlyan); (*9*) faults (*a*) disturbing the internal structure of the tectonic elements of BMA, (*b*) separating the BMA structures from the Uraltau and Ufalei zones; (*10*) large thrust surfaces and thrust bottom; (*11*) location of sample K13-206. (c) Geological scheme of the western limb of the Taratash anticline compiled using the State Geological Map, sheet N-40-VI (V.M. Moseichuk, Al.V. Tevelev, et al., 2017). (*1*) Paleozoic sequences, (*2–4*) Riphean sequences: (*2*) Upper Riphean (Caratavian), (*3*) Middle Riphean (Yurmatinian), (*4–5*) Lower Riphean (Burzyanian): (*4*) Satka Formation; (*5*) Ai Formation; (*6*) Early Precambrian metamorphic rocks and granitods (Taratash Complex); (*7*) (a) Ordovician magmatic rocks (body outlines are taken from [3]); (b) marker horizon made up of the Early Riphean (Navysh) basalts and trachybasalts; (*8*) (*a*) geological boundaries without signs of structural unconformity, (*b*) geological boundaries between complexes separated by structural unconformity (points from the side of the overlying rocks), (*c*) structural lines (boundaries between groups, formations, and members within shown stratified complexes); (*9*) faults: (*a*) disturbing the internal structure of the Early Precambrian Taratash granite–metamorphic complexes, (*b*) large thrust surface and thrust bases; (*10*) sampling localities (and their numbers) for detrital zircons; (*11*) location of sample K2218 for isotope dating of magmatic rocks.

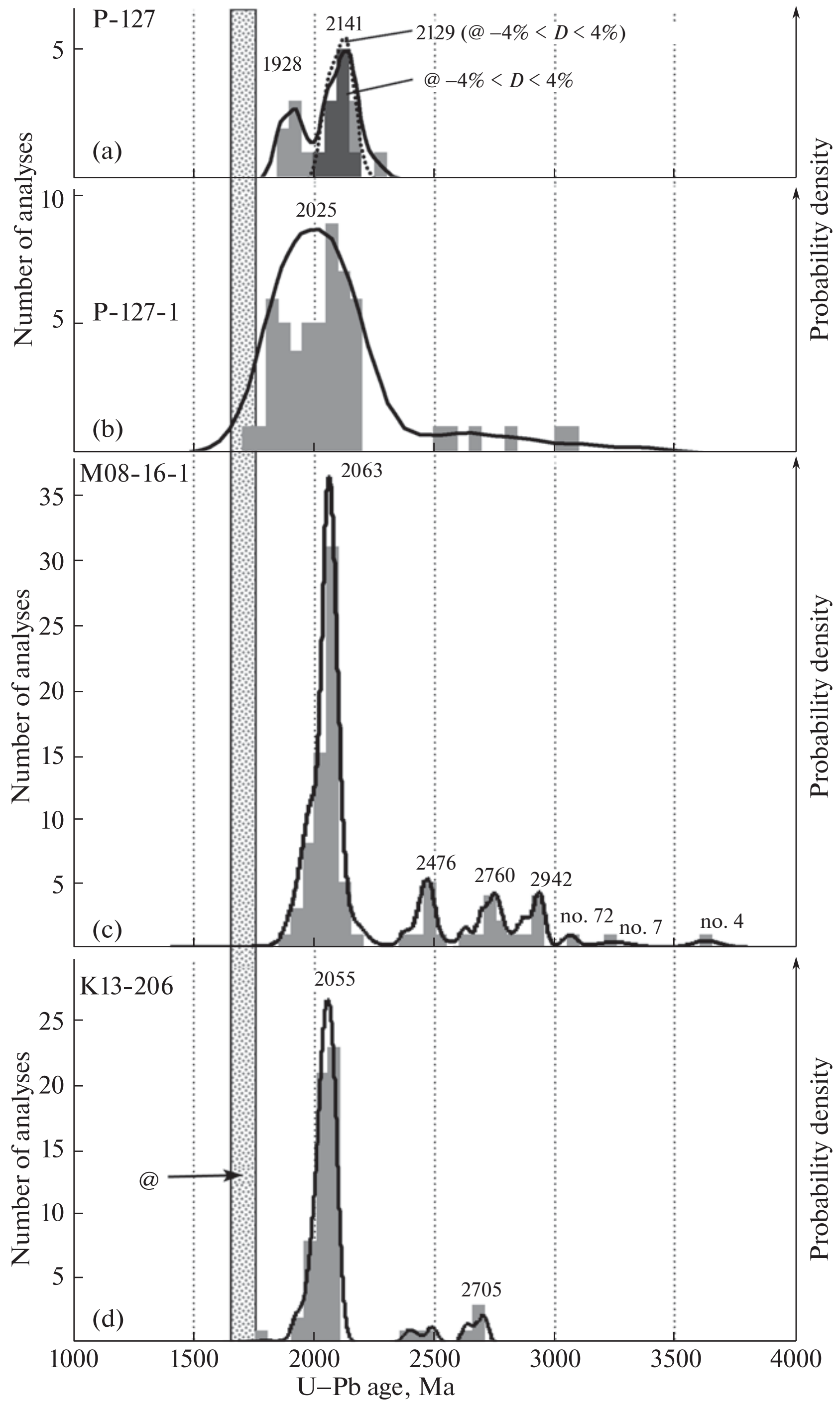

Fig. 2. Histograms and CPC of U/Pb "conditional" isotope ages of detrital zircons from sandstones of the Lower Riphean Ai Formation: (a) sample P-127 (sandy matrix of conglomerate); histogram and CPC are additionally shown for dates with $-4\% < D < 4\%$; (b) sample P-127-1 (quartzose inequigranular sandstone); (c) sample M-08-16-1 (quartz inequigranular sandstone) [6, 10, 11]; (d) sample K13-2016 (quartz inequigranular sandstone) [11].

regime. The isotope ratios were corrected using the GJ-1 standard. The MudTank standard was used as the internal standard. Processing of the analytical data and calculation of the isotope ratios and ages were carried out with the Iolite software. The results were corrected for common Pb after [15]. The age of ***dZr*** was calculated from the $^{206}Pb/^{207}Pb$ ratio. The standard cumulative probability curves (**CPC**) and histograms were plotted only for "conditional" analysis, which showed an initial analytical error no worse than 50 Ma and discordance D within $-5\% < D < 10\%$.

Sample P127. Nineteen conditional analyses were selected among 56 analyses (Fig. 2a). In the concordia

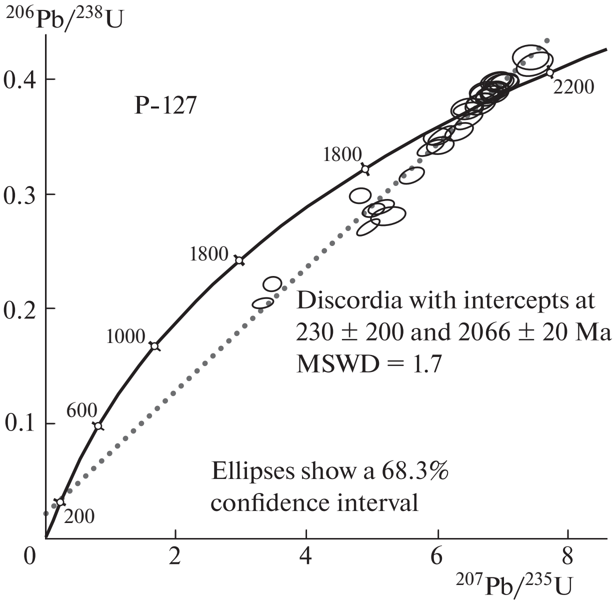

Fig. 3. Concordia diagram for zircons from sample P-127.

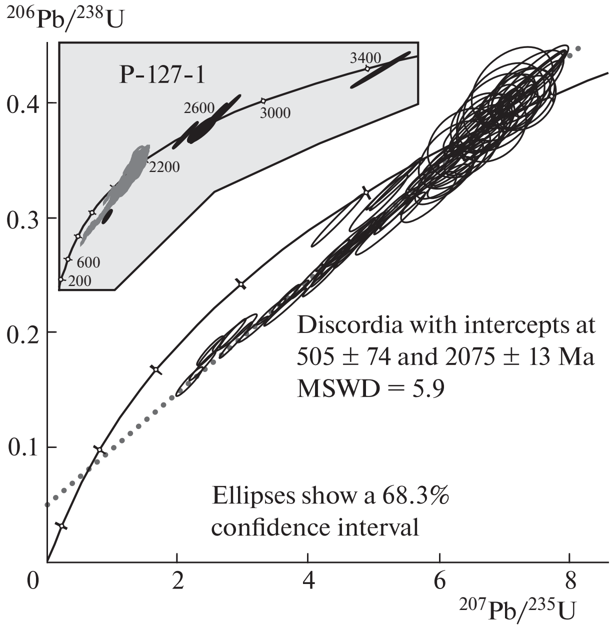

Fig. 4. Concordia diagram for all zircons from sample P-127-1 (a) and magnified fragment with Discordia; analyses shown in Fig. 4a by solid filling (b).

diagram, the data "points" (ellipses) of all dated zircons define a discordia with the upper and lower intercepts at 2066 ± 20 and 230 ± 200 Ma (Fig. 3). This is a strong argument in support of the fact that sample P127 practically in pure form recorded a signal from the local source peak of magmatic/metamorphic activity at 2.07 Ga (upper intercept). The sedimentary sequence that accumulated the disintegration products of this local source was subjected to thermal and/or fluid impact, the age of which is determined by the lower intercept. This event caused variable disturbance of the U/Pb isotope systems of ***dZr*** and caused partial loss of radiogenic Pb and the formation of discordia. Since the Pb loss in the dated ***dZr*** was insignificant, their data points plot closely to the upper discordia intercept. For this reason, the lower intercept is determined with low accuracy (±200 Ma).

The peaks on **CPC** plotted for dates meeting the criterion $-5\% < D < 10\%$ (Fig. 2a, light gray histogram) and supported by more than three dates correspond to values of 2141 and 1927 Ma. At such threshold values of discordance, the data set involved a significant number of discordant dates, which in part fall above the discordia, including discordant dates younger than 2 Ga. Only one peak at 2129 Ma was preserved in **CPC** plotted for dates satisfying a stricter criterion $-4\% < D < 4\%$ (Fig. 2a, dark gray histogram), which excluded most of the discordant dates. This indicates that the peaks 1929 and 2141 in the PDS are false. They appeared owing to the application of common statistical methods, which are suitable for analyzing U/Pb isotope data indicating a random distribution. A discordant data set does not meet this criterion.

Sample P127-1. Fifty-five conditional analyses (Fig. 2b) were selected from 98 analyses (Fig. 4a). The data points remained after discarding Archean dates and one strongly discordant analysis define discordia with the upper and lower intercepts at 2075 ± 13 and 505 ± 74 Ma (Fig. 4b).

We suggest that sample P-127-1, as sample P-127, in addition to the other ***dZr***, documented a signal from a local source with a peak of magmatic activity also at 2.07 Ga. Within the error, the values of the upper intercepts for samples P-127-1 and P-127 are identical. With a high probability, they may record the same source. As for sample P-127, the single peak in the CPC for sample P127-1 (2025 Ma) is considered to be false.

The estimated time intervals (with allowance for measurement error) of the lower intercepts of 430–580 Ma (sample P-127-1) and 30–430 Ma (sample P-127) intersected at ~430 Ma. This may indicate that the partial Pb loss in the studied discordant ***dZr*** of both samples was caused by a common reason. U/Pb dating of zircons from magmatic rocks lying in the vicinity of the P-127 and P-127-1 sampling location (slightly downstream along the Ushat River) yielded ages of 441.8 ± 8.2 and 437 ± 11 Ma (SHRIMP) [9], as well as 477.8 ± 8.6 Ma based on the $^{207}Pb/^{206}Pb$ ratio (SIMS) [3]. The value of ~430 Ma is slightly younger than the dates obtained, but the differences are much lower than the measurement accuracy of the lower intercepts for both samples. Thus, we may conclude that the Pb loss in some dated ***dZr*** from samples P-127 and P-127-1 was likely related to the emplacement of Ordovician magmatic bodies exposed on the right bank of the Ushat River [3, 9], near the geochronological sampling localities. This magmatism likely accompanied Ordovician rifting on the eastern Baltica margin at the initial stages of the evolution of the Uralian paleoocean [8, 9].

With high probability, the minimum age dates of ***dZr*** from samples P-127 and P127-1 are false, because are plotted in discordia. Hence, these dates cannot be used to constrain the sedimentation age of the rocks sampled. At the same time, there are no doubts that these rocks belong to the Ai Formation.

The model of the formation of the Ai Formation in the Navysh graben [1], the precursor of the Kama—Bel'sk aulacogen [10], was developed to explain the specifics of age dates of ***dZr*** from the previously studied rocks (K13-206 and M08-16-1) of the Ai Formation (Figs. 2c, 2d), as well as the peculiar geochemical and Hf isotope characteristics of these ***dZr*** [6, 10, 11]. New data on samples P-127 and P127-1 confirm the previous conclusion that erosion materials did not mixed significantly at the early stages of filling of the Navysh graben. Indeed, the frequency age maximums of ***dZr*** in samples K13-206 and M08-16-1 correspond to ~2.07 Ga and are obviously related to the local detrital source. In samples P-127 and P127-1, ***dZr*** values defining upper intercepts at ~2.07 Ga also indicate a local source with an age of 2.07 Ga.

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