

Nature of zircon clastics in the Riphean and Vendian sandstones of the Southern Urals

A.A. Krasnobaev¹, V.N. Puchkov¹, N.D. Sergeeva^{2*}, S.V. Busharina¹

¹Institute of Geology and Geochemistry of the Ural Branch of the Russian Academy of Sciences, Yekaterinburg, Russian Federation

²Institute of Geology of the Ufa Federal Research Centre of the Russian Academy of Sciences, Ufa, Russian Federation

Abstract. New age dates of detrital zircons of terrigenous rocks augmented the possibilities of interpretation of their provenance. Unfortunately this interpretation is restricted by a formal comparison of age-and-composition characteristics of detrital crystals with any very distant model objects. The paper deals with a situation when the role of a source of a detritus is claimed by local objects. When comparing the age parameters of primary and detrital crystals of zircons, the data on Riphean volcanics and ancient metamorphics of the Taratash complex of the Southern Urals were used. Specifying the ideas on the nature of the zircon clastics (detritus) and its relationships with primary zircons of sources, a role of processes of mechanical abrasion is pointed out, leading to a clearing of heterogenous primary grains of defect crystals, which results in an accumulation of crystals of more homogenous appearance. The analysis of SHRIMP and TIMS-dates of zircons and U and Th concentrations in them, and also a comparison of histograms of primary zircons from Riphean volcanics and rocks of the Taratash complex on one hand and the detrital zircons from the Vendian and Riphean sandstones of the Southern Urals on the other, have shown that the age variations of both are rather comparable. It means that the age characteristics of primary zircons from the Riphean volcanics and rocks of the Taratash complex as sources of zircon clastics for the Riphean and Vendian sandstones are regulated by processes of re sedimentation, and a detrital fraction of zircons is formed at the expense of local objects. The participation of very distant sources is not excluded, but in our case it is not detected.

Key words: zircons, Riphean, Vendian, series, formation, Asha, Ai, Mashak, Southern Urals

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Introduction

The interest in detrital zircons in the Riphean and Vendian strata of the Southern Urals is due to their new age definitions, according to which they cover the interval 755-3187 Ma (Kuznetsov et al., 2012) in the Asha sandstones of the Vendian, and 1891-3625 Ma in the sandstones of the Ai Formation of the Lower Riphean (Kuznetsov et al., 2013; Romanyuk et al., 2018a). Particular attention is drawn to the original conclusions of the authors about the sources of this zircon clastics. The Ural Baltic Territory and Australia's Queensland Territory are proposed for the Asha series, the Volga-Ural part of the Proto-Baltic – for the Ai Formation. Any vector paleogeography or mobilizing paleotectonic events that provided targeted transportation of detrital zircons for thousands of kilometers from the regions noted as the places of their accumulation is not proposed,

but then any point located on the areas of the above sources can be considered equivalent to the selected one. In addition, the role of craton blocks as sources and areas of transfer of detrital zircons requires more substantiated reasoning.

The main goal of our research is to establish the sources of “zircon cluster” in the Riphean sandstones of the Southern Urals. This will require determining the scales of age fluctuations of primary zircons in the putative source rocks.

The Taratash metamorphic complex of the Archean-Lower Proterozoic age in the Southern Urals (Kuznetsov et al., 2013) is mentioned as an additional source of detrital zircons. Acquaintance with the zircons of this complex allows us to assert that its role in such a bundle should be reconsidered. In this regard, Riphean volcanics themselves are also of undoubted interest. They are present in three stratigraphic levels in the section of the Riphean stratotype in the Southern Urals: the first (lower) is represented by the Navysh volcanics of the Ai Formation of the Burzyan series of the Lower Riphean and is distributed in the northern part of the

*Corresponding author: Nina D. Sergeeva
E-mail: riphey@ufaras.ru

Bashkir meganticlinorium; the second (middle) – unites the Mashak volcanics of the Yurmatinian series of the Middle Riphean, which are widely distributed within the Bashkirian meganticlinorium. The third-level Riphean volcanics are developed locally in the eastern part of the Bashkir meganticlinorium (in the Tirlyan syncline) and described as an Arshinian metabasaltic complex as part of the Igonino Formation of the Arshinian series of the final (Terminal) Riphean.

The position of samples taken for zircons on the geological map and in the section of the Riphean sediments

The object of the study was zircons from volcanogenic rocks of the Riphean Bashkir meganticlinorium, the sampling sites of which are shown in Figure 1.

The description of the selected samples is given in accordance with the stratigraphic sequence of Formations, including volcanogenic complexes.

Ai Formation. Burzyanian Series (RF₁). Samples – P9, P10, K2248, selected from the volcanic rocks of the Navysh complex. The zircons of the test trachybasalt porphyrite sample (K2152) were considered in detail in (Krasnobayev et al., 2013b).

Sample P9 (55°29'18.02"N, 59°39'31.87"E). Metabasalt plagioclase porphyrite. Mineral composition: pelitized, sericitized plagioclase, chloritized volcanic glass, turbid with iron oxides.

Sample P10 (55°29'18.02"N, 59°39'31.87"E). Metabasalt porphyrite, chloritized. Mineral composition: albitized plagioclase (60-62%), substituted by chlorite, volcanic glass (7-8%), clinopyroxene (25-30%), titanite micrograins, quartz (up to 2%).

Sample K2248 (55°28'9.46"N, 59°38'23.1"E). Quartzite, possibly formed from an acidic rock. Quartz grains ranging in size from 0.03 mm to 0.4-0.5 mm are characterized by wavy extinction, forming clusters of isometric or elongated shape. Between them are bands of chlorite after the plagioclase of the main mass, rarely with relics of plagioclase phenocrysts.

Mashak. Yurmatinian series (RF₂). **Sample K2014** (55°43'28.86"N, 59°50'1.86"E) extracted from the volcanic rocks of the Mashak complex. Basalt chloritized and amphibolized. The texture is massive, poikilophitic structure. Mineral composition: plagioclase (50-55%), substituted by chlorite, clinopyroxene (36-40%), sphene, rare quartz grains.

Igonino Formation. Arsha series (RF₄). The samples K2119 and K2065 are selected from the volcanic rocks of the Arsha complex.

Sample K2119 (54°18'06.99"N, 58°47'18.60"E). Metabasalt plagioclase porphyrite. The texture is almond-shaped, fluidal. Mineral composition: albite (20-25%), chlorite (30-35%), magnetite, rare epidote grains, carbonate.

Sample K2065 (54°18'25.87"N, 58°40'11.25"E). The metadacitic quartz-plagioclase porphyry, epidotized, fissured. The texture is poorly oriented, the structure is serial-porphyrific and microlepidogranoblastic in the matrix. Mineral composition: plagioclase (albite-25-28%), epidote (47-48%), quartz (18-20%), chlorite (4-5%), rare grains of sphene and zircon.

Zircons of Riphean volcanics have already been described (Krasnobaev et al., 2012; Krasnobaev et al., 2013a; Krasnobaev et al., 2013b; Krasnobaev et al., 2018), but only crystals related to age indicators of the boundaries of Riphean divisions were evaluated. The ancient grains, exceeding the age of these boundaries, were only recorded, but were not considered in detail. The following additional data obtained for the Riphean volcanic rocks, partly eliminate this gap. Only Archean crystals are considered in detail, and the rest are taken into account when analyzing U and Th in them and when building age histograms in the final part of the work.

Methods of study and petrological-geochemical characteristics of samples

Placement of samples is shown in Fig. 1, the composition and content (wt.%) of the petrogenic oxides in the rocks of the considered samples are given in Table 1 and displayed on the TAS diagram (Fig. 2a).

Rare earth elements (REE) in the Riphean volcanic rocks of the Southern Urals are determined by inductively coupled plasma mass spectroscopy (ICP-MS) on an ELAN 9000 instrument (PerkinElmer, Canada) at the Institute of Geology and Geochemistry, Ural Branch of the Russian Academy of Sciences (Yekaterinburg). The nature of the distribution of REEs in the rocks of the above samples is reflected in the spider diagram (Fig. 2b), where the REE content is normalized to chondrite (McDonough et al., 1995).

As can be seen from Table 1 and Fig. 2a, the studied rocks have rather diverse petrographic characteristic. In the TAS classification diagram (Fig. 2a), according to the content of petrogenic elements, the Ai volcanics hit the field of alkaline basalts and picro-basalt, the Mashak – the field of basalts and Igonino Formation – the field of trachybasalt and andesite-basalt. In terms of the composition of REEs (Fig. 2b), the rocks under consideration are also close to the volcanics of the Ai (Krasnobaev et al., 2013b), Mashak (Krasnobaev et al., 2013a) and Igonino Formations (Krasnobaev et al., 2012).

Zircons from the rocks were extracted by the classical method, but without the use of heavy liquids (crushing up to 0.3 mm, washing to gray concentrate, enrichment on a tray, manual selection of zircons under a binocular microscope).

The isotopic composition of most zircons was obtained using the SHRIMP method (Table 2), and for two samples (K2065, K2193) the TIMS method (Table 3).

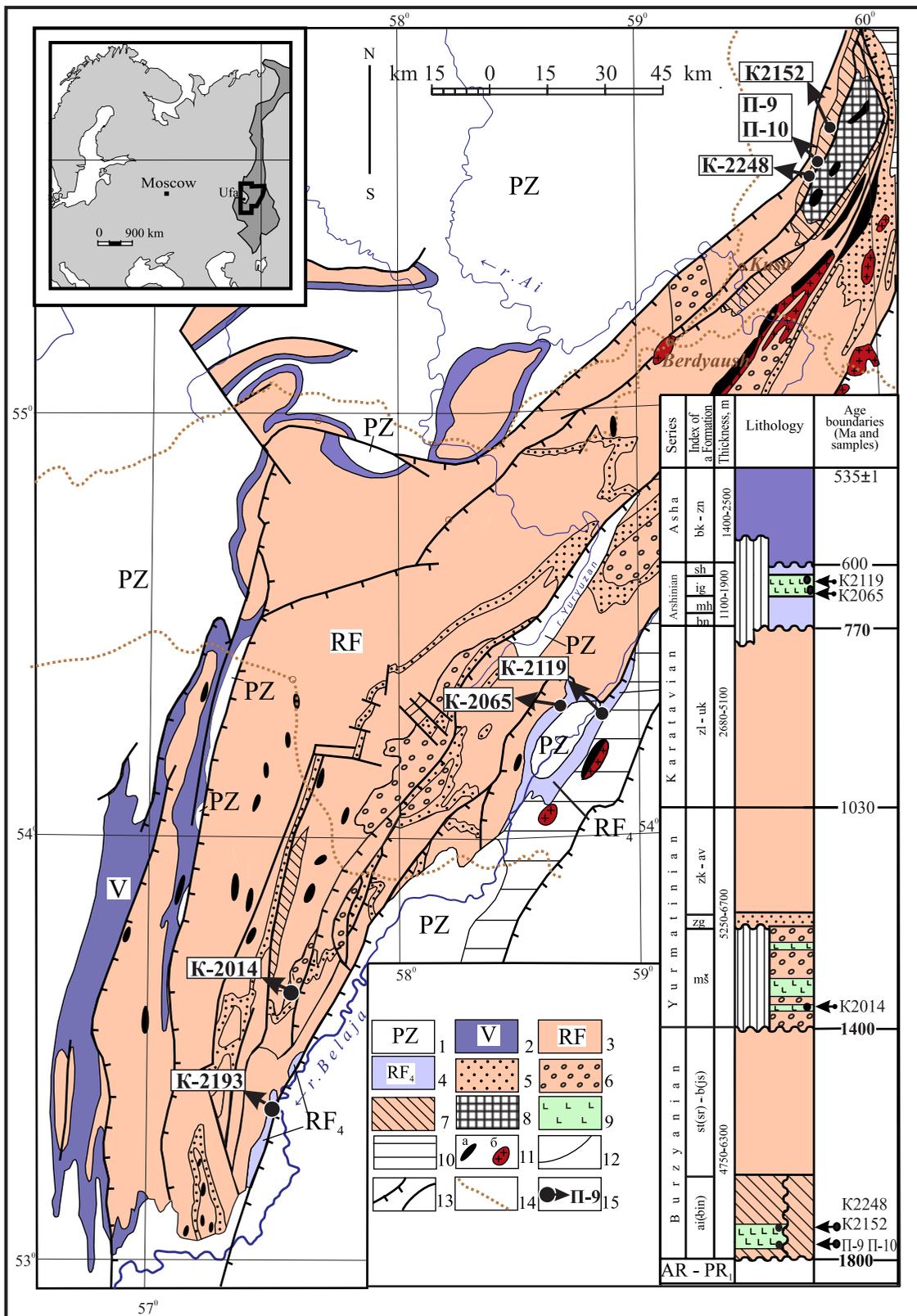


Fig. 1. Schematic geological map and stratigraphic column of the Riphean and Vendian formations of the Bashkir meganticlinorium (Southern Urals) with the location of samples of the investigated zircons. Compiled using (Geological map..., 2002; Kozlov et al., 2011; Puchkov et al., 2014). 1-4 – undifferentiated deposits: 1 – Paleozoic (PZ), 2 – Vendian (V), 3 – Lower-Upper (RF) and 4 – Terminal (RF₄) Riphean; 5-7 – Formations: 5 – Zigalga and 6 – Mashak Middle Riphean, 7 – Ai Lower Riphean; 8 – Taratash Complex; 9 – volcanic rocks; 10 – Uraltau and Ufaiei metamorphic complexes; 11 – igneous rocks: gabbro (a) and granites (b); 12 – geological boundaries; 13 – major tectonic faults; 14 – railways, 15 – location of samples and their numbers. The Formations are: ai(bin) – Ai (Bolsheizer), st(sr) – Satka (Suran), b(js) – Bakal (Yusha), ms – Mashak, zg – Zigalga, zk – Zigazino-Komarov, av – Avzyan, zl – Zilmerdak, uk – Uk, bn – Baynass, mh – Makhmutovo, ig – Igonino, sh – Shumsk, bk – Bakeevo, zn – Zigan. On the stratigraphic column, the lower age lines of the Burzyanian, Yurmatinian and Arshinian series are taken according to (Krasnobaev et al., 2012, 2013a, b); Karatau and Asha series – by (Stratigraphic code of Russia, 2006)

| Sample | P-9 | P-10 | K2119 | K2193 | K2248 |
|--------------------------------|-------|-------|-------|-------|-------|
| SiO ₂ | 45.85 | 45 | 47 | 46.6 | 84.6 |
| TiO ₂ | 2.6 | 2.61 | 2.46 | 2 | 0.04 |
| Al ₂ O ₃ | 14.4 | 13.5 | 15.4 | 16 | 4.6 |
| Fe ₂ O ₃ | 12.3 | 14.6 | 9.8 | 5 | 1.2 |
| FeO | | | 6.03 | 8.12 | 2.37 |
| MnO | 0.09 | 0.13 | 0.26 | 0.14 | 0.04 |
| CaO | 1.47 | 1.2 | 5.11 | 3.2 | 0.28 |
| MgO | 10 | 10.6 | 4.4 | 10 | 0.8 |
| Na ₂ O | 0.2 | 0.2 | 5.8 | 2.75 | 4.05 |
| K ₂ O | 6.4 | 6.4 | 0.25 | 0.85 | 4.25 |
| P ₂ O ₅ | 0.68 | 0.74 | 0.41 | 0.05 | 0.01 |
| mmn | 5.68 | 4.96 | 3.18 | 5.3 | 1.38 |
| Total | 99.67 | 99.94 | 100.2 | 100 | 99.46 |

Table 1. The chemical composition of igneous rocks of the Riphean, South Urals, wt. %. The determination of the chemical composition of rocks was carried out in the analytical laboratory of the Institute of Geology of the Ufa Federal Research Centre of the Russian Academy of Sciences (Ufa).

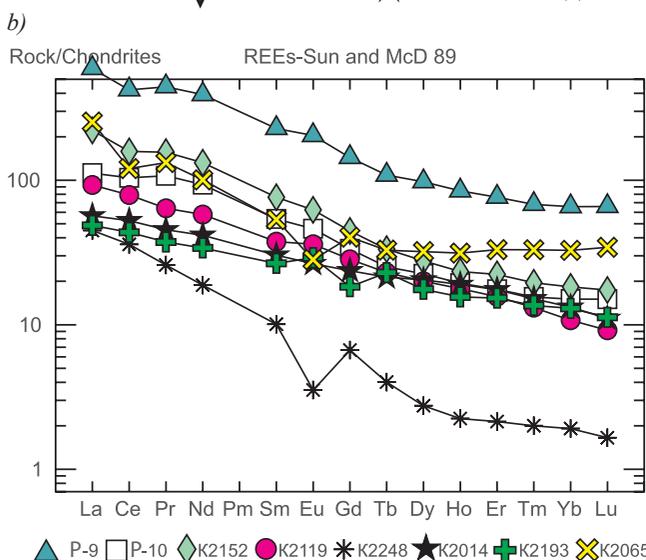
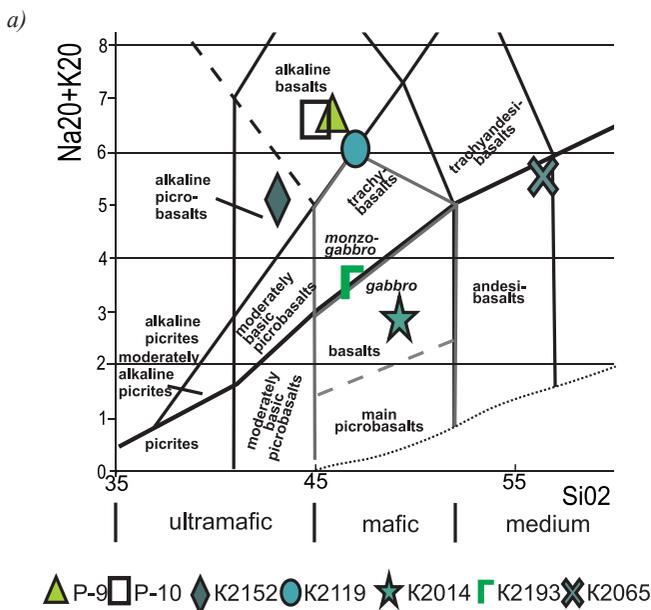


Fig. 2. Petrogenic (wt.%, 2a) and rare-earth (g/t, 2b) elements in the Riphean volcanics of the Southern Urals. The REE content is normalized to chondrite (McDonough et al., 1995).

The age of zircons was determined on the SHRIMP II ion microprobe in the CSI VSEGEI using the standard method (Williams, 1998; Larionov et al, 2004). Isotopic analyzes were preceded by a preparatory stage necessary for assessing the quality and nature of zircons. The crystals selected under a microscope were fixed together with standard 91 500 zircons (Wiedenbeck et al, 1995) and Temora (Black et al, 2003) in an epoxy matrix. The structure of crystals was studied by means of optical microscopy, cathodoluminescence (CL) and back-scattered electron (BSE). In general, this provided a choice of sites (points) of interest for isotopic analysis and a correct interpretation of analytical data. Ion currents were measured by wind turbines in the mass scanning mode. The ion current of the primary beam was 4.4-4.6 nA, the accelerating potential was 10 kV. The combination of the output slit (80 μm) of the ion source with a 100 μm width of the entrance slit of the wind turbine made it possible to achieve a resolution of 5200 (per ²⁵⁴UO), and to exclude isobar overlaps in the analyzed mass range. The analysis procedure includes the measurement of the following ions with the corresponding integration times (s): ZrO₂ – 2, ²⁰⁴Pb – 10, background (204.2) – 10, ²⁰⁶Pb – 7, ²⁰⁸Pb – 7, ²³⁸U – 2, ²⁴⁸ThO – 2 and ²⁵⁴UO – 2, and ZrO₂ and UO ions were also used to adjust the peak ion current in each of the four mass spectra. Each analytical session began and ended with the measurement of standard zircons 91500 and Temora, and in the process of measuring every fourth measurement was performed on standard Temora zircon, which is 416.75 million years old. The measured U/Pb ratios were normalized relative to the value of ²⁰⁶Pb/²³⁸U = 0.066, corresponding to this age. The obtained results were processed using the ISOPLOT/Ex 3.22 program (Ludwig, 2005), the decay constants were used according to (Steger, Jager, 1977), corrections for non-radiogenic lead were introduced according to the model (Stacey, Kramers, 1975).

The errors of the calculated concordant ages in the graphs are given at the 2σ level, the analytical data in the table are 1σ.

Table 2 shows all the analytical data, but only those that correspond to the most ancient dating are considered in detail. Analyzes are used fully in assessing the correlation relationship between U and Th in zircon, and representing 500 million years with a discordance of not less than 10 in the construction of age histograms. In the presentation of the material, the dating, obtained by Pb²⁰⁶/U²³⁸, is mentioned.

Description of zircons

Zircon in each of the studied samples (Fig. 3, Tables 2, 3) represents a set of crystals of different composition and age, the mineralogical features of which (appearance, internal structure, transparency) vary widely.

| Analysis | ²⁰⁶ Pb _c , % | Content, ppm | | | ²³² Th/ ²³⁸ U | D, % | Age, Ma (1) ²⁰⁶ Pb/ ²³⁸ U | Isotopic ratio (1) | | | | | |
|--------------|------------------------------------|--------------|------|--------------------|-------------------------------------|------|--|--|--|--|------|--------|-----|
| | | U | Th | ²⁰⁶ Pb* | | | | ²⁰⁷ Pb*/ ²⁰⁶ Pb*, ±% | ²⁰⁷ Pb*/ ²³⁵ U, ±% | ²⁰⁶ Pb*/ ²³⁸ U, ±% | | | |
| P 9 | | | | | | | | | | | | | |
| 4 | 2.35 | 27 | 44 | 5.23 | 1.70 | 2 | 1297±46 | 0.085 | 23 | 2.62 | 24 | 0.2228 | 3.9 |
| 2.1 | 0.15 | 1094 | 525 | 218 | 0.49 | 1 | 1341±30 | 0.08654 | 0.89 | 2.759 | 2.6 | 0.2312 | 2.5 |
| 2.2 | 0.45 | 796 | 441 | 165 | 0.57 | -2 | 1388±31 | 0.087 | 1.2 | 2.88 | 2.7 | 0.2402 | 2.5 |
| 3 | 0.54 | 389 | 196 | 82.8 | 0.52 | -1 | 1419±32 | 0.0891 | 1.8 | 3.025 | 3.1 | 0.2463 | 2.5 |
| 1 | 0.69 | 50 | 79 | 11.6 | 1.63 | 2 | 1528±39 | 0.0962 | 6.8 | 3.55 | 7.4 | 0.2676 | 2.9 |
| 5 | 0.59 | 1084 | 497 | 310 | 0.47 | 47 | 1837±39 | 0.18501 | 0.51 | 8.41 | 2.5 | 0.3297 | 2.5 |
| 8 | 0.34 | 102 | 166 | 40.3 | 1.69 | 5 | 2437±53 | 0.1704 | 1.6 | 10.79 | 3.1 | 0.459 | 2.6 |
| 6 | 0.59 | 611 | 276 | 245 | 0.47 | 9 | 2454±51 | 0.1823 | 0.66 | 11.64 | 2.6 | 0.463 | 2.5 |
| 7 | 0.03 | 734 | 98 | 299 | 0.14 | 7 | 2500±51 | 0.18145 | 0.4 | 11.85 | 2.5 | 0.474 | 2.5 |
| 9 | 0.15 | 306 | 155 | 146 | 0.52 | -5 | 2847±57 | 0.1855 | 0.69 | 14.2 | 21.6 | 0.555 | 2.5 |
| P 10 | | | | | | | | | | | | | |
| 6 | 0.07 | 1010 | 85 | 41.3 | 0.09 | -6 | 300±18 | 0.0519 | 1.8 | 0.341 | 6.3 | 0.0476 | 6.1 |
| 2 | 1.19 | 1175 | 124 | 50.9 | 0.11 | -35 | 314±19 | 0.0502 | 3.5 | 0.345 | 7.1 | 0.0498 | 6.2 |
| 9 | 0.40 | 1308 | 144 | 57.6 | 0.11 | 8 | 321±19 | 0.0535 | 2.5 | 0.377 | 6.6 | 0.0511 | 6.1 |
| 5 | 0.01 | 844 | 73 | 38.1 | 0.09 | 17 | 330±20 | 0.05436 | 1.5 | 0.394 | 6.3 | 0.0526 | 6.1 |
| 1 | 0.89 | 67 | 99 | 14.3 | 1.52 | -3 | 1418±79 | 0.0876 | 4.6 | 2.97 | 7.7 | 0.246 | 6.2 |
| 7 | 0.06 | 1255 | 793 | 311 | 0.65 | 20 | 1630±87 | 0.12005 | 0.51 | 4.76 | 6.1 | 0.288 | 6.1 |
| 4 | 0.21 | 868 | 63 | 237 | 0.07 | 2 | 1774±94 | 0.11031 | 0.53 | 4.82 | 6.1 | 0.317 | 6.1 |
| 10 | 0.43 | 79 | 42 | 22.9 | 0.54 | 1 | 1870±100 | 0.1154 | 2.2 | 5.35 | 6.5 | 0.337 | 6.1 |
| 3 | 0.23 | 236 | 402 | 76.3 | 1.76 | -5 | 2053±110 | 0.1194 | 1 | 6.18 | 6.2 | 0.375 | 6.1 |
| 8 | 0.18 | 172 | 95 | 74.6 | 0.57 | -4 | 2634±130 | 0.1678 | 1 | 11.68 | 6.2 | 0.505 | 6.1 |
| K2248 | | | | | | | | | | | | | |
| 5.1 | 0.71 | 128 | 103 | 8.67 | 0.83 | -30 | 487±11 | 0.0533 | 9.2 | 0.577 | 9.5 | 0.0785 | 2.4 |
| 5.2 | 0.96 | 57 | 2 | 3.93 | 0.45 | 5 | 490±13 | 0.0576 | 10 | 0.628 | 10 | 0.079 | 2.7 |
| 6.2 | 0.95 | 541 | 55 | 156 | 0.10 | 7 | 1849±33 | 0.1218 | 1.1 | 5.58 | 2.3 | 0.3321 | 2.1 |
| 2.2 | 2.22 | 173 | 50 | 65.6 | 0.30 | -4 | 2300±42 | 0.1391 | 3.2 | 8.22 | 3.9 | 0.4286 | 2.2 |
| 7.1 | 0.26 | 40 | 71 | 17.9 | 1.83 | -2 | 2678±54 | 0.1773 | 1.6 | 12.59 | 2.9 | 0.515 | 2.5 |
| 8.1 | 0.10 | 312 | 35 | 132 | 0.12 | 2 | 2585±43 | 0.17813 | 0.5 | 12.12 | 2.1 | 0.4934 | 2 |
| 3.1 | 0.13 | 401 | 175 | 183 | 0.45 | 2 | 2746±45 | 0.19601 | 0.44 | 14.35 | 2.1 | 0.531 | 2 |
| 1.2 | 1.36 | 35 | 19 | 16.6 | 0.57 | 1 | 2797±54 | 0.2001 | 1.9 | 14.99 | 3 | 0.543 | 2.4 |
| 4.1 | 0.62 | 58 | 12 | 29.2 | 0.22 | 0 | 2966±56 | 0.2173 | 1.6 | 17.51 | 2.9 | 0.584 | 2.3 |
| 1.1 | 0.10 | 190 | 207 | 94 | 1.12 | 1 | 2930±49 | 0.2176 | 0.62 | 17.27 | 2.2 | 0.575 | 2.1 |
| 6.1 | 0.38 | 33 | 15 | 17.5 | 0.47 | -3 | 3059±61 | 0.2177 | 1.4 | 18.23 | 2.9 | 0.607 | 2.5 |
| 9.1 | 0.23 | 101 | 27 | 58 | 0.28 | -3 | 3291±55 | 0.249 | 0.84 | 22.87 | 2.3 | 0.666 | 2.1 |
| 2.1 | 0.45 | 46 | 18 | 25.9 | 0.40 | -1 | 3238±58 | 0.2515 | 1.2 | 22.63 | 2.6 | 0.653 | 2.3 |
| K2014 | | | | | | | | | | | | | |
| 1.1 | 1.89 | 65 | 46 | 4.17 | 0.74 | 10 | 454±11 | 0.0573 | 16 | 0.576 | 17 | 0.073 | 2.5 |
| 2.1 | 0.04 | 1456 | 1360 | 946 | 0.97 | -5 | 3629±44 | 0.2969 | 0.32 | 30.94 | 1.6 | 0.756 | 1.6 |
| 2.2 | 0.25 | 218 | 213 | 129 | 1.01 | 1 | 3358±47 | 0.2833 | 2 | 26.7 | 2.7 | 0.684 | 1.8 |
| 3.1 | 0.06 | 393 | 110 | 230 | 0.29 | 0 | 3341±43 | 0.2764 | 0.45 | 25.88 | 1.7 | 0.679 | 1.6 |
| 3.2 | 0.14 | 207 | 165 | 104 | 0.82 | 0 | 2948±40 | 0.2141 | 0.65 | 17.12 | 1.8 | 0.5799 | 1.7 |
| 5.2 | 1.77 | 88 | 44 | 5.44 | 0.51 | 68 | 439.1±10 | 0.0639 | 15 | 0.621 | 15 | 0.0705 | 2.4 |
| 4.1 | 1.11 | 69 | 33 | 4.62 | 0.49 | 63 | 476±11 | 0.065 | 15 | 0.69 | 15 | 0.0767 | 2.4 |
| 6.1 | 0.79 | 327 | 340 | 19.8 | 1.07 | -16 | 435.7±7.6 | 0.0538 | 6.9 | 0.519 | 7.2 | 0.0699 | 1.8 |
| 6.2 | 1.36 | 99 | 45 | 6.25 | 0.47 | 65 | 449.7±9.6 | 0.0641 | 11 | 0.638 | 11 | 0.0722 | 2.2 |
| 5.1 | 0.86 | 243 | 151 | 15 | 0.64 | 2 | 443.2±7.9 | 0.0559 | 6.9 | 0.549 | 7.1 | 0.0712 | 1.8 |
| 7.1 | 2.36 | 58 | 33 | 3.72 | 0.59 | -36 | 457±13 | 0.052 | 25 | 0.53 | 25 | 0.0734 | 2.9 |
| K2119 | | | | | | | | | | | | | |
| 1.1 | 0.47 | 154 | 130 | 9.49 | 0.88 | -7 | 445.1±9.7 | 0.055 | 5.1 | 0.542 | 5.6 | 0.0715 | 2.3 |
| 1.2 | 0.79 | 173 | 91 | 10.9 | 0.54 | -15 | 451.6±9.8 | 0.0543 | 6.7 | 0.544 | 7.1 | 0.0726 | 2.3 |
| 2.1 | 0.07 | 104 | 71 | 45.3 | 0.70 | 1 | 2638±47 | 0.181 | 0.95 | 12.62 | 2.4 | 0.506 | 2.2 |
| 2.2 | 0.09 | 184 | 58 | 73.2 | 0.32 | 7 | 2445±44 | 0.1751 | 0.79 | 11.14 | 2.3 | 0.461 | 2.2 |
| 3.1 | 0.72 | 129 | 107 | 8.05 | 0.86 | 1 | 450±10 | 0.056 | 7 | 0.558 | 7.4 | 0.0722 | 2.3 |
| 3.2 | 0.54 | 134 | 68 | 8.27 | 0.53 | 0 | 445±10 | 0.0558 | 5.7 | 0.551 | 6.2 | 0.0715 | 2.4 |
| 4.1 | 0.14 | 296 | 16 | 22.4 | 0.06 | -1 | 545±11 | 0.0583 | 2.4 | 0.708 | 3.3 | 0.0882 | 2.1 |
| 4.2 | 0.58 | 202 | 45 | 15.2 | 0.23 | -4 | 539±11 | 0.0577 | 5.7 | 0.694 | 6.1 | 0.0872 | 2.2 |
| 5.1 | 0.92 | 101 | 60 | 9.55 | 0.61 | -3 | 665±15 | 0.0611 | 7.8 | 0.915 | 8.1 | 0.1087 | 2.4 |
| 5.2 | 0.33 | 107 | 36 | 10.3 | 0.35 | 5 | 684±15 | 0.0633 | 3.9 | 0.976 | 4.5 | 0.1119 | 2.3 |
| 6.1 | 0.22 | 163 | 140 | 15.8 | 0.89 | -5 | 687±14 | 0.0613 | 2.9 | 0.951 | 3.7 | 0.1125 | 2.2 |
| 7.1 | 0.72 | 83 | 45 | 5.13 | 0.56 | 27 | 443±11 | 0.0589 | 7.4 | 0.578 | 7.8 | 0.0712 | 2.6 |

Table 2. U-Pb age (SHRIMP) of zircons of Riphean volcanics of the Southern Urals (P9, P10, K2248 – Ai, K2014 – Mashak and K2119 – Igonino Formations). Pb_c and Pb* are total and radiogenic lead. (1) – correction according to measured ²⁰⁴Pb. Rho is the correlation coefficient. Calibration error of standard 0.74% for K9, K10; 0.60% for K2014 and 0.59% for K2119. D – discordance.

| Sample No. | Quantity weighed for analysis (mg) | Content ppm | | Isotopic ratio* | | | | Age, Ma** | | | % |
|------------|------------------------------------|-------------|------|-----------------------------------|---|--|--|--|--|---|------|
| | | Pb | U | $^{206}\text{Pb}/^{204}\text{Pb}$ | $^{207}\text{Pb}/^{206}\text{Pb} \pm 2\sigma$ | $^{207}\text{Pb}/^{235}\text{U} \pm 2\sigma$ | $^{206}\text{Pb}/^{238}\text{U} \pm 2\sigma$ | $^{206}\text{Pb}/^{238}\text{U} \pm 2\sigma$ | $^{207}\text{Pb}/^{235}\text{U} \pm 2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb} \pm 2\sigma$ | |
| K2193 | 0.1040 | 5.27 | 2.04 | 37.18 | 0.209±0.005 | 18.925±0.005 | 0.607±0.029 | 3054±147 | 3038±162 | 2898±63 | -5.4 |
| K2065 | 0.0394 | 3.11 | 1.44 | 35.44 | 0.172±0.005 | 12.573±2.276 | 0.509±0.046 | 2585±460 | 2588±468 | 2582±80 | -0.1 |

Table 3. U-Pb age (TIMS) of metabasalt (K2065) and gabbro-dolerite (K2193) in the Riphean in the Southern Urals. * All relationships are corrected for idle pollution of 1 ng for Pb and 10 ng for U and mass discrimination 0.12±0.04%; ** Correction for the admixture of ordinary lead is determined by age according to the model (Stacey, Kramers, 1975). K2065 – metabasalt of the Igonino Formation of the Arshinian series; K2193 – gabbro-dolerite (N 53°16'35"; E 59°31'231").

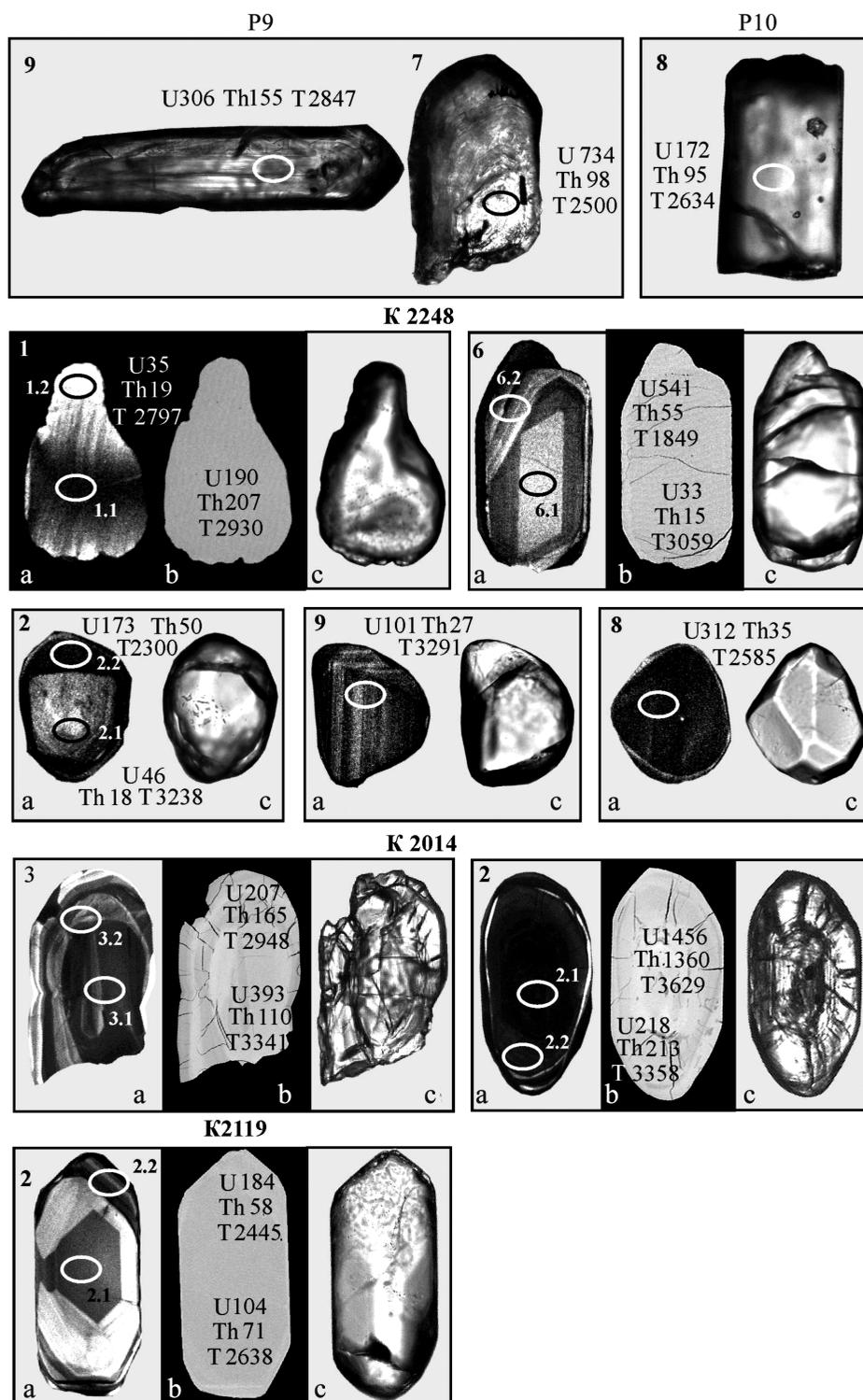


Fig. 3. Mineralogical, geochemical and age peculiarities of zircons from volcanic rocks of the Riphean sequences of the Southern Urals. P9, P10, K2248 – Ai, K2014 – Mashak and K2119 – Igonino Formations. The numbers are the numbers of crystals, the contents of U and Th (g/t), T is the age, Ma ($^{206}\text{Pb}/^{238}\text{U}$ each) (Table 2), a, b, c – pictures of CL, BSE, optical (transmitted light).

Some grains demonstrate combinations of early-late generations, others – the classical core-shell pair. Since the works (Krasnobaev et al., 2012; Krasnobaev et al., 2013a; Krasnobaev et al., 2013b; Krasnobaev et al., 2018), many of these crystals have already been considered, the Fig. 3 presents only the structural features of the most ancient.

Ai basalts contain only single ancient crystals, among which elongated – 9, broken, partially rounded – 7 (P9) and a fragment of a prismatic crystal – 8 (P10) (Fig. 3). They experienced crushing and dissolution, and their roundness is not associated with abrasion. The reduced discordance (<10; Table 2) of these crystals allows their dating to be associated with real events. Most of the remaining crystals in these samples belong to the interval of 1297-2053 Ma, which takes into account the underestimated dating (Krasnobaev et al., 2013b) of the changed grains.

Despite some arbitrariness of the nature definition, quartzite (K2248) is important because the zircons contained in it have a common history of existence with basalt zircons, which allows to solve some of their common questions of the geological past. The point is that the peculiarities of the evolution of quartzite zircons can be extended to zircons of basalts as coexisting with them in equal conditions. In addition, quartz zircons are also important for evaluating some features of the AiFormation as a whole. The most important of their properties are (Fig. 3): the presence among them of grains with a clear idiomorphism (cr. 8), with relics of the primary cut and secondary roundness (cr. 6), fragments that underwent recrystallization (cr. 2, 9). An example of combining traces of dissolution, substitution and composition change with rejuvenation is crystal 1. In general, all these data confirm the conclusion about the formation of the zircons appearance without the participation of abrasion, i.e., zircons from sample K2248 and detrital ones (Kuznetsov et al., 2012; Kuznetsov et al., 2013) are not equivalent in this respect. The peripheral zones of some crystals are characterized by lower ages (cr. 2.2 – 2300 Ma, cr. 6.2 – 1849 Ma), and one grain has an age of 490 Ma.

Crystals 2 and 3 of the Mashak basalts of K2014 sample possess unique features (Fig. 3). The BSE images show that they have very specific radial cracks in the peripheral zones, not affecting the central ones. Such situation arises due to a more intense increase in the parameters of the unit cell in the latter due to an increased dose of absorbed α -radiation, which ultimately leads to an “explosion” of the shell, and to the appearance of observed cracks. There are also noticeable differences in the primary structure between crystals 2 and 3. The former is characterized by the coexistence of early-late generations, and the occurrence of fracturing is confined only to late one. In the case of crystal 3,

cracking also occurs in the peripheral zone, but it already corresponds to the newly formed shell. The maximum dating of zircons of this sample reaches 3629 ± 44 Ma, and crystals with ages of 435-475 Ma prevail. Zircon crystals corresponding to the Mashak level were not found among them.

In the basalt (K2119) of the Igonino Formation, zircon crystals with an age of 450-690 million years are common, and only a single crystal 2 belongs to Archean – 2638 ± 57 Ma. The combination of primary zones (dark – light according to CL) reflects its magmatic nature, and the appearance of the late shell (2.2) is due to metamorphism, whose age for $206\text{Pb} / 238\text{U}$ is estimated at 2445 ± 44 Ma. The TIMS-dating of metadacitic porphyry (K2065) of the Igonino Formation turned out to be 2580 ± 5 Ma, which was confirmed by the SHRIMP method previously obtained.

U-Th in zircons

The distribution of U and Th in the zircons of samples P9 and P10, although it differs (Fig. 4), but collectively indicates that they belong to a single source.

This is confirmed not only by the coinciding nature of their evolution, but also by their belonging to three successive stages of crystallization of their magmatic melt (Tr I, Tr II, and Tr III). The limited extent of variations with a significantly increased content of U indicate that Tr III belongs to its final stage. The connection with the source of zircons from basalts of the Ai is also possible for zircons of Mashak (K2014) volcanics, which is confirmed by the similarity of their evolution trends (Tr II and Tr I). Undoubtedly, zircons of sample K2119 with a compact (“homogeneous”) distribution of U and Th reflect the participation of a new source. Apparently, for the zircons of the Ai and Mashak basalts, we can speak not only of the generality of formation, but also of a similar subsequent history of their existence. This is especially noticeable when comparing U and Th basalts with contrast analyzes of U and Th in quartzite zircons (K2248), which are “to the right” and “below” of magmatic zircons. However, the evolution of some crystals (cr. 1 and 2) does not contradict that noted for previous samples, and together with others (cr. 2, 4, 6, 8, 9) reflects their polygenic nature in quartzite.

Taken together, the peculiarities of the distribution of U and Th in the Archean zircons of the Timanides of the Urals reveal their connection with various sources, although for this age period this conclusion seems unexpected, giving rise to new questions about the early history of its development.

U-Pb Zircon Age

Figure 5 shows the distribution of the U-Pb ellipses of the SHRIMP age and TIMS analyzes of the most

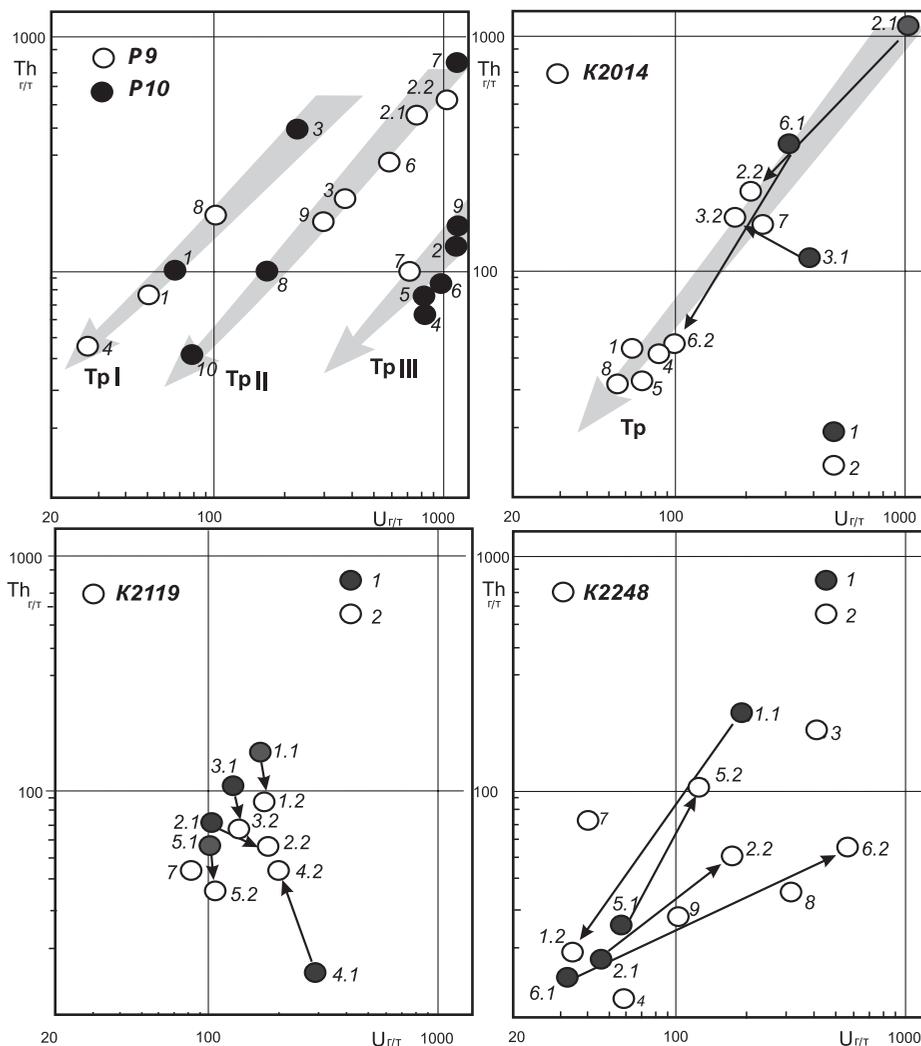


Fig. 4. Interrelation of U and Th in zircons from volcanogenic rocks of the Riphean sequences of the Southern Urals. Early (1) – late (2) generations coexisting in a single grain are connected by arrows. Trends (Tr) – the direction of the evolutionary development of zircons

ancient (Table 2) zircon crystals from the Ai, Mashak and Igonino Formations with respect to the concordia. It is easy to see that they are mostly located either on it or nearby, and are grouped within the boundaries of Neoproterozoic (2540-2690 Ma) or the upper half of the Paleoproterozoic (3190-3350 Ma). The binder includes the dating of some zircon crystals from quartzite (2966 and 2794 Ma). We emphasize once again that all the datings obtained relate to zircons extracted from igneous rocks.

For zircons of the Taratash Complex, age information is well known. About their ancient age, including Archean (up to 3420 Ma) was reported in 1965 (Krasnobaev et al., 1965). It was confirmed by subsequent research, supplemented by mineralogical studies (six types of zircons were described) using thermo-isochronous (Pb^{207}/Pb^{206}) (Krasnobaev, Sumin, 1983) and classical U-Pb (Krasnobaev, Cherednichenko, 2005) methods. The development of the SHRIMP technique contributed to the detection of crystals with an age of up to 3500 Ma (Krasnobaev et al., 2011). A significant contribution to the knowledge of Taratash zircons was made by the work of Yu.L. Ronkin with colleagues (Ronkin et al., 2012),

who confirmed the wide age variations of the Taratash zircons, and the preservation of crystals with an age exceeding 3500 Ma among them.

On the nature of zircon clastics

Before proceeding with the analysis of new data, it is necessary to clarify our understanding of the nature of zircon clastics (detritus), its relationship with the primary (igneous) zircons of the sources. Formally, their comparison seems both simple and obvious. However, the practice changes these ideas qualitatively. We can agree with the main mechanism of transformation of primary zircons to detrital ones, which is determined by rather rigid provisions. The main one is that the age of detrital grains cannot exceed the age of zircon sources. This is quite true if we are talking about the age of zircons, and not about the age of the rocks containing them.

This interrelation, as an indispensable one, should be observed in any manipulations with zircon clastics. Among the processes that determine the direct appearance of the detritus fraction, two main ones,

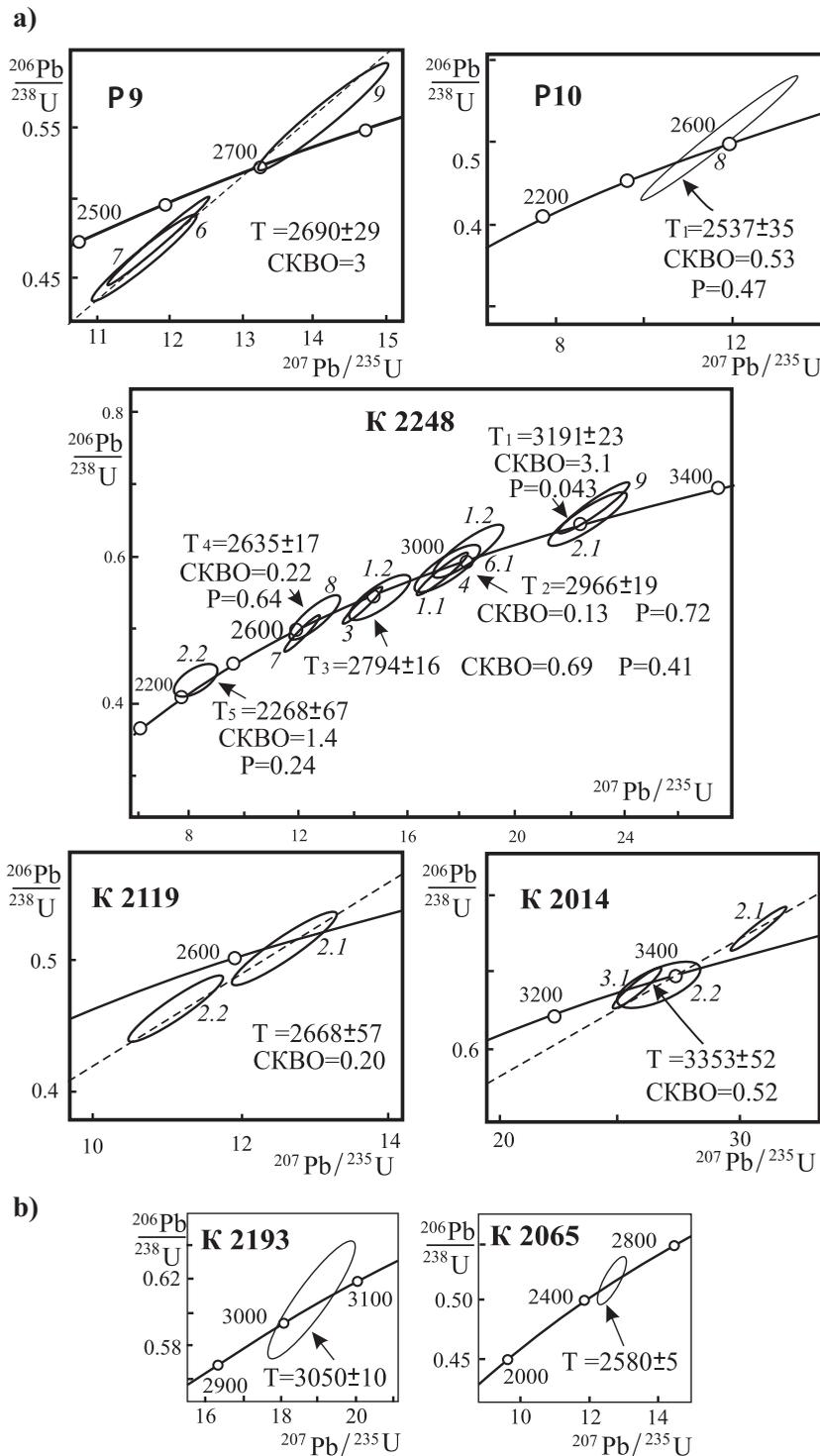


Fig. 5. U-Pb age of zircons of igneous rocks in the Riphean deposits of the Southern Urals. Methods: a – SHRIMP, b –TIMS

having the status of regular laws (LI and LII), should be noted. The first (LI) controls the cleaning (refining) of complicated organized, often heterogeneous primary crystals from defective grains mainly under the influence of mechanical abrasion. This leads to a gradual accumulation of more homogeneous (of the same type) grains with increased crystallinity, resistant to crushing and abrasion, i.e., the formation of a new detritus fraction, while fragments wear out and disappear in the first place. At the same time, the decay of the LI activates the participation of LII, according

to which the mineralogical memory of the emerging detritus grains about its primary crystals weakens and may even disappear completely. In the utmost case, with complete loss of memory about the latest stages of grain transformation, a polychronic community of detrital crystals is formed, in which it is practically impossible to detect any signs of belonging to specific sources. At the same time, unlimited possibilities open up to work out (test) various hypotheses on them, to carry out comparisons of their material-geochemical parameters with any model objects. Ultimately, all

newly installed analytic-rich genetic ligaments usually end with the delineation of any probable “primary” sources, often played by large masses (complexes) of rocks. These conclusions are often far from reality.

Potentially detrital crystals that previously participated in the structure of primary crystals could occupy a different structural position in them (early-late generation, nuclei, envelopes, traces of the influence of metamorphism, especially granulite). In contrast to the utmost case considered above, their formation may stop at the “intermediate” stage, ensuring the preservation of the relics of the primary structures in some grains. The probability of meeting such partially transformed crystals, although not high, is possible, and we should not forget about them when studying zirconclastic materials. However, it is often tempting to confine ourselves to the formal comparison of the material-age characteristics of detrital crystals with “assigned” virtual sources.

On detritus sources

A qualitatively different situation arises when local objects are claimed to be the source of detritus. An example is the situation with the mentioned Taratash complex. It is very symptomatic that the Taratash zircon varieties were found earlier in the Ai, and even in the Zilmerdak sandstones, Lower and Upper Riphean, respectively (Krasnobaev et al., 1965; Krasnobaev, 1967), which indicated their redeposition (!) in place.

When comparing the age parameters of primary (Tables 2, 3; Fig. 3, 4, 5) and detrital (Kuznetsov et al., 2013; Kuznetsov et al., 2012) zircon crystals in this study we used previously obtained data for zircons from Igonino volcanics (Krasnobaev et al., 2012), Mashakskian (Krasnobaev et al., 2013a) and Aiskain (Krasnobaev et al., 2013b; Krasnobaev et al., 2018) suites and rocks of the Taratash complex (Krasnobaev, 1967; Krasnobaev et al., 1965; Krasnobaev, Sumin, 1983; Krasnobaev, Cherednichenko, 2005; Krasnobaev et al., 2011; Ronkin et al., 2012). As in the analysis of the studied samples, only analyses of the most advanced crystals that met the requirements of age indicators were taken into account, as well as with discordance worse than 10. Naturally, crystals with wider mineralogical and geochemical properties were distributed in the initial samples, which is significant when zircon clastics are formed. For the Ai Formation, for example, zircon crystals with lower relative to the primary (1750 Ma) datings caused by secondary transformations (Krasnobaev et al., 2013b) are taken into account. In addition, the influence of Mashak volcanism on the preservation of zircons of the Ai Formation is not excluded.

The age variations of the zircons of the Taratash complex are most completely characterized by the results (1000-2900 Ma) of the thermoisochnous

method (Krasnobaev, Sumin, 1983). But in the total histograms (Fig. 6) we included only the data of the U-Pb methods. When comparing the total histograms of the U-Pb distribution of zircons from Riphean volcanics, rocks of the Taratash complex and detritic zircons from lower Riphean and Vendian sandstones (Kuznetsov et al., 2013), it is noteworthy that the age variations of both are comparable in many ways, despite of the mineralogical limitations of the crystals used in this study. It follows that the age characteristics of the primary (magmatic) zircons that are common in Riphean volcanics and rocks of the Taratash complex, as sources of detrital zircons in Riphean and Vendian sandstones, are mainly regulated by the redeposition at the place of their formation.

Earlier (Bekker, 1968; Orlova, 1960; Sergeeva, 2014), when studying accessory minerals, it was noted that the Riphean and Vendian sandstones in the Southern Urals are largely formed due to detrital material of local Ural rocks. Although the influence of remote sources is not excluded, their role in this case was not manifested.

Conclusion

1. For the first time, zircons from volcanogenic rocks represented in the Riphean section of the region by the Navysh trachybasalt complex in the Ai Formation of the

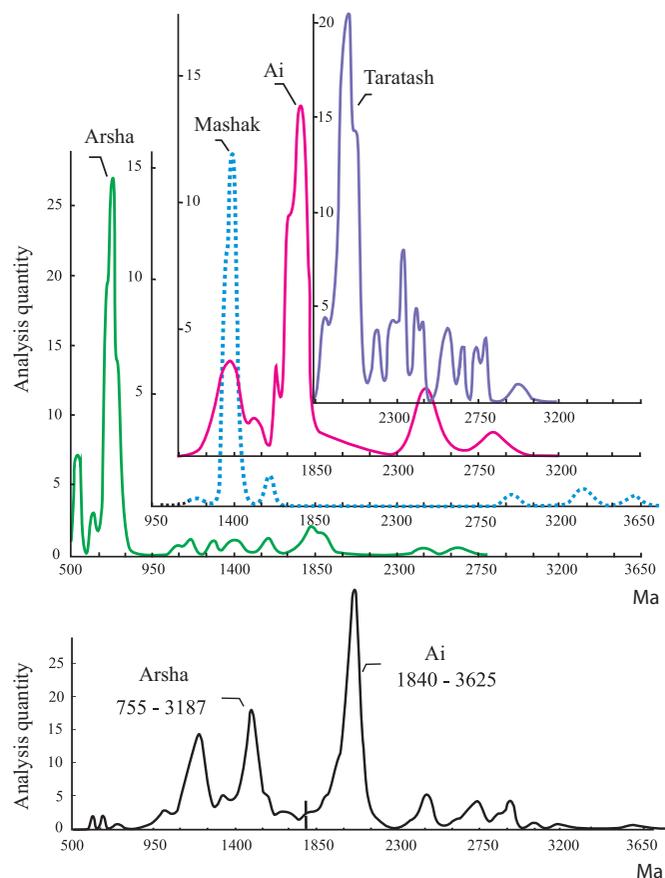


Fig. 6. Histograms of the U-Pb age distribution of zircons of Riphean volcanics and rocks of the Taratash complex (a) and detrital zircons of Ai-Asha sandstones (b) (Kuznetsov et al., 2013).

Burzyanian series of the Lower Riphean, by the Mashak rhyolite-basalt complex in the Mashak Formation of the Yurmantian Middle Riphean and Arshinian metabasalt complex in the Igonino Formation of the Terminal Riphean are considered to be the sources for the Riphean and Vendian sandstones.

2. When comparing the material-age characteristics of detrital crystals with possible sources of zircon clastics, it should be taken into account that when zircon clastics is formed from magmatic zircons, purification (refining) of complexly organized, often heterogeneous primary crystals from defective grains occurs, mainly due to mechanical abrasion, which leads to the accumulation of externally more homogeneous (of the same type) crystals with increased crystallinity. In the process of converting zircon crystals into detrital grains, the latter can preserve the relics of primary structures indicating the source of the zircon clastics, but the signs of belonging to particular sources can also disappear completely from zircons. In this case, the infinite possibilities of comparing the material-geochemical parameters of the zircon clastics with any model objects open up.

3. Analogy in the U-Pb distribution of zircon ages from Riphean volcanics, metamorphic rocks of the Taratash Archaean-Lower Proterozoic complex and detrital zircons of the Lower Riphean and Vendian sandstones (Fig. 6) indicates that the formation of the zircon clastics of Riphean and Vendian sandstones in the Southern Urals is due mainly to the recycling processes of zircons at the place of their formation.

The results of the U-Pb dating of the detritus zircons extracted from the sand matrix of conglomerates of the Ai Formation in the section along the River Ushat (Taratash anticlinorium) provide an additional argument for the important role of local sources of the detrital zircons. LA-ICP-MS analyzes were performed at the Analytical Research Centre of Geochronology of the Kazan Federal University, and the obtained materials are presented in an article with our participation (Romanyuk et al., 2018b), the main conclusion of which is that the source of detrital zircons was strictly local. On a diagram with concordia, the ellipses of analyzes of all dated zircon grains form discordia with upper and lower intersections with concordia – 2066 ± 20 and 230 ± 200 Ma. The upper date is interpreted as the age of zircons from the bedrock of the Taratash complex, and the lower one as the result of the thermal impact of Paleozoic volcanics located in the immediate vicinity of the sample.

Thus, the main source of detrital zircons in Riphean and Vendian sandstones in the Southern Urals are local (Riphean and Taratash) rock complexes. The appearance of the zircon clastics in the sandstones of these sequences is determined by the processes of redeposition at the place of their formation. It can be stated that this does not require the involvement of more distant and exotic sources.

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About the Authors

Artur A. Krasnobaev – DSc (Geology and Mineralogy),
Chief Researcher

Institute of Geology and Geochemistry of the Ural Branch
of the Russian Academy of Sciences

15, Vonsovsky st., Yekaterinburg, 620016, Russian
Federation

Tel: +7(343)287-90-44, e-mail: krasnobaev@igg.uran.ru

Viktor N. Puchkov – DSc (Geology and Mineralogy),
Corresponding Member of the Russian Academy of Sciences,
Chief Researcher

Institute of Geology and Geochemistry of the Ural Branch
of the Russian Academy of Sciences

15, Vonsovsky st., Yekaterinburg, 620016, Russian
Federation

Tel: +7(343)287-90-44, e-mail: puchkv@ufaras.ru

Nina D. Sergeeva – PhD (Geology and Mineralogy),
Leading Researcher

Institute of Geology of the Ufa Federal Research Centre
of the Russian Academy of Sciences

16/2, Karl Marx st., Ufa, 450077, Russian Federation

Tel: +7(347)272-82-56, e-mail: riphey@ufaras.ru

Sofiya V. Busharina – PhD (Geology and Mineralogy),
Senior Researcher

Institute of Geology and Geochemistry of the Ural Branch
of the Russian Academy of Sciences

15, Vonsovsky st., Yekaterinburg, 620016, Russian
Federation

Tel: +7 (343) 287-90-44, e-mail: cvb_77@mail.ru

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