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GEOLOGY

The Oldest Vendian (Ediacaran) Fossils of Eurasia: U–Pb Isotope Age of the Basa Formation (Asha Group, Southern Urals)

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Abstract—U–Th–Pb (SHRIMP II) isotopic dating of accessory zircons from Vendian (Ediacaran) ash tuffs of the Basa formation section (Asha Group, Southern Ural) was performed for the first time. The concordant age obtained (573.0 ± 2.3 Ma) can be interpreted as the upper age limit of the onset of the Timan Orogeny in the structure of the Southern Urals. Fossil remains of *Kuckaraukia multituberculata* and several paleopascichnids, belonging to the genera *Palaeopascichnus* and *Orbisiana*, were previously found in the rocks of the Upper Basa Subformation, and the first occurrence of *Arumberia banksi* was established. The age obtained indicates a more ancient age of this Vendian assemblage compared to the previously accepted one.

Keywords: Vendian, Ediacaran, Asha Group, Basa Formation, Southern Urals, *Kuckaraukia*, *Arumberia*, *Palaeopascichnus*, *Orbisiana*, U–Pb age

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The terrigenous Asha Group is distributed mainly in the western part of the Bashkirian meganticlinorium (BMA), where it overlaps the Upper Riphean sequences with parallel unconformity (Fig. 1) and is overlain with parallel unconformity by Lower Devonian (Emsian) terrigenous deposits of the Takata Formation, rarely Middle–Upper Ordovician ones. The Asha Group (from 1400 to 2600 m thick) is subdivided into several formations with gradual transitions between each other: Tolparovo, Suirovo, Bakeevo, Uryuk, Basa, Kukkarauk, Zigan, and Malyi Yamantau. The Tolparovo and Suirovo formations are considered the stratigraphic analogs of the Bakeevo Formation, or they are included in the Bakeevo section in the rank of sequences. Deposits of the Basa, Kukkarauk, Zigan, and Malyi Yamantau formations are interpreted as molasse ones, associated with the Timan Orogeny. The Kukkarauk Formation, composed of conglomerates, plays the role of a marking horizon, separating the sandy–siltstone sections of the Basa and Zigan formations [1, 2].

Recently, beds and lenses of volcanic tuffs were found in different parts of the Asha Group sections. Before our research, there was only one age of single zircon crystals extracted from tuffs of the section near the town of Ust-Katav. There are no marking conglomerates of the Kukkarauk Formation in this section. Due to similarity in the lithology, the Basa and Zigan formations are not separated unambiguously. Different researchers interpret the age of zircons from tuffs of 547.6 ± 3.8 Ma [3] as corresponding to the Basa or Zigan time.

We have studied the Asha Group section, which has been exposed in roadway excavations along a new Makarovo–Kulgunino segment of the Sterlitamak–Beloretsk road. The Basa and Zigan formations are separated by deposits of the Kukkarauk Formation (Fig. 1). The Basa Formation composes the low-angle limb of a fold, NW-dipping at angles of 5°–15°, complicated by rare low-amplitude fault zones. We found a lenticular tuff interbed (up to 7 cm) thinning to the west in the section of the Upper Basa Subformation. The base of the interbed is composed of tephra with a uniform particle size of 0.3–0.6 mm (up to 1 mm for mica) without signs of rewashing or sorting. The min-

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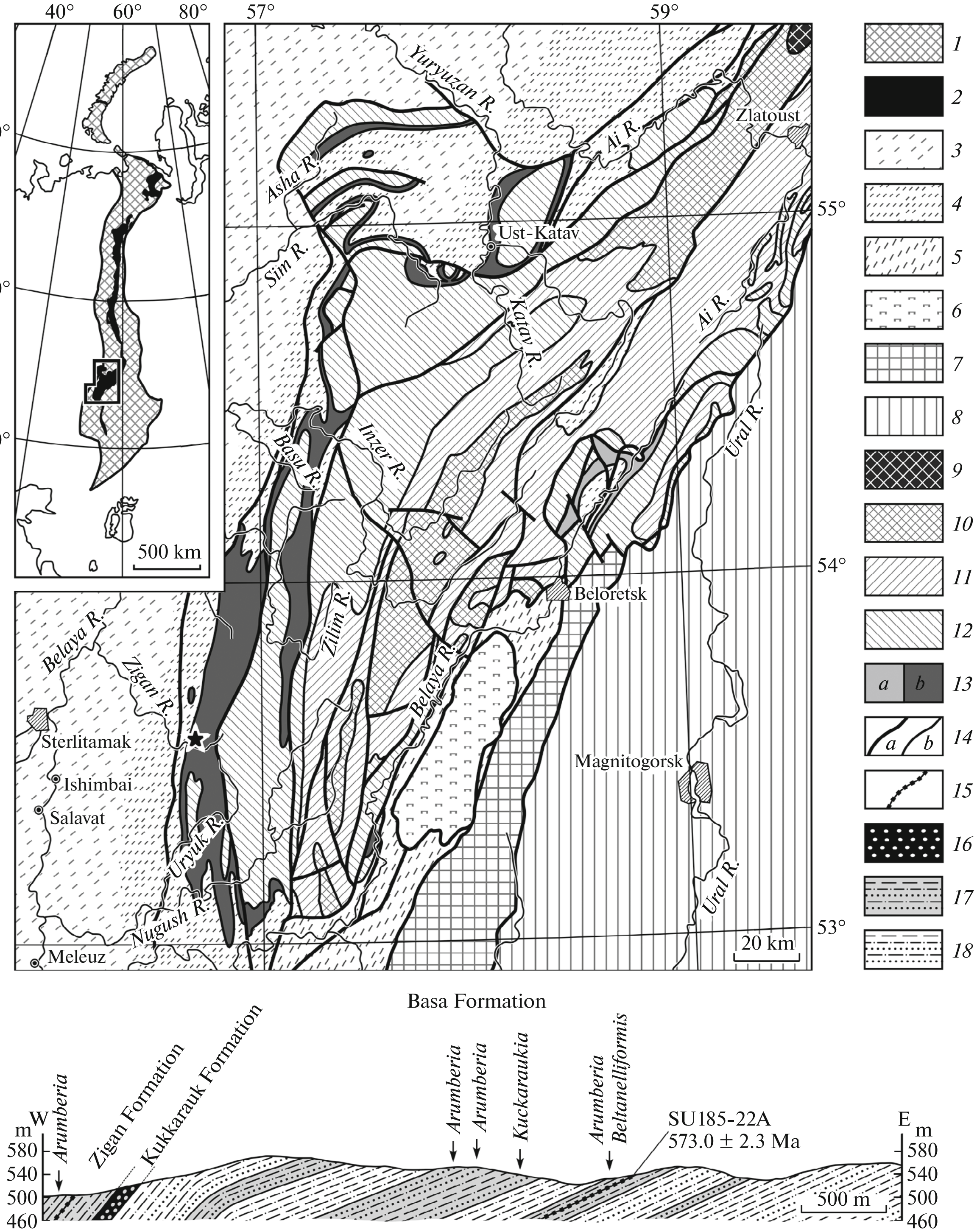

Fig. 1. The locality and main structural features of the studied section of the Basa Formation. (a) Structural–geological scheme of BMA and its framework, after [2]. The schematic geological section of the right bank of the Zigan River (upper reaches). The position of the studied section is marked by an asterisk. (b) Schematic section of the Asha Group, exposed on the sides of a roadway excavation of the Sterlitamak–Beloretsk road. Sites of finds of fossil remains are marked by arrows. Legend: (*1*) Ural Fold Zone; (*2*) Central Uralian zone; (*3–5*) Paleozoic sedimentary complexes of the eastern margin of the Volga–Ural anteclise of the Russian Platform and Cis-Uralian Foredeep (*3*), West Uralian zone of outer folding and Bashkirian meganticlinorium (*4*), and Zilair synclinorium (*5*); (*6*) Kraka allochthon; (*7*) Ural-tau anticlinorium; (*8*) Magnitogorsk Zone; (*9–13*) BMA complexes: (*9*) Archean–Early Proterozoic Taratash complex, (*10*) Lower Riphean complexes, (*11*) Middle Riphean complexes, (*12*) Upper Riphean complexes, (*13*) Arsha Group of the Terminal Riphean (*a*), Asha Group of the Vendian (*b*); (*14*) boundaries: tectonic (*a*), stratigraphic (*b*); (*15–18*) only in the section: (*15*) interbeds of ash tuffs–tuff siltstones; (*16*) conglomerates of the Kukkarauk Formation; (*17, 18*) sandstones, siltstones, silty pelites, and mudstones of the Basa and Zigan formations: (*17*) exposed in the roadway excavations, (*18*) not exposed.

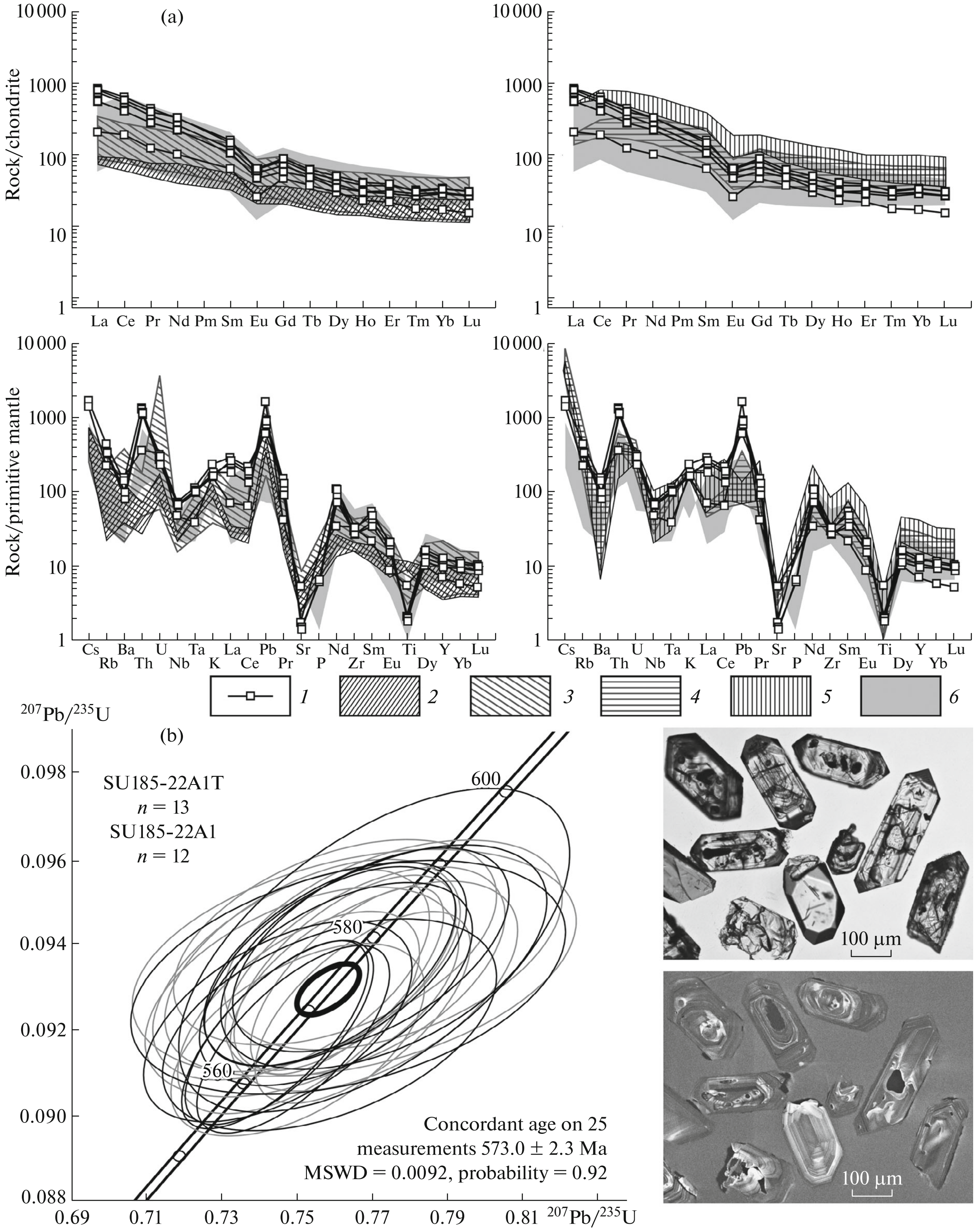

Fig. 2. Some features of the material composition and the isotope composition of tuffs. (a) Chondrite-normalized REE patterns and primitive mantle-normalized spidergrams of trace elements in Vendian volcanogenic rocks. (*1*) Basa Formation; (*2*, *3*) Sylvitsa Group of the Kvarkush–Kammenogorsk meganticlinorium, after [5]: (*2*) Staropechny Formation, (*3*) Chernyi Kamen Formation, (*4*, *5*) Mogilev–Podolian Group of Podolia, after [6]: (*4*) Mogilev Formation, (*5*) Yaryshev Formation; (*6*) Ergin Formation (previously distinguished as Erga and Mel'sk subformations of the Mezen Formation) in the Zimniy Coast area, after [4]. (b) The microprobe (SIMS SHRIMP-II) analyses of zircons from a volcanic tuff interbed of the Basa Formation. The diagram presents the concordia line and measurement error ellipses (2σ). The thick ellipse is the resulting estimate of the maximum age of the formation of the Upper Basa Subformation. Transmitted light and CL images of typical zircon grains from sample SU185-22A1T.

Table 1. The U–Pb (SHRIMP) age of tuffogenic zircon crystals from ash tuffs of the Basa Formation

Analysis point no.	$^{206}Pb_c$ (%)	Content, ppm			$^{232}Th/^{238}U$	Age, Ma (1)				D %	Isotope ratios (1)								Err. corr.
		U	Th	$^{206}Pb^*$		$^{238}U/^{206}Pb$	±Ma	$^{207}Pb^*/^{206}Pb^*$	±Ma		$^{238}U/^{206}Pb^*$	±%	$^{207}Pb/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	
Sample SU185-22A1																			
01.1	0.06	337	280	27.1	0.86	576.1	5.6	563	32	−2	10.7	1.0	0.05888	1.5	0.759	1.8	0.09348	1.0	0.565
02.1	0.03	660	393	52.1	0.62	567.0	5.2	560	21	−1	10.88	0.95	0.0588	0.98	0.745	1.4	0.09194	0.95	0.695
03.1	0.22	124	67	9.96	0.56	574.6	6.5	582	62	1	10.73	1.2	0.0594	2.8	0.764	3.1	0.0932	1.2	0.386
04.1	0.17	195	204	15.5	1.08	568.1	5.9	594	46	5	10.85	1.1	0.0597	2.1	0.759	2.4	0.0921	1.1	0.457
05.1	0.17	196	115	15.9	0.61	578.3	9.1	587	48	2	10.65	1.6	0.0596	2.2	0.771	2.8	0.0939	1.6	0.596
05.2	0.02	632	318	49.9	0.52	566.7	5.3	558	21	−2	10.88	0.97	0.05874	0.95	0.744	1.4	0.09189	0.97	0.714
06.1	0.11	278	213	22.4	0.79	578.4	5.7	585	36	1	10.65	1.0	0.05947	1.7	0.77	1.9	0.09387	1.0	0.530
07.1	0.06	622	491	49.0	0.82	566.1	5.3	574	22	1	10.90	0.97	0.05919	1.0	0.749	1.4	0.09178	0.97	0.696
08.1	0.07	243	131	19.4	0.56	573.7	5.7	577	36	1	10.74	1.0	0.05926	1.6	0.76	1.9	0.09307	1.0	0.532
09.1	0.07	258	152	20.4	0.61	568.5	5.6	553	36	−3	10.85	1.0	0.05861	1.7	0.745	2	0.0922	1.0	0.529
10.1	0.06	255	158	20.5	0.64	576.4	5.7	565	34	−2	10.69	1.0	0.05895	1.6	0.76	1.9	0.09353	1.0	0.551
11.1	0.00	134	96	10.8	0.73	577.3	6.3	598	43	4	10.67	1.1	0.0598	2.0	0.773	2.3	0.0937	1.1	0.497
Sample SU185-22A1T																			
01.1	0.35	167	146	13.5	0.90	576.6	6.4	579	64	0	10.69	1.2	0.0593	2.9	0.765	3.1	0.0936	1.2	0.366
02.1	0.17	458	247	36.2	0.56	566	5.4	578	33	2	10.90	1.0	0.0593	1.5	0.75	1.8	0.09178	10.0	0.543
02.2	0.00	501	403	39.8	0.83	570.5	5.4	610	25	7	10.81	0.98	0.06017	1.2	0.768	1.5	0.09252	0.98	0.647
03.1	0.15	242	184	19.3	0.79	572.6	5.9	555	44	−3	10.77	1.1	0.0587	2.0	0.751	2.3	0.09289	1.1	0.474
04.1	0.13	331	302	26.6	0.94	576.2	5.9	549	40	−5	10.69	1.1	0.0585	1.8	0.754	2.1	0.0935	1.1	0.508
05.1	0.13	281	188	22.5	0.69	575.4	5.8	592	36	3	10.71	1.1	0.05967	1.7	0.768	2.0	0.09337	1.1	0.537
06.1	0.00	193	144	15.5	0.77	574.9	5.9	537	37	−7	10.72	1.1	0.0582	1.7	0.749	2.0	0.0933	1.1	0.535
08.1	0.25	263	167	21.3	0.66	579.4	5.7	553	45	−4	10.63	1.0	0.0586	2.1	0.76	2.3	0.09405	1.0	0.450
09.2	0.12	275	99	22	0.37	573.4	5.9	606	37	6	10.75	1.1	0.0601	1.7	0.771	2.0	0.09302	1.1	0.530
10.1	0.04	328	469	26.1	1.48	569.7	5.7	564	31	−1	10.82	1.0	0.05891	1.4	0.751	1.7	0.09241	1.0	0.595
10.2	0.23	225	258	18.2	1.19	579.1	5.9	599	46	3	10.64	1.1	0.0599	2.1	0.776	2.4	0.09399	1.1	0.449
11.1	0.02	634	446	50.7	0.73	574.1	±5.2	583	21	2	10.74	0.96	0.05944	0.98	0.763	1.4	0.09315	0.96	0.697
12.1	0.00	397	235	31.9	0.61	575.2	±5.5	578	27	0	10.71	0.99	0.05929	1.2	0.763	1.6	0.09333	0.99	0.628

Measurement error is 1σ; Pb_c and Pb^* are common and radiogenic Pb; (1) values were corrected using measured ^{204}Pb; Err. corr., correlation coefficient. Standard calibration error: 0.32; D is discordancy.

eral composition of crystalloclasts is potassium FSp > 40%, biotite and phlogopite, 15–20%, and acid plagioclase, 10–15%. Volcanic glass is completely altered by the chlorite aggregate, not exceeding 15% of the total volume. Titanomagnetite, apatite, and zircon dominate among secondary and accessory minerals. The thickness of the basal tephra interbed is up to 4–5 mm. This is mottled reddish gray to beige-gray rock, followed higher in the section by ductile greenish gray tuff pelites, and then by bright (violet, pink, orange) rubble tuff siltstones, crowning the first volcano-sedimentary level of up to 4.0 cm thick. Higher in the section, the transition of ductile greenish tuff pelites to tuff siltstones is repeated. The basal tephra interbed is absent; the maximum thickness of the upper level is 3.5 cm. We have interpreted the structure of the tuff interbed as a reflection of two volcanic eruptions.

The tuff was sampled at the point with coordinates of 53°34.053′ N, 56°43.555′ E. The petrochemical composition of tuffs was studied at the Geological Institute, Russian Academy of Sciences (GIN RAS) (petrogenic oxides, XRF), and at the Analytical Certification Test Center, Institute of Microelectronics Technology and High Purity Materials, RAS (rare and trace elements, ICP-MS, with autoclave decomposition). It was established that tuffs correspond to trachyandesites in terms of composition: moderately alkaline ($Na_2O + K_2O$ – 5–9%) and high-Al ($Al_2O_3/(CaO + Na_2O + K_2O) > 2.5$) rocks with K-type alkalinity ($K_2O/Na_2O = 2–43$). The composition points of tuffs are located in the field of calc-alkaline series rocks (AFM diagram).

Tuffs are characterized by a pronounced rare-metal geochemical specialization. They are characterized by the following features (ppm): ΣREE, 929; La, 50–201; Ce, 117–394; Nd, 48–152; Zr, 335–380; Nb, 34–52. Rocks show a fractioned REE distribution pattern, $La_n/Yb_n = 12–25$ (Fig. 2a). Spidergrams show a Ta–Nb minimum and an indistinct negative Eu anomaly. As seen in the Pearce discriminant geodynamic diagram (Th–Hf/3–Nb/16), the composition points lie in the field of volcanic arc rocks. The formation of ash material could probably occur in the magmatic system of the back part of the active continental margin under conditions of bark-arc rifting, during the melting of blocks of the ancient continental crust. Tuffs similar in age and stratigraphic position are distributed in the southeastern White Sea Region [4], the Middle Urals [5, 6], Podolia [7], and other parts of the Russian Plate (Fig. 2a).

Sample SU185-22A1T, weighing <1 kg, collected from the basal tephra interbed, yielded many zircon crystals. Other fragments of the tuff lens were combined into a single sample SU185-22A1, weighing about 1 kg to select zircons. Both samples are dominated by elongated idiomorphic zircon crystals with oscillation zoning and melt inclusions (Fig. 2b) that indicate their magmatic genesis. The isotope system of zircons was studied using the local analysis (SIMS SHRIMP-II) at the Center for Isotopic Research, Karpinskii All-Russia Geological Research Institute (VSEGEI). In total, 13 and 12 grains with a minimum number of fractures, inclusions, and metamictic zones were selected from samples SU185-22A1T and SU185-22A1. Based on the isotope dating of zircon crystals from both samples (Fig. 2b, Table 1), the concordant age of 573.0 ± 2.3 Ma (MSWD = 0.0092, the probability is 0.92) was obtained.

The obtained zircon age can be interpreted as the upper age limit of the onset of the Timan Orogeny in the structure of the Southern Urals.

Fossil remains of *Kuckaraukia multituberculata* [2, 8] and several species of paleopascichnids, belonging to the genera of *Palaeopascichnus* and *Orbisiana* [2], were previously found in the studied and adjacent sections of the Basa Formation. Within the framework of the given work, the first occurrence of *Arumberia banksi* was established. The age obtained indicates that the studied fossil assemblage from the Basa Formation is the oldest compared to the known Vendian fossils of Eurasia, and it is chronologically close to the first representatives of the Ediacaran "fauna," the Avalon biota from the Drook and Briscal formations of the Newfoundland Peninsula [9].

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