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GEOLOGY

First Results of U–Pb Dating of Detrital Zircons from the Upper Ordovician Sandstones of the Bashkir Uplift (Southern Urals)

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Abstract—The first results of U–Pb dating of detrital zircons from Upper Ordovician sandstones of the Bashkir uplift in the Southern Urals and U–Pb isotopic ages available for detrital zircons from six stratigraphic levels of the Riphean–Paleozoic section of this region are discussed. It is established that the long (approximately 1.5 Ga) depositional history of sedimentary sequences of the Bashkir uplift includes a peculiar period lasting from the Late Vendian to the Emsian Age of the Early Devonian (0.55–0.41 Ga). This period is characterized by the following features: (1) prevalence of material from eroded Mesoproterozoic and Early Neoproterozoic crystalline complexes among clastics with ages atypical of the Volga–Urals segment of the East European Platform basement; (2) similarity of age spectra obtained for detrital zircons from different rocks of the period: Upper Vendian–Lower Cambrian lithic sandstones and Middle Ordovician substantially quartzose sandstones.

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The Bashkir uplift (BU) representing a large inlier of Precambrian (mostly Riphean–Vendian) rocks, which are unconformably overlain by Paleozoic sequences [3, Fig. 1], is located in the western Southern Urals. In terms of the structure, it consists of two stages separated by a distinct structural unconformity. The lower stage is formed by an Archean–Paleoproterozoic Taratash metamorphic complex, which constitutes the crystalline basement of the East European Platform (EEP) [7]. The upper stage is composed of a Riphean–Paleozoic complex represented mostly by sedimentary deposits, which accumulated in the East Bashkir basin (EBB). The lower part of its stratigraphic succession is known as representing the Riphean stratotype, the integral thickness of which amounts, according to some estimates [7, 14, etc.], to 10 km. Higher in the section, these rocks are overlain with disconformity by a sequence of clastic and clayey rock varieties up to 1.5 km thick united into the Upper Vendian Asha Group [7, etc.], although it is most likely Late Vendian–Early Cambrian in age [2]. In the southern part of the Bashkir uplift, rocks of the Asha Group are overlain with disconformity by Upper Ordovician terrigenous–carbonate rocks, which, in turn, give way first to Silurian–Lower Devonian carbonates and then to uppermost Lower Devonian sandstones (Emsian Takaty Formation) [1]. In the western part of the Bashkir uplift, the Takaty Formation rests with disconformity upon the Upper Vendian–Lower Cambrian Asha Group and is conformably overlain by a Middle Devonian–Lower Permian terrigenous–carbonate sequence. Thus, the Riphean–Paleozoic section of the East Bashkir basin is lacking structural unconformities and its constituting sedimentary successions are separated only by disconformities.

In the Riphean–Paleozoic section spanning an interval of approximately 1.5 Ga long, a substantial role belongs to sandstones (Fig. 1). The U–Pb dating of detrital zircons from heterogeneous sandstones of the East Bashkir basin makes it possible to elucidate some important aspects in the formation of sedimentary successions in the Southern Ural margin of the

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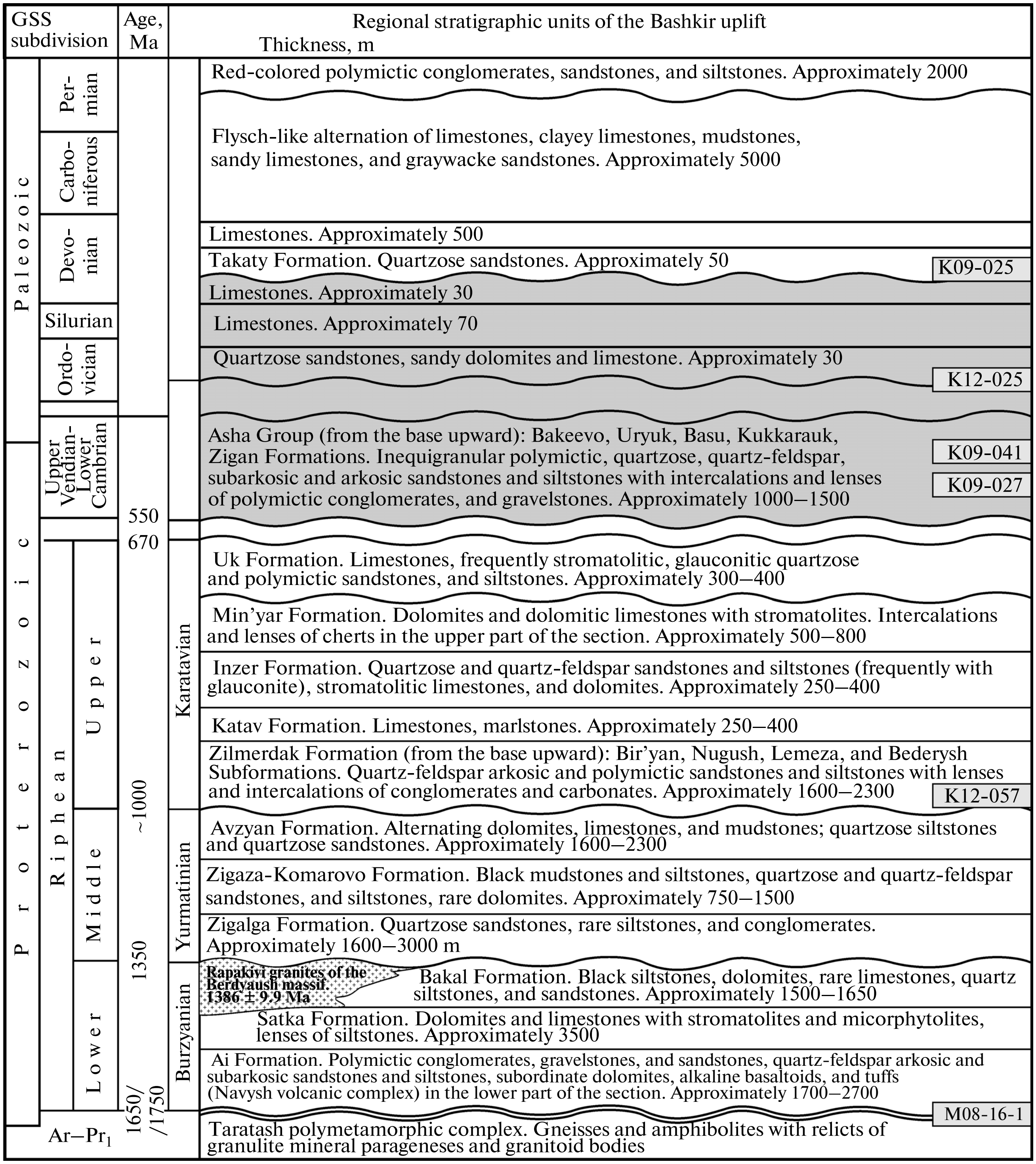

Fig. 1. Stratigraphy of Bashkir uplift deposits (compiled using materials from [7, 14], data by B.M. Keller, M.A. Semikhatov, V.I. Kozlov, and original observations). The stratigraphic positions of samples with detrital zircons dated by the U–Pb method: (M08-16-1) Ai Formation [4, 10], (K12-057) Lemeza Subformation [7–9], (K09-027) Basu Formation [3], (K09-041) Kukkarauk Formation [3], (K12-025) Upper Ordovician (this work), (K09-025) Takaty Formation [5]. The gray color designates the interval characterized by the "non-Baltic" age spectra of detrital zircons.

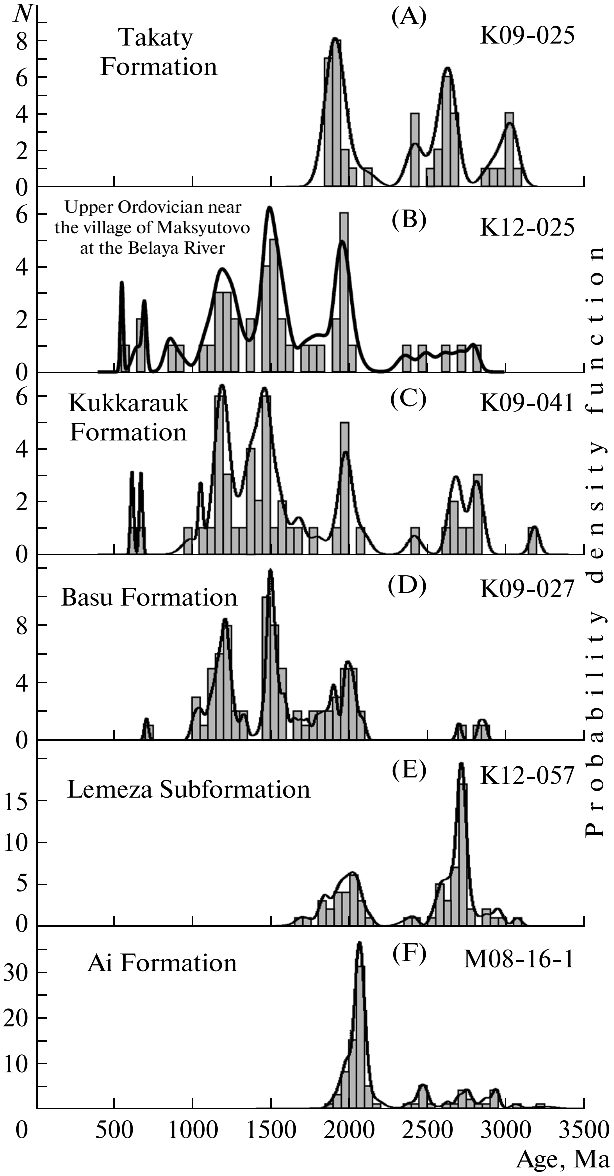

Fig. 2. Histograms and curves of the probability density function obtained for samples from the Riphean–Paleozoic section of the East Bashkir basin.

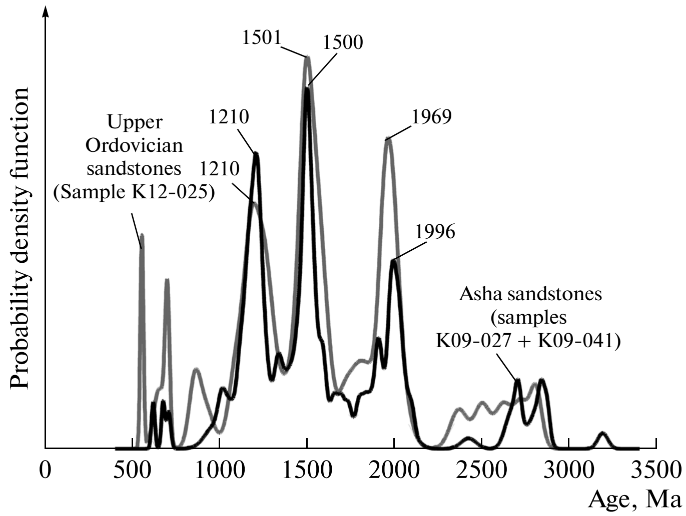

Fig. 3. Curves of the probability density function for ages of zircons from the Upper Ordovician sandstones and integral age spectrum for the Upper Vendian Kukkarauk and Basu formations.

East European Platform. Previously, detrital zircons were investigated from five levels in the Riphean–Paleozoic section of the East Bashkir basin (Figs. 1, 2A, 2C–2F): Lower Riphean, Upper Riphean, Upper Vendian, Lower Cambrian, uppermost Lower Devonian [3–5, 8–10]. In this communication, we present the first results of U–Pb dating of zircons from Upper Ordovician sandstones (Fig. 2B) accompanied by comparative analysis of the U–Pb ages obtained previously for zircons from sandstones of different stratigraphic levels in the East Bashkir basin section.

The Upper Ordovician section investigated is located in the southern part of the Bashkir uplift, where it is exposed on the right side of the Belaya River west of the village of Maksyutovo. In this area, the rocks of the Asha Group are overlain with disconformity by a thin member of small–pebble quartzose conglomerates, which is replaced higher in the section by a member of cross-bedded dolomitic sandstones with lenses of sandy dolomites 18 m thick. The member contains poorly preserved casts of brachiopods *Dalmanella* sp., *Camarotoenhia* sp., *Strophomena* sp., Orthidae, and *Didymelasma* sp., which were found 11–12 m below the contact with Silurian dolomites and indicate the Middle–Late Ordovician age of sandstones [1].

Sample K12-025 (53°0′29.30″ N, 56°56′36.40″ E) was taken from medium-grained cross-bedded substantially quartzose dolomitic sandstones. It yielded 208 zircon grains, 15% of which are fissured and many contain alien inclusions. The U–Th–Pb isotopic system was investigated in the GEMOC Center (Macquarie University, Sidney, Australia). In total, 60 grains were dated, of which 45 dates (75%) are concordant ($|D| \leq 10\%$); other dates were excluded from the analysis. The technical details of the equipment, dating technique, and constants used for processing of the analytical data are available in [13]. The concordant ages of zircons range from 554 ± 9 to 2806 ± 33 Ma being distributed among the main Precambrian units in the following manner: Neoproterozoic (5 grains), Mesoproterozoic (23 grains or >50%), Paleoproterozoic (14 grains), and Archean (3 grains). The curve of the probability density function exhibits three distinct maximums at 1210, 1506, and 1969 Ma (Fig. 3); other peaks are secondary, formed by a single or two age values.

The comparative analysis of all the available dates, which characterize the long (approximately 1.5 Ga)

Results of the Kolmogorov–Smirnov test (KS coefficients) for selections of U–Pb isotope ages of detrital zircons from terrigenous sequences of the Bashkir uplift

Sample number	M08-16-1	K12-057	K09-027	K09-041	K12-025	K09-025
M08-16-1		0.000	0.000	0.000	0.000	0.017
K12-057	0.000		0.000	0.000	0.000	0.386
K09-027	0.000	0.000		0.389	0.996	0.000
K09-041	0.000	0.000	0.389		0.894	0.000
K12-025	0.000	0.000	0.996	0.894		0.000
K09-025	0.017	0.386	0.000	0.000	0.000	

For positions of samples in the stratigraphic section, see Fig. 1; for age spectra and curves of probability density for tested selections of ages of detrital zircons, see Fig. 2. Calculations were performed using a special module to the standard program MS Excel available for free access at the site http://sites.google.com/a/laserchron.org/laserchron/home (authors G. Gehrels and J. Guynn, University of Tucson, Arizona, the United States). The KS test estimates the probability of the consistency of two empirical distributions to a single law. The standard level of KS test significance is accepted to be 95%. This means that if the KS coefficient value for tested age spectra for zircons exceeds a threshold value of 0.05, it may by assumed with a high degree of probability (95%) that zircons originate from the same source.

depositional history of sedimentary sequences in the East Bashkir basin, makes it possible to define a peculiar Late Vendian–Ordovician stage in its evolution. From the remaining Riphean–Paleozoic sedimentation history, this stage is separated by two significant reorganizations of paleogeographic and/or paleotectonic settings in the East Bashkir basin proper and/or adjacent structures with substantial changes in the sources of clastic material.

The Riphean (approximately 1.75–0.67 Ga) stage in the formation of sedimentary succession of the East Bashkir basin is insufficiently characterized by the data on the U–Pb ages of detrital zircons [4, 8–10]. The available data combined with the results of lithological–geochemical investigations allow the assumption that clastic material was transported to the basin mostly from the East European Platform [6], i.e., from "Baltic" sources. Moreover, paleodrainage areas during this extremely long period could naturally change their positions, sizes, and configurations [9, 10].

The results of the study of zircons from sandstones of the Asha Group provide grounds for assuming that in the late Vendian, the East Bashkir basin started receiving clastic material with Mesoproterozoic and Early Neoproterozoic zircons [3]. Rock complexes with such ages are now known only from the northwestern part of the East European Platform, which is located over 2000 km away from the basin [12]. Therefore, there are no grounds to consider them as the main/dominant source of clastics for sandstones of the Asha Group. In this connection, it was suggested that a new "non-Baltic" source of clastic material located east (in recent coordinates) of the Bashkir uplift appeared at the end of the Vendian [3].

The dating of zircons from sandstones of the Takaty Formation revealed that the next cardinal transformation of the source of clastic material took place by the end of the Early Devonian: only rock complexes with zircons older than 1.87 Ga were subjected to erosion at that time [5]. This gives reason to conclude that the Volga–Uralia block was the only likely provenance for the East Bashkir basin in the Early Devonian. The similarity between ages of zircons from Lower Devonian and Upper Riphean clastic rocks (table, KS coefficient 0.387) indicates the substantial contribution of material from two sources to their composition: eroded from the crystalline basement of the East European Platform and reworked from Riphean deposits.

The characteristic feature of this stage, which started in the Late Vendian and terminated by the Emsian time, is the remarkable similarity between age spectra obtained for zircons from sandstones of the Asha Group and the Upper Ordovician section. The age spectra of zircons from the Basu and Kukkarauk formations of the Asha Group demonstrate a high degree of similarity between each other (KS coefficient 0.386) and an extremely high similarity also with the age spectrum of zircons from the Upper Ordovician part of the section (KS coefficients 0.996 and 0.894, respectively). The comparison between curves of the probability density function of the distribution of ages obtained for zircons from the Upper Ordovician sandstone and integral age spectrum for zircons from the Asha Group reveals the almost complete identity of peaks for the Mesoproterozoic–Paleoproterozoic interval (Fig 3). Notable differences are registered only in the spectrum portion with ages younger than 1 Ga. Such a high degree of similarity between age spectra is unusual, if it is taken into consideration that depositional environments in the East Bashkir basin during the Late Vendian–Ordovician were highly variable.

The geological data for revealing directions of sediment fluxes and paleogeographic settings in the Vendian are insufficient. At the same time, the immaturity of lithic arkosic and, locally, polymictic and graywacke Asha sandstone indicates a close provenance with exposed diverse igneous rocks including granitoids, which practically avoided chemical weathering.

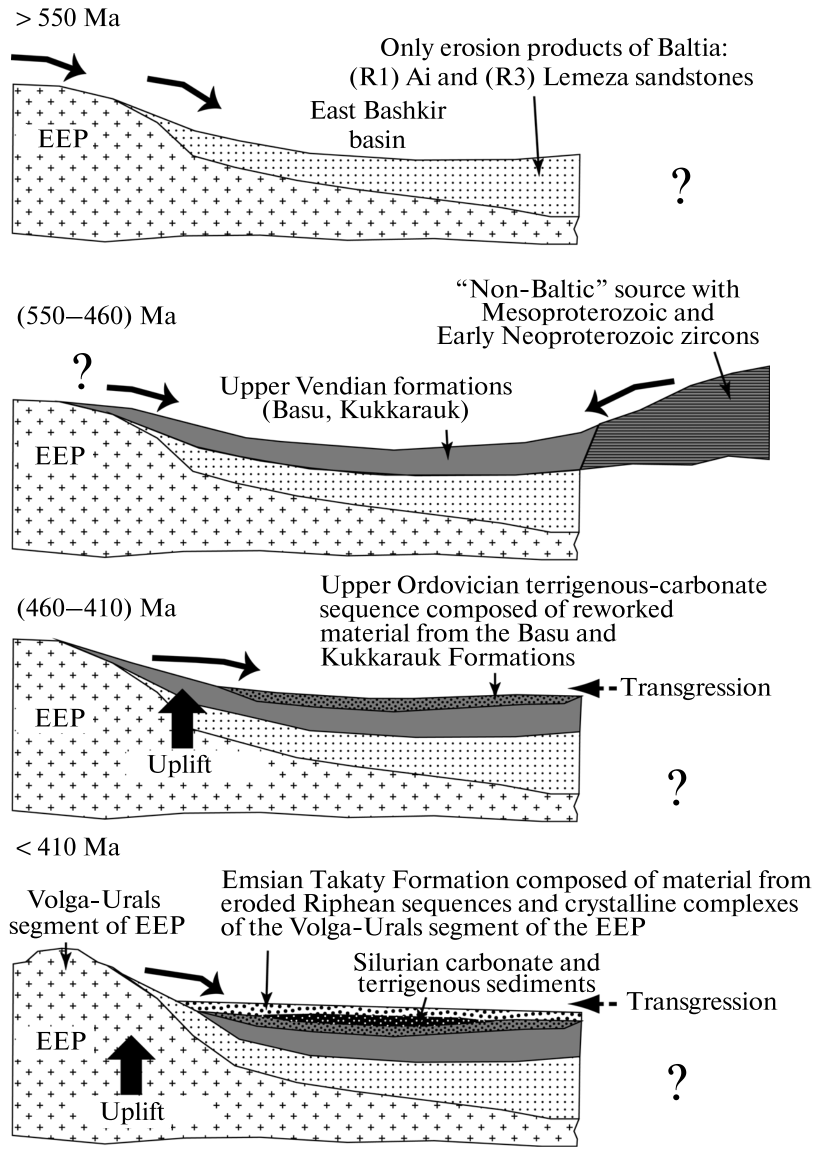

Fig. 4. Conceptual model (out of scale) of interpretation of zircon ages obtained for 6 samples from heterochronous sequences of the Bashkir uplift.

Moreover, variations in bedding patterns of rocks in the Asha Group imply different natures and intensities of tectonic movements in the sedimentary basin and zone of clastic material transportation. This is also evident from the distribution of ages obtained for detrital zircons from sandstones of the Asha Group indicating the dominant role of a "non-Baltic" source of clastic material at that time [3].

At the same time, Upper Ordovician sandstones of the East Bashkir basin demonstrate a highly mature substantially quartzose composition, associate with shallow-water carbonate rocks, and take part in the structure of the sequence characterized by insignificant sustained thickness. Paleotectonic and paleogeographic reconstructions available for the Late Ordovician epoch [15] imply the influx of clastics to the East Bashkir basin from the East European Platform and its accumulation in stable tectonic environments. This is quite consistent with the composition and structure of the Upper Ordovician terrigenous–carbonate sequence. Nevertheless, zircons from the Upper Ordovician sandstones suggest no substantial contribution of "Baltic" sources proper to their assemblage; on the contrary, age spectra demonstrate a significant similarity with ages of detrital zircons from sandstones of the Asha Group.

Such a paradox may be understood assuming that Upper Ordovician sandstones from the southern part of the Bashkir uplift were formed by material eroded from stratigraphic analogs of the Asha Group developed in the Shkapovo–Shikhan depression of the Volga–Urals region (Bizhbulyak Complex). At the beginning or in the middle of the Ordovician, these rocks were exhumed and, being subjected to chemical and mineralogical maturing, became sources of clastic material for Upper Ordovician deposits of the southern Bashkir uplift. The change in the development regime and direction of the clastic material transport is evident from the sedimentation break reflected in disconformity at the base of the Upper Ordovician sequence (Fig. 4). Single Late Neoproterozoic zircon grains could be transported together with erosion products from the Proto-Uralides–Timanides orogen, which accumulated partly in Lower Ordovician sandstones of the western Polar Urals [11].

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