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GEOCHEMISTRY

A Search for Sources of the Detritus of Ordovician Sandstones from the Sol-Iletsk Block (Ordovician-2 Borehole) Based on the First Data of the Geochemical and Lu/Hf Isotopic Systematics of Zircons

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Abstract—The primary isotope–geochemical and geochemical characteristics (by the TerraneChrone® technique) are presented for detrital zircons dated previously (U/Pb, LA–ICP–MS dating) from Ordovician sandstones (the Ordovician-2 borehole of the Sol-Iletsk block). The characteristics of the treated zircons were compared to the corresponding parameters of the complexes constituting the possible sources provinces.

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INTRODUCTION

The Sol-Iletsk block (SIB) is located at the juncture of the East European Craton (EEC) with the Caspian and the Cis-Uralian depressions. The boreholes of the SIB uncovered Ordovician rocks. Sample K15-501 of Ordovician sandstones was collected from the core of the 2-Ordovician borehole at the depth of 3439.7 m. These sandstones along with the separation procedure for detrital zircons (dZrs) were described in [2]. The primary results of the studies of trace elements (TEs) and the Lu/Hf isotope system in dZr of |D| < 10% discordance are presented below. The U/Pb system and TE content were examined in 120 zircons (Fig. 1), including 87 grains tested for the Lu/Hf system (Fig. 2a). The equipment, techniques, and constants used in the studies are described in [13]. The approach to the data interpretation (the TerraneChrone® technique) is considered in [11, 15].

The principles of the methodological approach. Zircons in different types of igneous rocks are characterized by different TE concentrations [1, 7, 8]. In view of this, the CART classification was created [8] to solve the inverse problem, i.e., to determine the types of parental rocks (granitoids and their effusive analogues) of dZrs by the TE content. These rocks are different in the silica content: decreased ($SiO_2 < 65\%$, diorites), normal (SiO_2 within 65–75%, granites), and increased ($SiO_2 > 75\%$, leucogranites), as well as rocks of medium composition and increased alkalinity (syenites/monzonites), carbonatites, etc. The dZrs of the material characteristics conforming to zircons from the groups of rocks listed are mentioned below as granite, diorite, carbonatite, etc., zircons.

The ε_{Hf} value is calculated by the results of examining the Lu/Hf isotope system of zircon. Positive ε_{Hf} values point to juvenile magmas of parental rocks of the zircon; values of $\varepsilon_{Hf} < 0$ show that the substance of the continental crust was incorporated in the substrate into which these magmas were melted [9, 10]. The time of separation of the crust substrate from the mantle (T^C_{DM}) may be estimated for each of the zircons with an accuracy of ~0.3 Ga.

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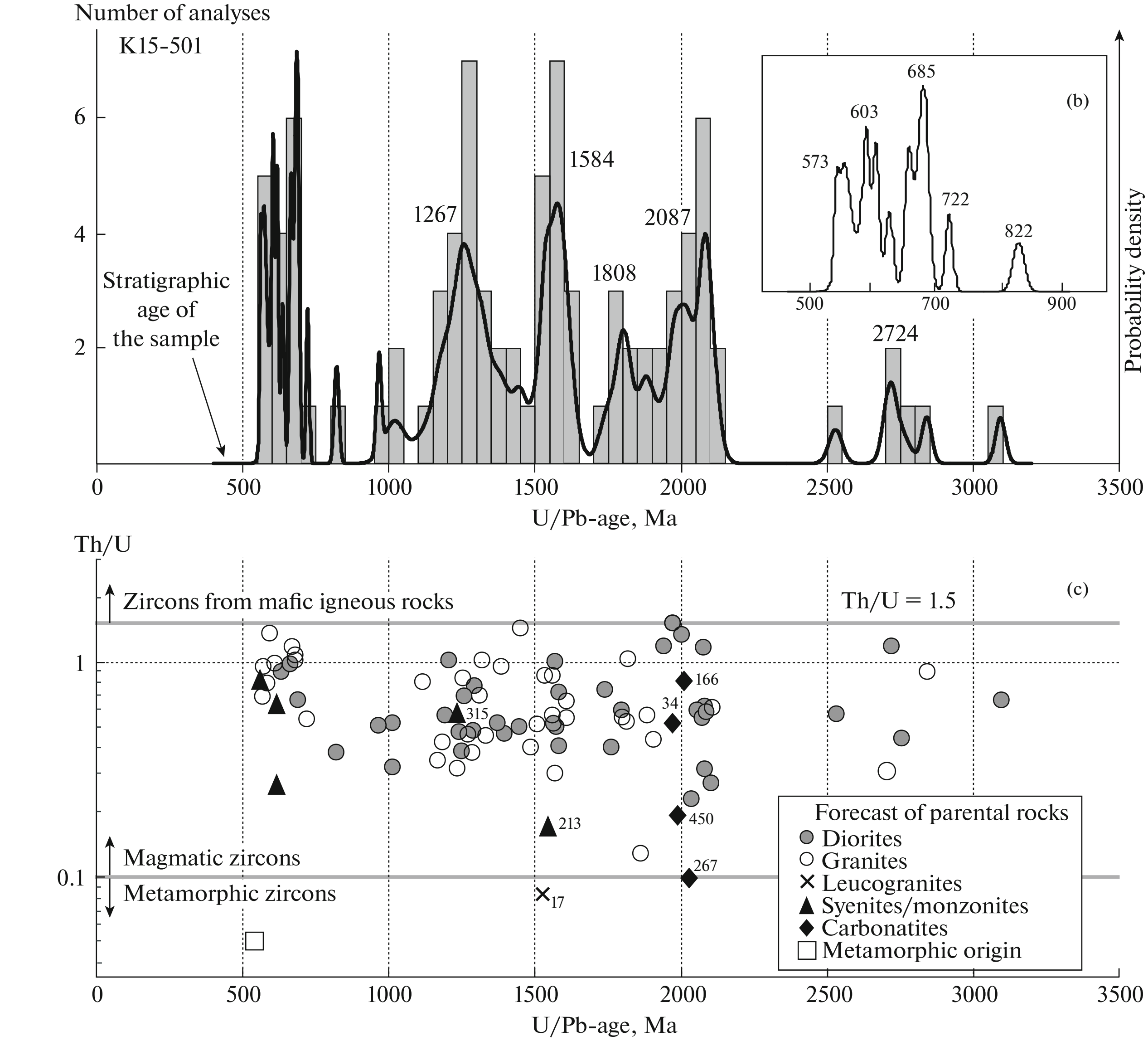

Fig. 1. Results of studies of trace elements and the U/Th/Pb isotope system in detrital zircons from sample K15-501. (a) Histogram and diagram of the probability density characterizing the age distribution of detrital zircons; (b) an enlarged fragment for the range of 500–1000 Ma; and (c) the U/Pb-isotope age–Th/U ratio diagram for detrital zircons. The symbols show the types of parental rocks for the zircons determined by the concentrations of trace elements using the CART algorithm. The numerals at the symbols are the nos. of analyses.

RESULTS

Values of ε_{Hf} from -12.9 ± 0.9 to $+11.7 \pm 0.8$ and of T_{DM}^{C} within 1.0–3.7 Ga were obtained for dZrs from sample K15-501. Excluding grain 223, all the dZrs from this sample were magmatogene. The parental rocks were diorites (57), granites (48), syenites/monzonites (8), carbonatites (4), and leucogranites (5).

All the zircons classified as leucogranite (5 grains) are characterized by quite similar cathode luminescence images with no visible zonality. Grain 17 showed an age of 1527±20 Ma, and a value of $T_{DM}^{C} = 2.14$ Ga. The Lu/Hf system was not studied for other leucogranite zircons because of the high discordance of dating, so no interpretation was possible for these grains.

All four carbonatite zircons showed ages of ~2.05 Ga. Three grains were of ε_{Hf} ~+5, which pointed to the juvenile substrate from which the parental magmas of these zircons were made. However, the dZr 267 showed a value of $\varepsilon_{Hf} = -5.8 \pm 0.4$ testifying to a considerable addition of crustal material that was isotopically mature within the magma-generating substrate. The same grain was characterized by a ratio of Th/U ~ 0.1; i.e., this grain was probably subjected to metamorphic transformation. Thus, the

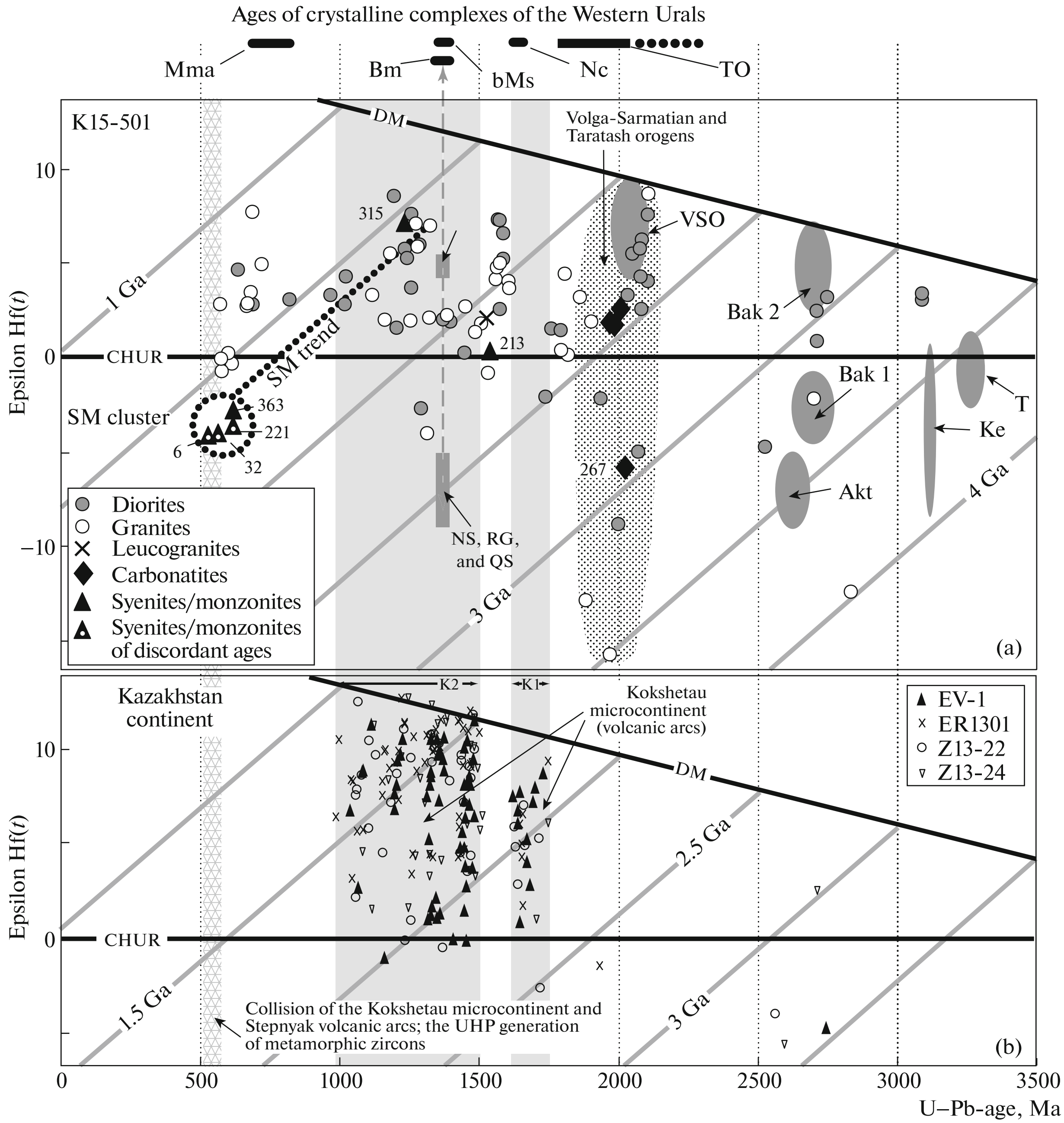

Fig. 2. The U/Pb-isotope age–ε_{Hf} diagram for detrital zircons from sample K15-501 (a) and from the microcontinents of the western part of the CAFB (b) by [14]. The CHUR line corresponds to chondritic unfractionated reservoir (CHUR – EpsilonHf(t) = ε_{Hf} = 0), and the DM line is that of the evolution of the depleted mantle. The evolution lines for the average continental crust ($^{176}Lu/^{177}Hf$ = 0.015) are shown in gray. The gray ellipses are the fields of figurative points of ages and T_{DM}^{C} values estimated by the Sm/Nd isotope system for the Bakaly block of Volgo-Uralia (the Tashlar (T), Bak 1, Bak 2, and Aktanysh (Akt) complexes), for the southern part of the Volga-Sarmatian orogen (VSO) sutured Volgo-Uralia and Sarmatia, and for the Kolyvan enderbites (KE) (see the collected data in [4, 5]). The gray rectangles are the fields of figurative points of ages for the rocks of the Berdyaush massif in the Western Urals (G is gabbro and NS, RG, and QS are nepheline syenites, rapakivi granites, and quartz syenodiorites, correspondingly) by [6]. Only the age ranges are shown at the top of the figure for other complexes of the Western Urals (see [4, 5]): TO, granitoids and metamorphites of the Taratash complex (relics of the Taratash orogen); Nc, alkaline basalts of the Navysh complex; Bm, the rocks of the Berdyaush massif; bMs, bimodal volcanics of the Mashak system (see [4, 5]), and Mma, granitoids and gabbroids of the Mazarin magmatic areal by [3]. The large shaded ellipse shows the area correlated with the zircons generated by the VSO and TO. The gray bands (K1 and K2) in Fig. 2b show the age intervals of the formation of island arcs constituting the basements of the Kokshetau and other microcontinents of the western part of the CAFB.

provenance signal from a short-living ultrabasic magmatic source was registered in sample K15-501.

Eight zircons (grains 6, 32, 43, 213, 221, 315, 363, and 366) were classified as syenite/monzonite dZrs. Grains 315 and 213 showed concordant ages of 1234 ± 25 and 1541 ± 43 Ma, correspondingly. The Lu/Hf system was studied for grains 32 and 221 despite the high discordance (13 and 16%). Grain 43 had insufficient volume to examine the Lu/Hf system. Six syenite/monzonite zircons appeared to be of close ages (within 527–618 Ma). The four grains for which Hf characteristics were obtained constituted a compact SM cluster forming an SM trend jointly with grain 315 (Fig. 2). This trend is close to the evolutionary line of the continental crust of 1.5–1.6 Ga in age (considering the accuracy of ε_{Hf} estimates). Hence, the syenite/monzonite zircons from sample K15-501 characterize the provenance signal of a magmatic source within the range of erosion, which was active at least since 1.2 Ga ago when the source of these magmas was still juvenile (positive ε_{Hf} values). Thereafter (within 527–618 Ma), the magmas of the same syenite/monzonite composition by the TE content in zircons were melted of the same substrate. Here, the Hf-isotope evolution of the substrate of these magmas coincides with the time of occurrence of the substrate within the crust.

The search for likely material sources. The sources of detritus constituting the Ordovician sandstones of the SIB might have been located in the Western Urals, at the Volga–Ural part of the EEC basement, in Paleozoic formations of the Central Asian fold belt (CAFB), and in Cadomides of the southern framing of the EEC.

A comparison of the characteristics of the zircons from sample K15-501 to those of crystalline complexes of the Western Urals and the Volga–Ural part of the EEC basement (Fig. 2) showed the following.

(1) The Late Proterozoic complexes of the Volga–Sarmatian and Taratash orogens (VSO and TO, correspondingly) along with the Late Proterozoic and Archean complexes of Volgo-Uralia might reasonably be the primary sources of Early Precambrian dZrs.

(2) Publications [4, 5] presented the collected geochemical characteristics of the rocks of the Tashlar and Aktanysh complexes, the Kolyvan enderbites, and diorites of the Bakaly block (Bak 1 and Bak 2) in Volgo-Uralia. Figurative points for isolated diorite zircons from sample K15-501 fell into the Bak 1 and Bak 2 fields (two points and one point, correspondingly).

(3) The figurative points for six zircons from sample K15-501 fell into the field of isotope parameters of the rocks of the southern part of the VSO, and seven dZrs were close to this field.

(4) The ages of several zircons from Ordovician sandstones (K15-501) were close to those of intrusive rocks of the Berdyaush massif in the West Urals. This fact might point to this massif as a likely primary source. The zircons from gabbro of this massif showed ε_{Hf} values of +4.6 ± 1.0, whereas the zircons from the nepheline syenites, rapakivi granites, and quartz syenodiorites were characterized by values of –5.32 ± 0.7, –5.99 ± 0.9, and –7.6 ± 1.4, correspondingly [6], which is characteristic in general for bimodal series. The erosion products of these series contained zircons of both negative and positive ε_{Hf} values. In view of the fact that zircons are less common in basic than in siliceous rocks, the probability of finding a bimodal series of granite dZrs of $\varepsilon_{Hf} < 0$ in erosion products should be much higher. However, no zircons of $\varepsilon_{Hf} < 0$ or of ages comparable to those of the rocks of the Berdyaush massif were found; hence, these rocks were unlikely the sources of dZrs in sample K15-501.

(5) The areas of the EEC basement close to the SIB contain no crystalline complexes with ages younger than 1.65 Ga. However, the sample K15-501 contains numerous zircons of the ages as such. The Precambrian complexes of microcontinents located to the west of the CAFB, as well as the Cadomides of the Scythian–Turanian plate, might be likely primary sources of these zircons. Up to now, no data have been available to examine the latter as sources of detritus. Data on the CAFB are available.

The Kokshetau block (KB) [12, 14], etc. and probably other microcontinents of the western part of the CAFB are constituted from the material of juvenile Late and Mesoproterozoic oceanic arcs. Events K1 and K2 (Fig. 2b) are the formation stages of these blocks. The consolidation of the basement of microcontinents took place within 1.1–1.2 Ga. The Upper Riphean rocks of the KB [14] contain individual Archean zircons along with Late and Mesoproterozoic (prevailing) grains of ages conforming events K1 and K2. The comparison of the characteristics of the zircons from sample K15-501 and of those from the KB Upper Riphean (Fig. 2b) shows that sample K1-501 (1) contains no dZrs of $\varepsilon_{Hf} > 7$, whereas the Kokshetau zircons of the group K2 are characterized by high positive ε_{Hf} values (even from +10 to +13); (2) no zircons were found with ages conforming to dZrs of the group K1; (3) numerous grains with ages within 1.5–1.6 Ga were registered, which were absent in the Kazakhstan samples. Thus, the characteristics of zircons from sample K15-501 do not coincide with those of the dZrs from the KB Upper Riphean constituted by the basement erosion products of microcontinents in the western part of the CAFB. These facts give no way to consider these erosion products of detrital zircons in sample K15-501.

CONCLUSIONS

Numerous detrital zircons with ages within 1.5–1.6 Ga registered in sample K15-501 point to material sources found neither in the Volga–Ural part of the EEC basement nor in the Western Urals and in the CAFB.

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