

Sandy Sediments in the Tokko Basin of the Baikal Rift Zone: Sources and Provenance Areas

T. M. Skovitina^{a,*}, Corresponding Member of the RAS A. B. Kotov^b, I. N. Buchnev^b, V. P. Kovach^b,
S. D. Velikoslavinskii^b, E. V. Tolmacheva^b, E. V. Adamskaya^b, O. V. Bobrovskaya^c, and V. A. Gorovoy^a

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Abstract—The results of U–Th–Pb (LA–ICP–MS) geochronological studies of detrital zircon from the Quaternary sands of the Tokko Basin on the eastern flank of the Baikal Rift Zone are reported. It is shown that their main sources were Mesoarchean tonalite–trondhjemite orthogneisses and metavolcanics, as well as Meso- and Neoproterozoic syn- and post-collision granitoids of the Chara–Olekma geoblock of the Aldan Shield, which are located near the Tokko Basin. Moreover, the input of sedimentary material into the basin could have occurred during the melting of glaciers that covered the Udokan Ridge to the south and the Kodar Ridge to the north in the Middle–Upper Quaternary.

Keywords: sandy sediments, detrital zircon, geochronology, Tokko Basin, Baikal Rift Zone

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I.D. Cherskii (1886) and V.A. Obruchev (1914, 1929, 1937) in the late 19th and early 20th centuries considered the origin of the Quaternary sands widely distributed in the intermountain basins/depressions of the Baikal region. This is still considered to be one of the central issues to understand the main features of the development of relief in the Baikal Rift Zone in the Cenozoic [1]. To solve the problem of the origin of the Quaternary sands, it is important and necessary (1) to identify sources and define provenance areas of the Quaternary sandy sediments, (2) to establish mechanisms and ways of transport of sand particles from sources to sedimentation basins, (3) to obtain data on the origin of the processes that transported loose material, and (4) to reconstruct the settings and paleogeographic conditions of accumulation of these sediments.

The geochronological study (U–Th–Pb method (LA–ICP–MS)) of detrital zircon grains is one of the most effective ways to solve the first problem, namely, to identify the sources and to define the provenance areas of terrigenous Quaternary sediments in the basins of the Baikal Rift Zone. In addition, the results of these studies provide data on the age boundaries of the continental crust formation in the southern part of

the Siberian craton and adjacent territories of the Central Asian Fold Belt.

In this paper we discuss the results of U–Th–Pb (LA–ICP–MS)—geochronological studies of detrital zircon grains from the Quaternary sandy sediments of the Tokko Basin, which is terminal on the eastern flank of the Baikal Rift Zone. This basin cannot be considered a “full” rift basin, as it is not distinctly expressed in terms of morphology typical of other Baikal-type basins; it is evidenced by its “roughly angular outlines and isometric form” [1]. Apparently, it is correct to refer it to an intermediate link between large and small basins of the Baikal Rift Zone [2]. Studies [1–6] give more comprehensive characteristics of the structural and tectonic features, analysis of relief and related sedimentary and volcanogenic formations, and the patterns of correlation between ancient and Cenozoic structures on the eastern flank of the Baikal Rift Zone and the attributed Tokko Rift Basin.

The structure of the geological substrate on which the Tokko Basin is developed, is determined by the correlation of the oldest structural elements and magmatic complexes of the western part of the Aldan Shield (Fig. 1).

The recent rift structure of the Tokko Basin is superimposed and oriented orthogonally to the main structural plan of the western part of the Aldan Shield [3–6].

The basin is about 80 km long and 10 to 30 km wide. It is located to the east of the Chara Rift Basin and together with it forms an extended negative morphostructure. The basin is separated from the latter by

^a*Institute of the Earth's Crust, Siberian Branch, Russian Academy of Sciences, Irkutsk, 664033 Russia*

^b*Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, St. Petersburg, 199034 Russia*

^c*St. Petersburg University, St. Petersburg, 199034 Russia*

**e-mail: tatiana_skovitina@mail.ru*

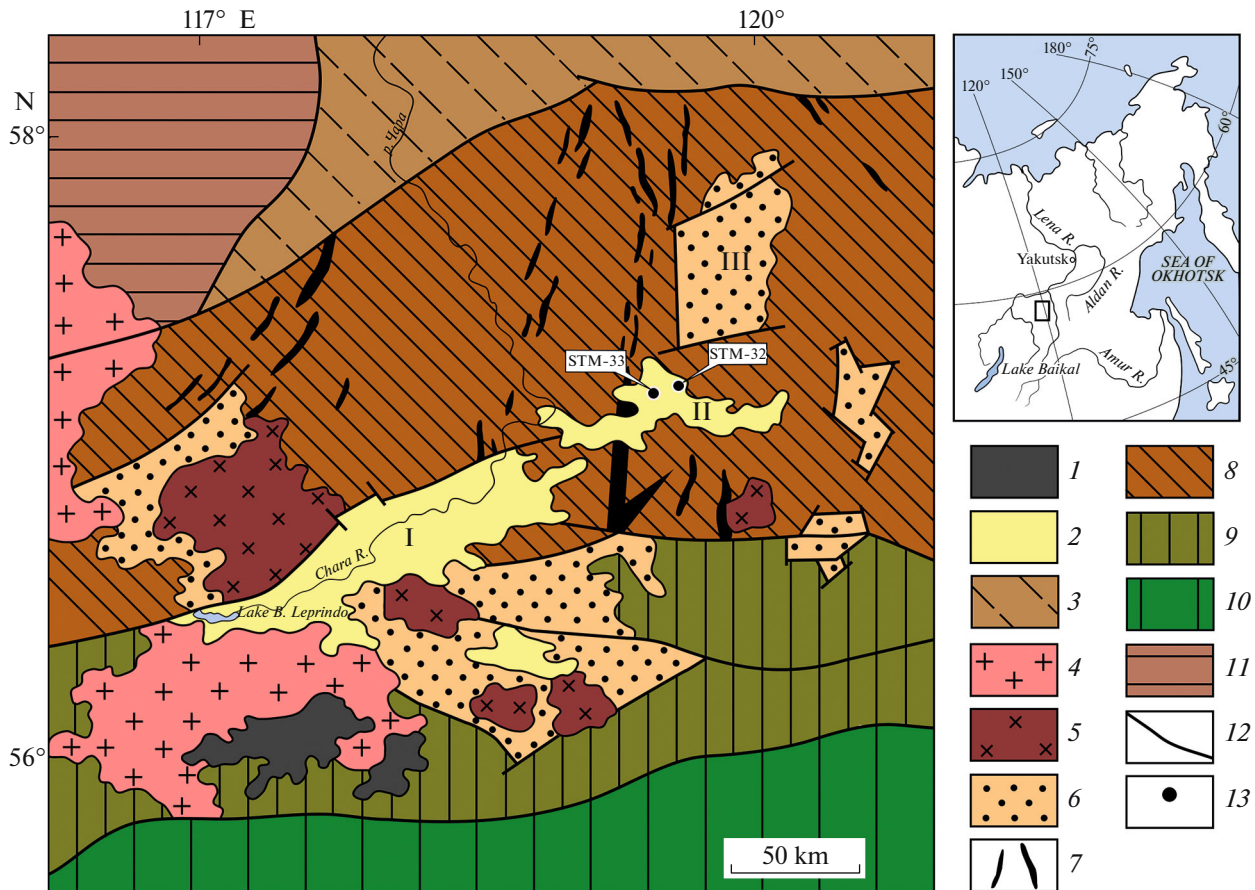


Fig. 1. The scheme of the geological structure of the western part of the Aldan Shield. 1, Cenozoic plateau-basalts (N_2 -Q); 2, Cenozoic sandy sediments of rift depressions; 3, Mesozoic, Paleozoic, and Neoproterozoic platform sediments; 4, Phanerozoic granitoids; 5, Paleoproterozoic granites of the Kodar complex; 6, Paleoproterozoic metasedimentary rocks of the Udokan series; 7, poorly metamorphosed sedimentary and volcanic rocks of Mesoarchean greenstone belts of the Subgan complex; 8, Meso- and Paleoproterozoic tonalite–trondhjemite orthogneisses and Mesoarchean intrusive granitoids of the Chara–Olekma geoblock of the Aldan Shield; 9, junction zone of the Aldan Shield and the Central Asian mobile belt (Stanovoi structural suture); 10, Selenga–Stanovoi superterrane of the Central Asian mobile belt; 11, Baikal–Patom area; 12, discontinuities; 13, sampling sites for geochronological studies and their numbers. Roman numerals indicate the following: I, Chara Basin; II, Tokko Basin; and, III, Ugui graben syncline.

a low (1000–1400 m) intertrough connecting barrier. The bottom of the Tokko Basin has the lowest absolute elevations of 580–620 m in its western part (Tokko River basin), reaching 700 m or more in the eastern part (Choroud River basin). It consists of three basins—the Taryn–Uryakh, Tokko, and Choroud basins, representing a single morphostructure called the Tokko Basin [3].

From the south and southeast this basin is bounded by the Udokan Ridge (maximum a.s.l. up to 2500 m) like the neighboring Chara Basin, and from the north and northwest, by the alpine-type Kodar Ridge (maximum a.s.l. up to 3000 m and higher) [6].

The Tokko Basin is composed of Quaternary sediments of various genetic types, among which the largest areas are occupied by glacial and fluvioglacial, and to a lesser extent alluvial, lacustrine, and proluvial complexes [3]. The thickness of loose sediments in the

most submerged parts of the depression reaches 500 m [5], and the total volume of the Cenozoic sediments is 370 km^3 [6].

Detrital zircon from two samples of the Quaternary sands of the Tokko Basin (sample STM-32 from lacustrine shore sediments; STM-33 from river alluvium sediments) was used for the U–Th–Pb (LA-ISP-MS) geochronological studies; the sampling points are shown in Fig. 1. Zircon was extracted from these samples in the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, St. Petersburg, according to the standard technique using heavy liquids. The morphological features of zircon were studied with the use of a TESCAN VEGA 3 scanning electron microscope with BSE- and CL-detectors. The Olympus BX 41 optical microscope with a high-temperature TS1400XY heating stage, TO95-STO temperature controller, and LMP95 cool-

ing system (Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences) was used to study inclusions of mineral-forming media in zircon. Geochronological studies of detrital zircon were carried out from fractions more than 85 μm in size.

The U–Th–Pb (LA-ICP-MS) geochronology was studied at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, using the NWR-213 laser ablation system with a TwoVolume camera combined with the ELEMENT XR ICP mass spectrometer. The laser “beam” diameter was 25 μm , and the duration of measurement was 100 s (40 s gas blank, 60 s ablation). Calibration was performed using GJ-1 standard zircon [7]. Crystal fragments of standard zircon Harvard 91 500 and Plešovice zircon were used for quality control of the analytical data. For the Harvard 91 500 standard zircon, the following parameters were obtained: the weighted average age is 1068 ± 5 Ma for the $^{207}\text{Pb}/^{206}\text{Pb}$ ratio (2σ , $n = 40$, MWCD = 0.44, probability = 0.999); for the $^{206}\text{Pb}/^{238}\text{U}$ ratio, it is 1067 ± 6 Ma (2σ , $n = 40$, MWCD = 0.080, probability = 1.000). For the Plešovice standard zircon, the weighted average age of 336 ± 2 Ma (2σ , $n = 43$, MWCD = 0.23, probability = 1.000) for $^{206}\text{Pb}/^{238}\text{U}$ ratio was obtained. The obtained ages for zircon standards agree well with the recommended data (Harvard 91 500: $^{207}\text{Pb}/^{206}\text{Pb}$ — 1066.01 ± 0.61 Ma, $^{206}\text{Pb}/^{238}\text{U}$ — 1063.51 ± 0.39 Ma; Plešovice: $^{206}\text{Pb}/^{238}\text{U}$ — 337 ± 2 Ma) [8]. The U–Th–Pb isotopic ratios were calculated in the GLITTER 4.0 GEMOC program [9]. Corrections for common lead were input using the ComPb program [10]. Concordia ages were calculated using the IsoplotR program [11]. Only concordant ($D \leq 5\%$) estimates of the zircon ages were used to plot the histograms, the relative probability curves of the age distribution, and calculation of the maxima of the ages (Peak Ages) [12].

Detrital zircon from the Quaternary sands of the Tokko Basin is represented by rounded grains. The main feature of their structure is determined by the presence of nuclei surrounded by a thin shell. The majority of zircon nuclei are characterized by distinctly manifested fine and coarse oscillatory zoning, typical for zircon of magmatic origin. In addition, they contain partially and fully crystallized melt inclusions. In the zircon shells, which, commonly, have a homogeneous structure, only gas-liquid, often decrypted, inclusions were found, indicating their metamorphic origin.

Figure 2 demonstrates the results of geochronological studies of detrital zircon from the Quaternary sands of the Tokko Basin. It should be emphasized that these results refer to the nuclei of detrital zircon grains, because study of the shells is not possible due to the technological features of the method of geochronological studies used.

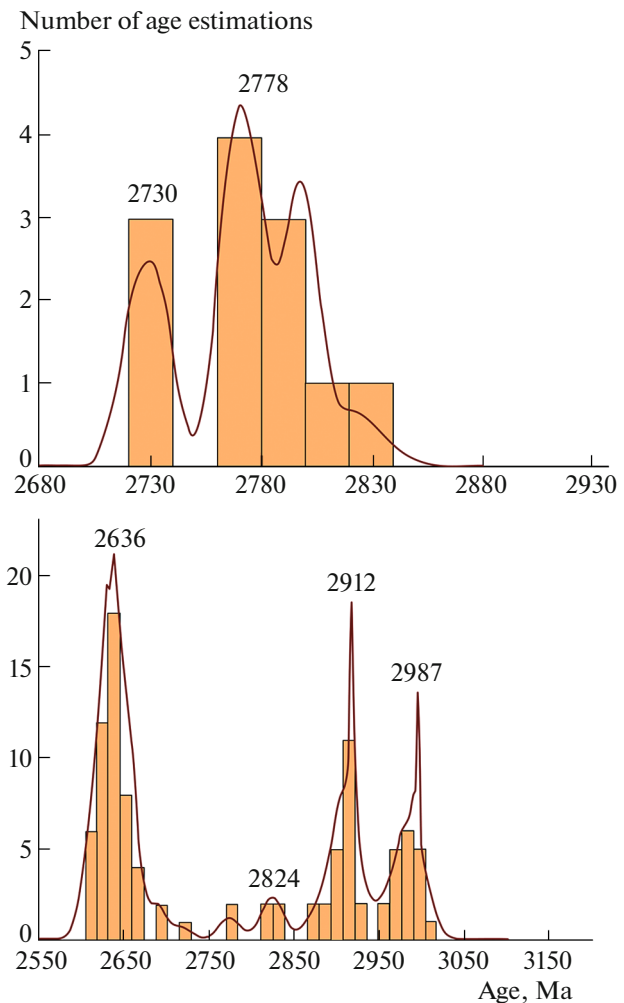


Fig. 2. The distribution histograms and relative probability curves of the detrital zircon ages from the Quaternary sands of the Tokko Basin (samples STM-32 and STM-33).

We studied 50 grains detrital zircon from the STM-32 sample; as a result, 12 concordant ages in the range of 2706–2829 Ma were obtained. On the relative probability diagram of the age distribution, two maxima are distinctly distinguished—2730 and 2778 Ma (Fig. 2). Geochronological data for detrital zircon from the STM-33 sample were obtained for 120 grains, and 98 zircon grains are characterized by concordant ages in the intervals of 2583–2720 Ma, 2745–2748 Ma, and 2790–3033 Ma. On the relative probability diagram of the age distribution, the maxima occur at 2636 Ma (47 grains), 2824 Ma (four grains), 2912 Ma (21 grains), and 2987 Ma (17 grains) (Fig. 2).

The diagrams illustrate that the age of detrital zircon from the Quaternary sands of the Tokko Basin is in the interval of 2.6–3.0 Ga. There is no doubt that their main sources were Mesozoic tonalite–trondhjemite orthogneisses and metavolcanites (2967 ± 10 – 3212 ± 8 Ma), as well as Mes- and Neoproterozoic syn- and postcollisional granitoids of the

Chara–Olekma geoblock (2738 ± 8 – 2913 ± 8 , 2608 ± 18 – 2675 ± 15 Ma) of the Aldan Shield [13, 14] surrounding the Tokko Basin.

It should be noted that the Early Proterozoic detrital zircon and Paleozoic detrital zircon are absent in the Quaternary sands of the Tokko Basin. These zircons were found in sandy sediments of the Chara Basin [15], the eastern boundary of which is located approximately 15–20 km from the western boundary of the Tokko Basin. This can be explained by the existence of the barrier between these basins, which was mentioned at the beginning of this work. We also noted the absence of Early Proterozoic detrital zircon in the sand samples studied, which, along with the Archean detrital zircon, is a significant component of the Early Proterozoic sandstones of the Ugui graben [16]. The distance to this graben from the northern boundary of the Tokko Basin is about 20 km.

Apparently, sediments were transported within the basin over a short distance, which did not exceed a few tens of kilometers. In contrast to the neighboring Chara Basin, where sedimentary material was transported from more distant sources [15], the accumulation of sandy sediments in the Tokko Basin was from proximal sources. It is possible that sedimentary material could have actively entered the basin during the melting of glaciers that covered Udokan Ridge in the south and Kodar Ridge in the north in the Middle–Upper Quaternary. As has been noted above, it is glacial and fluvio-glacial sediments that occupy the largest areas of the Tokko Basin [3].

It should also be noted that the data obtained confirm the concept [13] that the formation of the continental crust of the central part of the Chara–Olekma geoblock of the Aldan Shield is generally associated with the Mesoarchean and Neoarchean stages of its geological development.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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