ISSN 0869-5938, Stratigraphy and Geological Correlation, 2023, Vol. 31, No. 6, pp. 507–521. © Pleiades Publishing, Ltd., 2023.
Russian Text © The Author(s), 2023, published in Stratigrafiya, Geologicheskaya Korrelyatsiya, 2023, Vol. 31, No. 6, pp. 3–19.

The First Detrital Zircon Data on the Northwestern Precambrian Yenisei Ridge: Identification of the Continental–Arc Kiselikha Terrane

A. B. Kuzmichev[a,] *, A. A. Storozhenko[b], M. K. Danukalova[a], V. B. Khubanov[c], and A. S. Dubensky[a]

[a] *Geological Institute, Russian Academy of Sciences, Moscow, 119117 Russia*

[b] *AO Sibirskoe PGO, Rosgeologiya, Krasnoyarsk, Russia*

[c] *Geological Institute, Siberian Branch, Russian Academy of Sciences, Ulan-Ude, 670047 Russia*

**e-mail: nsi.kuzmich@yandex.ru*

Received September 30, 2022; revised December 22, 2022; accepted January 17, 2023

Abstract—Northwestern segment of the Precambrian Yenisei Ridge contains ophiolite and is known in literature as the Isakovka Terrane or Isakovka domain. We suggest to divide it into two belts: Kiselikha (western) and Torzhikha (eastern), which differed in geodynamic regime during the Late Neoproterozoic (750–600 Ma). It is believed that the Kiselikha belt is mostly composed of volcanic rocks erupted at island arc setting in the second half of the Neoproterozoic, and that collision of this arc with the Siberian Continent formed the Yenisei Ridge orogen. This idea has not been sufficiently supported by geological and geochronological data. Dating of four detrital zircons samples extracted from sedimentary and volcanic-sedimentary rocks in the southern part of the belt revealed that the sampled strata belong to three different Precambrian levels: the Mesoproterozoic, the mid-Neoproterozoic (800–750 Ma), and the end of the Neoproterozoic (620–600 Ma). Thus the authorized stratigraphic layout of the belt, as well as its proposed island-arc origin requires revision. By this paper we announce the identification of the Kiselikha Terrane , which was a part of active margin of the Siberian Paleocontinent at the beginning of the Neoproterozoic. Approximately in the middle of the Neoproterozoic, this block was rifted off Siberia and further evolved as a microcontinent bounded by an active margin from the outer side.

Keywords: Yenisei Ridge, Neoproterozoic, Mesoproterozoic, detrital zircons, Siberian Craton, Siberian Paleocontinent

DOI: 10.1134/S0869593823060060

INTRODUCTION

The Yenisei Ridge is the largest Precambrian inlier in the west of the Siberian Platform, which extends for almost 600 km at a width of up to 200 km. In the Neoproterozoic, this area was a margin of the Siberian Paleocontinent. It was bounded by the Paleoasian Ocean and was significantly reworked in suprasubduction and collision settings. Exactly the Neoproterozoic granites compose a main volume of igneous rocks exposed in the present-day erosion level of the ridge. In the northwestern part of the ridge, the ancient basement, which was reworked in the Neoproterozoic, contacts with a Precambrian block including ophiolites (Isakovka domain) (Kuzmichev, 1987; Vernikovsky et al., 2003). It extends along the Yenisei River for 150 km at a width of up to 45 km (Fig. 1). From the west, southwest, and north, the Precambrian rocks are submerged below the Meso-Cenozoic cover of the West Siberian Basin. It is considered that the Isakovka domain is composed of rocks of the second half of the Neoproterozoic, which were thrust on a margin of the Siberian Paleocontinent at the end of the Neoproterozoic (Vernikovsky et al., 2003). Whereas the Precambrian geological evolution of the main "cratonic" part of the Yenisei Ridge is generally clear (Kuzmichev and Sklyarov, 2016), too little data on the composition, age, and geodynamic setting of the Isakovka domain rocks are known now.

The Isakovka domain of the Yenisei Ridge is composed of two longitudinal belts, which are divided by a thick zone of blastomylonites. It is proposed to name the eastern and western belts Torzhikha and Kiselikha, respectively (Fig. 1). Both belts include the rocks of dismembered ophiolite association. The interpretation of the geodynamic setting is problematic for both belts. It was suggested that the Torzhikha belt was an accretionary prism, formed along the margin of the Siberian Paleocontinent in the second half of the Neoproterozoic and includes the nappes of the oceanic lithosphere (Kuzmichev et al., 2017). The island arc nature of the Kiselikha belt is suggested in (Vernikovsky et al., 2001, 2003 and later works of these

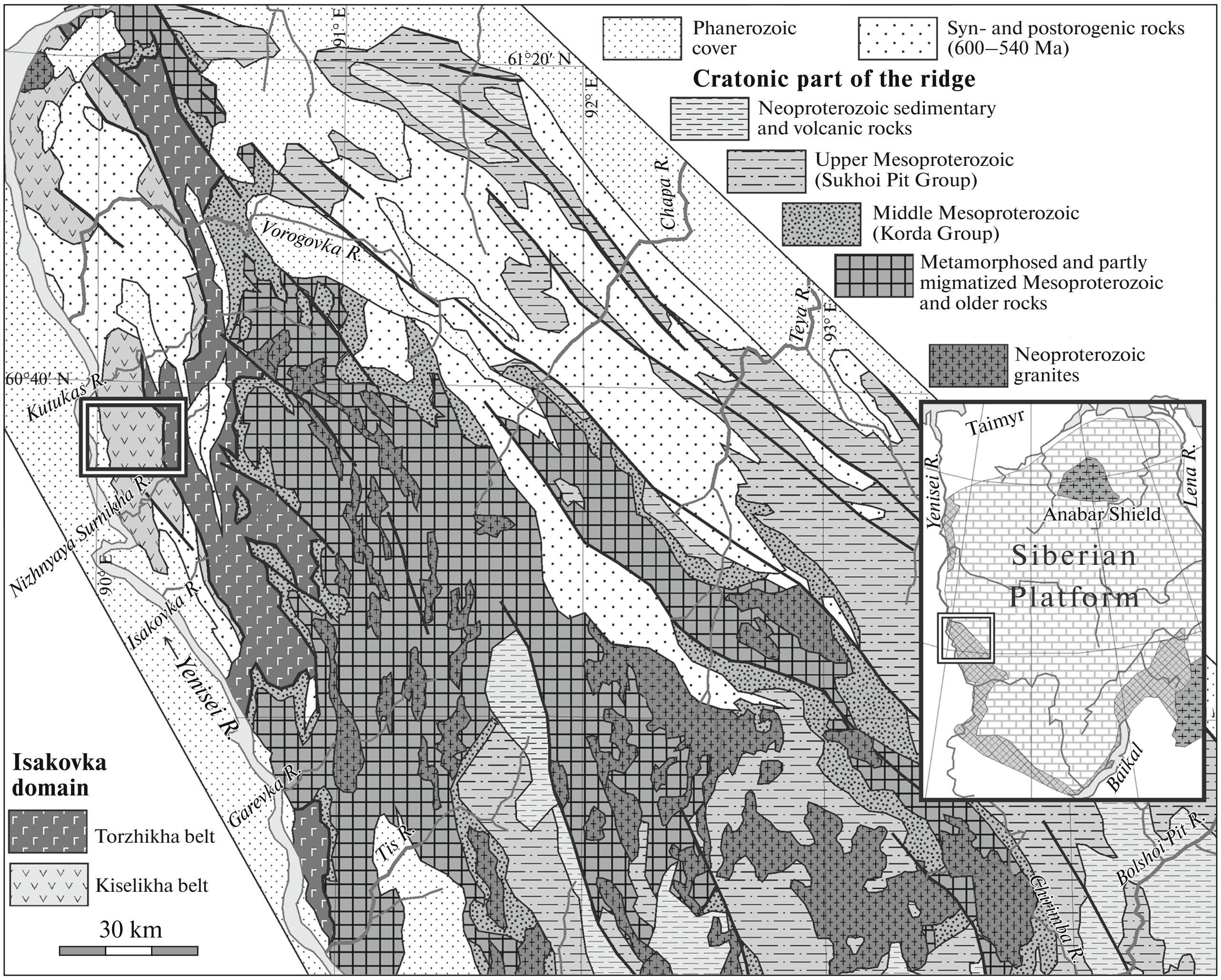

Fig. 1. Schematic geological map of the northern part of the Yenisei Ridge with distinguished cratonic part intruded by Neoproterozoic granites and the Isakovka domain with dismembered ophiolites, simplified after (Kachevskii et al., 1998; Storozhenko and Vasil'ev, 2012). The contour of Fig. 3 is marked by the rectangle. Inset: Siberian Platform and Precambrian inliers along its periphery. Rectangle shows the northern part of the Yenisei Ridge that corresponds to the main figure.

authors). It is considered that Ediacaran collision of this island arc with the margin of the Siberian Paleocontinent was a reason of the final orogeny, which formed the structure of the Yenisei Ridge. The preliminary results of our field observations of 2021–2022 are poorly consistent with the above interpretation of the geodynamic setting for each of these two belts. The geological situation for the Kiselikha belt with metamorphic rocks in the north is the least clear.

The belt was mapped on a scale of 1 : 50 000 by the Krasnoyarsk Geological Survey Expedition (L.K. Kachevskii, A.A. Storozhenko, V.K. Zuev, and others) in the 1970s–the beginning of the 1980s. A large volume of factual mapping data especially for the Precambrian complexes is still waiting for understanding and ordering. A volcanic-sedimentary substrate composing the belt is divided into a series of formations, whose volume and names (as well as the relative position in the section) have repeatedly been reconsidered (Kovrigina and Kovrigin, 1960, 1967; *Gosudarstvennaya*..., 1981; Kachevskii et al., 1998; Varganov et al., 2010; Storozhenko et al., 2019).

The current version of the stratigraphic division of the belt includes (bottom to top) the Khariusikha, Kiselikha, Otravikha, and Ust Kutukas formations, the last three are combined into the Kutukas Group (Storozhenko et al., 2019). This group was ascribed to the Upper Riphean (1030–600 Ma in the Russian Stratigraphic Chart) and is composed of sedimentary and volcanic-sedimentary rocks with a total thickness of >3.5 km, which are metamorphosed under a low degree of the greenschist facies. The previous version of the stratigraphic division (Kachevskii et al., 1998) suggested an opposite sequence of the formations. It was later established that the Ust Kutukas Formation lies upon the Otravikha Formation with angular unconformity and basal conglomerates in the basement. The lower contacts of other formations were interpreted as thrusts. The rocks are intensely deformed up to the formation of isoclinal folds and are densely faulted. The schematic succession of the strata is shown in Fig. 2.

The Khariusikha Formation is exposed in a tectonic wedge at the boundary with the Torzhikha belt. It is composed of green schists with limestone interlayers. The gray-coloured Kiselikha Formation consists of alternating poorly sorted sandstones, siltstones, and shales; the rocks are interpreted mostly as tuffites and tuffs (as well as a significant portion of sandstones and shales of the overlying Otravikha Formation). The sandstones are composed of dominant quartz grains (mostly angular) and subordinate feldspars and felsic and mafic volcanic rocks. There are lenses (up to a few meters) of metadacites and their tuffs. The Otravikha Formation hosts the interlayers of carbonate rocks almost over the entire section and is crowned by a homogeneous member of marblized limestone 100–150 m thick. The formation also includes green schists and interlayers of volcaniclastic sandstones, with a significant amount of clasts of differentiated volcanic rocks. Some sections of the formation contain metabasaltic bodies up to 250–300 m thick. The section is crowned by the Ust Kutukas Formation (250–300 m), the lower half of which is mostly composed of amygdaloidal basalts, basaltic andesites, and trachibasaltic andesites, locally, with pillow structures, and lava breccias, whereas the upper half consists of dark gray shales with tuff interlayers of dacitic andesites.

This scheme of stratigraphic division is based on the observations in the coastal outcrops of the lower reaches of the Kutukas River (Storozhenko et al., 2019). These formations are weakly traced over the territory of the Kiselikha belt and, as a result, the most part of the belt is mapped as the Kiselikha Formation (Storozhenko and Vasil'ev, 2012). The scheme does not include the entire diversity of stratified rocks of the Kiselikha belt, and the combination of all rocks into one group is poorly substantiated. To the north of the reference section, the degree of metamorphism of the Kiselikha Formation increases and there is an evident difference in metamorphism with the rocks of the Ust Kutukas Formation, which correspondingly belongs to another stage of regional evolution. The green schists of the Khariusikha Formation should probably be included in the Torzhikha belt.

The dramatic history of changes in ideas on the Precambrian stratigraphy of the belt illustrates the objective reasons that hamper the elaboration of an adequate stratigraphic scheme and include poor exposure, complex structure, rapid facies changes, uneven distribution of volcanic rocks, and uneven metamorphism. If we add the almost complete absence of modern isotope data on the age of rocks critical for the Precambrian, it is found that our ideas on the geological structure of the belt rely on a shaky foundation. Only two ages are published, both for granites from the northern part of the belt: 700 Ma for the preorogenic

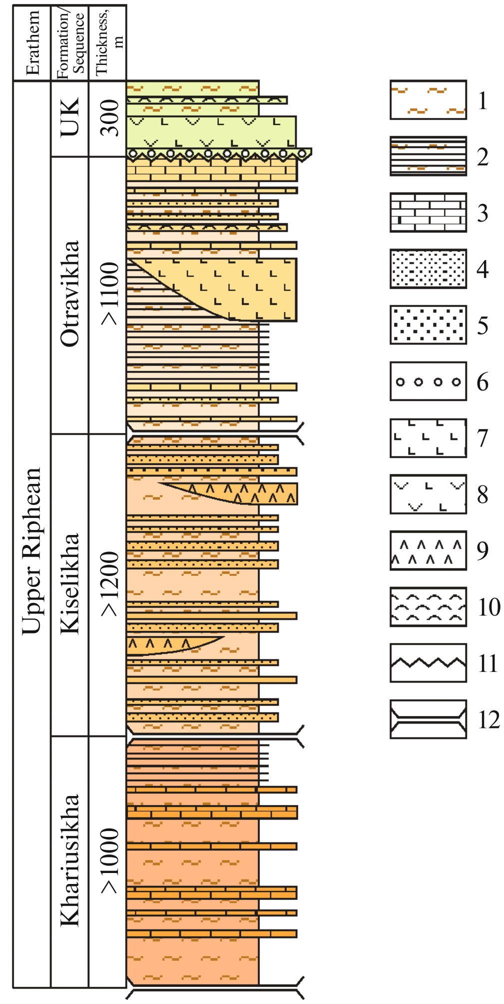

Fig. 2. Schematic stratigraphic sequence of pre-Vendian rocks of the Kiselikha belt, after (Storozhenko et al., 2019). (1) Quartz–albite–sericite–chlorite schist of variable composition, including carbonaceous and carbonate ones; (2) similar schist enriched in silt; (3) marbleized limestone; (4) sandstone, tuffaceous sandstone; (5) gritstone, tuffaceous gritstone; (6) conglomerate; (7) basalt; (8) trachibasaltic andesite; (9) dacite; (10) felsic–intermediate (?) tuff; (11) angular unconformity; (12) tectonic contacts. UK, Ust Kutukas Formation. Three upper formations are combined into the Kutukas Group. All rocks are metamorphosed in greenschist facies.

Porozhnaya pluton (Vernikovsky et al., 2001) and 540–550 Ma for postorogenic Osinovka pluton (Nozhkin et al., 2017). Both ages, according to our data, require significant refinement (Kuzmichev et al., 2022; unpublished authors' data).

The age of volcanic rocks of the belt can be judged only indirectly, namely from the age of detrital zircons in synorogenic Ediacaran rocks. At three stratigraphic levels of the Vorogovka Group, which partly overlies the Kiselikha belt, a significant portion of detrital zircons showed age of 700–600 Ma (Letnikova et al., 2017). These zircons could have been sourced either from the rocks of the Kiselikha belt or the rocks in

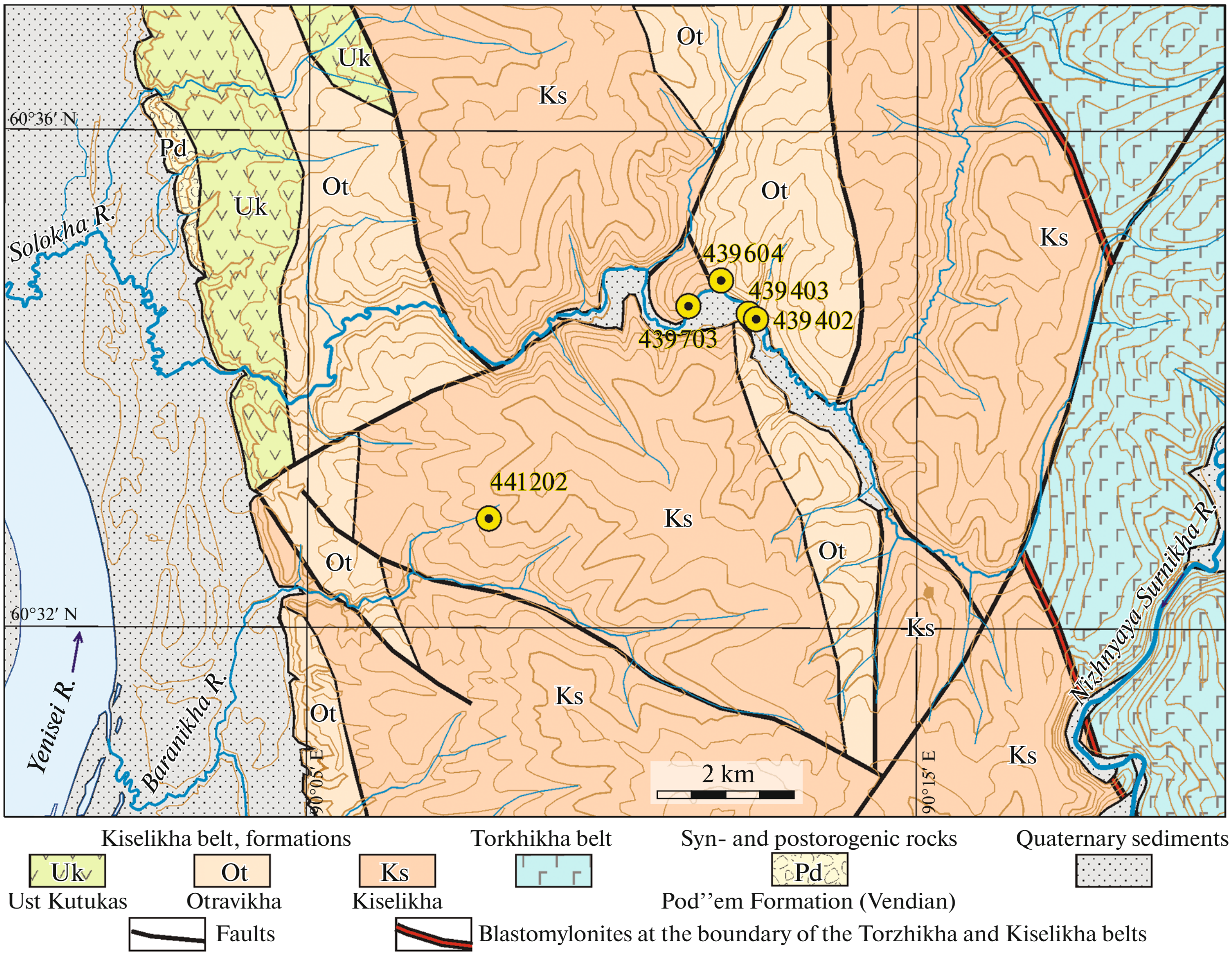

Fig. 3. Geological map of basins of the Solokha and Baranikha rivers compiled according to the results of a1 : 50000 State geological mapping and updated according to a stratigraphic scheme of (Storozhenko et al., 2019). Circles with numbers are locations of samples discussed in text.

westward regions. The igneous rocks of this age at the remaining part of the Yenisei Ridge are rare. The greatness of the Ediacaran Orogen, whose most part was probably located to the west of the present day Yenisei Ridge, is evident from similar patterns of detrital zircons from sandstones of the Taseeva Group sampled along the Angara River and its tributaries (Letnikova et al., 2017; Kochnev et al., 2020). This paper describes our attempt to obtain direct age data for presumably volcanic or volcanic-sedimentary rocks of the Kiselikha belt.

FACTUAL MATERIAL

Direct dating of volcanic rocks of the northwestern part of the Yenisei Ridge became technically possible several years ago. The first author, who initiated this study, conducted the field works at other objects and asked geologists of the Krasnoyarsk Geological Survey Expedition to provide samples of volcanic rocks of the Kiselikha belt. A.A. Storozhenko collected samples in the basins of the Solokha and Baranikha rivers from rocks that were mapped as the Kiselikha and Otravikha formations and extracted zircons from five samples (nos. 439402, 439403, 439604, 439703, 441202) amounting to 40–500 grains per sample. The sampling points are shown in Fig. 3. All samples were interpreted in the field as tuffs or tuffites. Sample 439703 (no thin section) was excluded from further discussion because of only 29 correct datings, some of which presumably were interpreted as a result of contamination.

The samples were taken in parallel with other works, which did not suppose detailed field observations; thus, our factual material includes only thin sections and zircon grains. The zircon dating had a reconnaissance aim for the preparation of a full field study of the western part of the ridge. The results, however, were unexpected and, in our opinion, deserve to be published. It was important to conduct a full geological study of sampled objects at the Solokha and Baranikha rivers and verify the data on detrital zircons. The study of these objects, however, suggests the walking of field routes for days through thick bushes and fallen trees and is unlikely in the foreseeable future.

ANALYTICAL METHOD OF ZIRCON DATING

Zircons were analyzed on Element XR singlecollector inductively coupled plasma (ICP) mass spectrometer at the Geological Institute, Siberian Branch, Russian Academy of Sciences (Ulan-Ude) (polished section no. 5 with large zircons), and on Element 2 ICP mass spectrometer at the Geological Institute, Russian Academy of Sciences (Moscow) (polished section no. 4 with small zircons). In both cases, the mass spectrometers were equipped with a NWR 213 solid state laser focused on a spot 20–25 μm in diameter. The parameters of laser and mass spectrometer adjustment and XLS tables of analytical data are provided in Supplementary Materials (ESM). All available zircons were emplaced in polished sections for four of five samples. The large and small zircons (>100 and <100 μm, respectively) were emplaced in different polished sections to make even polishing of grains approximately to the middle. Pure inclusion-free areas of the crystals were chosen under a microscope and were outlined on cathodoluminescent (CL) images. In both laboratories, the isotopic measurements followed similar methods. Two zircon standards 91500 (Wiedenbeck et al., 1995) and Plesovice (Slama et al., 2008) were analyzed after every five analyses of the sample; each standard could be used as a reference for data reduction. The standard session included 60 or 65 analyses of samples and 17–19 analyses of each standard. The data were processed in the Iolite 2.5 program (Paton et al., 2010, 2011) with a VizualAge plug-in (Petrus and Kamber, 2012). The concordant segments of the analyses were integrated; thus, the completely discordant analyses were omitted from final data tables. No further mathematic attempts were undertaken to estimate the degree of the discordance. The analyses with a high error were deleted. The isotope diagrams were plotted using Isoplot macros (Ludwig, 2008). The histograms and curves of age density of zircons were plotted in the Kernel Density Estimation (KDE) program (Vermeesch, 2012).

RESULTS OF STUDY OF THIN SECTIONS AND ISOTOPIC ANALYSIS OF ZIRCONS

Sample 441202 (Feldspar–Quartz Sandstone)

Approximately half of the thin section is composed of quartzite, which probably represents a granulated quartz vein. The second half of the thin section represents poorly sorted feldspar–quartz sandstone (Fig. 4a). The rounded and semirounded quartz grains are regenerated. If quartz grains have contacts, they are characterized by stylolite intergrowths. Plagioclase occurs as rare large grains. It is weakly altered and has twins. K-feldspar is also found (both fresh and sericitized). There are many zircon grains. The low amount of matrix is composed of a sandy–silty mixture, locally, ferruginized. The clay component of the matrix is replaced by small-scaly chlorite and sericite. Mostly granitic clastic material underwent erosion, but there are also clasts of granoblastic quartzite.

Zircon includes unbroken poorly rounded crystals (Fig. 5a). The rounded zircon grains with inner structure discordant to the contour that indicate remote transfer and redeposition, are atypical of sample and rarely occur in large-sized fractions. The inner structure is diverse, but the crystals with "granitic" oscillatory zoning are dominant. No evidently granulitic zircons were found. Some crystals contain more or less evident metamorphic rims, which are locally discordant to the core. The rims in several crystals were dated and their ages are similar to those in the core (Fig. 5a).

The sample contains only Paleoproterozoic and Archean zircons (123 correct determinations). One analysis corresponds to the boundary of the Paleo- and Mesoproterozoic. The Paleproterozoic in a range of 1800–2400 Ma with peak values at 1860, 1920 (main peak), and 1990 Ma (Fig. 5b) was determined in 82 analyses, whereas 40 analyses correspond to the Archean in a range of 2500–2830 Ma with a peak at 2540 Ma. An unclear peak is also visible at 2580 Ma.

Sample 439604 (Volcaniclastic Sandstone)

This sample represents completely unaltered sorted coarse-grained volcaniclastic sandstone (Fig. 4b) with dominant clasts of devitrified felsic volcanic rocks, locally, with small phenocrysts of quartz or feldspar (sanidine?) and numerous clasts of andesite (or basaltic andesite) crowded by plagioclase microlites. There are grains of monocrystalline transparent "rhyolitic" quartz, plagioclase crystals, sanidine, and their fragments. Clasts are compacted with almost absent matrix. Small sericite scales are locally observed along the grain boundaries.

Zircons from this sample are angular or slightly rounded with a diverse inner structure and numerous sectorial grains (Fig. 6a). There are rare crystals with cores and metamorphic rims. The zircons are probably derived from volcanic, plutonic, and metamorphic rocks.

The age of almost all analyzed zircons (105 grains of 121) occurs in a range of 750–560 Ma and most values are confined to a range of 730–620 Ma (Fig. 5b). The main peak corresponds to the age of 650 Ma with an unclear additional peak at 710 Ma. In addition to the dominant late Neoproterozoic group, eight grains have the Archean age of 2500–2600 Ma with a peak value at 2570 Ma on the KDE plot. Three grains have Paleoproterozoic age, one grain is dated to the end of the Mesoproterozoic, and one more grain is dated to the Early Neoproterozoic.

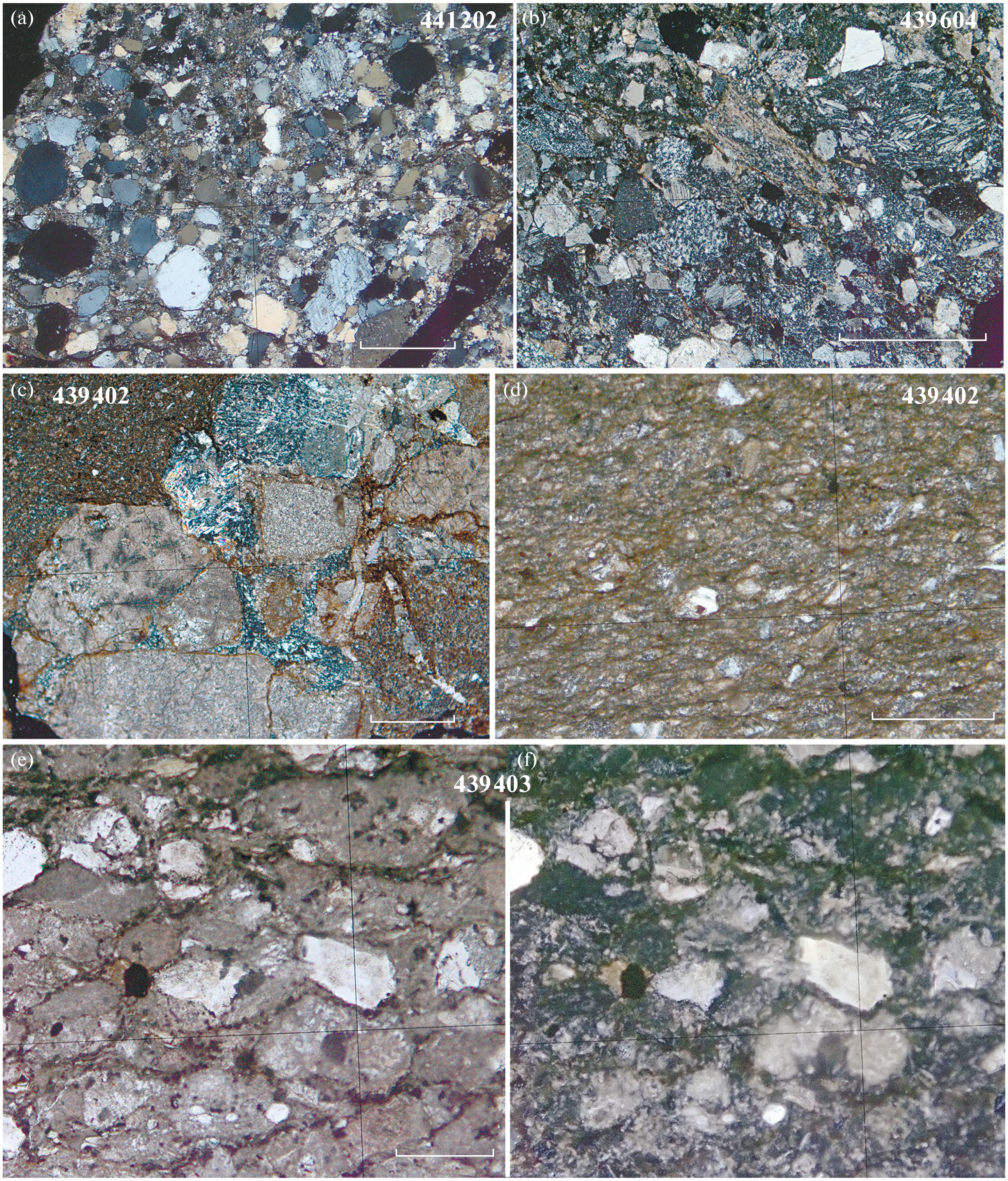

Fig. 4. Photos of thin sections of discussing samples. (a) Sample 441202, unevenly grained sandstone with dominant quartz clasts. Large clasts are well rounded and exhibit a regeneration rim; small clasts can be angular. There are also large rare plagioclase and K-feldspar grains. Interstices between large grains are filled with similar sandy and silty clasts. (b) Sample 439604, volcaniclastic sandstone with angular clasts of mostly dacites and rhyolites and rare andesites and basalts and crystal clasts of quartz, plagioclase, and sanidine (?). (c, d) Sample 439402, carbonate gritstone with tuff matrix and clasts of carbonate rocks of various structure (these are partly carbonatized silicate grains); the matrix area is in the left (c) and enlarged matrix with compacted clasts of partly crystallized volcanic rocks and feldspar, and rare quartz grains (d). (e, f) Sample 439403, basaltic tuff composed of lumps of partly crystallized basaltic glass: plane polarized light (e) cross polarized light (f). Scale bar is 500 μm (a, b), 250 μm (c), 50 μm (d), and 150 μm (e, f).

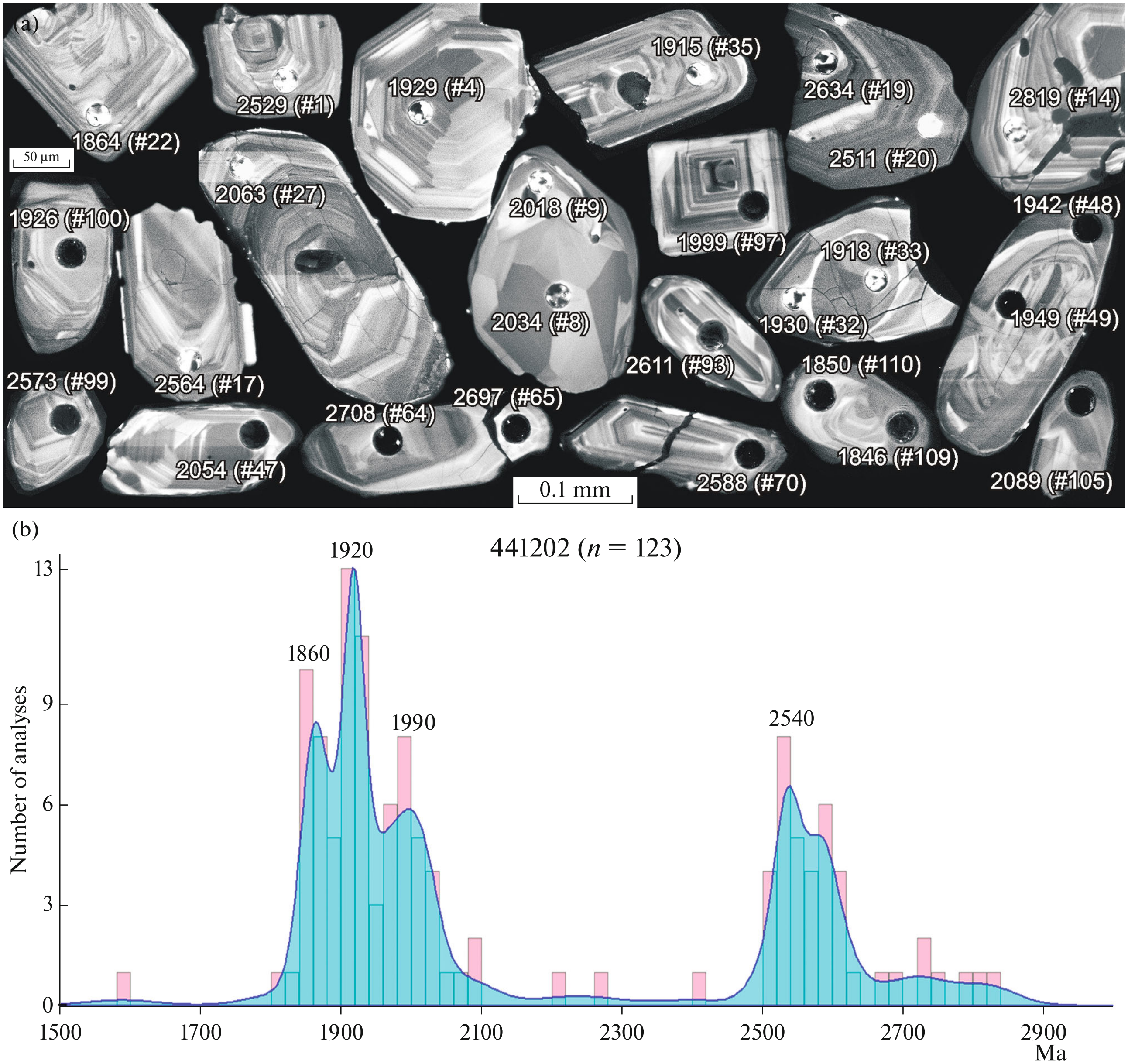

Fig. 5. Characteristics of zircons from Sample 441202. (a) Selected CL images of the analyzed zircons with obtained age (Ma) and # of analysis (in brackets) are shown; the numbers correspond to those in the Table of Isotope Data (ESM). Hereinafter, the $^{206}Pb/^{238}U$ ages are provided for Archean and Paleoproterozoic zircons, the $^{206}Pb/^{238}U$ ages are given for Neoproterozoic zircons. (b) Histogram of $^{206}Pb/^{238}U$ age distribution and KDE plot with the age of main peaks.

Sample 439402
(Carbonate Gritstone with Sandy Matrix)

The sample represents an unsorted gritstone with dominant large (up to a centimeter) carbonate clasts and an unevenly foliated sandy–silty partly carbonitized matrix (Fig. 4c). Some carbonate clasts are granoblastic, whereas other clasts contain heterogeneous carbonate (probably, secondary), which was developed after a silicate matrix of scaly pale chlorite and zeolite aggregate. One carbonate grain is spherolitic (radial carbonate). This was probably carbonatized spherolitic lava. The matrix is heterogeneous in mineral and granulometric composition. A significant fraction of it consists of partly carbonatized small lumps, which are probably the fragments of devitrified glass (Fig. 4d). Some of them retained the structure of andesite or basalt, which are composed of variously oriented plagioclase microlites, and some clasts probably are felsite. The matrix hosts unevenly distributed grains of quartz, sericitized K-feldspar, plagioclase, quartzite, and quartz–chlorite–muscovite aggregate.

The zircons from this sample differ in roundness and inner structure. The examples of zircons of the

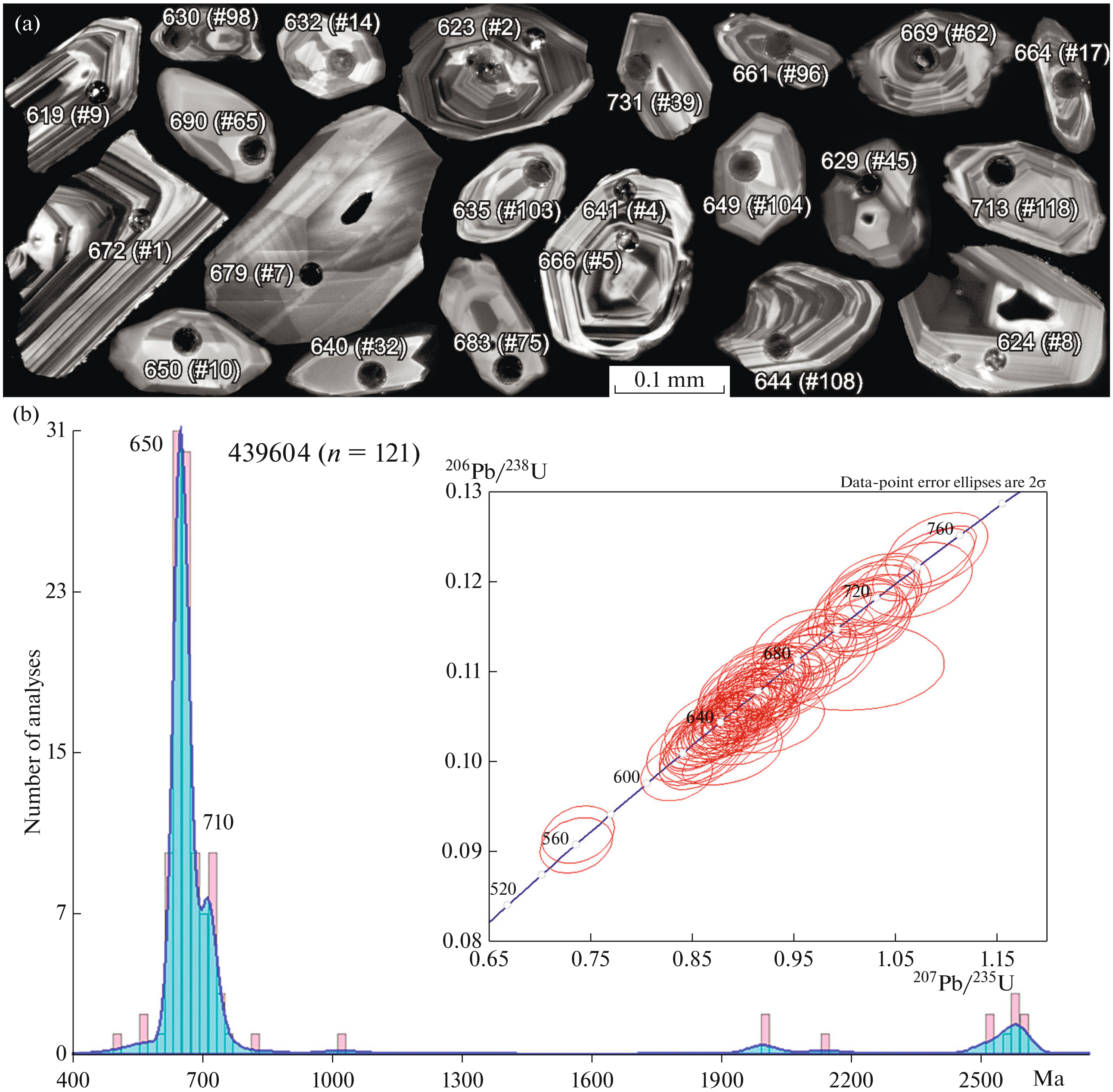

Fig. 6. Characteristics of zircons from Sample 439604: (a) CL images of most informative Late Neoproterozoic (618–672 Ma) grains for age distribution; (b) histograms and KDE plots. In the inset, the Pb/U isotope diagram for late Neoproterozoic analyses. See also caption to Fig. 4.

main populations are shown in Fig. 6a and are discussed below.

Sample 439402 yielded 85 concordant ages. Most analyses (45) correspond to Early Neoproterozoic age and 43 of them fit a range of 880–920 Ma. This entire cluster is spanned by a narrow KDE peak at 900 Ma (Fig. 7b). Other ages are distributed as follows: 24 grains have a Paleoproterozoic age (1808–2070 Ma) and most of them are focused in a range of 1900–2000 Ma with a KDE peak at 1980 Ma; one grain has a Late Neoproterozic age; the age of other 15 grains is 490–513 Ma (Cambrian) with a KDE peak at 500 Ma, which coincides with a concordant age of this cluster on the U–Pb isotope diagram (Fig. 7b).

Sample 439403 (Poorly Sorted Carbonatized Sandstone)

A significant area of the thin section is occupied by almost completely carbonatized sandstone with preserved large quartz clasts and partly preserved large feldspar clasts. The rest of the thin section is com-

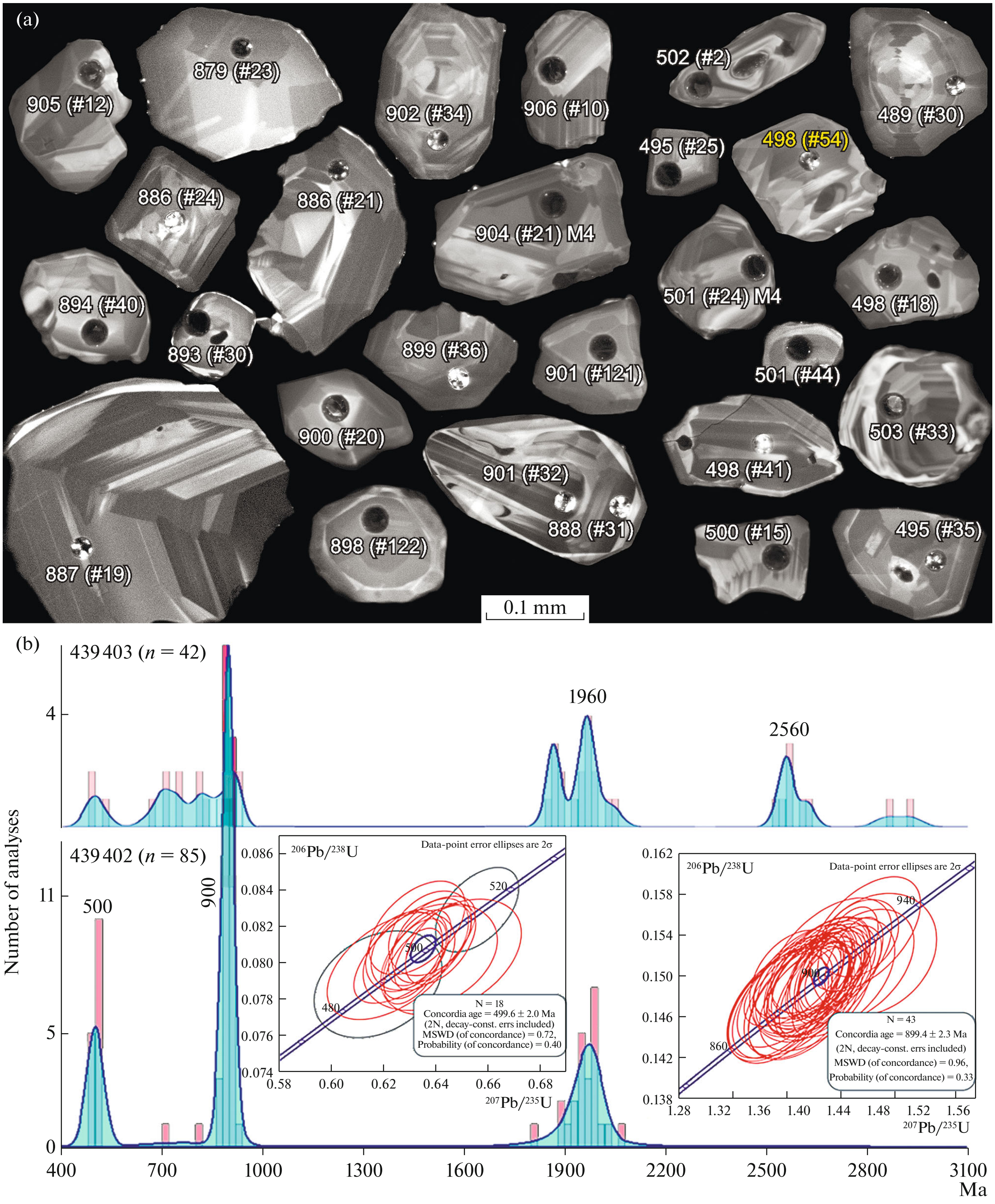

Fig. 7. Characteristics of zircons from Sample 439402. (a) CL images of zircons of ~900 (left) and 500 (right) Ma clusters. Analysis no. 54 (yellow type in electronic version) corresponds to a zircon grain from related Sample 439403. There are two pairs of grains with the same numbers (21 and 24) from different mounts (grains from mount M4 are indicated). (b) Histograms and KDE plots. The isotope U–Pb diagrams for clusters of 900 and 500 Ma are also shown.

posed of quartz and feldspar grains, and muddy carbonatized lumps of a hardly identified aggregate, which locally exhibit microlites and unclear relics with a regular structure (Fig. 4e). There are large (up to 0.7 mm) grains of weakly sericitized plagioclase, orthoclase-perthite, monocrystalline quartz, and anhedral fragments of green chlorite.

Sample 439403 yielded 42 concordant ages: Archean (2538–2934 Ma) with a peak at 2560 Ma for nine grains, Paleoproterozoic (1845–2049 Ma) with two peaks at 1870 and 1960 Ma for 17 grains, Early Neoproterozoic with a weak peak at 905 Ma for eight grains, and Late Neoproterozoic with a weak peak at 720 Ma for five grains (Fig. 7b).

INTERPRETATION OF RESULTS

Early Precambrian zircons are present in all samples in various amounts, but all 122 (excluding one) analyzed zircon crystals in Sample 441202 are Early Precambrian. This sample probably collected from the most ancient rocks of the sampled area and can hardly be correlated with any of mentioned formations, because they all contain Neoproterozoic volcanic material. The Early Precambrian zircons are sourced from the basement of the Siberian Craton, which is confirmed by their comparison with age populations of definitely Siberian detrital zircons extracted from Mesoproterozoic rocks of the eastern part of the Yenisei Ridge (Fig. 1) (Priyatkina et al., 2016, 2019; unpublished authors' data). Two conclusions follow from this fact: (i) the Kiselikha belt was part of the Siberian Continent during the formation of this sedimentary rock and was not separated by an ocean from the continent, and (ii) the Early Precambrian clastic material was transported from the east to the west (in the present-day coordinates) through the territory of the future (or former) orogen of the Yenisei Ridge. The absence of Neoproterozoic zircons in this clastic material, which are typical of this orogen, can be interpreted as follows: either the orogen was fully peneplenized during the sedimentation period, or the territories of the present-day Yenisei Ridge had not been transformed to the orogen yet and were not the arena of intense magmatism. The first scenario suggests the Ediacaran (or even younger) age of the sampled sedimentary rock, whereas the second scenario indicates the Mesoproterozoic age.

The first scenario, at first glance, is attractive: in fact, the Ediacaran rocks of the eastern (cis-platform) zone of the Yenisei Ridge are strongly dominated by the Early Precambrian ("Siberian") ages of detrital zircons (Priyatkina et al., 2016; Kuznetsov et al., 2018). A similar age distribution is also demonstrated by zircons from the Ediacaran strata of the Siberian Platform in Sayan and Baikal regions (Letnikova et al., 2013; Priyatkina et al., 2018; Gladkochub et al., 2019). It is evident that nothing hampered the contribution of clastic material to the Ediacaran basins from the inner part of the Siberian Craton. The paleogeographic setting of the Ediacaran basin within the Kiselikha belt, however, was different. In this belt, the Ediacaran rocks include the Vorogovka Group, which accumulated in a trough separated by a rise from the Siberian Platform (Sovetov and Le Heron, 2016). The spectrum of ages of detrital zircons in sandstones of the group sampled at three stratigraphic levels has nothing in common with the spectrum of Sample 441202: the Neoproterozoic zircons are dominant in the Ediacaran sandstones of the Vorogovka Group (Letnikova et al., 2013; Vishnevskaya et al., 2017). Even later (in the Cambrian), when the orogen of the Yenisei Ridge was fully peneplenized and became an area of sedimentation of carbonate rocks and evaporites, the age spectrum of detrital zircons also contained Neoproterozoic datings even in the eastern cis-platform zone of the Yenisei Ridge (Kuznetsov et al., 2020b).

Taking this into account, the second scenario suggesting the Mesoproterozoic age of the sandstone is more substantiated. We consider that the sequence with Sample 441202 is an analog of one of the formations of the Mesoproterozoic Sukhoi Pit Group, which are mapped in the eastern and central regions of the Yenisei Ridge (Fig. 1) and which have a similar age spectrum of detrital zircons, all of which are sourced from the basement of the Siberian Craton (Priyatkina et al., 2016, 2019; our unpublished data). Moreover, a prominent peak at 2540 Ma on the KDE plot (Fig. 5) coincides with precision of up to ±1% with the age of the most abundant Late Archean granites in the basement of the western part of the Siberian Platform. The granites are reached by numerous boreholes to the east from the Yenisei Ridge and have the SHRIMP age from 2563 ± 10 to 2525 ± 10 Ma (Samsonov et al., 2021, 2022). During the accumulation of the sandstone (Sample 441202), the future Yenisei Ridge did not turn into granite-hosted orogen, the Isakovka oceanic basin was not yet opened, and the Kiselikha belt was part of the Mesoproterozoic passive margin of the Siberian Paleocontinent. Poorly rounded zircon grains (Fig. 5a) and the presence of large alkali feldspar and plagioclase clasts (products of erosion of granites) suggest a direct transport of clastic material from a nearby source. It is likely that it was the crystalline basement, which in the Mesoproterozoic cropped out not only in remote parts of the Siberian Paleocontinent, but also within the territory occupied now by the Yenisei Ridge (Kuzmichev and Sklyarov, 2016; Kuznetsov et al., 2020a). The same data indicate the presence of the basement of the Siberian Craton in the Kiselikha belt.

The period of 1800–925 Ma with a duration of almost 900 m.y. is totally omitted in our zircon collection.

The first half of the Neoproterozoic is the next age cluster of our datings. The range of ages for individual zircon grains is 925–800 Ma. It occurs in three samples, but Sample 439402 (carbonate gritstone) is typical with dominant zircons of this stage (45 analyses of 85). The range of individual datings in this sample is narrower: 880–910 Ma. On the U–Pb isotope diagram, the concordant age of this cluster based on 43 analyses is 899 ± 2 Ma (Fig. 7b), which coincides with the peak on the KDE plot. The zircons are angular or poorly rounded, with a characteristic inner structure combining sectorial and oscillatory zoning, and the cores of some zircons are surrounded by discordant outward zone; there are also metamorphic rims (Fig. 7a). The younger Neoproterozoic zircons in this sample are almost absent (two grains). The Paleoproterozoic age is characteristic of 24 crystals, which have no signs of long transport; there are grains with a granulitic inner structure; no Archean grains are detected. It is likely that the erosion affected a local rise composed of the Paleoproterozoic crystalline rocks (or Mesoproterozoic metasedimentary rocks containing only Early Precambrian zircons), which were intruded by granites with the age of 900 Ma. This age cluster requires discussion.

In the first half of the Neoproterozoic, the Yenisei Ridge was a segment of an active margin of the Siberian Paleocontinent (Kuzmichev and Sklyarov, 2016). Among the currently dated Neoproterozoic granitoids in the main (“cratonic”) part of the Yenisei Ridge (Fig. 1), the most ancient age was determined for porphyroblastic plagiogneisses of the middle reaches of the Garevka River: 882 ± 8 Ma (Kozlov et al., 2012). Similar (slightly younger) age is characteristic of biotite granites of the Yeruda and Kalami plutons from the central part of the Yenisei Ridge: 878.5 ± 1.5 and 875 ± 7 Ma, respectively (Vernikovsky et al., 2007). An assemblage of ages of the analyzed zircons of any mentioned plutons does not correspond to a peak of 900 Ma. We suggest that the Kiselikha belt, which was an outer zone of the Siberian active margin in the beginning of the Neoproterozoic, records the evidence of magmatic events, which were absent in the inner part of this margin. This conclusion is supported by independent data on detrital zircons from the northern part of the belt, which indicate similar (as well as earlier) magmatic events at the beginning of the Neoproterozoic (Danukalova et al., 2022). If we omit the Cambrian zircons (which are discussed below) from gritstone (Sample 439402), it is likely that it accumulated prior to a strong volcanic eruption in the Kiselikha belt (750–620 Ma), because this stage includes only one grain. The beginning of the second half of the Neoproterozoic (800–750 Ma) is the most probable age of the accumulation. In this period, the region evolved in rifting conditions and the erosion area could have included a local source mentioned above.

The zircons of the second half of the Neoproterozoic are abundant only in Sample 439604 (104 analyses of 117). The rock is a volcaniclastic sandstone, and, actually, with it we have sampled an igneous province, the analogs of which are absent in the main part of the Yenisei Ridge. Most (98) ages are in the range of 726–606 Ma with an evident concentration at 672–622 Ma (70 analyses). The diversity of volcanic clasts in a thin section indicates a differentiated (suprasubduction) volcanic complex. The inner structure of the zircon crystals reflects the episodes of dissolution and overgrowing; there are grains with both oscillatory and sectorial zoning; both volcanic and plutonic rocks were probably eroded. Taking into account the data on zircons from sandstone (Sample 441202), this magmatism occurred in an active continental margin rather than in an island arc and lasted for 120 m.y., including a range of continuous mass volcanism with a duration of 50 m.y. The concordant age of the cluster of the five youngest analyses is 620 ± 6 Ma (2σ, MSWD = 3.9) corresponds to the beginning of the Ediacaran. This value is accepted as the maximum age of sedimentation. This estimate does not take into account two Late Ediacaran ages (560 and 566 Ma), which are insufficient for undoubted conclusions.

No similar mass products of the Late Neoproterozoic differentiated volcanism occur in the Yenisei Ridge. There are only small outcrops of riftogenic basalts or bimodal volcanic rocks with the age of 715–700 Ma (Nozhkin et al., 2007, 2013; Kuznetsov et al., 2019; Rud’ko et al., 2020). Presumably, the volcanic belt sampled by Sample 439604 was located westward of the present-day Yenisei Ridge and is now buried under the cover of the West Siberian basin.

Fifteen Cambrian zircons are present in Sample 439402 and form a cluster with the age of 500 Ma (Late Cambrian) (Fig. 7b). Another three grains with similar age are present in Sample 439403. In CL images, these zircons exhibit igneous sectorial and oscillatory zoning, which is locally disturbed by metamorphic impact; there are crystals with metamorphic rims (Fig. 7a). These grains could belong to some migmatite complex, meaning thus the erosion of a full-blown Late Cambrian orogen. Two scenarios of interpretation of this fact are possible: either a sampled unit is Upper Cambrian–Ordovician, or it is Neoproterozoic and the presence of Cambrian zircons is a result of contamination.

A platform cover including Late Cambrian and Ordovician rocks, which are expected to contain the zircons with the age of 500 Ma, overlapped the entire Yenisei Ridge during some period. The relics of the Lower Paleozoic cover are present in the northern part of the ridge shown in Fig. 1. This is a an area with inscription “Vorogovka” (50 km NE of the studied area) and a northern part of a vast field of the Middle–Upper Cambrian (Evenk Formation) and Ordovician rocks with “Tis” inscription (100 km to the SSE). No age of detrital zircons directly from these outcrops is available, but it is known for zircons from rocks of the Evenk Formation of the eastern subplatform part of the ridge. The analyzed sandstone from this formation hosts zircons with a broad spectrum of ages, including almost the entire Neoproterozoic, Paleoproterozoic (most grains), and Archean (Priyatkina et al., 2016). There are also ages of 500 Ma, and their peak on the density distribution curve is slightly older than 500 Ma (it cannot be determined more precisely from the figure in this paper). A similar peak (480 Ma) is also present in the Middle Ordovician sandstones from the lower reaches of the Podkamennaya Tunguska River (Kuznetsov et al., 2022). The discussed zircon population is most similar to that of the Siberian Platform cover on the territory located ~1000 km SSE from the studied region. Two samples from the uppermost part of the Cambrian section taken from two points at a distance of 500 km from each other revealed similar age spectra. The combined analyses (137 concordant values) demonstrate the following age distribution: Archean and Paleoproterozoic (23 grains), Mesoproterozoic (4 grains), Neoproterozoic (59 grains with KDE peaks at 800 and 620 Ma), and Paleozoic (50 grains). The Paleozoic includes the Cambrian grains (except for one Lower Ordovician), which form one solid population with a peak at 506 Ma (Gladkochub et al., 2022).

The Cambrian zircons from all discussed samples have been derived from the Lower Paleozoic orogens, which rimmed the Siberian Paleocontinent from the south. It should be emphasized that, to the beginning of the Paleozoic, its area increased owing to amalgamation of the Neoproterozoic terranes. At the latitude of the Yenisei Ridge, the boundary of the Cambrian Siberian Paleocontinent probably occurs 200–300 km west of the Yenisei River. The Cambrian volcanic sequence was drilled by Vezdekhodnaya-4 borehole 270 km WSW of the Solokha River. The Lower Cambrian basalts and deep-water sediments with a total thickness of 1300 m were penetrated by the well and interpreted as a complex of a back-arc basin (Kontorovich et al., 1999). Such rocks are unlikely to contain many zircons, but the felsic and intermediate tuffs episodically occur in the Middle–Upper Cambrian and Lower Ordovician sediments (platform facies) in many boreholes drilled in the left bank of Yenisei River much closer to the studied region (Saraev and Filippov, 2015). It is suggested that the volcanic material was contributed from the southwest. Similar material could have been present in rocks of the Middle–Upper Cambrian Evenk Formation, which overlapped the entire western part of the Yenisei Ridge for some period, and the presence of the zircon population with an average age of 500 Ma in it is quite relevant. The problematic Samples 439402 and 439403 could therefore be assigned to nondocumented outcrops of the Evenk Formation. The absence of metamorphic alteration in these rocks (judging from thin sections) is in agreement with this supposition.

Nonetheless, we consider that the second scenario is more plausible: we sampled Neoproterozoic rocks, and a population of 500 Ma is a result of contamination. This is supported by the following. (1) If we exclude the Cambrian values, the age spectrum of detrital zircons of Samples 439402 and 439403 is similar to that of rocks of the Kiselikha Formation of the northern part of the belt. Six samples of detrital zircons from this formation were demonstrated by Kuzmichev et al. (2022), and three samples with similar Neoproterozoic clusters were discussed by Danukalova et al. (2022). (2) The Neoproterozoic and Paleoproterozoic zircons of Sample 439402 were derived from a local source composed of Mesoproterozoic (or Paleoproterozoic) rocks intruded by granites with the age of 900 Ma (see discussion above). The exposure of this source in the sampling area during accumulation of the Evenk Formation is unlikely. The Cambrian zircons in this sample could really have been sourced from this formation. During the erosion of the platform cover, stable heavy minerals, including zircon, sink into the weathered underlying rocks along the fractures and were further sampled together.

CONCLUSIONS

(1) Sample 441202 is an unsorted feldspar–quartz sandstone consisting of erosion products of the crystalline basement of the Siberian Craton transported for a short distance. By analogy with the Mesoproterozoic rocks of the Sukhoi Pit Group of eastern and central regions of the Yenisei Ridge with a similar assemblage of the detrital zircons ages, we believe that this sandstone also accumulated in the Mesoproterozoic on a passive margin of the Siberian Continent. The Isakovka oceanic basin, which separated the Kiselikha belt from the continent in the Neoproterozoic, had not been opened yet.

(2) Two samples of carbonatized sandstone and gritstone (439402 and 439403) taken from adjacent outcrops contain the Early Precambrian zircons of the basement of the Siberian Craton and zircons of the first half of the Neoproterozoic. These data are precarious because of (i) the low amount of zircons extracted and (ii) the presence of the Paleozoic zircons, which are considered a result of contamination. If the Cambrian zircons are omitted, however, the age spectra of these samples are similar to those of rocks mapped as the Kiselikha Formation in the northern part of the belt (Kuzmichev et al., 2022; Danukalova et al., 2022). These samples are important, because they confirm the possible tracing of some stratified unit (it is not critical how to name it) along the entire belt from its northernmost part, where rocks are turned to crystalline schists, to the southern part, where they are slightly metamorphosed. The mid-Neoproterozoic (800–750 Ma) is a possible time of its formation, when relevant sources were exposed in the course of rifting.

(3) The volcaniclastic sandstone (Sample 439604) composed of clasts of various volcanic and, to a lesser extent, plutonic rocks has sampled the Late Neoproterozoic igneous province. The diversity of volcanic

rocks with different SiO_2 content indicates a suprasubduction setting. The volcanic belt is probably buried below the Phanerozoic cover of the West Siberian basin and only its margin extends to the Kiselikha belt. Magmatism lasted more than 100 m.y. and included an episode of mass continuous volcanism in the range of 672–622 Ma. The sandstone has Ediacaran age, and the maximum age of sedimentation is 620 ± 6 Ma (2σ, a concordant cluster of five analyses).

(4) The studied samples were taken from three different levels of the Precambrian section: Mesoproterozoic, the lowermost part of the upper half of the Neoproterozoic, and the upper part of the Neoproterozoic, which could be assined to different stratigraphic groups. The accumulation of these groups was interupted by deformation stages, responsible for exposure and erosion of new complexes of igneous and metamorphic rocks, which is evident from the age spectra of detrital zircons. The accepted stratigraphic sequence of the Kiselikha belt requires reconsideration.

(5) In the light of above results and the data on the northern part of the belt (Danukalova et al., 2022; Kuzmichev et al., 2022), our former scenario of tectonic evolution of the Yenisei Ridge (Kuzmichev and Sklyarov, 2016) must be corrected. In the first half of the Neoproterozoic (1000–800 Ma), the Kiselikha belt belonged to the external part of the active margin of the Siberian Paleocontinent. This part registers subprasubduction magmatism that began earlier than it was considered previously. This external zone was detached from the continent due to rifting that occurred in the range of 800–750 Ma. The main present-day part of the Yenisei Ridge therefore preserves only a rear part of the Early Neoproterozoic active margin with incomplete tectonic zoning. In the second half of the Neoproterozoic (750–600 Ma), the Kiselikha belt evolved as a microcontinent with the basement of the Siberian Craton reworked in the Neoproterozoic and was not an oceanic island arc, as was suggested in (Vernikovsky et al., 2003). The microcontinent had active margin from the external (western) side. In the current structure, the belt should be termed the Kiselikha Terrane, with its most part being hidden below the cover of the West Siberian basin.

ACKNOWLEDGMENTS

We are grateful to B.B. Kochnev for careful analysis of the manuscript and constructive criticism and recommendations that allowed its more logical presentation and to N.B. Kuznetsov for review and useful comments.

FUNDING

This work was supported by the Russian Science Foundation (project no. 22-77-10096).

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

SUPPLEMENTARY INFORMATION

The online version contains supplementary material available at https://doi.org/10.1134/S0869593823060060.

Reviewers B.B. Kochnev and N.B. Kuznetsov

REFERENCES

Danukalova, M.K., Kuzmichev, A.B., Babitskii, E.F., and Dubenskii, A.S., Searching for a terrane, collided with the Yenisei margin of the Siberian paleocontinent in Late Neoproterozoic. 2. "Archean block" in the north-west of the Isakovka domain of the Yenisei Ridge, in *Geodinamicheskaya evolyutsiya litosfery Tsentral'no-Aziatskogo podvizhnogo poyasa (ot okeana k kontinentu). Mater. Nauchn. konf. Vyp. 20* (Proc. Conf. "Geodynamic Evolution of the Lithosphere of the Central Asian Orogenic Belt (from Ocean to Continent)." Vol. 20), Irkutsk: Inst. Zemn. Kory Sib. Otd. Ross. Akad. Nauk, 2022, pp. 63–65.

Gladkochub, D.P., Donskaya, T.V., Stanevich, A.M., Pisarevsky, S.A., Zhang, S., Motova, Z.L., Mazukabzov, A.M., and Li, H., U–Pb detrital zircon geochronology and provenance of Neoproterozoic sedimentary rocks in southern Siberia: New insights into breakup of Rodinia and opening of Paleo-Asian Ocean, *Gondwana Res.*, 2019, vol. 65, pp. 1–16.

Gladkochub, D.P., Motova, Z.L., Donskaya, T.V., Khubanov, V.B., and Sizov, A.V., Cambrian/Ordovician boundary as a milestone in the sedimentation history of the southern Siberian craton: evidence from U–Pb dating of detrital zircons, *J. Asian Earth Sci.*, 2022, vol. 8, 100107. https://doi.org/10.1016/j.jaesx.2022.100107

Gosudarstvennaya geologicheskaya karta SSSR. Masshtab 1 : 1000000 (nov. ser.). List R-46, 47 – Baikit. Ob"yasnitel'naya zapiska (The 1 : 1000000 State Geological Map of the USSR (New. Ser.). Sheet R-46, 47 (Baikit). Explanatory Note), Kovrigina, E.K., Ed., Leningrad: Leningr. Kart. Fabr. Ob"ed. "Aerogeologiya," 1981 [in Russian].

Kachevskii, L.K., Kachevskaya, G.I., and Grabovskaya, Zh.M., *Geologicheskaya karta Eniseiskogo kryazha. Masshtab 1 : 500000* (The 1 : 500000 Geological Map of the Yenisei Ridge), Krasnoyarsk: Krasnoyarskgeols"emka, 1998 [in Russian].

Kochnev, B.B., Proshenkin, A.I., Pokrovskii, B.G., an Letnikova, E.F., Vendian Taseeva Group, southwestern margin of the Siberian Platform: Isotope, geochemical, and geochronological data, age, and correlation, *Russ. Geol. Geophys.*, 2020, vol. 61, no.10, pp. 1121–1135.

Kontorovich, A.E., Saraev, S.V., Kazanskii, A.Yu., Kashtanov, V.A., Kontorovich, V.A., Ponomarchuk, V.A., Tishchenko, V.M., and Filippov, Yu.F., The new Cambrian terrigenous-volcanogenic sequence and the position of the western boundary of the Siberian Craton (based on parametric drilling in the Vezdekhodnya area, Tomsk oblast), *Geol. Geofiz.*, 1999, vol. 40, no. 7, pp. 1022–1031.

Kovrigina, E.K. and Kovrigin, F.P., Igneous rocks of the Northwestern part of the Yenisei Ridge, in *Tr. VSEGEI* (Trans. Russ. Geol. Res. Inst.), 1967, vol. 112, pp. 140–154.

Kovrigina, E.K. and Kovrigin, F.P., Precambrian stratigraphy of the western slope of the Yenisei Ridge in the basin of Verkhnyaya Surnikha, Nizhnyaya Surnikha, Stolbovaya, and Isakovka rivers, *Inform. Sb. VSEGEI*, 1960, no. 40, pp. 3–15.

Kozlov, P.S., Likhanov, I.I., Reverdatto, V.V., and Zinov'ev, S.V., Tectonometamorphic evolution of the Garevka polymetamorphic complex (Yenisei Ridge), *Russ. Geol. Geophys.*, 2012, vol. 53, no. 11, pp. 1133–1149.

Kuzmichev, A.B., Tectonics of the Isakovka synclinorium of the Yenisei Ridge, *Cand. (Geol.-Mineral.) Dissertation)*, Moscow: Geol. Inst. Russ. Acad. Sci., 1987.

Kuzmichev, A.B. and Sklyarov, E.V., The Precambrian of Transangaria, Yenisei Ridge (Siberia): Neoproterozoic microcontinent, Grenville-age orogen, or reworked margin of the Siberian craton? *J. Asian Earth Sci.*, 2016, vol. 115, pp. 419–441.

Kuzmichev, A.B., Danukalova, M.K., and Khubanov, V.B., Fragments of the oceanic lithosphere in the structure of the Isakovka accretionary prism (Yenisei Ridge): Substantiation of the subduction beneath the margin of the Siberian paleocontinent in Late Neoproterozoic, in *Mater. XLIX Tekton. Soveshch. "Tektonika sovremennykh i drevnikh okeanov i ikh okrain"* (Proc. XLIX Tecton. Conf. "Tectonics of Modern and Ancient Oceans and their Margins"), Moscow: GEOS, 2017, pp. 204–207.

Kuzmichev, A.B., Danukalova, M.K., Babitskii, E.F., Somsikova, A.V., Khubanov, V.B., Bryanskii, N.V., and Dubenskii, A.S., Searching for a terrane, collided with the Yenisei margin of the Siberian paleocontinent in Late Neoproterozoic. 1. Composition, age, and geodynamic position of "island-arc" Porozhnaya granite complex at the NW margin of the Yenisei Ridge, in *Geodinamicheskaya evolyutsiya litosfery Tsentral'no-Aziatskogo podvizhnogo poyasa (ot okeana k kontinentu). Mater. Nauchn. konf. Vyp. 20* (Proc. Conf. "Geodynamic Evolution of the Lithosphere of the Central Asian Orogenic Belt (from Ocean to Continent)." Vol. 20), Irkutsk: Inst. Zemn. Kory Sib. Otd. Ross. Akad. Nauk, 2022, pp. 158–160.

Kuznetsov, N.B., Priyatkina, N.S., Rud'ko, S.V., Shatsillo, A.V., Collins W.J., and Romanyuk T.V., Primary Data on U/Pb-isotope ages and Lu/Hf-isotope geochemical systematization of detrital zircons from the Lopatinskii Formation (Vendian–Cambrian transition levels) and the tectonic nature of Teya–Chapa Depression (Northeastern Yenisei Ridge), *Dokl. Earth Sci.*, 2018, vol. 479, pp. 286–289.

Kuznetsov, N.B., Rud'ko, S.V., Shatsillo, A.V., Rud'ko, D.V., Dubenskii, A.S., Sheshukov, V.S., Kanygina, N.A., and Romanyuk, T.V., U–Pb dates of zircons of diamictites of the Vorogovka River in the north of the Yenisei Ridge: The first geochronological evidence of the Sturtian glaciation in Siberia, in *Problemy tektoniki kontinentov i okeanov. Mater. LI Tekton. soveshch.* (Proc. LI Tecton. Conf. "Problems of Tectonics of Continents and Oceans"), Moscow: GEOS, 2019, vol. 1, pp. 310–315.

Kuznetsov, N.B., Kolesnikova, A.A., Priyatkina, N.S., Romanyuk, T.V., and Shatsillo, A.V., Age of geochemistry of metagranites of the Yenisei Ridge: Siberian roots of the Central Angara terrane, in *Geodinamicheskaya evolyutsiya litosfery Tsentral'no-Aziatskogo podvizhnogo poyasa (ot okeana k kontinentu). Mater. soveshch. Vyp. 18* (Proc. Conf. "Geodynamic Evolution of the Lithosphere of the Central Asian Orogenic Belt (from Ocean to Continent). Vol. 18), Irkutsk: Inst. Zemn. Kory Sib. Otd. Ross. Akad. Nauk, 2020a, pp. 193–196.

Kuznetsov, N.B., Shatsillo, A.V., Romanyuk, T.V., Kolesnikova, A.A., Dubenskii, A.S., Sheshukov, V.S., Lyapunov, S.M., and Moskovskii, D.V., The primary sources of detrital zircons in Neoproterozoic and Early Paleozoic sequences of the East Angara zone (the north of the Yenisei Ridge), in *Geodinamicheskaya evolyutsiya litosfery Tsentral'no-Aziatskogo podvizhnogo poyasa (ot okeana k kontinentu). Mater. soveshch. Vyp. 18* (Proc. Conf. "Geodynamic Evolution of the Lithosphere of the Central Asian Orogenic Belt (from Ocean to Continent). Vol. 18), Irkutsk: Inst. Zemn. Kory Sib. Otd. Ross. Akad. Nauk, 2020b, pp. 197–199.

Kuznetsov, N.B., Pokrovskii, B.G., Romanyuk, T.V., Strashko, A.V., Novikova, A.S., Dubenskii, A.S., Erofeeva, K.G., Sheshukov, V.S., and Dronov, A.V., Sources of detrital material for Middle Ordovician deposits of the Baikit Formation (Baikit sandstones) in the lower reaches of the Podkamennaya Tunguska River (Baikit Anteclise), in *Geodinamicheskaya evolyutsiya litosfery Tsentral'no-Aziatskogo podvizhnogo poyasa (ot okeana k kontinentu). Mater. Nauchn. konf. Vyp. 20* (Proc. Sci. Conf. "Geodynamic Evolution of the Lithosphere of the Central Asian Orogenic Belt (from Ocean to Continent)." Vol. 20), Irkutsk: Inst. Zemn. Kory Sib. Otd. Ross. Akad. Nauk, 2022, pp. 153–154.

Letnikova, E.F., Kuznetsov, A.B., Vishnevskaya, I.A., Veshcheva, S.V., Proshenkin, A.I., and Geng, H., The Vendian passive continental margin in the southern Siberian Craton: geochemical and isotopic (Sr, Sm–Nd) evidence and U–Pb dating of detrital zircons by the LA-ICP-MS method, *Russ. Geol. Geophys.*, 2013, vol. 54, no. 10, pp. 1507–1529.

Letnikova, E.F., Proshenkin, A.I., Vishnevskaya, I.A., and Ivanov, A.V., Change of provenance areas of Riphean and Vendian terrigenous deposits at the margins of the Siberian Craton (north, west, south): Results of U–Pb dating of detrital zircons and Sm–Nd isotopic data, in *Mater. XLIX Tekton. Soveshch. "Tektonika sovremennykh i drevnikh okeanov i ikh okrain"* (Proc. XLIX Tecton. Conf. "Tectonics of Present-Day and Ancient Oceans and Their Margins"), Moscow: GEOS, 2017, pp. 243–246.

Ludwig, K.R., Isoplot 3.6. A Geochronological Toolkit for Microsoft Excel, *Berkeley Geochronol. Center Spec. Publ.*, 2008, no. 4.

Nozhkin, A.D., Poctnikov, A.A., Nagovitsin, K.E., Tpavin, A.V., Ctanevich, A.M., and Yudin, D.C., Chingasan Group in the Yenisei Ridge: new data on age and deposition environments, *Russ. Geol. Geophys.*, 2007, vol. 48, no. 12, pp. 1015–1025.

Nozhkin, A.D., Kachevskii, L.K., and Dmitrieva, N.V., The Late Neoproterozoic rift-related metarhyolite-basalt association of the Glushikha trough (Yenisei Ridge): Petrogeochemical composition, age, and formation conditions, *Russ. Geol. Geophys.*, 2013, vol. 54, no. 1, pp. 44–54.

Nozhkin, A.D., Likhanov, I.I., Bayanova, T.B., and Serov, P.A., First data on Late Vendian granitoid magmatism of the Northwestern Sayan–Yenisei accretionary belt, *Geochem. Int.*, 2017, vol. 55, pp. 792–801.

Paton, C., Woodhead, J.D., Hellstrom, J.C., Hergt, J.M., Greig, A., and Maas, R., Improved laser ablation U–Pb zircon geochronology through robust downhole fractionation correction, *Geochem. Geophys. Geosyst.*, 2010, vol. 11, Q0AA06.
https://doi.org/10.1029/2009GC002618

Paton, C., Hellstrom, J., Paul, B., Woodhead, J., and Hergt, J., Iolite: Freeware for the visualization and processing of mass spectrometric data, *J. Anal. At. Spectrom.*, 2011, vol. 26, no. 12, pp. 2508–2518.

Petrus, J.A. and Kamber, B.S., VizualAge: A novel approach to laser ablation ICP-MS U–Pb geochronology data reduction, *Geostand. Geoanal. Res.*, 2012, vol. 36, no. 3, pp. 247–270.

Priyatkina, N.S., Khudoley, A.K., Collins, W.J., Kuznetsov, N.B., and Huang, H.-Q., Detrital zircon record of Meso- and Neoproterozoic sedimentary basins in northern part of the Siberian Craton: Characterizing buried crust of the basement, *Precambrian Res.*, 2016a, vol. 285, pp. 21–38.

Priyatkina, N.S., Kuznetsov, N.B., Shatsillo, A.V., Rud'ko, S.V., Khudolei, A.K., and Collins, W.J., The results of the U–Pb dating of zircons from Late Precambrian and Early Paleozoic sandstones of the Yenisei Ridge, in *Geodinamicheskaya evolyutsiya litosfery Tsentral'no-Aziatskogo podvizhnogo poyasa (ot okeana k kontinentu). Mater. soveshch.* (Proc. Conf. "Geodynamic Evolution of the Lithosphere of the Central Asian Orogenic Belt (from Ocean to Continent))", 2016b, vol. 14, pp. 230–232.

Priyatkina, N., Collins, W.J., Khudoley, A.K., Letnikova, E.F., and Huang, H.-Q., The Neoproterozoic evolution of the western Siberian Craton margin: U–Pb–Hf isotopic records of detrital zircons from the Yenisey Ridge and the Prisayan Uplift, *Precambrian Res.*, 2018, vol. 305, pp. 197–217.

Priyatkina, N.S., Kuznetsov, N.B., Rud'ko, S.V., Shatsillo, A.V., Khudolei, A.K., Romanyuk, T.V., and Maslov, A.V., The Proterozoic Pogor'uy Formation of Yenisei Ridge: Age and provenance sources according to U/Pb dating of detrital zircons, *Dokl. Earth Sci.*, 2019, vol. 484, no. 1, pp. 28–31.

Rud'ko, S., Kuznetsov, N., Shatsillo, A., Rud'ko, D., Malyshev, S., Dubenskiy, A., Sheshukov, V., Kanygina, N., and Romanyuk, T., Sturtian glaciation in Siberia: evidence of glacial origin and U–Pb dating of the diamictites of the Chivida Formation in the north of the Yenisei Ridge, *Precambrian Res.*, 2020, vol. 345, 105778. https://doi.org/10.1016/j.precamres.2020.105778

Samsonov, A.V., Postnikov, A.V., Spiridonov, V.A., Larionova, Yu.O., Larionov, A.N., Travin, A.V., Postnikova, O.V., Solov'eva, N.V., Sabirov, I.A., and Spiridonov, I.V., Neoarchean granitoids in the western part of the Tunguska Superterrane, Basement of the Siberian Platform: Geochronology, petrology, and tectonic significance, *Petrology*, 2021, vol. 29, no. 5, pp. 449–474.

Samsonov, A.V., Erofeeva, K.G., Larionova, Yu.O., Larionov, A.N., Kuznetsov, N.B., Romanyuk, T.V., Solov'eva, N.V., Zhilicheva, O.M., Dubenskii, A.S., and Sheshukov, V.S., Eastern margin of the Neoarchean Tunguska Superterrane: Data from boreholes in the central part of the Siberian Platform, *Petrology*, 2022, vol. 30, no. 6, pp. 628–639.

Saraev, S.V. and Filippov, Yu.F., Pre-Jurassic magmatic complexes of the Cis-Yenisei sedimentary complex in the south-east of Western Siberia, in *Mezhd. nauchn. konf. "Nedropol'zovanie. Gornoe delo. Napravleniya i tekhnologii poiska, razvedki i razrabotki mestorozhdenii poleznykh iskopaemykh. Geoekologiya". Sb. mater.* (Proc. Int. Res. Conf. "Subsoil Use. New Trends and Technologies of Prospecting, Exploration, and Development of Mineral Deposits. Geoecology". Coll. Sci. Works), Novosibirsk, 2015, vol. 1, pp. 145–149.

Slama, J., Košler, J., Condon, D.J., Crowley, J.L., Gerdes, A., Hanchar, J.M., Horstwood, S.A.M., Morris, G.A., Nasdala, L., Norberg, N., Schaltegger, U., Schoene, B., Tubrett, M.N., and Whitehouse, M.J., Plešovice zircon—A new natural reference material for U–Pb and Hf isotopic microanalysis, *Chem. Geol.*, 2008, vol. 249, nos. 1–2, pp. 1–35.

Sovetov, Ju.K. and Le Heron, D.P., Birth and evolution of a Cryogenian basin: Glaciation, rifting and sedimentation in the Vorogovka Basin, Siberia, *Sedimentology*, 2016, vol. 63, pp. 498–522.

Storozhenko, A.A. and Vasil'ev, N.F., *Karta zolotonosnosti severnoi chasti Eniseiskogo kryazha. Masshtab 1 : 200000* (The 1 : 200000 Map of Gold Mineralization of the Northern Part of the Yenisei Ridge), Krasnoyarskgeols"emka, 2012 [in Russian].

Storozhenko, A.A., Vasil'ev, N.F., Pimanov, A.V., Dmitrieva, E.V., Dmitriev, G.A., and Miller, V.Ya., *Gosudarstvennaya geologicheskaya karta Rossiiskoi Federatsii masshtaba 1 : 200000. Seriya Eniseiskaya. List R-46-XXV (r. Vorogovka). Ob"yasnitel'naya zapiska* (The 1 : 200000 State Geological Map of the Russian Federation. Sheet R-46-XXV (Vorogovka). Explanatory Note), Moscow: Mosk. Fil. Vseross. Nauchno-Issled. Geol. Inst., 2019 [in Russian].

Varganov, A.S., Moskalev, V.A., Barmin, V.A., Kachevskii, L.K., et al., *Gosudarstvennaya geologicheskaya karta Rossiiskoi Federatsii masshtaba 1 : 1000000 (tret'e pokolenie). Seriya Angaro-Eniseiskaya. List R-46 (Severo-Eniseiskii). Komplekt kart i ob"yasnitel'naya zapiska* (The 1 : 1000000 State Geological Map of the Russian Federation (3rd ed.). Ser. Angara–Yenisei. Sheet R-46 (North Yenisei). Map Set and Explanatory Note), St. Petersburg: Kart. Fabr. Vseross. Nauchno-Issled. Geol. Inst., 2010 [in Russian].

Vermeesch, P., On the visualization of detrital age distribution, *Chem. Geol.*, 2012, vols. 312–313, pp. 190–194.

Vernikovsky, V.A., Vernikovskaya, A.E., Chernykh, A.I., Sal'nikova, E.B., Kotov, A.B., Kovach, V.P., Yakovleva, S.Z., and Fedoseenko, A.M., Porozhnaya granitoids of the Yenisei Ophiolite Belt: Indicators of Neoproterozoic events on the Enisei Ridge, *Dokl. Earth Sci.*, 2001, vol. 381A, no. 9, pp. 1043–1046.

Vernikovsky, V.A., Vernikovskaya, A.E., Kotov, A.B., Sal'nikova, E.B., and Kovach, V.P., Neoproterozoic accretionary and collisional events on the western margin of the Siberian craton: New geological and geochronological evidence from the Yenisey Ridge, *Tectonophysics*, 2003, vol. 375, pp. 147–168.

Vernikovsky, V.A., Vernikovskaya, A.E., Wingate, M.T.D., Popov, N.V., and Kovach, V.P., The 880–864 Ma granites of the Yenisey Ridge, western Siberian margin: Geochemistry, SHRIMP geochronology, and tectonic implications, *Precambrian Res.*, 2007, vol. 154, pp. 175–191.

Vishnevskaya, I.A., Letnikova, E.F., Proshenkin, A.I., Maslov, A.V., Blagovidov, V.V., Metelkin, D.V., and Priyatkina, N.S., The Vendian Vorogovka Group of Yenisei Ridge: Chemostratigraphy and results of U–Pb dating of detrital zircons, *Dokl. Earth Sci.*, 2017, vol. 476, no. 1, pp. 1016–1020.

Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J.C., and Spiegel, W., Three natural zircon standards for U–Th–Pb, Lu–Hf, trace element and REE analysis, *Geostand. Newsl.*, 1995, vol. 19, pp. 1–23.

Translated by I. Melekestseva