Correlation of Chukotka, Wrangel Island and the Mendeleev Rise

M. I. Tuchkova, S. P. Shokalsky, S. D. Sokolov, and O. V. Petrov

Abstract The paper analyzes Mendeleev Rise sandstones as compared with Triassic sediments of continental Chukotka and Wrangel Island. The study of sedimentological characteristics showed that in the samples, there is gradual maturation of clastic material from the south (continental Chukotka) to the north (Mendeleev Rise). Moreover, in the samples from the Mendeleev Rise, there is no geochemical evidence of redeposition of clastic material, but severe weathering of the rocks from the provenance area has been recorded. High content of clastic quartz with microfractures (18% of all counted grains) in the sample from the Mendeleev Rise indicates that there is continental land in the vicinity from which quartz grains were eroded. Southwards, the amount of the quartz with microfractures decreases: in the Triassic sandstone of Wrangel Island, it occupies 8% and in the samples from Chukotka 3%. Analysis of lithological data indicates the presence of a large continental block in the northern part of the eastern Arctic, near which Upper Triassic shallow-marine deposits of the Mendeleev Rise were formed.

Paleogeographic reconstructions of the Triassic time indicate the existence of a large basin in the present-day northeastern Arctic (Kos'ko 2007; Blakey 2018; Golonka 2011; Scotese 2011, etc.). Studying Triassic turbidite deposits of Chukotka and Wrangel Island made it possible to establish a northern provenance area (Tuchkova 2011; Tuchkova et al. 2014).

Northern provenance area, which was named the Crockerland, was also found for the Triassic sediments of the Sverdrup Basin (Embry and Dixon 1994; Anfinson et al. 2016). Shatsky (1935) assumed the existence of the Hyperborea continent in the

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center of the present-day Eastern Arctic. Later, in mobilist paleotectonic reconstructions, this continental block was named Arctida (Zonenshain et al. 1990). Concepts about Arctida were described in literature (Kuznetsov 2006; khain and Filatova 2009; Laverov et al. 2013; Vernikovsky et al. 2013). In the modern structure, fragments of tectonically dispersed Arctida can be found in Taimyr, Severnaya Zemlya, New Siberian Islands, Chukotka, and Alaska.

In these publications, it is supposed that main structures of Central Arctic Uplifts of the Arctic Ocean (Lomonosov Ridge, Mendeleev, Alpha and Chukchi Rises, Makarov and Podvodnikov Basins) also belong to this ancient continent. Modern structural style of the Eastern Arctic was formed during the Mesozoic and Cenozoic as a result of tectonic rearrangement and relative movements of large continental blocks to form the Amerasian Basin in the Early Cretaceous and the Eurasian basin in the Cenozoic.

It is shown (Sokolov et al. 2015; Sokolov et al. 2014) that when the Proto-Arctic (South-Anyui) ocean was closed, a large continental block, the Chukotka microcontinent, became part of Eurasia. The collision of the Chukotka microcontinent with structures of the active margin of Siberia took place in the Hauterivian-Barremian. In the Triassic, the Chukotka microcontinent was part of the Arctic Canada. Turbidite accumulated on the passive margins of the North American continent. Now they are widespread in Chukotka and Wrangel Island, where they are rather well studied (Tuchkova 2011; Tuchkova et al. 2009, 2014).

There is no information on the composition of the Triassic deposits on the vast water area of the Russian shelf of the Eastern Arctic, since they form part of the acoustic basement, which is overlapped by the Aptian-Albian and possibly Hauterivian-Barremian deposits (Drachev 2011; Verzhbitsky et al. 2012; Nikishin et al. 2014; Arctic Basin … 2017). Undeformed or slightly deformed Triassic deposits are widespread north of the Wrangel-Herald front of Late Mesozoic deformations. According to seismic data, they are part of the sedimentary cover of the North Chukchi Trough.

In the area of Central Arctic Uplifts, Triassic sediments were not found among the rocks raised from the seabed by Russian and foreign scientific expeditions: R/V *Academician Fedorov* (*Arctic* 2000, 2005, 2007), icebreakers *Healy* (2008, 2009) and *Polarstern* (2008).

During the Russian expedition *Arctic-2012,* on escarps and steep slopes of underwater mountains of the Mendeleev Rise, sampling was carried out using not only traditional methods (dredge, grabbing excavator, box corer, bottom sampler), but also for the first time deep-sea core drilling at a shallow depth (up to 2 m) and sampling with manipulators of the research submarine. Bottom-stone material is dominated by carbonaceous rocks, mainly dolomite; terrigenous rocks (sandstone, siltstone, mudstone) occupy 20–25%. Geochronological studying detrital zircons testifies to the Triassic age of several sandstone samples, including fine-grained quartz sandstone with carbonate cement from a boulder taken by the submarine from the escarp of the steep southeastern slope of the Shamshur Seamount (Morozov et al. 2013).

The purpose of this work was to compare sandstone of Chukotka, Wrangel Island, and Mendeleev Rise for the restoration of Triassic paleogeography in the Russian offshore sector of the Eastern Arctic.

1 Geologic Framework

In the tectonic zoning of the Russian offshore sector of the Eastern Arctic, the most difficult is the correlation of individual blocks located on the continent, islands and the Arctic shelf. Previously, tectonic structures of Taimyr, New Siberian Islands, Wrangel Island and significant areas of the Arctic shelf were referred to the Eastern Arctic fold system, which borders the Hyperborean Platform in the north (Tectonics… 1980). Later, tectonic setting was performed on the basis of terrane analysis (Parfenov et al. 1993a, b; Nokleberg et al. 1994; Geodynamics… 2006; Sokolov 2010). In the Chukotka fold area, there are the New Siberian-Wrangel, Anyui-Chukotka, and South Anyui fold systems, which consist of separate terranes and subterranes (Figs. 1 and 2). The New Siberian-Wrangel fold system includes the Kotelny, Bennett and Wrangel terranes. The Anyui-Chukotka fold system includes the Chukchi and East Chukchi (Bering) terranes.

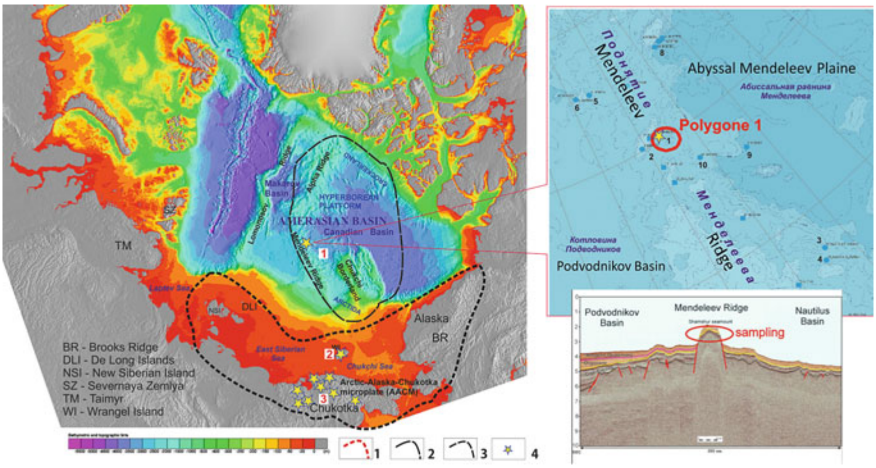


Fig. 1 Map of the Arctic Region. 1—Alaska-Chukotka microcontinent and 2—Hyperborean platform. 3—Contemporary outline of the ancient paleocontinent (Hyperborean Platform, Arctida, Crockerland), cited from (Metelkin et al. 2005; Laverov et al. 2013, with simplifications). 4—Position of the examined sections. Red numbers in the map indicate sampling points: 1—Mendeleev Rise, sample USO-4, 2—Wrangel Island; 3—Chukotka terrane. In the inset—at the top: a fragment of the Mendeleev Rise map with a marked sampling point position at polygon 1 (red oval); an asterisk shows the position of sample USO-4. Below—a fragment of the seismic line of Shamshur Mt. with an area of underwater sampling

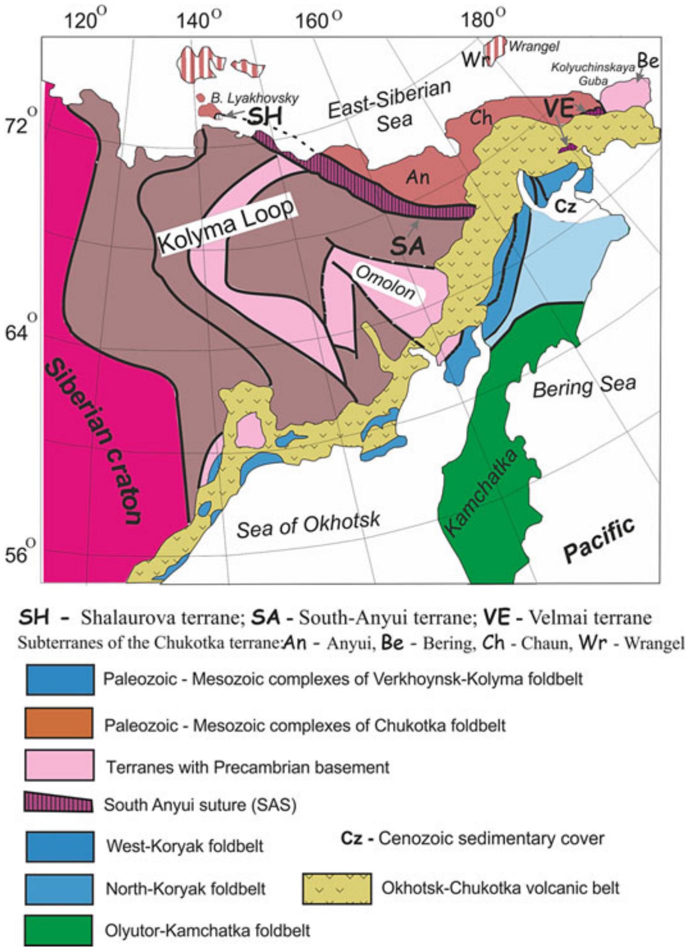


Fig. 2 Tectonic scheme of Northeast Asia, according to (Sokolov et al. 2010)

Structures of the Chukotka fold area were resulted from the Chukchi (Late Cimmerian) phase of deformations in the late Early Cretaceous during the collision of the Chukotka microcontinent with structures of the active margin of Siberia (Parfenov et al. 1993a, b; Sokolov 2010; Sokolov et al. 2015). Traces of Ellesmerian deformations have been identified on New Siberian Islands, Wrangel Island, and in Chukotka (Verzhbitsky et al. 2015; Luchitskaya et al. 2015; Sokolov et al. 2017). The South Anyui suture, a result of the Proto-Arctic (South Anyui) ocean closure, separates Arctic structures of the Chukotka fold area from the Pacific structures of the Verkhoyansk-Kolyma fold area.

Triassic deposits accumulated on passive margins of the Chukotka microcontinent. At present, they are widespread within the Chukotka, Wrangel and South Anyui terranes. The most complete sections were preserved in the Anyui-Chukotka

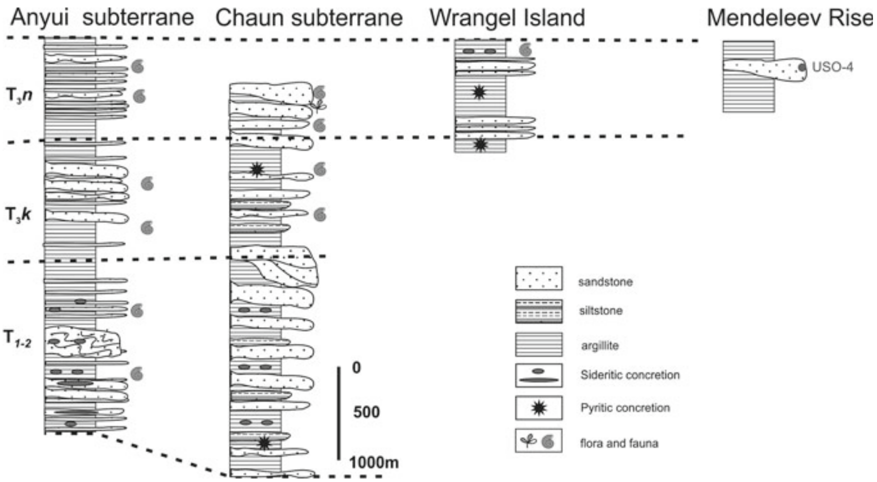


Fig. 3 Structure of the Triassic sections in Chukotka, Wrangel Island, and Mendeleev Rise

fold system. Facies analysis made it possible to identify deposits of the shelf, continental slope, and sea-plain with the southward deepening of the sedimentary basin (Tuchkova, 2011; Tuchkova et al. 2009, 2014). The Wrangel and South Anyui terranes also contain Upper Triassic deposits. The former is characterized by proximal facies of turbidite (Kos'ko et al. 2003), and the latter, by distal turbidite, which occupy the lower structural position among the South Anyui suture allochthons.

Chukotka terrane. Triassic sediments are represented by three rock sequences: Lower-Middle Triassic, Carnian and Norian (Fig. 3) The lower rock sequence is represented by interlayering of fine rhythmic siltstone with interbedded sandstone and argillite, which ratio can vary in different sections (Tuchkova et al. 2007, 2009). Up the section, the amount of sandstone and the thickness of the rhythms increase. The sandstone is characterized by graded, laminar, and oblique layering. There are landslide textures and inclusions of mudstone fragments of the underlying layer. The sequence contains a large number of siderite nodules. The nodules can be small oval-shaped (Fig. 4a) and concretionary interlayers with uneven lower boundary and gradation structure of the layer (Fig. 4b).

Lower-Middle Triassic deposits contain numerous gabbro-dolerite dikes, sills and stocks (Tectonics… 1980; Ledneva et al. 2011).

Carnian sandstones are structureless, there are graded and cross-bedded series, traces of slumping and erosion in the bottom of layers, as well as upward coarsening of deposits up to the emergence of small-pebble conglomerates.

Norian deposits are characterized by fine rhythmic structure with abundant *Monotis* shell remains and trace fossils. Large plant fragments occur.

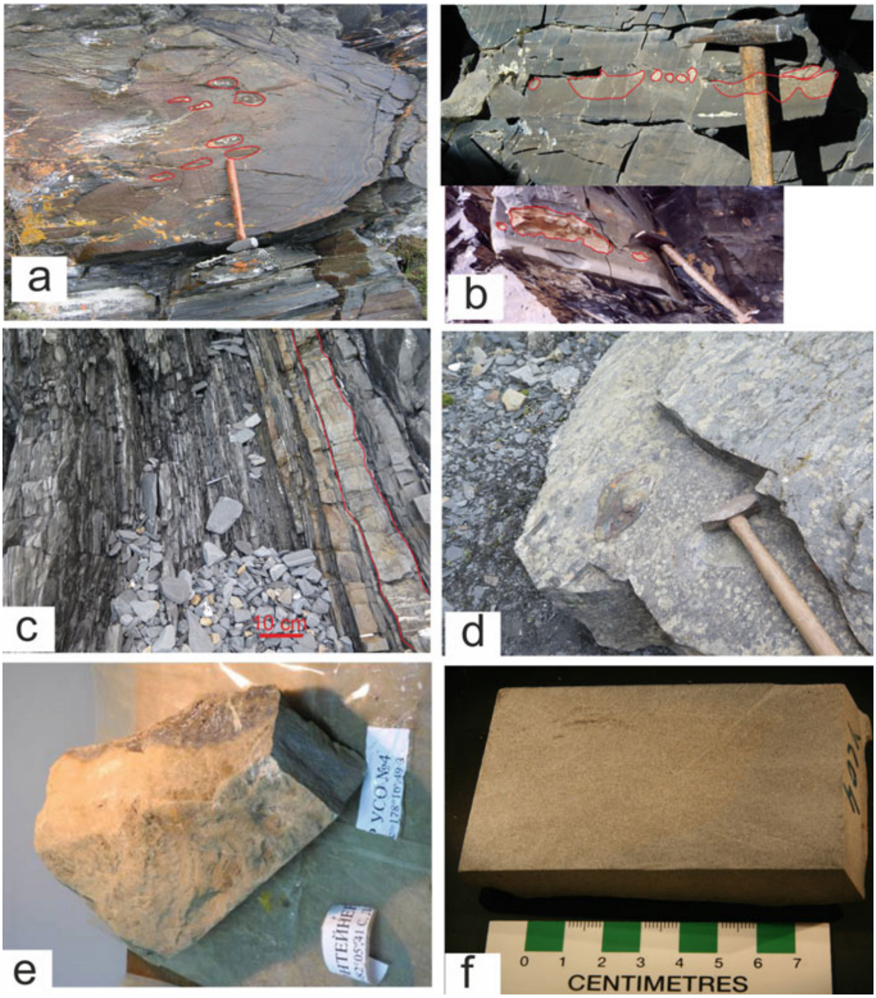


Fig. 4 Photographs of the Triassic deposits: **a** single oval siderite concretions in the Lower-Middle Triassic, Vernitakayveem River, Chukotka terrane; **b** single small concretions and concretionary interbeds in the sediments of the Lower-Middle Triassic reference section, Enmynveem River, Chukotka terrane; **c** bed of calcareous sandstone in the Upper Triassic deposits, Krasnaya River, Wrangel Island; **d** large single concretion in the Upper Triassic deposits, Chertov Ravine, Wrangel Island; **e** sample of calcareous silt-sandstone (USO-4), Shamshur Mt., Mendeleev Rise; **f** sawn sample USO-4 structureless sandstone

Wrangel terrane. On Wrangel Island, Upper Triassic deposits are only known, which are mainly represented by the Norian and upper part of the Carnian stages (Kos'ko et al. 2003). Contact between Triassic, Permian and older deposits is tectonic (Sokolov et al. 2017). The lower part of the Triassic section is composed of interbedded siltstone-mudstone and sandstone with dominating fine-grained varieties. The upper part of the section is dominated by sandstones.

Sandstone is grey, sometimes greenish-grey, fine- to medium-grained, mostly structureless, although there are interlayers with graded-bedding. At the base of the sandstone beds, traces of sediment flow and slightly rounded large (10–12 cm across) flattened mudstone intraclasts are recorded. The thickness of the sandstone beds is 10–30 cm; sometimes it can reach 50–60 cm or more. Some interlayers consist of calcareous sandstone with carbonate cement, in which Norian faunistic remains are embedded. In the section, these beds are notable for the well-expressed uneven lower boundary of the layer (Fig. 4c). In some sandstones, there are large single siderite nodules (Fig. 4d). Thin rubbly rocks are characterized by laminar stratification and thin-rhythmical alternation of mudstone and siltstone.

Mendeleev Rise. Quartz sandstone was found among the silicoclastic rocks in the bottom rock collection (Morozov et al. 2013). It is characterized by a high silica content of up to 98%, often cross-bedded structure, illite or carbonate dolomite-calcite, sometimes recrystallized cement. High maturity and good sorting of detrital material typical of sedimentary rocks of the craton platform cover are recorded (Morozov et al. 2013).

On the Shamshur Seamount (Fig. 3), research submarine manipulator raised dense, hard grey rocks with brownish incrustation oxidized to a depth of 1 cm (sample USO-4, Fig. 4e, f). In addition, two samples of uncemented silty sandstone (samples SS-63 and SS-65) were selected from the Arctica-2012 collection. These samples (described below) are also classified as Upper Triassic based on the age of the youngest detrital zircon population (205–233 Ma).

2 Petrographic Data

In mainland Chukotka, the Lower-Middle Triassic sandstone is characterized by grains of silty dimension and a clay matrix content of more than 15%. According to the classification of F. Pettijohn, they are defined as lithic greywackes (Fig. 5). In Upper Triassic sandstone of Chukotka and the Wrangel Island, matrix content is 3–10%, so they are classified as lithic arenite (Tuchkova et al. 2007, 2009). Sample USO-4 also belongs to the lithic arenite (Fig. 5). Samples SS-63 and SS-65 can be assigned to the same group conditionally, since they are not cemented.

Chukotka terrane. In lithic greywacke of the Anyui subterrane, the clay matrix content varies from 15 to 30%. The ratio of rock-forming components is as follows: quartz 19–47%, feldspars 7–32%, rock fragments 29–68% (Tuchkova 2011; Tuchkova et al. 2009, 2014). Low- and medium-metamorphosed rocks were identified in the rock fragments. Some of them contained fragments of altered mafic effusive.

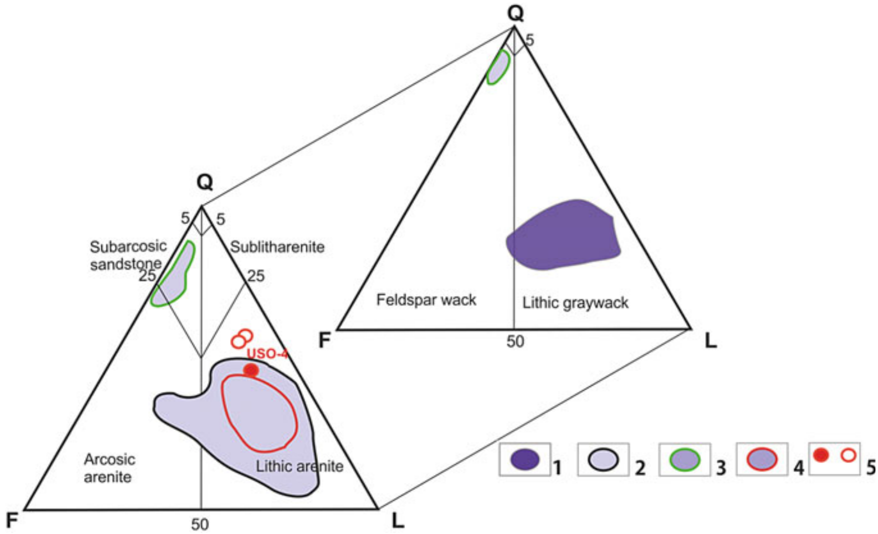


Fig. 5 Classification diagram of sandstones from Chukotka, Wrangel Island, and Mendeleev Rise (classification fields are based on Pettijohn 1975). In the diagram, the composition of sandstones from: 1—Lower-Middle Triassic; 2 to 4—Upper Triassic: 2—Anyuy subterrane, 3—Chaun subterrane, 4—Wrangel Island, 5—samples from the Mendeleev Rise: red circle—sample USO-4, red circle with white filling—samples SS-65 and SS-63

In lithic arenites, quartz occupies 12–46%, feldspars, 9–68%, rocks fragments, 14–68%. The rock fragments are dominated by metamorphic rocks becoming more and more diverse from the Lower to Upper Triassic.

Concretions and concretion interlayers in Lower-Middle Triassic sections are represented by micrite or calcareous silty sandstone (Fig. 6a, b). Cement is dominated by calcite and Mg–Fe calcite, clastic grains are poorly or practically unsorted, rock fragments of different degree of roundness occupy 5–15% per thin section (Fig. 6b). Pyrite grains sometimes can be found (Fig. 6a). In the upper part of the lower Triassic section of the Enmynveem River, undeterminable microfauna is present in the most fine-grained carbonate concretions (Tuchkova et al. 2007).

In the sandstone of the Chaun subterrane, quartz grains occupy 45%, feldspars 20%, rock fragments 26%. Among the rock fragments, there are rhyolite and fine-grained metamorphic rocks of quartz-micaceous composition. In addition, biotite and muscovite can be found as well as chloritized mica, in places sideritized.

Wrangel Island. Upper Triassic sandstone and siltstone belong to the lithic arenite. The rocks are cleavage; ferriferous carbonate, which corrodes clastic grains, occurs as spots in thin sections. The sorting of grains is poor and medium, the grain size ranges from 0.15 to 0.25 mm, the cement is of chlorite-micaceous composition (Fig. 6c). Sandstone composition consist of quartz (20–40%), feldspars (plagioclase, microcline) (34–62%), rock fragments (11–23%) including clasts of granite, cherts, fragments of sedimentary and micaceous shale, altered fragments of mafic and felsic effusives; dehydrated biotite have been also identified.

Dimensions of clastic grains in sandstone beds with basal calcite cement vary from 0.1 to 0.4 mm. The grains are angular and semi-rounded, the edges are intensively corroded by carbonate mineral enclosing clastic grains and debris of faunal remains. Many clastic grains are replaced by calcite (Fig. 6d). Quartz and granitoid rock fragments are dominated; Feldspars are completely replaced by calcite.

Mendeleev Rise. Sample USO-4 is a fine-grained quartz-feldspar sandstone (Fig. 6e). There is no initial matrix in the rock, but basal calcite cement with embedded clastic grains is present. The cement is composed of calcite and dolomite, Mg-calcite is present also. Clastic material is dominated by quartz; there are feldspar, mica, fragments of schist, granite and limestone, effusives of acidic composition. Quartz grains are characterized by predomination of grains with microfractures filled with clay or a mixture of clay minerals (Fig. 6f).

X-ray phase analysis showed that main minerals are quartz (70%), calcite (about 20%), dolomite (about 15%), illite, and K–Na feldspar (not more than 5%).

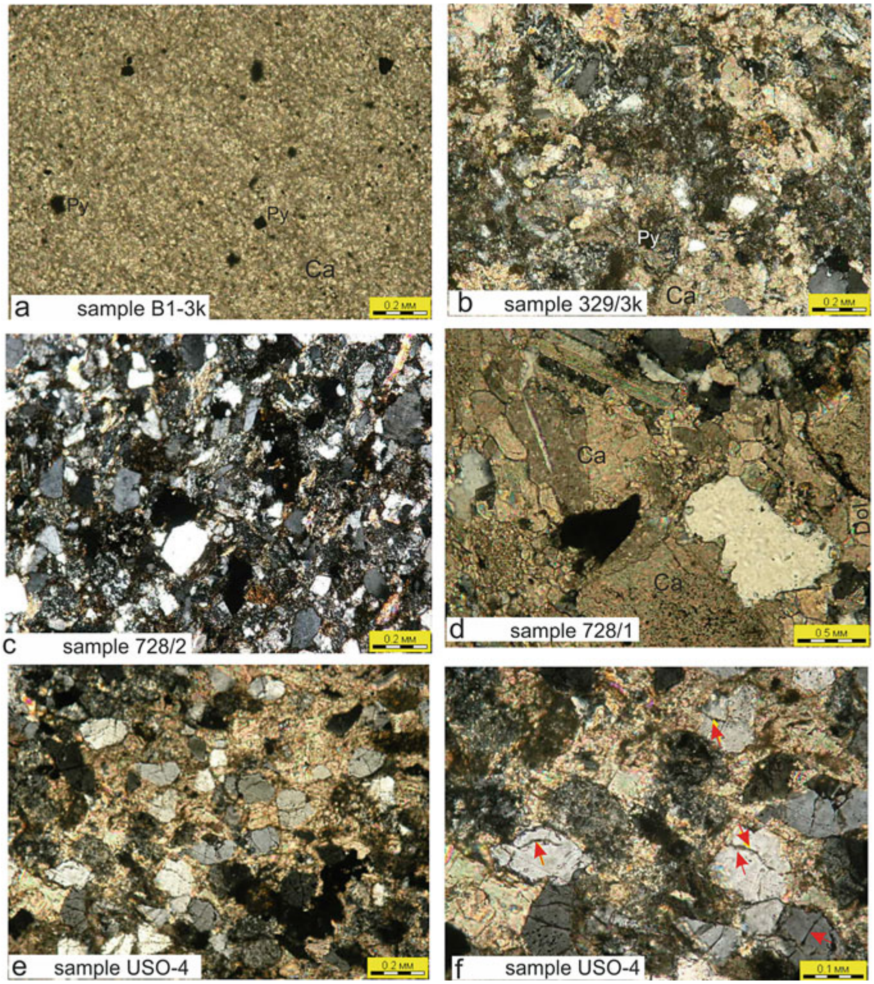


Fig. 6 Photomicrographs of the Triassic nodules and sandstones from Chukotka, Wrangel Island, and Mendeleev Rise: **a** concretion, carbonate rock consisting mainly of calcite (Ca), contains single pyrite (Py) grains, Enmynveem River, Anyuy subterrane, Chukotka; **b** concretionary interbed, fine-grained calcareous sandstone with clastic grains of quartz, feldspar, and mica, Enmynveem River, Anyuy subterrane, Chukotka; **c** sandstone, lithite arenite, with chlorite mica cement, Wrangel Island, Krasnaya River; **d** calcareous sandstone, Krasnaya River, Wrangel Island; calcite (Ca) and dolomite (Dol) in cement; **e** calcareous silt-sandstone is composed mainly of quartz, Mendeleev Rise; **f** quartz fragments with microcracks, along which clay mineral develops (red arrows), Mendeleev Rise

3 Geochemical Data

Chemical composition of sedimentary rocks and the content of impurity elements in them are widely used for deciphering the composition of provenance areas and sedimentary environments in sedimentary basins. This paper analyzes the geochemical features of sample USO-4 in comparison with the data on the Triassic sandstones from Chukotka and Wrangel Island. Diagrams and relationships were used that show the composition of the provenance area, the level of maturation and redeposition of the rock components. The data of whole analysis make it possible to determine the similarity and difference in the composition of rocks and to determine their classification affiliation.

In Pettijohn's diagram (Fig. 7), sample USO-4 occupies a position in the field of quartz arenites, whereas samples of the Triassic sandstones from Chukotka and Wrangel Island are characterized by a less mature composition and occupy greywacke and lithic arenite fields.

In addition, the maturity of deposits by the degree of mechanical sorting can be estimated on the basis of the "titanium module", i.e. by TiO_2/Al_2O_3 ratio (Interpretation of geochemical data 2001). It is believed that the maximum value of 0.09 is characteristic of mature rocks, such as quartzites and quartz sandstones. For sample USO-4, this index is 0.048, which is quite comparable with the samples from Wrangel Island (TiO_2/Al_2O_3 is 0.04–0.06) and somewhat lower in comparison with Chukotka (0.05–0.08). Such a low index may indicate that the sandstones from the Mendeleev Rise were formed at the expense of a more mature clastic matter, which underwent considerable weathering.

To determine the degree of weathering, the CIA (Chemical Index of Alteration) is used, which is an indicator of climate in the erosion area (Nessbitt and Young 1982;

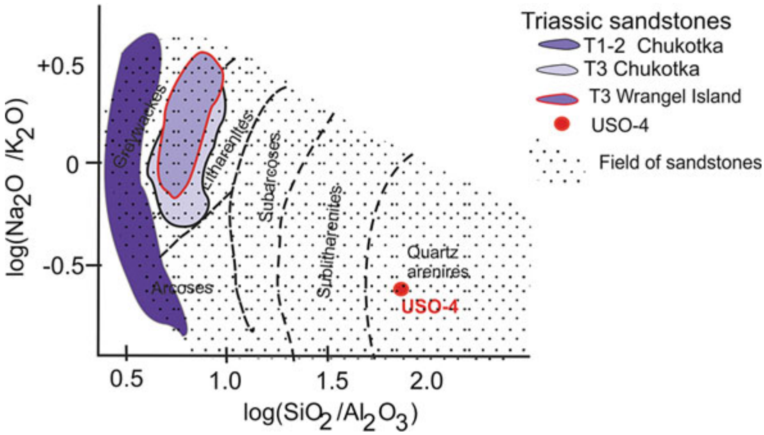


Fig. 7 Classification diagram after Pettijohn (1975) showing distribution of major components in the Triassic sandstones of the Anyuy-Chukotka fold belt

Visser and Young 1990). In the diagram (Fig. 8), sample USO-4 occupies a position in the field with a high level of weathering, although in composition it occupies a position close to the average shale.

Another important parameter is the level of redeposition of clastic material. To determine the level of resedimentation, a diagram is used that reflects Th/Sc–Zr/Sc ratio (Fig. 9). The proportions of these elements are not subject to significant changes in the process of sediment transformation into rock and are characterized by similar

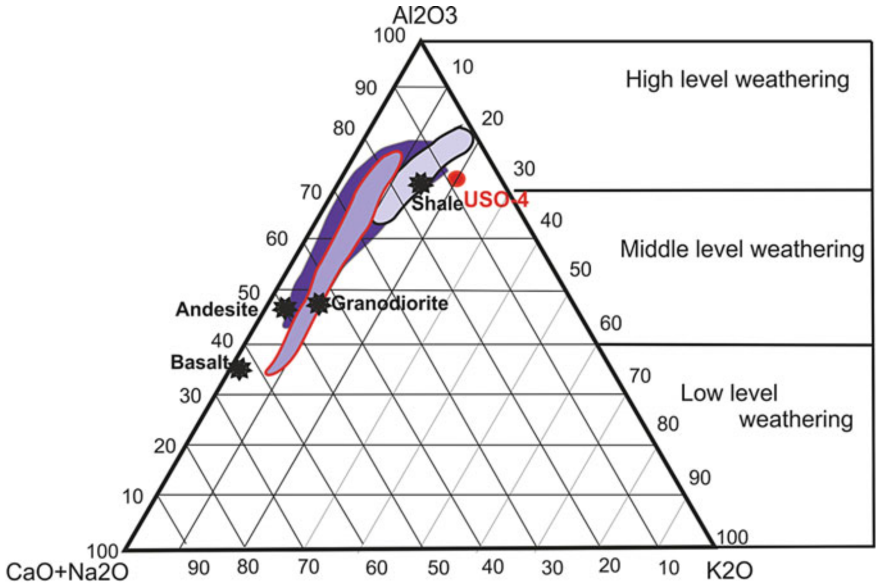
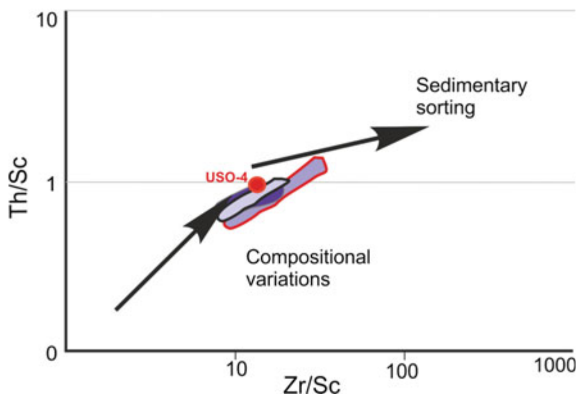


Fig. 8 Al_2O_3–$CaO + Na_2O$–K_2O diagram (Nesbitt and Young 1984) showing compositions for the Triassic sandstone of Chukotka, Wrangel Island and samples (molar proportions). Average values for basalt, andesite, and granodiorite are from McLennan et al. (2003). For legend see Fig. 7

Fig. 9 Diagrams Th/Sc versus Zr/Sc, illustrating the sedimentary recycling of the Triassic samples of Chukotka –Wrangel Island– (USO-4), diagrams by McLennan et al. (2003). For legend see Fig. 7



behaviour during sedimentation. Sample USO-4 is at the boundary of the recycling trend and the field of the composite variety of sandstones. Compared with the samples from Chukotka, it is characterized by high recycling, whereas in comparison with the field of samples from Wrangel Island it occupies the middle position.

In addition to this diagram, the analysis of Th/Sc ratio shows a tendency to increase from the continental sections of Chukotka (avg. 0.52) to Wrangel Island (avg. 0.78) and in sample USO-4 is 1.082.

Based on this parameter, it is possible to evaluate the possibilities of using diagrams reflecting the composition of provenance areas. In the case of repeated redeposition of clastic material, the use of genetic diagrams is difficult and undesirable. In this case, the geochemical parameters of sample USO-4 can be assessed, since the position of this sample lies on the boundary between the recycled and non-recycled rocks.

Preliminary conclusions about the prevailing provenance area can be made on the basis of the $CaO + MgO–Na_2O + K2O–SiO_2/10$ diagram analysis (Fig. 10). In connection with the fact that, according to petrographic data, there is carbonate cement in sandstone from sample USO-4, CaO content was recalculated to $CaCO_3$ by the standard procedure described in (Kossovskaya and Tuchkova 1988). After the procedure, sample USO-4 occupies the field of felsic (granite) source area and is in relation to the samples from Chukotka and Wrangel Island in the area of the most mature rocks. A similar conclusion is obtained on the basis of DF1-DF2 diagram analysis, according to which sample USO-4 occupies a position in the field of quartz sandstones.

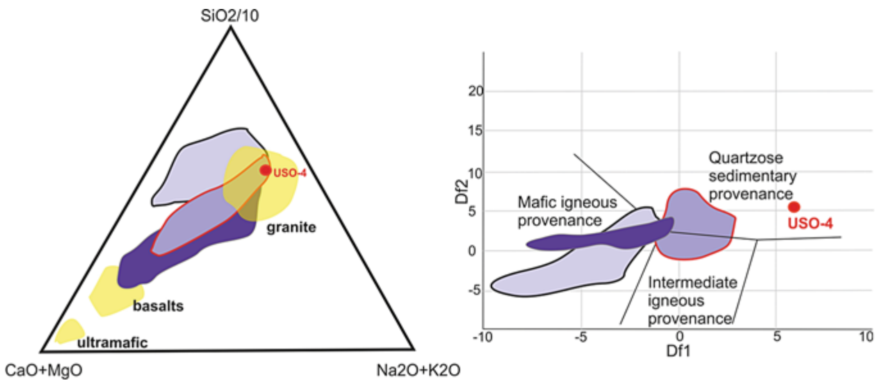


Fig. 10 Discriminant diagrams illustrating the compositions of assumed provenances for samples of the Triassic sandy rocks of Chukotka—Wrangel Island—Mendeleev Rise. In the left diagram after McLennan et al. (2003). In the right discriminant diagram for major component provenance, after Roser and Korsch (1988). Discriminants and fields are $DF1 = 30.6038\ TiO_2/Al_2O_3–12.541\ Fe_2O_3(total)/Al_2O_3 + 7.329\ MgO/Al_2O_3 + 12.031\ Na_2O/Al_2O_3 + 35.42\ K_2O/Al_2O_3 - 6.382$. $DF_2 = 56.500\ TiO_2/Al_2O_3 - 10.879\ Fe_2O_3(total)/Al_2O_3 + 30.875\ MgO/Al_2O_3 - 5.404\ Na_2O/Al_2O_3 + 11.112\ K_2O/Al_2O_3 - 3.89$. For legend see Fig. 7

In more detail, the composition of the sources areas can be determined by analyzing a diagram constructed from Co/Th–La/Sc ratios (Fig. 11). In this diagram, the sandstones from Chukotka, Wrangel Island, and the Mendeleev Rise are characterized by a composition close to the average composition of the continental crust. At the same time, there is an increase in the role of felsic rocks from the Lower Triassic to the Upper Triassic sandstones.

In the diagram constructed from La/Th–Hf ratio, the field of Triassic sandstones is characterized by a mixed composition of felsic and mafic provenance areas (Fig. 12). Points of Chukotka, Wrangel Island, and Mendeleev Rise sandstones form the fields, practically coinciding with each other.

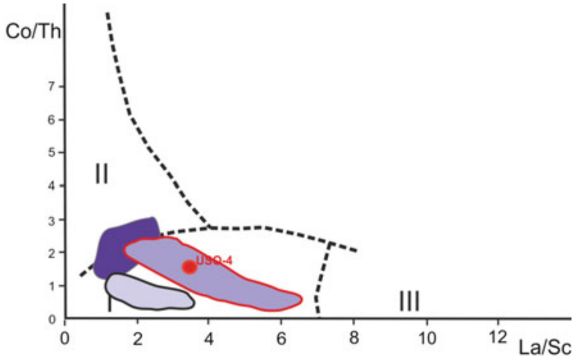


Fig. 11 Discriminant diagram of Co/Th versus La/Sc showing various provenances for clastic rocks: fields: (i) erosion of rocks that are close to the average composition of the continental crust (granodiorites), (ii) increase of the role of mafic rocks, (iii) increase of the role of felsic rocks. From Gu et al. (2002). For legend see Fig. 7

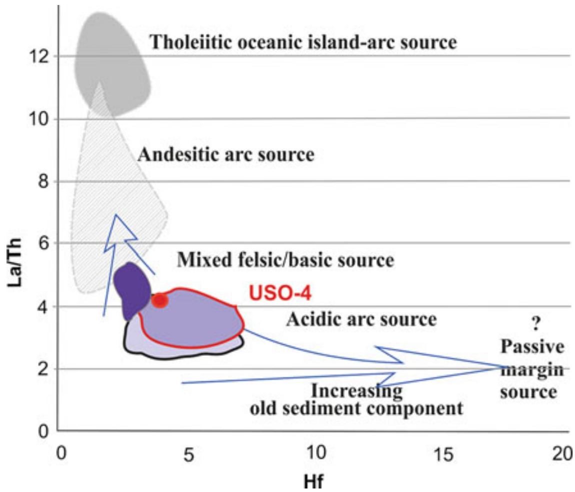


Fig. 12 Hf versus La/Th plot (after Floyd and Leveridge 1987; Gu 1994) for the sandstones of the Chukotka—Wrangel Island—Mendeleev Rise. For legend see Fig. 7

4 U-Pb Dating

Samples from the Triassic deposits of the Chukotka terrane are characterized by practically identical age spectra of zircons (Fig. 13). The youngest population of zircons with the ages of 235–260 Ma is the most numerous. The Upper Triassic samples comprise a small population of old zircons with peaks at 1200, 1500, 1800, 2000 Ma, 5–18 grains each.

Detrital zircons in sandstones from Wrangel Island have a maximum in the range of to 282–331 Ma, with peaks at 210, 305, and 410 Ma. Older populations of zircons are less widespread; however, they have many small peaks in the range 800–1500 Ma and a slightly higher maximum in the range 600–2400 Ma (15–30 grains).

Detrital zircons from the Mendeleev Rise sandstone are characterized by the distribution of populations typical of the Triassic sandstones from Wrangel Island and Chukotka. The most numerous group of zircon grains covers the interval 235–425 Ma with peaks at 205, 235, 250, 300, 405 Ma. Older zircons are represented by individual grains with ages from 550 to 2500 Ma.

Thus, the correlation of the Triassic sequences in Chukotka and Wrangel Island shows gradual deepening of the marine basin from north to south, supply of clastic material from the north with the help of several small river systems operating on the shelf and a large underwater prodelta that moved sediments to a deeper area. A

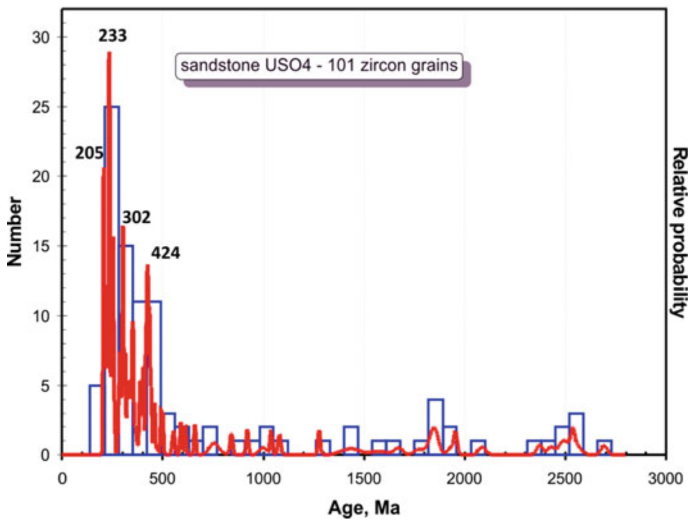


Fig. 13 Distribution of U–Pb detrital zircon ages in the Triassic clastic rocks of Chukotka, Wrangel Island and Mendeleev Rise; **a** sample USO-4; **b** relative probability distribution diagram for detrital zircon U-Pb ages from Triassic sandstones from the Wrangel Island (samples 641/1, 728/1, 497/3, 06/47, and sample C145741 from Miller et al. 2006); **c** relative probability distribution diagram for detrital zircon U-Pb ages from the Triassic sandstones from Chukotka (Upper Triassic samples: 417/4, 06/12-5, L-23-6-1, L11-2-1, 09/321; Lower-Middle Triassic samples: L19-2-1, B-1-5, 09/358 and samples from Miller et al. 2006)

sample of calcareous sandstone from the Mendeleev Rise can be roughly correlated with carbonate (siderite) concretions from the Lower-Middle Triassic sandstones of Chukotka and an interlayer of carbonate sandstones from Wrangel Island.

Comparison of petrographic and geochemical composition of sample USO-4 with coeval sandstones from Chukotka and Wrangel Island shows that the mineral composition of USO-4 sandstone is characterized by the highest content of carbonate cement. A similar type of cement in the Triassic sandstones of the region occurs mainly in the concretionary interlayers of the Lower-Middle Triassic of Chukotka, or in single sandstone beds from the Triassic sequences of Wrangel Island containing numerous faunal remains.

Petrographically, the sandstone from sample USO-4 refers to lithic arenites and is characterized by an increased content of quartz and other stable rock-forming component. Two other non-cemented samples are also most likely lithic arenites. In the Chukotka-Wrangel-Mendeleev Rise line, all three samples from the Mendeleev Rise are sandstones of the most mature composition with quartz content of about 45%.

Quartz grains in the samples are specific; they are characterized by numerous microfractures healed by a clayey mineral. Moreover, when studying sandstone with an electron microscope (SEM), kaolinite was found in some feldspar grains. Kaolinite replaces clastic feldspar, both around the periphery and in the central part of the grains.

The presence of quartz grains with microfractures in the Mendeleev Rise sandstones indicates the arrival of sandy material from nearby land (Table 1). Quartz

Table 1 Composition of Quartz grains with and without microfractures in sandstones and siltsandstones of Chukotka, Wrangel Island and Mendeleev Rise

Mendeleev Rise, Shamshure Mt.						
	USO-4	SS-65	SS-63			
Q without microfractures	80	20	22			
Q with microfractures	14	9	4			
Q all	**94**	**29**	**26**			
Wrangel Island						
	724/1	729/01	708/6	626/1	728/2	729/2
Q without microfractures	32	43	63	59	55	55
Q with microfractures	5	4	5	2	9	2
Q all	37	47	68	61	64	57
Chukotka						
	456/12	400/3-2-1	400/2sand	400/5b	457/1	453/1
Q without microfractures	42	54	50	62	38	29
Q with microfractures	1	2	1	2	2	1
Q all	43	56	51	64	40	30

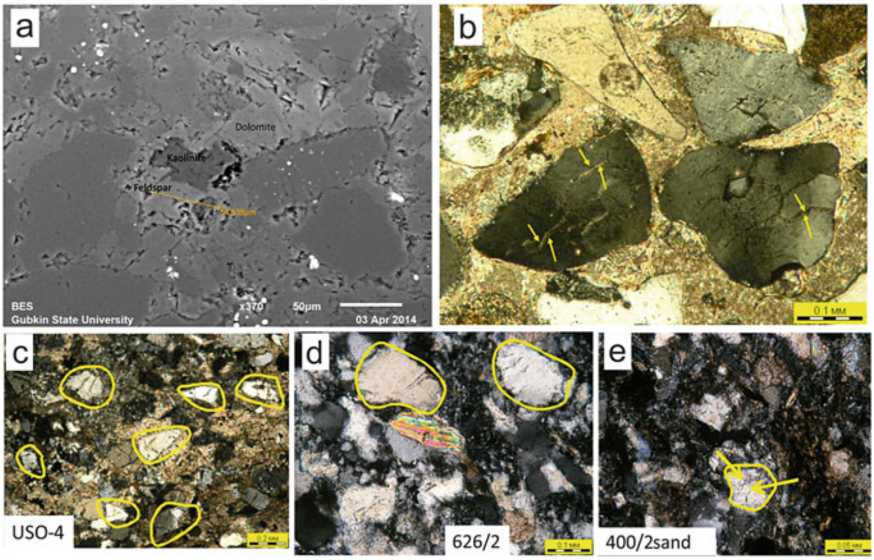


Fig. 14 **a** photomicrograph of silty sandstone with relics of kaolinite replacing feldspar (in the centre). Sample USO-4, Mendeleev Rise, scanning electron microscope; **b** photomicrograph of the thin section with rounded quartz grains, with microfracture, in which chlorite-mica mixture develops (yellow arrows), continental coal deposits, sandstone, Permian, Anabar River, thin section with analyzer; **c** silty sandstone, quartz grains with different degree of roundness, with microfracture, in which chlorite-mica and sometimes kaolinite are determined, sample USO-4, Mendeleev Rise, thin section with analyzer; **d** fine-grained sandstone, quartz grains, subrounded, micro cracks with chlorite-mica are present, sample 626/2, Wrangel Island, Khishnikov River, thin section with analyzer; **e** silty sandstone, single quartz grain with a relic of microfracture, sample 400/2, Chukotka, Maly Anyuy River, thin section with analyzer

grains of this type are observed mainly in continental environments and are associated with eolian action (Fig. 14). During transportation, such grains crack and crumble, so their preservation is possible only at a short distance with the rapid burial and sediment lithification.

The number of quartz grains with microfractures from the Mendeleev Rise's samples is to 30% of all quartz grains. In the Triassic sandstones from Wrangel Island, the number of such quartz grains is 7–14%. In the Triassic sandstones from Chukotka, the amount of quartz grains with microfractures is no more than 2%. Thus, sandstones from the Mendeleev Rise are the closest to the continental deposits in this parameter.

Based on the analysis of the Th/Sc–Zr/Sc diagram for sample USO-4 is located on the border with the clinic (Fig. 9), which indicates that the sandstone components are not recycled and all genetic geochemical diagrams can be applied to the image. Provenance area for sample USO-4 (Fig. 13) suggests a complex of rocks close to the average composition of the continental crust (granodiorite).

Petrochemical parameters also indicate the most mature composition of rock from the Mendeleev Rise. In Pettijohn's classification diagram (Fig. 7), quartz arenites from the Mendeleev Rise differ from the Upper Triassic sandstones of Wrangel Island and Chukotka, which are in the field of lithic arenites. Older, Lower-Middle Triassic sandstones of Chukotka differ from the Mendeleev Rise sandstones even more, since they are in the field of lithic greywacke.

Sandstones from the Mendeleev Rise have the most mature composition, but they did not undergo intensive recycling. At the same time, the level of weathering in the provenance area, determined by the CIA index in sandstones, is very high, i.e. the area of erosion was for a long time in the zone of weathering. Persistent minerals in the rocks have been preserved, and only relics have remained of unstable ones, in particular, kaolinite replacing feldspars, and clay minerals that heal microfracture in detrital quartz, enclosed in carbonate cement.

5 Results of the Studies

Thus, in the Triassic deposits in the Chukotka-Wrangel-Mendeleev Rise line, there is a distinct trend in the change of deep-sea sediments with ever shallower ones with an ever more mature composition of rocks, which indicates a consistent approach to the continental source of detrital material. At the same time, the amount of quartz grains grown in continental environment increases in sandstones.

Position of this continental land is currently being established approximately, as evidenced by continuing discussions. However, the lithology and paleogeography of the Triassic deposits make it possible to clarify this situation. The Proto-Arctic Ocean, which was connected with the Paleo-Ural Ocean, had existed during the Paleozoic and before the beginning of the Late Jurassic. During the Permian-Triassic, the Proto-Arctic Ocean diminished in size as a result of the Paleo-Ural Ocean closure and collision of the Kara block with Siberia, and turned into the Pacific Bay (Laverov et al. 2013). Turbidites of Chukotka, Wrangel Island, and South Anyuy suture accumulated in its northern passive margin during the Triassic (Tuchkova 2011; Tuchkova et al. 2014). Sandstones of the Mendeleev Rise, occupying the most northern position, (in modern coordinates) are the shallowest facies. The presence of the northern provenance area is also confirmed by sedimentological observations (Tuchkova 2011; Tuchkova et al. 2014). These data contradict the notion of the Baltic as a source area (Miller et al. 2010, 2017).

U-Pb dating of detrital zircons in the Triassic sandstones from Wrangel Island shows a strong influence of the Paleozoic zircons with ages in the range 250–500 Ma in all the analyzed samples (Fig. 7). It is obvious that their source was the Paleozoic granitoids of the Caledonides and Ellesmerides. As mentioned above, in the age spectra of sandstones, an important role is played also by Precambrian detrital zircons.

Thus, there is no doubt today in the existence of the ancient continental block with a high standing during the Late Paleozoic–Early Mesozoic, as the source area of sediments in peripheral paleobasins such as Sverdrup and the marginal basins of the East Siberian Shelf. At the same time, questions about the age and spatial boundaries of this continental block are now being actively discussed.

6 Conclusions

1. Genesis of the Triassic quartz sandstones from the Shamshur Seamount in the northern part of the Mendeleev Rise occurred in coastal-marine settings close to the continental ones. In the Triassic terrigenous deposits of Wrangel Island and Chukotka southward, the paleogeographic conditions become more marine, with the formation of local prodelta and inter-delta sites; in the same direction, the petrographic composition of sandstones becomes more mature, without recycling.
2. Systematically analyzed from the south (from Chukotka) to the north (from Wrangel Island to the Mendeleev Rise) petrographic, geochemical, and geochronological data indicate the existence of a long-lived provenance area in the Central Arctic Uplifts area; the source is characterized by a long exposure, a high degree of weathering and the absence of significant tectonic rearrangements.
3. Source area for the Triassic sandstones of Eastern Chukotka was mainly Paleozoic rocks, as well as ancient Proterozoic granite and metamorphic rocks.

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