

Neoproterozoic Diamictites of the Middle Tianshan, Kyrgyzstan: Age, Depositional Environments and Provenance

D. V. Alexeiev^{a,b,*}, A. K. Khudoley^b, S. A. DuFrane^c, A. V. Kushnareva^b,
N. V. Bryanskiy^{d,e}, and A. A. Karimov^{d,e}

Presented by Academician K. E. Degtyarev April 27, 2023

Received April 27, 2023; revised May 15, 2023; accepted May 16, 2023

Abstract—The Upper Precambrian section in the Sandalash, Talas, and Chatkal ranges are studied to refine the age and genesis of Neoproterozoic diamictites of the Middle Tianshan. The results of detrital zircon dating show that diamictites were deposited in the Cryogenian and Ediacaran. The diamictites in the lower part of the Shorashu Formation comprise tillites, which were likely deposited at the end of the Cryogenian during the Marino glaciation (~640–635 Ma). In the upper part of the Shorashu Formation, the diamictites represent debris flows and grain flows associated with turbidites and, apparently, have nonglacial origin; their age is no older than the Early Ediacaran 616 ± 7 Ma. The pinching out of the Shorashu Formation to the north and the predominantly southerly directions of sediment transport in turbidites indicate that a non-depositional uplift located north of the basin. The distribution of detrital zircon ages in the studied samples are characterized by the main peaks within the ranges of 700–800 and 1800–1900 Ma and subordinate peaks at 2400–2500 Ma and are almost identical to the distributions of ages in the Proterozoic sedimentary rocks of the Tarim Craton. The comparison of the studied sequences with the sections of the Kuruktag Range in the northeastern Tarim Craton suggests that the diamictites of the lower part of the Shorashu Formation are analogs of the Tereeken tillite, which deposited at the end of the Cryogenian, whereas the slope facies of the upper part of the section are correlated with turbidites of the Zhamokti and Yukkengol formations of the early Ediacaran.

Keywords: detrital zircons, U–Pb dating, diamictites, Neoproterozoic, Middle Tianshan

DOI: 10.1134/S1028334X23601062

INTRODUCTION

Diamictites are terrigenous sedimentary rocks with unsorted clasts from small pebbles to boulders and blocks enclosed in a clayey or sandy matrix. The diamictites may comprise glacial sediments (moraines, ice-rafted sediments, etc.), as well as a broad range of rocks of nonglacial origin, e.g., continental and submarine debris flows, lahars, landslides, and olistostromes and, in some cases, weathering mantles and

impact breccias [1]. The glacial diamictites (tillites), which accumulated during the Late Precambrian global glaciations, are excellent markers for stratigraphic correlation due to their widespread occurrence in different continents [2]. The substantiation of the genesis and age of rocks, however, remains a necessary condition for the correct comparison of sections, the identification of glaciation epochs, and the reconstruction of sedimentary basins.

In Central and East Asia, the Neoproterozoic diamictites occur on Tarim and Yangtze cratons, as well as the southern part of the Siberian Craton and a series of Precambrian continental crustal blocks of the Central Asian Orogenic Belt (CAOB) [2, 3]. In the Ishim–Middle Tianshan Microcontinent (IMT) in the western part of the CAOB (Fig. 1, inset), diamictites extend for a distance of ~2000 km from the Ulu-tau Mountains of Central Kazakhstan to the basin of the Sarydjaz River in East Kyrgyzstan [4, 5]; however, in spite of widespread occurrence, their age was estimated only at a few points [6, 7]. To refine the age, genesis, and stratigraphic position of diamictites of the Middle Tianshan, we studied the Neoproterozoic sec-

^a Geological Institute, Russian Academy of Sciences, Moscow, 119017 Russia

^b St. Petersburg State University, St. Petersburg, 199034 Russia

^c Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada

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

^e Vinogradov Institute of Geochemistry, Siberian Branch, Russian Academy of Sciences, Irkutsk, 644033 Russia

*e-mail: dvalexeiv@mail.ru

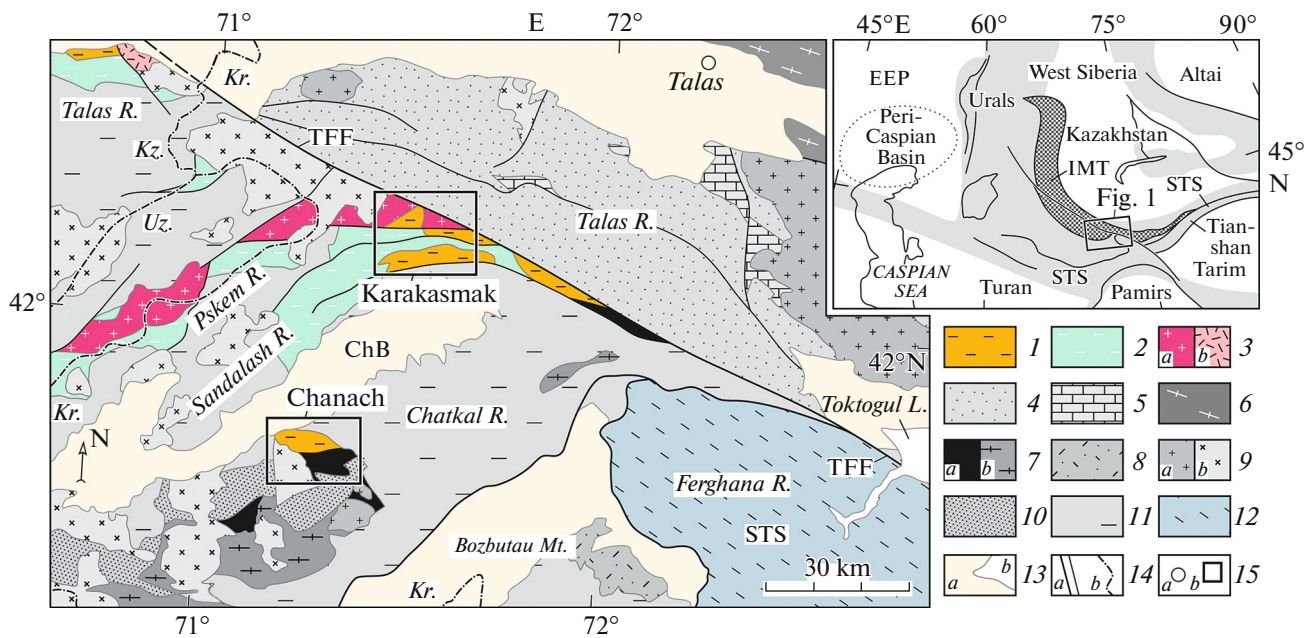


Fig. 1. Geological map of the region, modified after [8]. (1–3) Middle Tianshan: 1, Late Neoproterozoic siliciclastic strata, diamictites; 2, Cambrian and Ordovician shale, carbonate, chert, sandstone; 3 (a) Neoproterozoic granite and (b) felsic volcanic rocks; 4, 5, Karatau–Talas zone: 4, Early Neoproterozoic siliciclastic strata; 5, Cambrian and Ordovician carbonate; 6, North Tianshan, Mesoproterozoic schist and gneiss; 7 (a) Cambrian–Ordovician Karatek ophiolite complex and (b) Late Ordovician Kassansai metamorphic complex; 8, Middle to Late Ordovician volcanic rocks of the Chatkal–Atbashi arc; 9 (a) Ordovician and Silurian and (b) Devonian, Carboniferous, and Permian granitoids; 10, Silurian; 11, Devonian, Carboniferous, Permian; 12, South Tianshan; 13 (a) Mesozoic and Cenozoic (b) lakes; 14 (a) fault, (b) international boundary; 15 (a) town, (b) study areas. Inset: position of the region of study in the structure of the Ural–Mongolian belt. Abbreviations: ChB, Chatkal Basin; STS, South Tianshan; TFF, Talas–Ferghana Fault; Kr, Kyrgyzstan; Kz, Kazakhstan; Uz, Uzbekistan; IMT, Ishim–Middle Tianshan Microcontinent; EEP, East European Platform.

tions in the mountains framing the Chatkal Basin: in Sandalash, Talas, and Chatkal ranges (Fig. 1).

STRATIGRAPHY

The diamictites in the region studied occur in the Shorashu Formation [9]. Sections of two types are distinguished in the northern part of the region in the basin of the Karakasmak River (Fig. 1). In the northern band of outcrops, in the watershed area of the Sandalash and Talas ranges, the sections have a reduced thickness. The base of the section is composed of granites of the Beshtor Complex, which yielded U–Pb (SHRIMP) age of 815 ± 6 Ma [10]. The granites are overlain with erosional contact and basal conglomerates by siliciclastic sediments, subalkaline and alkaline volcanic rocks of various compositions, and tuffs of the Mursash Formation (~100 m), which transit upward to diamictites (~20 m) and turbidites of the Shorashu Formation (Fig. 2-1) [4, 11].

The Precambrian sections have higher thickness to the south, in the middle reaches of the Karakasmak River and adjacent valleys. The base of the section is unexposed. The lower part of the section consists of sandstones and shales with horizons of gravelites and conglomerates identified as the Uzunbulak Formation

[9]. The turbidite members occur in its upper part. The total thickness of the formation is >500 m [4] (Fig. 2-2). These change stratigraphically upward to diamictites of the lower subformation of the Shorashu Formation, also referred to as the Ayakterek Formation. The diamictites are massive dark gray and black mostly small-pebbel matrix-supported conglomerates with single boulders and blocks up to 0.5–1.5 m in size (Fig. 2a). They compose homogeneous members with variable thickness from 10–20 to 300 m or lenticular bodies intercalated with sandstones. The pebbles consist mainly of granitoids, gneisses, sandstones, and carbonate rocks. Some fragments have a wedge and bullet-like shapes and striation on surfaces, which imply glacial origin [4].

The upper part of the Shorashu Formation consists of turbidites with a total thickness of >500–600 m. The turbidites are characterized by graded bedding, the A-B, A-B-C and A-C Bouma sequences, erosional soles of turbidite rhythms with channel forms and numerous flute casts (Fig. 2c). They also contain thick layers of massive and graded sandstones and lenses of matrix-supported conglomerates, which represent grain flow and debris flow strata, respectively. The matrix-supported conglomerates contain rare,

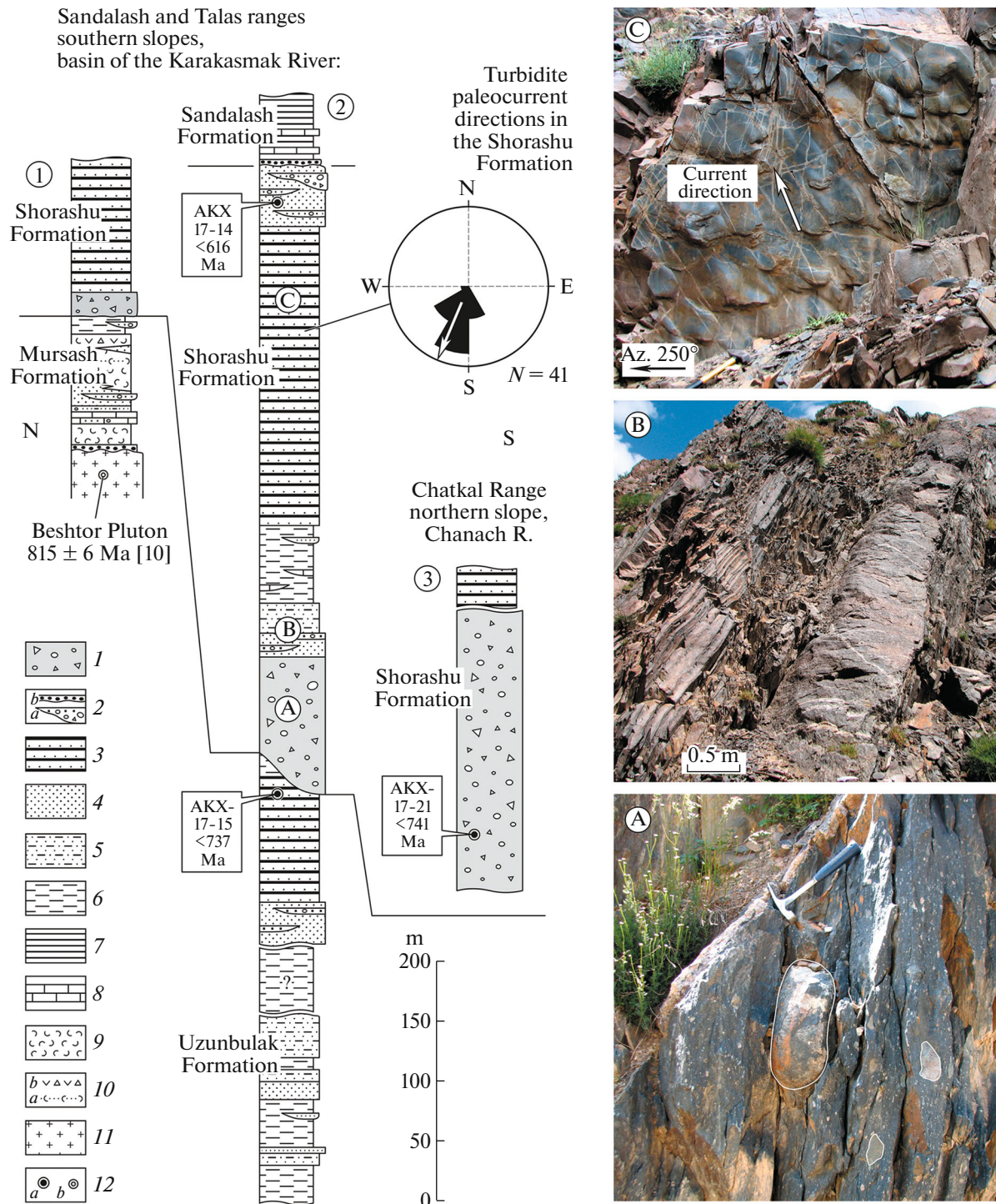


Fig. 2. Stratigraphic sections of the Neoproterozoic strata of the studied region, using data from [4]. (1) Diamictite with glacial clasts: tillite; (2) (a) Matrix-supported debris-flow conglomerate and (b) fluvial conglomerate; (3) turbidite; (4) sandstone; (5) sandstone, siltstone; (6) siltstone, mudstone; (7) carbonaceous and siliceous shales; (8) limestone; (9) tuff; (10) (a) tuff sandstone, (b) lava breccia; (11) granite of the Beshtor Complex; (12) dated samples: (a) this paper, (b) data of other researchers. Field photos of outcrops of the Shorashu Formation in the Karakasmak River: (A) diamictite with large boulders in the lower part of the formation, (B) grain flows and turbidites in the middle part of the section, (C) sole marks: flute casts in turbidites of the upper part of the formation. Letters in circles show the position of images in column 2.

usually well-rounded pebbles and single boulders up to 30–40 cm in size. No angular clasts with glacial striation are found at this level.

The upper boundary of the Shorashu Formation follows the base of carbonates and siliceous and carbonaceous shales of the overlying Sandalash Formation,

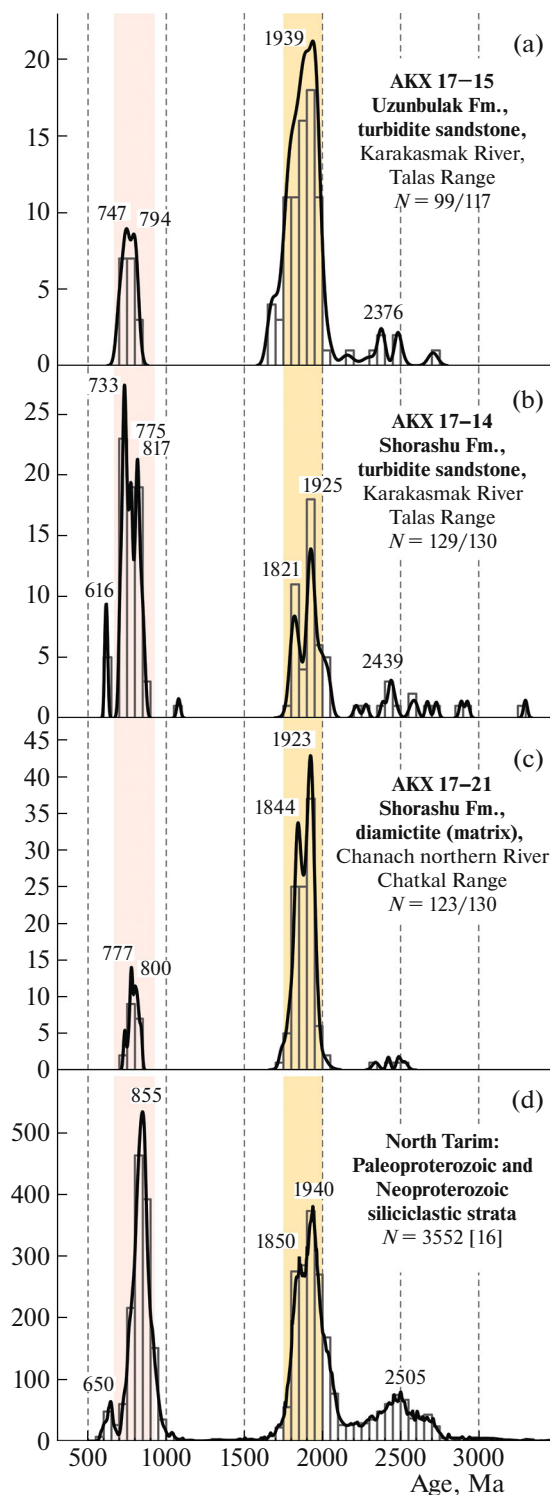


Fig. 3. Probability density plots and histograms of the distribution of the ages of detrital zircons in rocks of the (a) Uzunbulak and (b, c) Shorashu formations of the Middle Tianshan (this paper) and (d) Proterozoic strata of North Tarim [16]. Numbers indicate ages of peaks calculated in the Age Pick program. N , number of the analysis plotted in diagram and the total amount of dated grains in the sample.

which contains the Lower Cambrian fossils [9]. A thin bed of the small-pebble fluvial conglomerate, which locally occurs in the base of the Sandalash Formation, indicates a stratigraphic hiatus between the Shorashu and Sandalash formations. The Shorashu Formation pinches out to the northwest, and the Sandalash Formation in the Pskem Range (Fig. 1) overlies volcanic rocks comparable with rocks of the Mursash Formation [4].

In the southern part of the region (on the northern slopes of the Chatkal Range in the valley of the Chanach River) (Fig. 1), the Shorashu Formation compose a tectonic block, which has fault contacts with conglomerates and sandstones of unidentified age in the north and with the Cambrian–Ordovician Karaterek ophiolite massif in the south [12]. The diamictites are the small-pebble matrix-supported conglomerates with relatively rare pebbles and single boulders dispersed in black massive silty mudstone. The thickness of the diamictite unit reaches a few hundred meters but cannot precisely be measured because of intensive deformation and shearing of the rocks and lack of layering. Similarly to the area of the Karakasmak River, the upper part of the Shorashu Formation consists of turbidites [4] (Fig. 2-3).

According to previous geochronological data, the maximum age of the Shorashu Formation is ~815 Ma based on the age of the underlying granites [10] and the youngest detrital zircons dated in the lower part of the section [7]. The minimum age of the formation is determined by the finds of Lower Cambrian fossils in the overlying Sandalash Formation [9].

MATERIALS AND METHODS

Three samples were taken for the study of detrital zircons to substantiate the age of diamictites: two samples in the valley of the Karakasmak River and one sample in the valley of the Chanach River (Fig. 1). Sample AKX-17-15 ($42^{\circ}08'09.6''$ N, $71^{\circ}33'11.4''$ E) from the valley of the Karakasmak River was collected at the top of the Uzunbulak Formation directly below the diamictites, and sample AKX-17-14 ($42^{\circ}09'00.2''$ N, $71^{\circ}32'00.7''$ E) was taken in the upper horizons of the Shorashu Formation. Both samples are medium- to coarse-grained polymictic turbidite sandstones (Fig. 2-2). Sample AKX-17-21 ($41^{\circ}46'44.3''$ N, $71^{\circ}17'43.5''$ E), taken in the valley of the Chanach River, is a massive small- to medium-grained sandstone from the matrix of small-pebble diamictite in the lower part of the Shorashu Formation (Fig. 2-3).

The samples were treated and the zircons were extracted at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences (St. Petersburg, Russia), following the standard method using heavy liquids. The U–Pb age of zircons was determined using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The zir-

cons from samples AKX-17-14 and AKX-17-21 (130 grains in each) were analyzed at the Canadian Center for Isotopic Microanalysis at the University of Alberta (Edmonton, Canada) on an ICAP-Q mass spectrometer equipped with a New Wave UP-213 laser. The zircons from sample AKX-17-15 (117 grains) were analyzed at the Center for Collective Use Geodynamics and Geochronology, Institute of the Earth Crust, Siberian Branch, Russian Academy of Sciences (Irkutsk), on an Agilent 7900 mass spectrometer equipped with an Analyte Excite excimer laser. Only results with a discordance of <10% and not corrected for common lead were used in further analysis and shown in diagrams. The age values were calculated by the $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{206}\text{Pb}/^{238}\text{U}$ ratios for zircons with ages of more and less than 1 Ga, respectively. The results of dating are presented on probability density plots (PDP) (Figs. 3a, 3b, 3c), which also show the ages of all statistically meaningful peaks calculated in the AgePick program [13] and formed by three or more grains. The maximum depositional age (MDA) was estimated by the age of the youngest peak and the average age value of the youngest grains overlapping within the error of 2σ [14].

The ages of 99 grains in sample AKX-17-15 from the top of the Uzunbulak Formation plotted in Fig. 3a vary from 701 ± 40 to 2707 ± 63 Ma and form three groups: (i) Early Neoproterozoic 701–823 Ma (17 grains) with peaks at 747 and 794 Ma, (ii) Late Paleoproterozoic 1661–2040 Ma (75 grains) with a dominant peak at 1939 Ma, and (iii) Early Paleoproterozoic 2303–2385 Ma (three grains) with a peak at 2376 Ma. Single grains beyond the groups have the age of 2159, 2481, 2493, and 2707 Ma. The age of the youngest peak and the average age of the youngest grains coincide within the error and are ~ 747 and 736 ± 16 Ma, respectively.

The age of 129 grains of sample AKX-17-14 from the upper part of the Shorashu Formation plotted in Fig. 3b vary from 609 ± 13 to 3298 ± 25 Ma and form four groups: (i) Ediacaran 609–623 Ma (five grains) with a peak at 616 Ma, (ii) Early Neoproterozoic 703–864 Ma (64 grains) with peaks at 733, 775, and 817 Ma, (iii) Late Paleoproterozoic 1794–2044 Ma (45 grains) with peaks at 1821 and 1925 Ma, and (iv) Archean–Paleoproterozoic 2386–2597 Ma (seven grains) with a peak at 2439 Ma. Single grains have ages of 1080, 2216, 2279, 2671, 2728, 2889, 2927, and 3298 Ma. The age of the youngest peak and the average age of the youngest grains coinciding in this case determine the MDA as the early Ediacaran 616 ± 7 Ma.

The ages of 123 grains of sample AKX-17-21 from the matrix of diamictites in the lower part of the Shorashu Formation vary from 731 ± 14 to 2525 ± 40 Ma and form two groups: (i) Early Neoproterozoic 731–841 Ma (18 grains) with peaks at 777 and 800 Ma and (ii) Late Paleoproterozoic 1736–2019 Ma (101 grains) with peaks at 1844 and 1923 Ma. Four grains have ages of 2339, 2422, 2486, and 2525 Ma (Fig. 3c). The aver-

age age of the three youngest grains is 741 ± 32 Ma, and the age of the youngest peak is 777 Ma.

DISCUSSION

The abundance of turbidites in the sections, which host diamictites in the region studied (Fig. 2), indicates the slope depositional environments. The diamictites in the lower part of the Shorashu Formation contain clasts of wedge and bullet-like shapes with typical striations on the surface indicating their glacial origin [4]. The almost complete absence of stratification and a significant thickness of members reaching several hundreds of meters suggest that these sediments, at least in part, may represent subglacial or marginal moraines deposited in subaqueous environments. However, sediments with a similar composition can also be formed by debris flows that have re-deposited clastic material of glacial origin [1, 15]. Taking into account the widespread occurrence of slope facies in the sections studied, the second interpretation seems more likely. In the upper part of the Shorashu Formation (sample AKX-17-14), the diamictites represent typical deposits of sediment-gravity flow i.e. debris flow, localized in a well-stratified turbidite sequence. Their glacial origin is not supported.

A decrease in the thickness of the Shorashu Formation to the north up to complete pinching out in the Pskem Range (Fig. 1) [4] suggests that the sedimentary basin was bordered by a non-depositional uplift in the north. The regional slope to the south is also indicated by turbidite paleocurrent directions suggesting the southward transportation of clastic material (the average azimuth is SSW $\sim 200^\circ$, Fig. 2). The erosion area was likely located within the Middle Tianshan to the north from the Pskem Range (Fig. 1). It also could have included the Karatau–Talas zone, where Cryogenian and Ediacaran sediments are absent, and the uppermost Ediacaran and Cambrian strata transgressively overlay the Tonian rocks [16].

The results of detrital zircon dating show that tillites in the lower part of the Shorashu Formation have an age not older than 740 Ma (samples AKX-17-15, AKX-17-21), and the age of turbidites in the upper part of the formation (sample AKX-17-14) is not older than the early Ediacaran 616 ± 7 Ma (Fig. 3). The high sedimentation rates typical of slope sediments suggest that the deposition of turbidites ~ 500 – 600 m thick, which constitute the upper part of the formation, could have occurred during the period from a few to 10–20 million years. In this case, the age of tillites in the base of the Shorashu Formation may correspond to the end of Cryogenian and the Marino glaciation ~ 640 – 635 Ma.

The distribution of detrital zircon ages in the studied samples have similar main peaks at ~ 700 – 800 and 1800 – 1900 Ma (Figs. 3a–3c) indicating a common source of detrital material. Slightly different quantita-

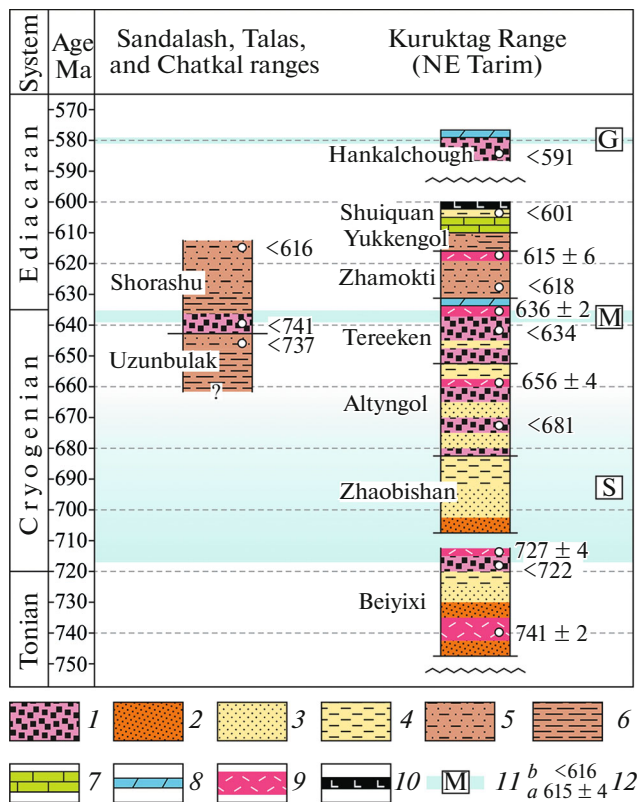


Fig. 4. Correlation of the Neoproterozoic sections of the Middle Tianshan and the Kuruktag Range in the northeastern Tarim. 1, Diamictite; 2, clastic continental facies; 3, 4, shallow-marine facies: 3, sandstone; 4, siltstone, mudstone; 5, 6, deep-water facies: 5, sandstone, siltstone, turbidite; 6, siltstone, mudstone; 7, limestone; 8, cap dolomite; 9, volcanic rocks of mixed composition; 10, basalt; 11, glaciation epochs: S, Sturtian; M, Marinoan; G, Gaskiers; 12, U–Pb age of zircons from (a) volcanic and (b) sedimentary rocks. The section of the Neoproterozoic rocks of the Kuruktag Range after [16, 17, 19, 20].

tive ratios of Neoproterozoic and Paleoproterozoic zircons in different samples can reflect either or both the local variations in provenances and/or mixing of grains of various ages in various proportions during transportation. The almost complete absence of ages in the range of ~900–1600 Ma is the most distinct feature of the obtained age spectra. This reflects the lack of magmatism in the provenance during the entire Mesoproterozoic and, in particular, indicates the absence of sediment transport from Grenville orogens, which contain abundant igneous complexes with an age of ~1000–1300 Ma.

An almost identical distribution of ages of detrital zircons is observed in the Neoproterozoic sedimentary rocks of the Karatau–Talas Zone (Fig. 1), Bolshoi Karatau Range, and Baikonur Synclinorium, which are located to the north of the study area, as well as in the North Tarim (Fig. 3d) and northwestern areas of the Yangtze Craton [16]. The significant similarity of geological history suggests that these areas and Middle

Tianshan represented a single continental block in the Late Precambrian. The Cryogenian and Ediacaran sediments accumulated in large linear troughs, probably, of riftogenic origin [16]. The comparison of the studied sequences with the Neoproterozoic sequences of the Kuruktag Range in northeastern Tarim [17, 18] shows that the glacial sediments of the lower part of the Shorashu Formation are likely analogs of Tereeken tillite, which accumulated during the Marino glaciation, whereas the slope facies of the upper part of the section are correlated with turbidites of the early Ediacaran Zhamokti and Yukkengol formations [17, 19] (Fig. 4).

ACKNOWLEDGMENTS

We are grateful to A.K. Rybin Director of the Scientific Station of the Russian Academy of Sciences in Bishkek and colleagues from this station for assistance in organization of field work in Tianshan.

FUNDING

This work was supported by the Russian Science Foundation, project no. 23-27-00126.

REFERENCES

1. N. Eyles and M. Lazorek, in *Reference Module in Earth Systems and Environmental Sciences* (Elsevier, 2014), pp. 1–12.
2. N. M. Chumakov, *Transactions of the Geological Institute RAS* (Geos, Moscow, 2015), Issue 611 [in Russian].
3. *Precambrian Geology of China*, Ed. by M. G. Zhai (Springer-Verlag, Berlin-Heidelberg, 2015).
4. V. G. Korolev and R. A. Maksumova, *Precambrian Tillites and Tilloids of the Tianshan* (Ilim, Frunze, 1984) [in Russian].
5. K. E. Degtyarev, A. S. Yakubchuk, A. A. Tretyakov, A. B. Kotov, and V. P. Kovach, *Gondwana Res.* **47**, 44–75 (2017).
6. N. A. Kanygina, E. F. Letnikova, K. E. Degtyarev, A. A. Tretyakov, F. I. Zhimulev, and A. I. Proshenkin, *Dokl. Earth Sci.* **483** (1), 1384–1387 (2018).
7. Y. Rojas-Agramonte, A. Kröner, D. V. Alexeiev, T. Jeffreys, A. K. Khudoley, J. Wong, H. Geng, L. Shu, S. A. Semiletkin, A. V. Mikolaichuk, V. V. Kiselev, J. Yang, and R. Seltmann, *Gondwana Res.* **26** (3-4), 957–974 (2014).
8. *The 1 : 500 000 Geological Map of the Kirgiz Soviet Socialist Republic*, Ed. by S. A. Igemberdiev (Karpinsky Russian Geological Research Institute, Leningrad, 1982).
9. A. V. Djenchuraeva, I. L. Zakharov, Yu. V. Zhukov, O. F. Getman, R. A. Maksumova, A. V. Neevin, L. P. Nogaeva, and R. E. Rinenberg, *Stratified Formations of Kyrgyzstan* (Kyrgyz-Russian Slavic Univ., Bishkek, 2015) [in Russian].

10. D. Konopelko, R. Klemd, S. V. Petrov, F. Apayarov, B. Nazaraliev, O. Vokueva, A. Scherstén, and S. Sergeev, *Ore Geol. Rev.* **86**, 537–547 (2017).
11. K. S. Sagyndykov, *Izv. Akad. Nauk Kirg. SSR*, No. 1, 23–29 (1976).
12. E. Hegner, D. V. Alexeiev, N. Messling, T. Yu. Tolmacheva, and M. Willbold, *Lithos* **410–411**, 106576 (2022).
13. G. Gehrels, in *Tectonics of Sedimentary Basins: Recent Advances*, Ed. by C. Busby and A. Azor (Blackwell Publ., 2012), Chapter 2, pp. 47–62.
14. W. R. Dickinson and G. E. Gehrels, *Earth Planet. Sci. Lett.* **288**, 115–125 (2009).
15. G. V. Middleton and M. A. Hampton, in *Turbidites and Deep-Water Sedimentation. SEPM Pacific Section Short Course*, Ed. by G. V. Middleton and A. H. Bouma (Anaheim, CA, 1973), pp. 1–38.
16. D. V. Alexeiev, A. K. Khudoley, S. A. DuFrane, S. Glorie, I. A. Vishnevskaya, S. A. Semiletkin, and E. F. Letnikova, *Gondwana Res.* **119**, 313–340 (2023).
17. R. Ren, S. W. Guan, S. C. Zhang, L. Wu, and H. Y. Zhang, *Precambrian Res.* **339**, 105612 (2020).
18. G. Y. Zhu, Z. Y. Chen, W. Y. Chen, H. H. Yan, and P. H. Zhang, *Precambrian Res.* **352**, 106013 (2021).
19. B. Xu, S. H. Xiao, H. B. Zou, Y. Chen, Z. X. Li, B. Song, D. Y. Liu, C. M. Zhou, and X. L. Yuan, *Precambrian Res.* **168**, 247–258 (2009).
20. J. W. He, W. B. Zhu, and R. F. Ge, *Precambrian Res.* **241**, 44–60 (2014).

Translated by I. Melekestseva