Origin of coarse-grained (> 1 cm) clasts from the Mendeleev Ridge area (Central Arctic Ocean)

A. A. Krylov[1,2,3], *J. Matthiessen*[4], *S.-I. Nam*[5], *R. Stein*[4,6], *E. A. Bazhenova*[2], *E. S. Mirolubova*[1], *E. A. Gusev*[1], *S. A. Malyshev*[1,3], *A. S. Makarov*[3]

[1] VNIIOkeangeologia,
1, Angliyskiy pr., St. Petersburg, 190121, Russian Federation
[2] St. Petersburg State University,
7–9, Universitetskaya nab., St. Petersburg, 199034, Russian Federation
[3] Arctic and Antarctic Research Institute,
38, ul. Beringa, St. Petersburg, 199397, Russian Federation
[4] Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research,
12, Am Handelshafen, Bremerhaven, 27570, Germany
[5] Korea Polar Research Institute, Division of Polar Paleoenvironment,
26, Songdomirae-ro, Incheon, 21990, Republic of Korea
[6] MARUM — Center for Marine Environmental Sciences
and Faculty of Geosciences, University of Bremen,
8, Leobener str., Bremen, D-28359, Germany

For citation: Krylov, A. A., Matthiessen, J., Nam, S.-I., Stein, R., Bazhenova, E. A., Mirolubova, E. S., Gusev, E. A., Malyshev, S. A., Makarov, A. S. (2020). Origin of the coarse-grained (> 1 cm) clasts from the Mendeleev Ridge area (Central Arctic Ocean). *Vestnik of Saint Petersburg University. Earth Sciences*, 65 (4), 795–809. https://doi.org/10.21638/spbu07.2020.411 (In Russian)

The morphometric and petrographic characteristics of coarse-grained clasts (> 1 cm) sampled from sediments of the Amerasian Basin, Central Arctic Ocean, were studied. Most of the clasts are represented by dolomites (46.4 %), sandstones (22.8 %) and limestones (19.8 %); the amount of other rock fragments (chert, shale, igneous) is about 10 %. A variety of lithological types were identified among the studied rock fragments. Limestones and dolomitic limestones often contain fragments of fauna. The majority of clasts are poorly rounded and characterized by a wide variety of shapes. More than 50 % of the studied clasts have a size of 1–2 cm, 25 % are 2–3 cm, and larger clasts only occur in insignificant amounts. Geophysical surveys across the sampling sites showed a lack of bedrock outcrops, so the studied coarse-grained clasts are not of local origin. It is concluded that they were predominantly delivered from the Canadian Arctic Archipelago (likely from the platform area, e. g., Victoria Island), mainly due to iceberg rafting during deglaciation periods. The maximum possible contribution of clasts from Siberian sources is less than 23 %. The distribution of coarse-grained clasts argues for the existence of quite a stable ice drift path in the past, which is similar to the modern Beaufort Gyre.

Keywords: Mendeleev Ridge, Arctic Ocean, dropstones, iceberg rafting.

1. Introduction

The quantification and characterization of coarse-grained (psephitic) clasts (> 1 cm) as carried out within this study is an important approach for both understanding the geology of the Arctic Ocean and performing paleoceanographic reconstructions in terms of ice drift and ice sheet history. Hence, criteria that can be used to reconstruct the clasts' origin/source are needed. These rock fragments can be of local origin or transported with sea ice and/or icebergs from the surrounding continents/islands into the Arctic Ocean. A similar approach, but based on the coarse fraction > 2 mm, has been successfully used by Phillips and Grantz (2001).

Direct observations and sampling of coarse-grained clasts from sea ice and icebergs in the Central Arctic Ocean (e. g., Clark and Hanson, 1983; Lisitzin, 2002; Shevchenko et al., 2003; Stein, 2008; Melnikov and Zezina, 2010) confirmed the importance of sea ice/iceberg transport of coarse material. Modern sea ice carries mostly fine silty-clay particles (e. g., Reimnitz et al., 1993; Nuernberg et al., 1994; Lisitzin, 2002; Dethleff, 2005; Stein, 2008; Vogt and Knies, 2008; Dethleff and Kuhlmann, 2010; Darby et al., 2011), which are massively released in the area of the Fram Strait. For the whole Central Arctic Ocean, formation of about 23 % of recent (late Holocene) sediments have probably resulted from sea-ice transport (Stein, 2008). However, in the geological past, during periods of glaciation and deglaciation, the situation changed dramatically. Climate cooling resulted in the formation of ice caps on the Barents-Kara shelf, the Canadian Arctic Archipelago, and possibly on the Chukchi Plateau and on the East Siberian shelf (e. g., Niessen et al., 2013; Jakobsson et al., 2014). The dimensions of these ice caps varied in different periods and are still debated (e. g., Gusev et al., 2013; 2017; Jakobsson et al., 2014). During late Quaternary glaciations, the Arctic Ocean was covered with massive pack ice (Jakobsson et al., 2016), which led to a general decrease in sedimentation rates (e. g., Nørgaard-Pedersen et al., 2003; Polyak et al., 2009). The decay of ice sheets during the subsequent deglaciations were accompanied by calving of numerous icebergs that transported coarse-grained material to the Central Arctic Ocean (e. g., Spielhagen et al., 2004; Darby and Zimmerman, 2008; Stein, 2008; Polyak et al., 2010; Stein et al., 2010; Taldenkova et al., 2010; Krylov et al., 2011; Cronin et al., 2013; Kaparulina et al., 2016; Dong et al., 2017).

Results of the Integrated Ocean Drilling Program's (IODP) drilling of the Lomonosov Ridge close to the North Pole revealed that seasonal sea ice began to transport terrigenous material to the Central Arctic Ocean in the Middle Eocene at about 46.3 Ma (e. g., St. John, 2008). A consensus on the time of the first occurrence of perennial sea ice, however, has not been reached yet. Based on mineralogical proxies it has been proposed that perennial ice already started to occur in the middle Miocene at about 13 Ma (Krylov et al., 2008; 2018) or even much earlier, i. e., in the Middle Eocene (Darby, 2014). Micropaleontological and organic-geochemical proxy data (Matthiessen et al., 2009; Stein et al., 2014; 2016) as well as modeling data (Tremblay et al., 2015), indicate a seasonal sea-ice coverage that was still predominant during these time intervals. Thus, additional studies are still needed to solve this discrepancy.

On the other hand, some studies provide evidence for a local origin of rock fragments in some areas of the Arctic Ocean including the local elevation "Shamshura" (formerly called "RV Akademik Fedorov") on the northern Mendeleev Ridge (Kabankov et al., 2004), and the western slope of the Geophysicists Spur at the Lomonosov Ridge (Rekant et al., 2012; 2019; Nikolaev et al., 2013). Exposed bedrock was found in a number of scarps surveyed on the Mendeleev Ridge during the expedition Arctic-2012 (Morozov et al., 2013; Gusev, 2014; Gusev et al., 2014; Kossovaya et al., 2018) and in later sampling by a submarine (Skolotnev et al., 2019).

The purpose of this paper is to describe the petrographic and morphological characteristics of coarse-grained clasts (> 1 cm) sampled during the expeditions of RV "Polarstern" ARK-XXIII/3 (2008) and ARK-XXVI-3 (2011) (Jokat, 2009; Schauer, 2012). The materials obtained in the TRANSARKTIKA-2019 project were also used (Frolov et al., 2019). Sub-bottom profiling data collected by the PARASOUND system (DS III- P70, 4 kHz) showed the absence of bedrock outcrops in the vicinity of sampling sites (Niessen and Matthiessen, 2009; Matthiessen and Kollaske, 2012; Boggild et al., 2020), which suggests that the studied coarse clasts were delivered with sea ice and/or icebergs. Most of the seismic profiles crossing the Alpha and Mendeleev Ridges show undisturbed sediment accumulation at the coring sites, whereas seafloor erosion has a local distribution (Bruvoll et al., 2010; Hegewald and Jokat, 2013; Weigelt et al., 2014). Indeed, in the central part of the Alpha Ridge the thickness of sediment varies from 0.5 to 1.2 km, and on the Mendeleev Ridge — between ~0.6–0.8 km at the elevations and up to ~1.8 km in grabens (Bruvoll et al., 2010). The uppermost 200 meters of deposits have largely conformable acoustic stratification (e. g., Bruvoll et al., 2010). Thus, the studied clasts can be considered as reference material of sea ice/iceberg rafting and we can identify them as dropstones. In this regard, it is important to investigate the petrographic composition of the dropstones, their morphometric characteristics (roundness and shape) and to assess these parameters for revealing the origin of the rocks. This paper fills a gap in the study of morphometric characteristics of large-sized clasts in the Central Arctic Ocean, as these data are virtually absent in previous publications.

2. Materials and methods

In total, 535 clasts larger than 1 cm were collected in the Barrow Strait between the Somerset and Devon islands (PS72/287), in the Canada Basin (PS72/289, 291, 393), on the Chukchi Abyssal Plain (PS72/340), on the Mendeleev Ridge (PS72/341, 342, 396, 399, 404, 408, 410, 413, 418, 422, PS78/238, 241), the Alpha Ridge (PS78/231), the Arlis Plateau (PS72/343), the slope of the East Siberian Sea (PS72/344), the Mendeleev Abyssal Plain (PS72/392), the Makarov Basin (PS72/430), the slopes of the southern part of the Lomonosov Ridge (PS72/438) and the Gakkel Ridge (PS72/471) (Fig. 1). The majority of samples were obtained with a Kastenlot and giant box corer. Several sites were also cored with a gravity corer and multicorer.

Rock fragments were selected from the box corer by washing sediments through a sieve with a mesh size of 1 cm. Samples from the Kastenlot, gravity corer and multicorer were taken during the visual lithological description. The clasts larger than 1 cm were chosen to simplify the visual determination of the rock types, as well as the preparation of thin sections.

All clasts from the giant box corers (~0–40 cm core depth) were combined into one sample. The clasts accumulated from Marine Isotope Stages (MIS) 1–2 to 1–4/5a, depending on the sedimentation rates at the coring site (Stein et al., 2010; Jang et al., 2013), which increase towards the shelves (e. g., Polyak et al., 2009; Stein et al., 2010; Levitan, 2015). Samples from Kastenlot and gravity core sections combine intervals up to 8 MIS at the southern sites and up to around 16 MIS on the northern sites, based on a still preliminary age model (Stein et al., 2010).

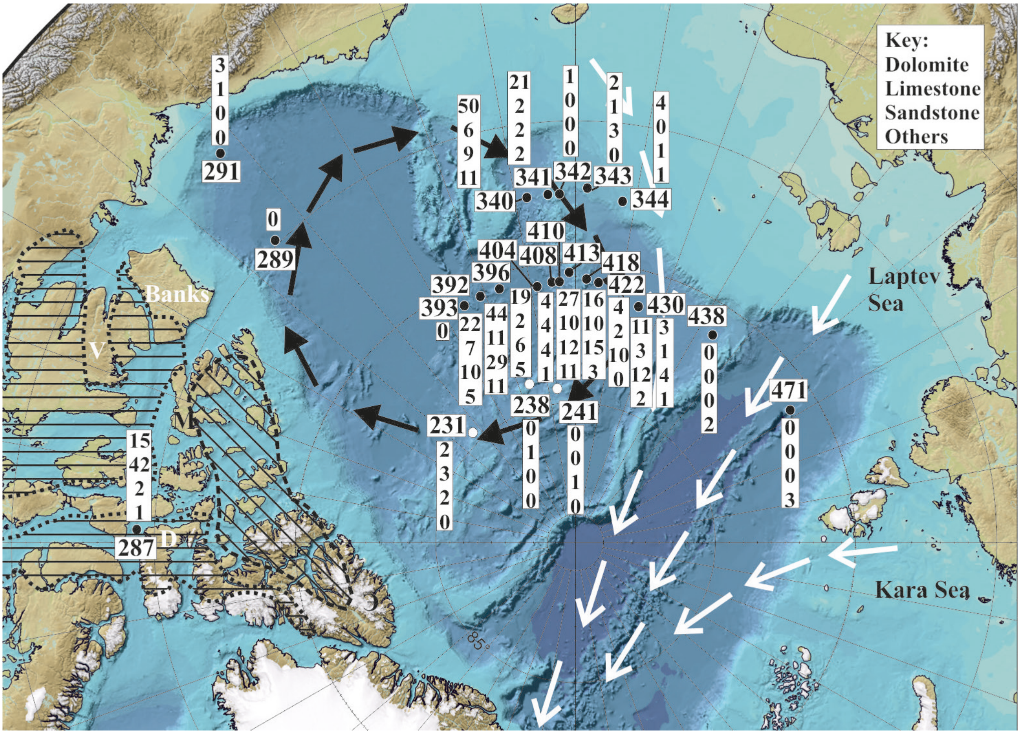

Fig. 1. Location of the coring sites during expeditions ARK-XXVII/3 (black dots) and ARK-XX-VI-3 (white dots) and petrographic composition of sampled large-sized rock fragments.

Inside the small white rectangles, station numbers are shown. Arrows — the main ice drift systems: black — Beaufort Gyre, white — Trans Polar. In the Canadian Arctic Archipelago Sverdrup Basin is shaded by oblique lines, and the Arctic Paleozoic platform by horizontal lines. Bathymetry IBCAO (Jakobsson et al., 2008). V — Victoria Island, D — Devon Island

The petrographic composition of the samples was determined both visually and using thin sections.

The shape (sphericity) of the clasts was determined by the classical Zingg method (Zingg, 1935). Initially, the sizes of the three major mutually perpendicular axes were measured. Then the degree of elongation and the degree of flattening were calculated using the ratios of **mid**dle axis (mid) to **max**imum axis (max) and **s**hort (s) to **mid**dle (mid) axis, respectively. These parameters allowed the identification of the four shape classes: 1) discoid/oblate — mid/max > 0.66, s/mid < 0.66; 2) equant — mid/max > 0.66, s/mid > 0.66; 3) bladed — mid/max < 0.66, s/mid < 0.66; and 4) rod/prolate — mid/max < 0.66, s/mid > 0.66.

Special charts linked to the well-known coefficients of Wadell and Khabakov helped to determine the roundness of clasts visually (Khabakov, 1962). Non-rounded dropstones are characterized by the minimum values of the abovementioned coefficients (0.11–0.20 and 0, respectively), whereas perfectly rounded dropstones are characterized by the maximum values (0.81–0.90 and 4, respectively). Angular (0.21–0.40 and 1, respectively), semi-rounded (0.41–0.60 and 2, respectively), and well-rounded (0.61–0.80 and 3, respectively) dropstones have intermediate values of coefficients.

3. Results

Large sea ice/iceberg-rafted material prevails on the ridges rather than in the basins due to lower sedimentation rates at submarine elevations and deposition of mass flows (e. g., turbidites) in the deeper areas (e. g., Grantz et al., 1996; Krylov et al., 2011).

When considering the petrographic composition of all dropstones sampled (Table 1), a strong predominance of carbonates (dolomite + limestone = 66.2 %) is obvious. Most of them are represented by dolomites (average value of 46.4 %, Table 1), with their amounts decreasing towards the Eurasian Basin (Fig. 1). Sediments retrieved locally in the Barrow Strait between the Somerset and Devon islands (site PS72/287, Fig. 1), contain mainly limestones (70 %) with a total amount of carbonate rocks (including dolomites) of 95 %. The high average limestone content in Table 1 (19.8 %) was obtained due to the very high limestone number at only one site (PS72/287; Fig. 1). The following types can be distinguished among the dolomites: 1) micritic dolomites, sometimes silicified, in some cases containing up to 30 % silt and sand grains; 2) fine stromatolithic dolomite with a biogenic-layered structure; 3) medium-grained dolomites with crystals of clear rhomboid shape. Limestones and dolomitic limestones, as a rule, contain fragments of fauna: ostracods, brachiopods, fragments of crinoids, trilobites, corals fragments, bryozoans and gastropods.

Terrigenous clastic rocks are also common in the studied samples (22.8 %, mainly sandstones and a few siltstones). They include quartzitic sandstones with a granoblastic texture and sandstones with various composition of grains and cement.

The amount of other types of rocks is just over 10 %, so they do not play a significant role in the overall composition (Table 1). Admixture of igneous rocks is represented by dolerites, basalts, gabbro, granodiorites and granite.

Important results were obtained by separately examining the samples from the subsurface sediments (0–40 cm) and from the deeper Kastenlot and gravity core sections. In both cases carbonates (dolomites) predominate. However, a slight enrichment of the sections with dolomites (55.4 % vs 42.3 %) and cherts (6.0 % vs 1.1 %), and depletion with limestone (12.0 % vs 23.3 %) and sandstones (18.1 % vs 25.2 %) is noticeable. The petrographic composition of clasts from the northern (sites 392, 396, 404, 408, 413, 418, 422) and southern (sites 340, 341, 342, 343, 344) transects across the Mendeleev Ridge (Fig. 1) is slightly different, due to a larger distance from the shoreline and lower sedimentation rates of the northern profile: deposits in the south are significantly enriched in dolomites (67.2 % vs 44.0 %) and depleted in terrigenous rocks (12.9 % vs 30.2 %). It is important to note that the petrographic assemblages of the dropstones from the "subsurface" (Box Corer) samples are similar to those of the > 2 mm clasts collected in the Amerasian Basin (Phillips and Grantz, 2001).

The overwhelming majority of the investigated clasts are non- or poorly-rounded (0–1 point according to the Khabakov scale (Fig. 2) and 0.24 according to the average value of the Wadell coefficient (Table 1)). It is important to note that among the dolomites, non-rounded clasts (Khabakov's class 0) predominate (Fig. 2). However, analysis of the average values shows that the least roundness, expectedly, corresponds to shales, and the most — to limestones (Table 1).

More than half (59.4 %) of the studied clasts have a size of 1–2 cm, a quarter (25.2 %) — 2–3 cm, and larger clasts only occur in insignificant amounts (Table 2). The individual rock types show the same trends, with the exception of cherts, as their dominant size is 2–3 cm (Table 2).

Table 1. **Basic characteristics of large-size fragments: composition, roundness, shape (sphericity)**

Rock	Amount		Average roundness	Shape (sphericity) according to Zingg: number (%)			
	num	%	(Wadell)	discoid	equant	bladed	rod
Dolomite	248	46.4	0.23	77 (31.0 %)	80 (32.3 %)	30 (12.1 %)	61 (24.6 %)
Limestone	106	19.8	0.26	45 (42.5 %)	25 (23.6 %)	14 (13.2 %)	22 (20.8 %)
Terrigenous (sandstones, siltstones)	122	22.8	0.25	52 (42.6 %)	27 (22.1 %)	18 (14.8 %)	25 (20.5 %)
Chert	14	2.6	0.24	2 (14.3 %)	1 (7.1 %)	4 (28.6 %)	7 (50.0 %)
Shale	9	1.7	0.21	5 (55.6 %)	0 (0 %)	2 (22.2 %)	2 (22.2 %)
Igneous acid	14	2.6	0.25	4 (28.6 %)	3 (21.4 %)	2 (14.3 %)	5 (35.7 %)
Igneous basic	16	3.0	0.25	6 (37.5 %)	6 (37.5 %)	1 (6.3 %)	3 (18.8 %)
Not determined	6	1.1	0.18	1 (16.7 %)	1 (16.7 %)	4 (66.7 %)	0 (0 %)
Total	535	100		192 (35.9 %)	143 (26.7 %)	75 (14.0 %)	125 (23.4 %)

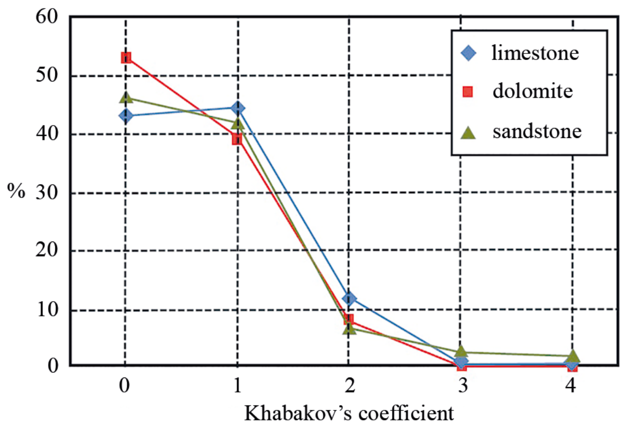

Fig. 2. The roundness of main large-sized rock fragments (main petrographic types) (Khabakov, 1962).

The coefficients of roundness: 0 — non-rounded clasts, 1 — angular clasts, 2 — semi-rounded clasts, 3 — well-rounded clasts, 4 — perfectly-rounded clasts

Table 2. **Distribution of large-sized material by size**

		1–2 cm	**2.1–3 cm**	**3.1–4 cm**	**4.1–5 cm**	**5.1–6 cm**	**>6 cm**	**sum**
limestone	number	56	26	8	8	2	6	106
	%	52.8	24.5	7.5	7.5	1.9	5.7	100
dolomite	number	153	65	11	9	6	4	248
	%	61.7	26.2	4.4	3.6	2.4	1.6	100
terrigenous	number	75	27	9	3	3	5	122
	%	61.5	22.1	7.4	2.5	2.5	4.1	100
shale	number	6	2	0	0	0	1	9
	%	66.7	22.2	0	0	0	11.1	100
igneous	number	9	1	1	0	2	1	14
(acid)	%	64.3	7.1	7.1	0	14.3	7.1	100
igneous	number	10	5	0	0	1	0	16
(basic)	%	62.5	31.3	0	0	6.3	0	100
chert	number	5	8	0	0	1	0	14
	%	35.7	57.1	0	0	7.1	0	100
not	number	4	1	1	0	0	0	6
determined	%	66.7	16.7	16.7	0	0	0	100
total	number	318	135	30	20	15	17	535
	%	59.4	25.2	5.6	3.7	2.8	3.2	100

When considering the shape of clasts, outstanding characteristics are not established: all possible types are present (Table 1, Fig. 3). Bladed shapes are the least common (14 %). The most abundant are discoid/oblate forms (35.9 %). Quantities of equant and rod/prolate forms are similar: 26.7 % and 23.4 %, respectively. Among the specific types of rocks, however, these ratios may vary. For example, isometric shapes predominate for dolomites, whereas they are not common among cherts and shales (Table 1). The surface of the studied clasts is usually covered with small pits and furrows (traces of dissolution and deformation), or, more rarely, smooth. With rare exceptions, unidirectional hatching that may be formed by glacial ice moving across the rocks was not observed. The surface of many samples was coated with manganese, usually on one side only, which likely means that clasts were exposed for a long time on the sea floor.

4. Discussion

The poor roundness of the majority of the studied coarse-grained clasts suggests that they were neither transported by rivers nor influenced by significant wave activity in coastal marine environments. Theoretically, non-rounded rock fragments might be of

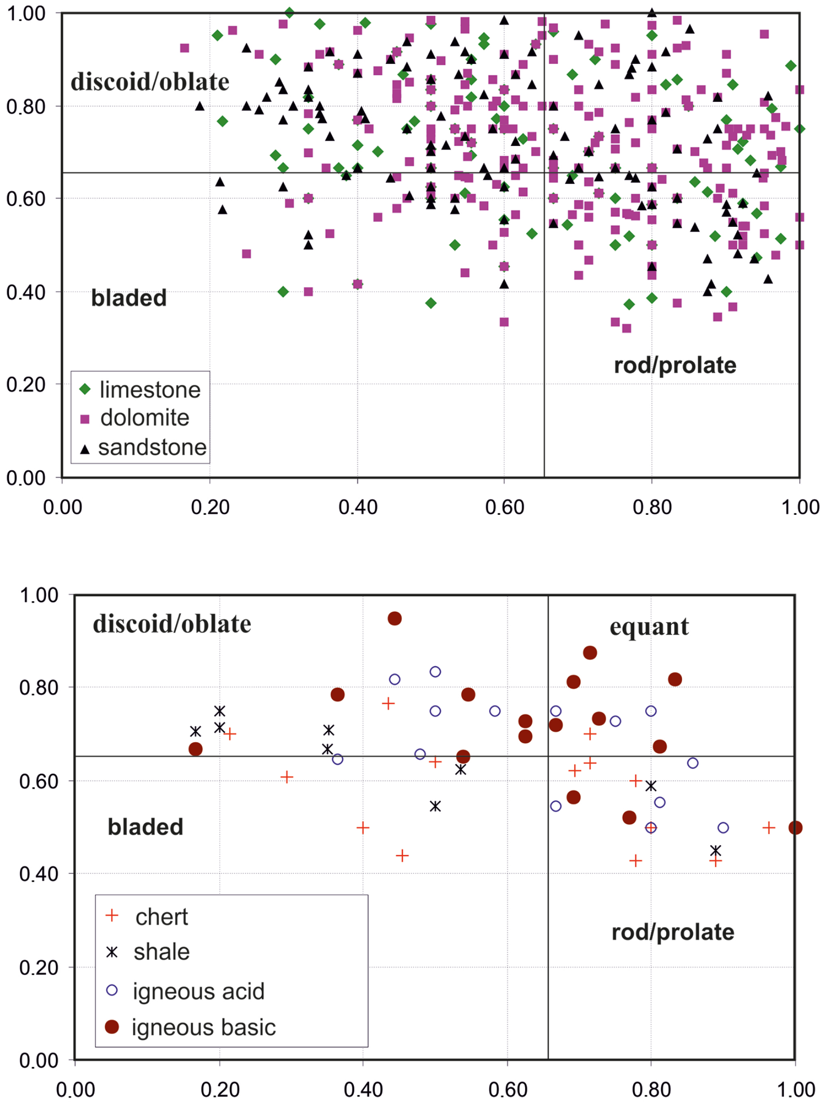

Fig. 3. The shape (sphericity) of large-sized rocks according the Zingg classification (Zingg, 1935). Upper figure — the most common rocks, bottom — remaining rocks

local origin or be captured by icebergs during glacier degradation. Significant predominance of sharp-edged fragments was mentioned earlier for diamicton of the northern part of the Barents Sea (Frolov et al., 2019). An interesting fact is that the shapes of the clasts vary with some general predominance of discoid samples (Table 1).

As stated above, geophysical surveys across the sampling sites showed a lack of bedrock outcrops, so the studied coarse-grained clasts are not of local origin. It should be noted that very few basic igneous rocks were found among the studied clasts (3 %, Table 1), which is another (indirect) indication of the absence of basement outcrops at the coring sites, since basalts of the High Arctic Large Igneous Province (HALIP) were discovered during shallow drilling at the Mendeleev Ridge (Morozov et al., 2013; Petrov et al., 2016). Wide distribution of HALIP at the Mendeleev Ridge has also been confirmed by geophysical surveys (e. g., Chernykh et al., 2018; Avetisov et al., 2019). Therefore, iceberg and probably sea-ice transport were the main mechanisms of supplying the clasts to the studied sites. Considering the geology of the surrounding land masses, analysis of the petrographic composition of the coarse-grained clasts allows us to make assumptions about the clast provenance.

The strong predominance of dolomites among the studied clasts suggests their preferential delivery from the platform area of the Canadian Arctic Archipelago that was impacted by the Laurentide Ice Sheet and is composed mainly of Paleozoic dolomites (e. g., Victoria Island) (e. g., Trettin, 1991; Harrison et al., 2013; Dewing et al., 2015). A similar conclusion was reached earlier on the basis of a petrographical study of clasts >2 mm collected by box corers in the central Arctic Ocean (Phillips and Grantz, 2001), as well as a geochemical study of dolomitic "pink-white" layers at the Mendeleev Ridge (Bazhenova et al., 2017). It is unlikely that the dolomites were delivered from Alaska, which has not undergone significant glaciations at the shoreline (e. g., Jakobsson et al., 2014), and therefore could not supply a large number of icebergs that are the main carrier of the large rock fragments. The restricted distribution of dolomites in northern Eurasia (e. g., Drachev et al., 2010) clearly testifies against its essential role in the delivery of coarse material to the studied sites.

The folded Sverdrup Basin includes Late Paleozoic conglomerates, limestones, white and black cherts, sandstones and black shales with a small amount of evaporites, which are replaced by Mesozoic sandstones, mudstones and the igneous rocks of HALIP (e. g., Embry and Beauchamp, 2008; Hadlari et al., 2016). The Sverdrup Basin can unlikely be regarded as a considerable source of dropstones found at the Alpha and Mendeleev Ridges, because this area could not provide the rock assemblages discovered at the studied sites in the Amerasian Basin. Darby and Zimmerman (2008) inferred that the amount of material supplied by icebergs from the Sverdrup Basin (Innuitian Ice Sheet) to the Mendeleev Ridge is comparable or, in some cases, even exceeds the amount of material from the platform areas of the Canadian Arctic Archipelago (Victoria and Banks Islands). Our results, which show a significant predominance of sources from the latter area, do not confirm this conclusion.

Nevertheless, variable lithological types of carbonates observed in the thin sections, as well as the presence of sandstones and other rocks suggests that the platform part of the Arctic Canadian Archipelago was not the only source area for dropstones. Carbonates are present locally in the "Eurasian geological sections" as well, while sandstones are more prevalent there.

The maximum amounts of dolomites along the southern profile (Fig. 1) indicate a mostly consistent ice drift path within the past, similar to the modern Beaufort Gyre, with the unloading of drift material along the periphery of the Amerasian Basin. Fluctuations of the Beaufort Gyre, such as observed in the last several decades (Arctic Oscillation, e. g., Darby et al., 2006) are unlikely to be identified in sediment records due to very low sedimentation rates in the Central Arctic Ocean. Overall, the main features of the Arctic circulation system seem to have been relatively stable in the geological past, as evidenced by the consistent clasts in the sediment records (e. g., Nørgaard-Pedersen et al., 1998; Phillips and Grants, 2001; Spielhagen et al., 2004; Krylov et al., 2008). On the other hand, studies of iron oxide minerals seem to indicate an instability of the ice drift system in geological history (Bischof and Darby, 1997; Darby et al., 2015). More studies are needed to reconcile differences in provenance identification based on different methods.

We can try to provide a very rough estimate of the sea ice/iceberg contribution from Siberia, which was generally the prevailing source of clastic rocks (Drachev et al., 2010; Harrison et al., 2011) in comparison with the platform part of the Canadian Arctic Archipelago covered by glaciers in the past (Trettin, 1991). Assuming that all sandstones on the Mendeleev Ridge area are derived from Siberia, we can estimate the maximum possible contribution from these sources as less than 20–25 % (see the amount of terrigenous rocks in Table 1). However, sandstones could have also originated from Canada, for example, the Sverdrup Basin (Trettin, 1991; Embry and Beauchamp, 2008; Harrison et al., 2011) or Alaska (Harrison et al., 2011). Thus, the share of Siberian sources is most likely less than the indicated maximum estimate. We note also that some small portion of dolomites could be delivered from local Siberian outcrops, such as on Wrangel and Kotelnyi islands (e. g., Lopatin, 1999; Kos'ko and Ushakov, 2003).

5. Conclusion

The following facts should be taken into account when interpreting the origin of coarse-grained clasts in the Arctic Ocean sediment cores.

1. Ice/iceberg-rafted material is characterized by a wide variety of shapes; however, the "bladed" shape is the least abundant. The most abundant are discoid/oblate forms.

2. Non-rounded rock fragments dominate among the sea ice/iceberg-rafted material regardless of its petrographic composition. A similar poor roundness is expected to prevail in the shape of "local" rocks. This implies that the poor roundness of the coarse-grained clasts can hardly be used as a reliable criterion to distinguish between the local and the sea ice/iceberg-rafted dropstones. Perhaps only well-rounded rocks can be confidently referred to as material of sea ice (but not iceberg) rafting, as such degree of roundness can only be achieved at the beach or in alluvium. "Anchor" capture by the ice while freezing is the most likely mechanism for entrainment of such coarse-grained clasts into the sea ice.

3. The prevalence of dolomites among the studied clasts provides evidence for their predominant origin from the western platform area of the Canadian Arctic Archipelago (likely from the platform area). The main inferred mechanism for their delivery was iceberg rafting during deglaciation periods.

This research is supported by the Russian Ministry of Education and Science, project "Arctic Transpolar System in Transitional Climatic Conditions" (RFMEFI61619X0108). Comments from anonymous reviewers helped improve the manuscript.

References

Avetisov, G. P., Butsenko, V. V., Chernykh, A. A. et al. (2019). The Current State of the Arctic Basin Study. In: A. Piskarev et al., ed., *Geologic Structures of the Arctic Basin*. Springer International Publishing AG, 1–69. https://doi.org/10.1007/978-3-319-77742-9_1

Bazhenova, E., Fagel, N. and Stein, R. (2017). North American origin of "pink-white" layers at the Mendeleev Ridge (Arctic Ocean): New insight from lead and neodymium isotope composition of detrital sediment component. *Marine Geology*, 386, 44–55. http://doi.org/10.1016/j.margeo.2017.01.010

Bischof, J. and Darby, D. (1997). Mid- to Late Pleistocene ice drift in the western Arctic Ocean: Evidence for a different circulation in the past. *Science*, 277, 74–78. http://doi.org/10.1126/science.277.5322.74

Boggild, K., Mosher, D. C., Travaglini, P., Gebhardt, C. and Mayer, L. (2020). Mass wasting on Alpha Ridge in the Arctic Ocean: new insight from multibeam bathymetry and sub-bottom profiler data. In: A. Georgiopoulou, L. A. Amy, S. Benetti, J. D. Chaytor, M. A. Clare, D. Gamboa, P. D. W. Haughton, J. Moernaut,

J. J. Mountjoy, ed., *Subaqueous Mass Movements and their Consequences: Advances in Process Understanding, Monitoring and Hazard Assessments*. Geological Society, London, Special Publications, 500, 323–340. https://doi.org/10.1144/SP500-2019-196

Bruvoll, V., Kristoffersen, Y., Coakley, B. J. and Hopper, J. (2010). Hemipelagic deposits on the Mendeleev and Alpha sub-marine ridges in the Arctic Ocean: acoustic stratigraphy, depositional environment and inter-ridge correlation calibrated by the ACEX results. *Marine Geophysical Research*, 31, 149–171. https://doi.org/10.1007/s11001-010-9094-9

Chernykh, A., Glebovsky, V., Zykov, M. and Korneva, M. (2018). New insights into tectonics and evolution of the Amerasia Basin. *J. Geodynamics*, 119, 167–182. http://doi.org/10.1016/j.jog.2018.02.010

Clark, D. L. and Hanson, A. (1983). Central Arctic Ocean sediment texture: A key to ice transport mechanisms. In: B. F. Molnia, ed., *Glacial-marine sedimentation*. New York: Plenum Publishing Corporation, 301–330.

Cronin, T. M., Polyak, L., Reed, D., Kandiano, E. S., Marzen, R. E. and Council, E. A. (2013). A 600-ka Arctic sea-ice record from Mendeleev Ridge based on ostracodes. *Quatern. Sci. Rev.*, 79, 157–167. http://doi.org/10.1016/j.quascirev.2012.12.010

Darby, D. A. (2014). Ephemeral formation of perennial sea-ice in the Arctic Ocean during the middle Eocene. *Nature Geoscience*, 7, 210–213. https://doi.org/10.1038/ngeo2068

Darby, D. A., Polyak, L. and Bauch, H. A. (2006). Past glacial and interglacial conditions in the Arctic Ocean and marginal seas — a review. *Progress in Oceanography*, 71, 129–144. https://doi.org/10.1016/j.pocean.2006.09.009

Darby, D. A., Myers, W. B., Jakobsson, M. and Rigor, I. (2011) Modern dirty sea ice characteristics and sources: The role of anchor ice. *J. Geophys. Res.*, 116, C09008, 1–18. https://doi.org/10.1029/2010JC006675

Darby, D. A., Myers, W., Herman, S. and Nicholson, B. (2015). Chemical fingerprinting, a precise and efficient method to determine sediment sources. *J. Sedim. Res.*, 85, 247–253. http://doi.org/10.2110/jsr.2015.17

Darby, D. A. and Zimmerman, P. (2008). Ice-rafted detritus events in the Arctic during the last glacial interval, and the timing of the Innuitian and Laurentide ice sheet calving events. *Polar Research*, 27, 114–127. http://doi.org/10.1111/j.1751-8369.2008.00057.x

Dethleff, D. (2005). Entrainment and export of Laptev Sea ice sediments, Siberian Arctic. *J. Geophys. Res.*, 110, C07009. http://doi.org/10.1029/2004JC002740

Dethleff, D. and Kuhlmann, G. (2010). Fram Strait sea-ice sediment provinces based on silt and clay compositions identify Siberian Kara and Laptev seas as main source regions. *Polar Research*, 29, 265–282. http://doi.org/10.1111/j.1751-8369.2010.00149.x

Dewing, K., Hadlari, T., Rainbird, R. H. and Bedard, J. H. (2015). *Phanerozoic geology, northwestern Victoria Island, Northwest Territories;* Geological Survey of Canada, Canadian Geoscience Map 171 (preliminary), scale 1:500 000. http://doi.org/10.4095/295530

Dong, L., Liu, Y., Shi, X., Polyak, L., Huang, Y., Fang, X., Liu, J., Zou, J., Wang, K., Sun, F. and Wang, X. (2017). Sedimentary record from the Canada Basin, Arctic Ocean: implications for late to middle Pleistocene glacial history. *Climate of the past*, 13, 511–531. http://doi.org/10.5194/cp-13-511-2017

Drachev, S. S., Malyshev, N. A. and Nikishin, A. M. (2010) Tectonic history and petroleum geology of the Russian Arctic Shelves: an overview. In: B. A. Vining, S. C. Pickering, ed., *Petroleum Geology: From Mature Basins to New Frontiers — Proceedings of the 7th Petroleum Geology Conference*, 591–619. http://doi.org/10.1144/0070591

Embry, A. and Beauchamp, B. (2008). Sverdrup Basin. In: *Sedimentary Basins of the World*, 5, 451–471. http://doi.org/10.1016/S1874-5997(08)00013-0

Frolov, I. E., Ivanov, V. V., Filchuk, K. V. et al. (2019). Transarktika-2019: winter expedition in the Arctic Ocean on the R/V "Akademik Tryoshnikov". *Problemy Arktiki i Antarktiki. Arctic and Antarctic Research*, 65 (3), 255–274. http://doi.org/10.30758/0555-2648-2019-65-3-255-274

Grantz, A., Phillips, R. L., Mullen, M. W., Starratt, S. W., Jones, G. A., Sathy, N. A. and Finney, B. P. (1996). Character, paleoenvironment, rate of accumulation, and evidence for seismic triggering of Holocene turbidites, Canada Abyssal Plain, Arctic Ocean. *Marine Geology*, 133, 51–73.

Gusev, E. A. (2014). Stones on the Arctic Ocean Bottom. *Priroda*, 8, 31–38. (In Russian)

Gusev, E. A., Rekant, P. V., Bolshiyanov, D. Yu., Lukashenko, R. V. and Popko, A. O. (2013). Pseudoglacial structures of Mendeleev Rise Seamounts (Arctic Ocean) and East Siberian continental margin. *Problemy Arktiki i Antarktiki. Arctic and Antarctic Research*, 4, 43–55. (In Russian)

Gusev, E.A., Lukashenko, R.V., Popko, A.O., Rekant, P.V., Mirolubova, E.S. and Pyatkova, M.N. (2014). New data on the structure of slopes of the Mendeleev Ridge Seamounts (Arctic Ocean). *Doklady Earth Sciences*, 455 (1), 250–253. http://doi.org/10.1134/S1028334X14030179

Gusev, E., Rekant, P., Kaminsky, V., Krylov, A., Morozov, A., Shokalsky, S. and Kashubin, S. (2017) Morphology of seamounts at the Mendeleev Rise, Arctic Ocean. *Polar Research*, 36 (1), 1298901. http://doi.org/10.1080/17518369.2017.1298901

Hadlari, T., Midwinter, D., Galloway, J.M., Dewing, K. and Durbano, A.M. (2016). Mesozoic rift to post-rift tectonostratigraphy of the Sverdrup Basin, Canadian Arctic. *Mar Petrol Geol*., 76, 149–158. http://doi.org/10.1016/j.marpetgeo.2016.05.008

Harrison, J.C., Christie, R.L., Rainbird, R.H. and Ford, A. (2013). *Geology, Tectonic assemblage map of the Cambridge Bay area, southeastern Victoria Island, Nunavut*; Geological Survey of Canada, Canadian Geoscience Map 78 (preliminary), scale 1:500 000. http://doi.org/10.4095/292813

Hegewald, A. and Jokat, W. (2013). Relative sea level variations in the Chukchi region — Arctic Ocean — since the late Eocene. *Geophys. Research Letters*, 40 (1–5). http://doi.org/10.1002/GRL.50182

Jakobsson, M., Macnab, R., Mayer,L., Anderson, R., Edwards, M., Hatzky, J., Schenke, H.W. and Johnson, P. (2008). An improved bathymetric portrayal of the Arctic Ocean: Implications for ocean modeling and geological, geophysical and oceanographic analyses. *Geophysical Research Letters*, 35, L07602, 1–5. http://doi.org/10.1029/2008GL033520

Jakobsson, M., Andreassen, K., Bjarnadottir, L.R., Dove, D., Dowdeswell, J.A. et al. (2014). Arctic Ocean glacial history. *Quaternary Science Reviews*, 92, 40–67. https://doi.org/10.1016/j.quascirev.2013.07.033

Jakobsson, M., Nilsson, J., Anderson, L. et al. (2016). Evidence for an ice shelf covering the central Arctic Ocean during the penultimate glaciation. *Nature Communication*, 7 (10365), 1–10. http://doi.org/10.1038/ncomms10365

Jokat, W. (ed.) (2012). The Expedition of the Research Vessel "Polarstern" to the Arctic in 2008 (ARK-XXIII/3). *Reps. Pol. Mar. Res.*, 597, 221.

Kaban'kov, V., Andreeva, I., Ivanov, V. and Petrova, V. (2004). The geotectonic nature of the Central Arctic Morphostructures and geological implications of bottom sediments for its interpretation. *Geotectonics*, 6, 33–48.

Kaparulina, E., Strand, K. and Lunkka, J.P. (2016). Provenance analysis of central Arctic Ocean sediments: Implication for circum-Arctic ice sheet dynamics and ocean circulation during Late Pleistocene. *Quaternary Sci. Rev.*, 147, 210–220. http://doi.org/10.1016/j.quascirev.2015.09.017

Khabakov, A.V. (ed.). (1962). *Atlas of textures and structures of sedimentary rocks. Part 1: clastic and clay rocks.* Moscow: Gosgeoltekhizdat Publ. Available at: http://www.lithology.ru/node/456 [Accessed Nov. 28, 2020]. (In Russian)

Kos'ko, M.K. and Ushakov, V.I. (eds.). (2003). Wrangel island. geological structure, mineralogy, geoecology. *Proceedings of NIIGA-VNIIOkeangeologia*, 200. St. Petersburg. (In Russian)

Kossovaya, O.L., Tolmacheva, T.Yu., Petrov, O.V., Isakova, T.N., Ivanova, R.M., Mirolyubova, E.S., Rekant, P.V. and Gusev, E.A. (2018). Palaeozoic carbonates and fossils of the Mendeleev Rise (eastern Arctic): A study of dredged seafloor material. *Journal of Geodynamics*, 120, 23–44. http://doi.org/10.1016/j.jog.2018.05.001

Krylov, A.A., Andreeva, I.A., Vogt, C., Backman, J., Krupskaya, V.V., Grikurov, G.E., Moran, K. and Shoji, H. (2008). A shift in heavy and clay mineral provenance indicates a middle Miocene onset of a perennial sea ice cover in the Arctic Ocean. *Paleoceanography*, 23, PA1S06. http://doi.org/10.1029/2007PA001497

Krylov, A.A., Shilov, V.V., Andreeva, I.A. and Mirolubova, E.S. (2011). Stratigraphy and accumulation of Upper Quaternary sediments in the northern part of the Mendeleev Rise (Amerasian Basin, Arctic Ocean). *Problemy Arktiki i Antarktiki. Arctic and Antarctic Research*, 2 (88), 7–22. (In Russian)

Krylov, A.A., Gusev, E.A., Mirolubova, E.S. and Chernykh, A.A. (2018). Geological and paleooceanological significance of psephite from the cretaceous-cenozoic deposits from the near-pole part of the Lomonosove ridge. *Problemy Arktiki i Antarktiki. Arctic and Antarctic Research*, 64 (2), 182–199. http://doi.org/10.20758/0555-2648-2018-64-2-182-199. (In Russian)

Levitan, M.A. (2015). Sedimentation rates in the Arctic Ocean during the last five marine isotope stages. *Oceanology*, 55 (3), 425–433. https://doi.org/10.1134/S000143701503011X

Lisitzin, A.P. (2002). *Sea-ice and iceberg sedimentation in the ocean. Recent and past. Heidelberg*, Berlin: Springer-Verlag.

Lopatin, B.G. (ed.). (1999). *State geological map of sheet S 53–55 (new series). New Siberian Islands. Scale 1: 1000000.* St. Petersburg: VSEGEI Publ. (In Russian)
Matthiessen, J., Knies, J., Vogt, C. and Stein, R. (2009). Pliocene palaeoceanography of the Arctic Ocean and subarctic seas. *Phil. Trans. R. Soc.* A, 367, 21–48. http://doi.org/10.1098/rsta.2008.0203
Matthiessen, J. and Kollaske, T. (2012). Marine sediment echosounding using Parasaund. In: U. Schauer, ed., The Expedition of the RV "Polarstern" to the Arctic in 2011 (ARK-XXVI/3 — TransArc). *Rep. Pol. Mar. Res.*, 649, 124–129.
Melnikov, I.A. and Zezina, O.N. (2010). Bottom animals on the ice of the central Arctic. *Priroda*, 6, 43–47. (In Russian)
Morozov, A.F., Petrov, O.V., Shokalskyi, S.P. et al. (2013). New geological data supporting continental origin of the Central Arctic Rises. *Regional'naia geologiia i metallogeniia*, 53, 34–55. (In Russian)
Niessen, F. and Matthiessen, J. (2009). Marine sediment echosounding using Parasaund. In: W. Jokat, ed., The Expedition ARK-XXIII/3 of RV Polarstern in 2008. *Rep. Pol. Mar. Res.,* 597, 15–23.
Niessen, F., Hong, J.K., Hegewald, A., Matthiessen, J., Stein, R., Kim, H., Kim, S., Jensen, L., Jokat, W., Nam, S.-I. and Kang, S.-H. (2013). Repeated Pleistocene glaciation of the East Siberian continental margin. *Nature Geoscience*, 6, 842–846. http://doi.org/10.1038/ngeo1904
Nikolaev, S.D., Taldenkova, E.E., Rekant, P.V., Chistyakova, N.O. and Mirolyubova, E.S. (2013). Paleogeography of the Eurasian part of the submarine Lomonosov Ridge in the Neo-Pleistocene. *Vestnik Moskovskogo Universiteta, Seriia 5: Geografiia*, 5, 51–59. (In Russian)
Nørgaard-Pedersen, N., Spielhagen, R.F., Thiede, J. and Kassens, H. (1998). Central Arctic surface ocean environment during the past 80000 years. *Paleoceanography*, 13, 193–204. https://doi.org/10.1029/97PA03409
Nørgaard-Pedersen, N., Spielhagen, R.F., Erlenkeuser, H., Grootes, P.M., Heinemeier, J. and Knies, J. (2003). Arctic Ocean during the Last Glacial Maximum: Atlantic and polar domains of surface water mass distribution and ice cover. *Paleoceanography,* 18 (3), 1063, 1–19. http://doi.org/10.1029/2002PA000781
Nürnberg, D., Wollenburg, I., Dethleff, D., Eicken, H., Kassens, H., Letzig, T., Reimnitz, E. and Thiede, J. (1994). Sediments in Arctic sea ice: Implications for entrainment, transport and release. *Mar. Geol.*, 119, 185–214. https://doi.org/10.1016/0025-3227(94)90181-3
Petrov, O.M., Morozov, A., Shokalsky, S., Kashubin, S., Artemieva, I.M., Sobolev, N., Petrov, E., Ernst, R.E., Sergeev, S. and Smelror, M. (2016). Crustal structure and tectonic model of the Arctic region. *Earth-Science Reviews*, 154, 29–71. http://doi.org/10.1016/j.earscirev.2015.11.013
Phillips, R.L. and Grantz, A. (2001). Regional variations in provenance and abundance of ice-rafted clasts in Arctic Ocean sediments: implications for the configuration of late Quaternary oceanic and atmospheric circulation in the Arctic. *Mar. Geol.*, 172, 91–115. https://doi.org/10.1016/S0025-3227(00)00101-8
Polyak, L., Bischof, J., Ortiz, J., Darby, D., Channell, J., Xuan, C., Kaufman, D., Lovlie, R., Schneider, D. and Adler, R. (2009). Late Quaternary stratigraphy and sedimentation patterns in the western Arctic Ocean. *Global Planet. Change,* 68, 5–17. https://doi.org/10.1016/j.gloplacha.2009.03.014
Polyak, L., Alley, R.B., Andrews, J.T. et al. (2010). History of sea ice in the Arctic. *Quaternary Science Reviews*, 29, 1757–1778. https://doi.org/10.1016/j.quascirev.2010.02.010
Reimnitz, E., McCormick, M., McDougall, K. and Brouwers, E. (1993). Sediment export by ice rafting from a coastal polynya, Arctic Alaska, U.S.A. *Arctic Alpine Research*, 25, 83–98. http://doi.org/10.2307/1551544
Rekant, P.V., Pyatkova, M.N., Nikolaev, S.D. and Taldenkova, E.E. (2012). Stones from the Geophysics spur as a petrotype of the basement of the Southern part of the Lomonosov Ridge (Arctic Ocean). In: *Geology and Geoecology of the Eurasian continental margins. Issue 4.* Moscow: GEOS Publ., 29–40. (In Russian)
Rekant, P., Sobolev, N., Portnov, A., Belyatsky, B., Dipre, G., Pakhalko, A., Kaban'kov, V. and Andreeva, I. (2019). Basement segmentation and tectonic structure of the Lomonosov Ridge, Arctic Ocean: Insights from bedrock geochronology. *J. Geodynamics*, 128, 38–54. https://doi.org/10.1016/j.jog.2019.05.001
Schauer, U. (ed.). (2012). The Expedition of the Research Vessel "Polarstern" to the Arctic in 2011 (ARK-XXVI/3 — TransArc). *Reps. Pol. Mar. Res.*, 649, 203.
Shevchenko, V.P., Lisitzin, A.P., Kharin, G.S., Haas, Ch., Thiede, J., Stein, R., Spielhagen, R.E. and Taldenkova, E.E. (2003). Sediment transport in the central Arctic by icebergs. In: *Geology of seas and oceans: Proceedings of XV International Conference on Marine Geology*, 1, 63–64. (In Russian)
Spielhagen, R.F., Baumann, K.-H., Erlenkeuser, H. et al. (2004). Arctic Ocean deep-sea record of northern Eurasian ice sheet history. *Quaternary Science Rev.*, 23, 1455–1483. https://doi.org/10.1016/j.quascirev.2003.12.015

St. John, K. (2008). Cenozoic History of Ice-Rafting in the Central Arctic: Terrigenous Sands on the Lomonosov Ridge. *Paleoceanography*, 23, PA1S05. https://doi.org/10.1029/2007PA001483

Stein, R. (2008). Arctic Ocean sediments: processes, proxies, and paleoenvironment. Elsevier.

Stein, R., Matthiessen, J., Niessen, F., Krylov, A., Nam, S.-I. and Bazhenova, E. (2010). Towards a better (litho-) stratigraphy and reconstruction of Quaternary Paleoenvironment in the Amerasian Basin (Arctic Ocean). *Polarforschung*, 79 (2), 97–121.

Stein, R., Weller, P., Backman, J., Brinkhuis, H., Moran, K. and Palike, H. (2014). Cenozoic Arctic Climate History: Some highlights from the Integrated Ocean Drilling Program Arctic Coring Expedition. *Developments in Marine Geology*, 7, 259–293.

Stein, R., Fahl, K., Schreck, M. et al. (2016). Evidence for ice-free summers in the late Miocene central Arctic Ocean. *Nat. Commun.*, 7, 11148. http://doi.org/10.1038/ncomms11148

Taldenkova, E., Bauch, H.A., Gottschalk, J., Nikolaev, S., Rostovtseva, Yu., Pogodina, I., Ovsepyan, Ya. and Kandiano, E. (2010). History of ice-rafting and water mass evolution at the northern Siberian continental margin (Laptev Sea) during Late Glacial and Holocene times. *Quaternary Sci. Rev.*, 29, 3919–3935. http://doi.org/10.1016/j.quascirev.2010.09.013

Tremblay, L.B., Schmidt, G.A., Pfirman, S., Newton, R. and De Repentigny, P. (2015). Is ice-rafted sediment in a North Pole marine record evidence for perennial sea-ice cover? *Phil. Trans. R. Soc. A*, 373, 20140168. http://doi.org/10.1098/rsta.2014.0168

Trettin, H.P. (ed.). (1991). Geology of the Innuitian orogeny and Arctic platform of Canada and Greenland. *Geology of Canada*, (3), 569.

Vogt, C. and Knies, J. (2008). Sediment dynamics in the Eurasian Arctic Ocean during the last deglaciation — The clay mineral group smectite perspective. *Marine Geology*, 250, 211–222. https://doi.org/10.1016/j.margeo.2008.01.006

Weigelt, E., Jokat, W. and Franke, D. (2014). Seismostratigraphy of the Siberian Sector of the Arctic Ocean and adjacent Laptev Sea Shelf. *J. Geophys. Res. Solid Earth*, 119, 5275–5289. http://doi.org/10.1002/2013JB010727

Zingg, T. (1935). Beitrag zur Schotteranalyse. *Schweizer Mineralog. U. Petrog. Mitt.*, 15, 39–140.

Received: July 14, 2020
Accepted: October 12, 2020

Contact information:

Alexey A. Krylov — akrylow@gmail.com
Jens Matthiessen — Jens.Matthiessen@awi.de
Seung-Il Nam — sinam@kopri.re.kr
Ruediger Stein — Ruediger.Stein@awi.de
Evgenia A. Bazhenova — evgeniabazhenova@gmail.com
Elena S. Mirolubova — mirolubova@mail.ru
Evgeny A. Gusev — gus-evgeny@yandex.ru
Sergey A. Malyshev — serg.i-karamba@yandex.ru
Alexander S. Makarov — makarov@aari.ru

Происхождение грубозернистых (> 1 см) обломков из района хребта Менделеева (Северный Ледовитый Океан)

А. А. Крылов[1,2,3], *Й. Маттиссен*[4], *С.-И. Нам*[5], *Р. Штайн*[4,6], *Е. А. Баженова*[2], *Е. С. Миролюбова*[1], *Е. А. Гусев*[1], *С. А. Малышев*[1,3], *А. С. Макаров*[3]

[1] ВНИИОкеангеология,
Российская Федерация, 190121, Санкт-Петербург, Английский пр., 1

[2] Санкт-Петербургский государственный университет,
Российская Федерация, 199034, Санкт-Петербург, Университетская наб., 7–9

[3] Арктический и антарктический научно-исследовательский институт,
Российская Федерация, 199397, Санкт-Петербург, ул. Беринга, 38

[4] Институт Альфреда Вегенера, Центр полярных и морских исследований имени Гельмгольца, Германия, 27570, Бремерхафен, Ам Ханделшафен,12
[5] Корейский институт полярных исследований, Отдел полярной палеосреды, Республика Корея, 21990, Инчхон, Сонгдомирае-ро, 26
[6] MARUM — Центр морских экологических наук и факультет наук о Земле, Бременский университет, Германия, D-28359, Бремен, ул. Леобенер, 8

Для цитирования: Krylov, A. A., Matthiessen, J., Nam, S.-I., Stein, R., Bazhenova, E. A., Mirolubova, E. S., Gusev, E. A., Malyshev, S. A., Makarov, A. S. (2020). Origin of the coarse-grained (> 1 cm) clasts from the Mendeleev Ridge area (Central Arctic Ocean). *Вестник Санкт-Петербургского университета. Науки о Земле*, 65 (4), 795–809. https://doi.org/10.21638/spbu07.2020.411

В работе представлены результаты исследований морфометрических характеристик и петрографического состава крупномерного псефитового материала (>1 см), отобранного из осадков Амеразийского бассейна Северного Ледовитого океана в экспедициях научно-исследовательского ледокола «Поларштерн» (ARK-XXIII/3, 2008 г. и ARK-XXVI-3, 2011 г.). Большинство изученных псефитов представлено доломитами (46.4%), песчаниками (22.8%) и известняками (19.8%); количество остальных пород (кремневые, глинистые сланцы, магматические) составляет около 10%. Среди изученных псефитов были идентифицированы различные литологические типы. Известняки и доломитистые известняки часто содержат фрагменты фауны. Морфометрический анализ показал, что большинство изученных псефитов являются плохоокатанными и характеризуются значительным разнообразием форм. Более чем половина из исследованных обломков имеет размер от 1 до 2 см, четверть — от 2 до 3 см, более крупные разности встречены в незначительном количестве. Геофизические съемки через точки отбора псефитов на хребте Менделеева показали отсутствие выходов коренных пород и значительные мощности накопленных синокеанических осадков, что является важным доказательством привнесенной природы исследованного нами псефитового материала. Сделан вывод о преимущественной доставке псефитов со стороны платформенной части Канадского Арктического архипелага (в частности, о. Виктория), главным образом за счет айсбергового разноса во время периодов дегляциации. Максимальный возможный вклад псефитов со стороны сибирских источников составляет менее 23%. Распределение крупномерных обломков в четвертичных осадках Амеразийского бассейна свидетельствует в пользу существования здесь достаточно стабильной системы ледового дрейфа в прошлом, похожей на современную систему ледового круговорота Бофорта.

Ключевые слова: хребет Менделеева, Северный Ледовитый океан, дропстоуны, айсберговый разнос.

Статья поступила в редакцию 14 июля 2020 г.
Статья рекомендована в печать 12 октября 2020 г.

Контактная информация:

Крылов Алексей Алексеевич — akrylow@gmail.com
Маттиссен Йенс — Jens.Matthiessen@awi.de
Сынь-Иль Нам — sinam@kopri.re.kr
Штайн Рюдигер — Ruediger.Stein@awi.de
Баженова Евгения Александровна — evgeniabazhenova@gmail.com
Миролюбова Елена Сергеевна — mirolubova@mail.ru
Гусев Евгений Анатольевич — gus-evgeny@yandex.ru
Малышев Сергей Андреевич — serg.i-karamba@yandex.ru
Макаров Александр Сергеевич — makarov@aari.ru