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Duration, Causes, and Geodynamic Significance of the Middle Cenozoic Hiatus in Sedimentation in the Near-Polar Part of the Lomonosov Ridge (Based on IODP-302-ACEX Drilling Data)

A. A. Chernykh[a, b, *] **and A. A. Krylov**[a, b]

[a]*All-Russia Scientific Institute of Geology and Mineral Resources of the World Ocean n.a. Academician I.S. Gramberg (VNIIOkeangeologia), St. Petersburg, Russia*

[b]*St. Petersburg State University, Institute of Earth Sciences, St. Petersburg, Russia*

**e-mail: andy@vniio.nw.ru*

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Abstract—The paper analyzes the duration and causes of the Middle Cenozoic hiatus in sedimentation in the near-polar part of the Lomonosov Ridge, revealed during biostratigraphic research of ACEX borehole deposits. Arguments are presented against the existence of a long hiatus between sediments of lithological complexes 1/5 and 1/6. The Lomonosov Ridge naturally subsided in the Cenozoic as a result of cooling of the lithosphere after riftogenesis. However, the level of the Arctic Ocean in its isolation period (49(?)–36.6 Ma) could have been lower than the level of the World Ocean due to decelerated spreading in the Eurasian Basin. A brief hiatus in sedimentation was caused by opening of the Fram Strait around 36.6 Ma and the infiltration of intermediate Atlantic waters, which could have interacted with the Lomonosov Ridge, leading to the erosion or nondeposition of particles on its surface.

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INTRODUCTION

The Cenozoic history of the central Arctic still remains poorly studied. Before the appearance of the first (and at present only) boreholes drilled in the near-polar part of the Lomonosov Ridge within the Integrated Ocean Drilling Project, Expedition 302, Arctic Coring Expedition (IODP-302-ACEX), the ideas on the evolution of the Arctic Ocean were based on the results of geophysical surveys and geological data from the Arctic onshore. Interpretation of the obtained core material allowed significant progress in understanding the main aspects of the geology and tectonics of the Arctic Ocean. However, our knowledge proved substantially limited after the results of biostratigraphic studies revealed a long hiatus in sedimentation that lasted 26.2 Ma, spaning an interval of 44.4–18.2 Ma [12–14].

The existence of such a long hiatus is possible only if the Lomonosov Ridge was in shallow-water (or subaerial) conditions, which leads to problems in geodynamic modeling. Factual material has begun to amass pointing to inconsistency in the initial interpretation of the stratigraphic division of borehole sediments. The aim of this study is to integrate the available factual material with a model of normal postrift sinking of the Lomonosov Ridge as a result of cooling of its lithosphere.

EVOLUTION OF IDEAS ON THE MIDDLE CENOZOIC HIATUS IN SEDIMENTATION

The ACEX drilling points were chosen at the crest of the near-polar part of the Lomonosov Ridge along the AWI-91090 seismic profile [23] (Fig. 1). A total of five boreholes were drilled, differing in depth and core material [12]. Two of them (M0002 and M0004) were combined to obtain a unified stratigraphic column with a depth of 428 m, divided into four lithological units (LUs, Fig. 2). Below we present a brief description using an age model based on Os-isotope dating [40]. It should be noted that the differences between the two main stratigraphic models [13, 40] exist only in the interval of 151.3–299.9 m. Subsequent sections of this paper describe this problem in detail while analyzing the duration of the Middle Cenozoic hiatus.

LU1 consisted of six subunits. LU1/1 includes from 1.1 to 5.3 m of Holocene–upper Pleistocene sediments, which have strong colored banding typical of bottom sediments of the central Arctic Ocean. LU1/2 consists of 18 m of upper Pleistocene deposits, the color of which varies from olive-brown in the upper

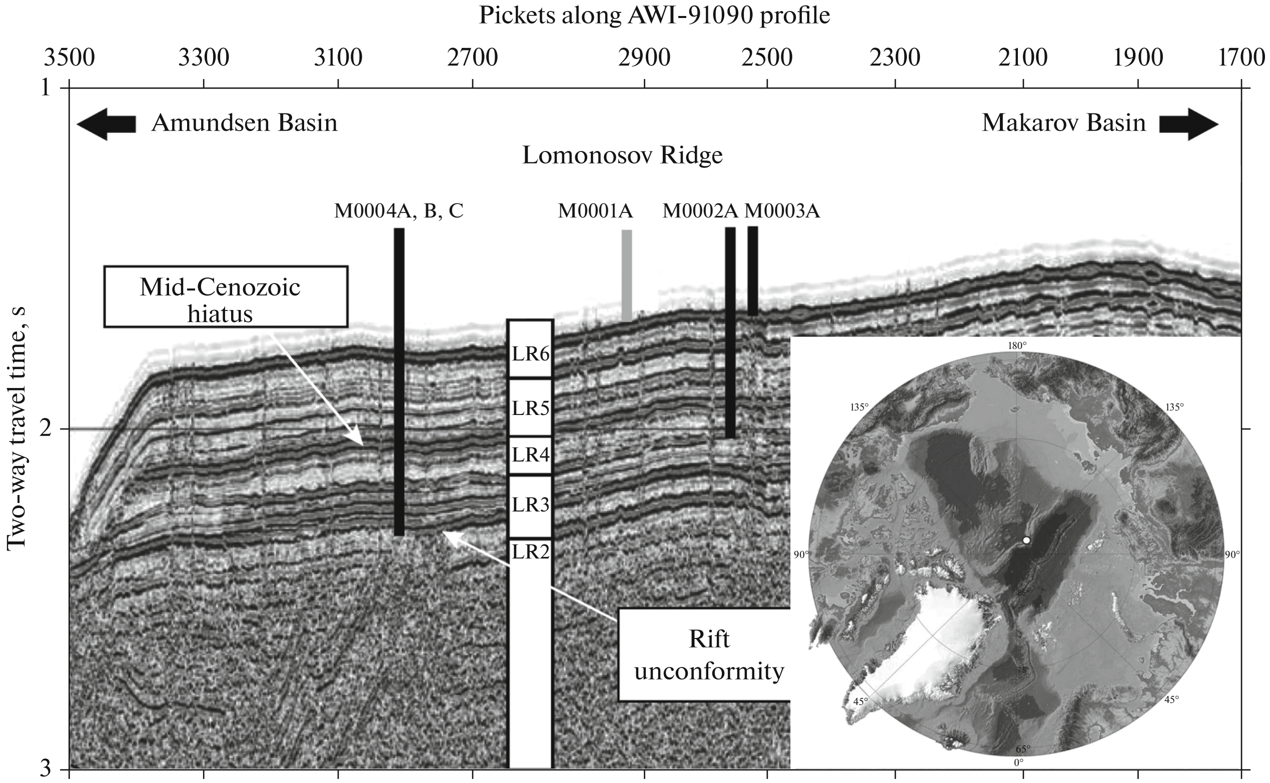

Fig. 1. Location of four ACEX boreholes on the Lomonosov Ridge along AWI-91090 seismic profile [23]. In the time seismic section: position of Middle Cenozoic hiatus, rift unconformity, and SSCs LR2–LR6, highlighted in [24]. Figure borrowed from [36]. Inset: physicogeographical map of circumpolar Arctic and ACEX drilling area (white dot) near North Pole. Inset borrowed from [33].

part to dark brown near the bottom. The considerably larger (21.2–168.5 m below the surface of the bottom—mbsb) LU1/3 is represented by Pleistocene–lower Miocene silty clay with sand lenses; deposits are colored different shades of brown. LU1/4 (168.5--192.9 mbsb) consists of upper Eocene–lower Miocene silts with sand lenses; deposits are different shades of brown. LU1/5 (192.9–198.7 mbsb) consists of upper Eocene (Priabonian) silty clay with small sand lenses; in the lower half, it consists of alternating black and gray layers (so-called "zebra" interval). The upper Eocene LU1/6 (198.7–223.6 mbsb) in our opinion has been wrongly referred to LU1: genetically and lithologically, it is closer to LU2 deposits and consists, in addition to terrigenous material, of opal-A with a small amount of siliceous organisms. LU2 (223.6–313.6 mbsb) is represented by lower–middle Eocene deposits consisting mainly of siliceous organisms; approximately from a level of 285 mbsb down section, transformation of opal-A to opal-C/T begins (Fig. 2) [37]. LU3 sediments (313.6–404.8 mbsb) are represented by terrigenous varieties lower Eocene–upper Paleocene in age. LU4 terrigenous sediments (424.5–427.7 mbsb) are of Campanian (possible Maastrichtian) age [2, 13].

The Middle Cenozoic hiatus was established in borehole M0002 at a level of 198.7 m, corresponding to the boundary between LU1/5 and LU1/6 [12, 33]. The age of the lower boundary of the hiatus was based on the last appearance of a large number of *Phthanoperidinium clithridium* dinoflagellates at a level of 202.95 mbsb (however, singular representatives of this species were encountered up to 201.19 mbsb and possibly higher, up to the middle of LU1/5 [12]) and the last appearance of *Cerodinium depressum* dinoflagellates at a level of 209.30 mbsb in LU1/6 [13]. These levels have been dated to the Lutetian stage of the middle Eocene: 44.6 and 44.9 Ma, respectively [12]. Dinoflagellates are presented in the entire range of LU1/6 and do not contain species with an age from the later part of the middle Eocene to the late Eocene. Conversely, diatoms and silico-flagellates presented in LU1/6 indicate a younger age of sediment. Thus, the first appearance of *Coscinodiscus aff. tenerrimus* (203.12 mbsb) shows an age corresponding to the Priabonian stage of the late Eocene: 36.7 Ma [13]. Hence it follows that the difference in the age estimates for *C. aff. tenerrimus* and *P. clithridium* is 7.9 Ma. The stratigraphic model of the Paleogene part of the column was nevertheless based on dinoflagellate datings [13]. The refusal to use biosiliceous organisms was probably related to their insufficient stratigraphic calibration for the conditions of the central Arctic. Nevertheless, from the viewpoint of biostratigraphy, it is far more logical to establish the age of sediment

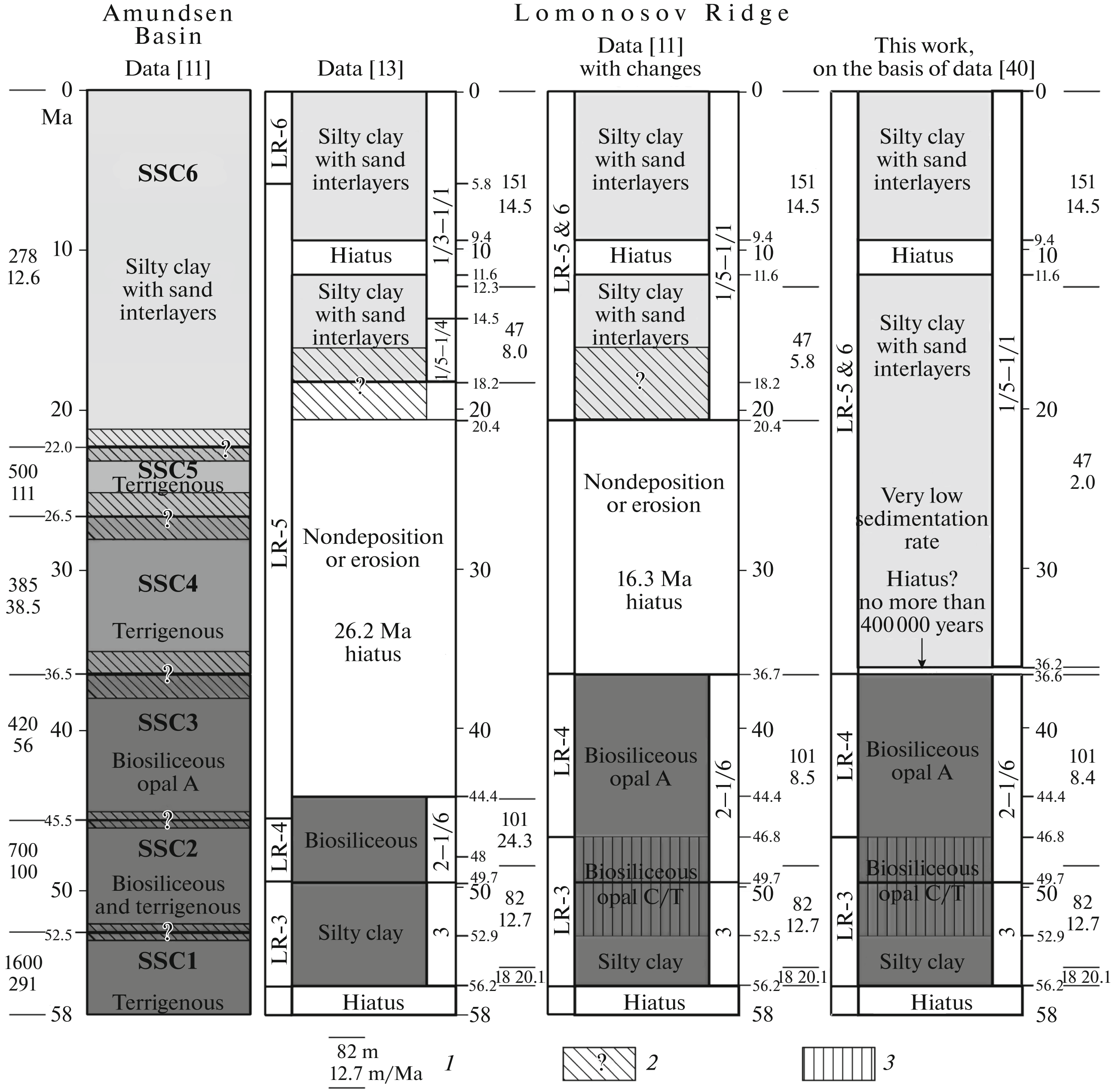

Fig. 2. Correlation of seismostratigraphic complexes (SSCs) in Amundsen Basin (column 1) and on Lomonosov Ridge (near ACEX boreholes) based on three different models: from [13], column 2; from [11], column 3; and from data of present study, column 4. Vertical axis for columns, geological time, Ma. (*1*) Thickness of sediments (m) and sedimentation rate (m/Ma) in indicated interval; (*2*) uncertainty range in estimating age of boundaries; (*3*) C/T opal interval [37].

based on the first, and not the last, appearance of species, which in our opinion should give an advantage to diatomic algae.

The age of the upper boundary of the hiatus at the bottom of LU1/5 is based on a finding of two new species of *Arcticacysta* dinoflagellates (*A. backmanii* and *A. moraniae*), consisting of from 40 to 100% of the association [41]. These two species are reminiscent of *Batiacasphaera baculata*, an indicator of the Burdigalian stage (16.0–20.4 Ma), which made possible to date the bottom of LU1/5 as 18.2 Ma (the middle of the Burdigalian) [13]. Thus, in the age estimate for the upper boundary of the hiatus, there is an uncertainty of 4.4 Ma (Fig. 2). It should be noted that the use of these new species is unreliable for valid stratigraphic association of the borehole's sediment. No new data confirming their age have been obtained to date.

According to the above-mentioned datings, the extent of the Middle Cenozoic hiatus is 26.2 Ma.

Below, we call this model, which is described the mostly completely in [13, 14], as stratigraphic model 1.

The work by Kim and Glezer [3] is based on another interpretation of the primary micropaleontological data presented in the ACEX field report of the expedition [12]. The authors based it primarily on an analysis of the distribution of dinoflagellates and silico-flagellates. In their opinion, the boundary between LU1/5 and LU1/6 corresponds to boundary between the Priabonian stage of the upper Eocene and the Rupelian stage of the lower Oligocene, which rules out a significant hiatus [3]. They placed the hiatus with an extent of around 12 Ma (between the lower Oligocene and the middle Miocene) in the lower part of LU1/3, at the level of 158 mbsb. An argument in favor of this treatment is the presence of a single specimen of the dinoflagellate *Impagidinium dispertitum*, which lived in the middle Eocene–late Oligocene at a level of 159.17 mbsb [3]. However, the authors of the ACEX field report are convinced of the redeposited character of this species [12]. It is interesting that nearby (in the area of 156.5 mbsb), a distinct change in the mineral association from clinopyroxene–black ore to black ore–hornblende was discovered, related to the first appearance of perennial ice in the Arctic Ocean [27].

Arguments in favor of a significant reduction in the duration of the Middle Cenozoic hiatus were proposed by Chernykh and Krylov [11] from the results of a joint interpretation of geophysical data and the ACEX borehole cores. The authors proposed reducing the hiatus to 16.3 Ma (an interval of 36.7–20.4 Ma; Fig. 2, column 3), using *C. aff. tenerrimus* diatoms to date its lower boundary [11]. The preferred use of diatoms for dating LU1/6 has also been supported by other researchers [15].

The results of Os-isotope dating of sediments support the absence of a long hiatus between LU1/5 and LU1/6 [39, 40]. In the opinion of these authors, the hiatus in this interval was less than 400 ka, and the boundary between LU1/5 and LU1/6 corresponds to the Priabonian stage of the late Eocene (~36.2–36.6 Ma), which confirms the correctness of using biosiliceous organisms (in particular, *C. aff. tenerrimus*) for stratigraphic division of the Paleogene part of the section. Thus, there are serious grounds for an essential re-evaluation of the age model of ACEX borehole sediments and, as a result, the history of the central Arctic development. For convenience, we call this stratigraphic model 2.

It should be noted that any estimates suggesting a long Middle Cenozoic hiatus are difficult to explain when considering the evolution of the central Arctic using plate tectonics. Indeed, the sedimentation/erosion conditions over the period of 26.2 (or 16.3) Ma could have existed with the ridge being all this time in neritic (or even subaerial) conditions. This concept has been reflected in multiple publications on different aspects of the Cenozoic history of the Arctic Ocean [6, 22, 28, 35, 41, 46]. However, during cooling of the continental lithosphere after its extension, the Lomonosov Ridge should have naturally subsided [32]. The onset of subsidence of the considered part of the ridge below sea level dated by 56.2 Ma, when sediment above the Middle Cenozoic hiatus appeared (a rift unconformity of 80–56.2 Ma ago, Fig. 2). Based on this, the fact that the crest part of the Lomonosov Ridge was in shallow-water conditions by the middle of the Cenozoic needs to be explained. A number of researchers have attempted to reconcile these contradictions. Thus, O'Regan et al. [36] proposed that a delay in subsidence of the ridge occurred as a result of a predominant compressive tectonic regime in the Eurasian Basin. After its termination, the ridge actively (within ~18 Ma) subsided by approximately 1200 m in the Miocene [36]. Essentially, this hypothesis is consonant with the "collapse of central Arctic rises" model proposed by Kiselev et al. [4]. Minakov and Podladchikov [31] expressed the idea of "uplifting" of the ridge during the postrift period, which allowed the existence of erosion conditions at its crest. Then, it also underwent intensive subsidence [31].

In contrast to the above, the authors of [17] explained the prolonged neritic conditions of sedimentation or erosion on the Lomonosov Ridge as a significant drop (the first hundreds of meters) in the level of the ocean, which was isolated at that time, which occurred concurrently with natural subsidence of the Lomonosov Ridge. The main idea is that, just like in the case of global variations in the level of the World Ocean, decelerated spreading in the Eurasian Basin (Fig. 3) of the isolated Arctic Ocean could have led to a significant drop in its level [17]. Deceleration of spreading rates in the Eurasian Basin was recorded, starting around 46 Ma. The minimal rates have been established in an interval of approximately 33–23 Ma, and then they increased (Fig. 3) [1]. Isolation of the Arctic Ocean likely began around 49–50 Ma, after the closing of the Turgai Strait [15]. Evidence of such isolation, which ended by the beginning of the Oligocene, was established, e.g., based on the presence of endemic species of silico-flagellates [35] and foraminifera [30], and confirmed later by isotopic studies [39, 40].

It should be added that the results of detailed geochemical and mineralogical studies of ACEX borehole cores in the vicinity of the proposed hiatus [28] showed significant differences in the composition of sediments above and below the hiatus. This allowed the authors [28] to agree with the existence of a prolonged hiatus (or, as a minimum, the absence of continuous sedimentation between LU1/6 and LU1/5). We assume that these studies make it possible to judge only the fundamental possibility of a hiatus, but not its duration.

Recent publication [15], devoted to global propagation of biosiliceous organisms in the Eocene, proposed yet another hiatus (46–39 Ma), placing it between LU1/6 and LU2 (its location is not directly mentioned in the work). The arguments in favor of possible existence of a hiatus between LU1/6 and LU2 were given earlier in [41]. In our opinion, a much more serious biostratigraphic analysis of the ACEX materials is required to confirm the reality of the suggested hiatus.

As a result of substantial uncertainty, when studying different aspects of the Cenozoic evolution of the Arctic Ocean, it is often necessary to take into account both of the best substantiated age models [38, 44, 45]; some authors incline toward stratigraphic model 2 (e.g., [18]); most others prefer stratigraphic model 1 [6, 21, 26, 28, 31], etc. Thus, study of this question seems extremely important, and this paper strives to answer it.

MATERIALS AND METHODS

To solve the question on the duration of the Middle Cenozoic hiatus, the authors used all available (their own and previously published) data: biostratigraphic, geochemical, lithological and geophysical.

We analyzed the results of multichannel reflection seismic (MCS) surveys obtained during the Arktika-2011 and Arktika-2012 expeditions [9]. We used them to check the seismostratigraphic model for the central part of the Amundsen Basin, proposed earlier by the authors, according to which sediments are subdivided into six seismostratigraphic complexes (SSCs) [11]. The age of the seismic horizons separating the SSCs was estimated from the age of points of the oceanic basement where they pinch out. The basement was dated by identification and tracing of striped magnetic anomalies. It was assumed that this principle is applicable to the sedimentary cover of the Eurasian Basin in the age range from ~58 to ~22 Ma ago.

We also used the results from a study of the lithological composition of sediments: data on the pyrite distribution in the 0.1–0.05 mm fraction and psephites.

RESULTS

Psephite distribution. The Table 1 lists the number of psephites in each LU. In order to assess their sedimentation dynamics, we used a coefficient that shows the number of psephitic material in 1 m of sediment for each LU (P/M coefficient, Table 1). It is clear that the psephite sedimentation rates sharply increase starting from LU1/5, located above the hiatus, which is explained by activation of ice rafting. Arguments in favor of the predominantly ice/iceberg mechanism of delivery of coarse material to the area of the ACEX boreholes, starting from LU2, have been presented in a number of publications [18, 46]. A single specimen of angular pebble-sized stone from LU3 may have both a local and foreign nature. Psephites in the LU1/6 and LU1/5 encompassing the hiatus are represented by quartzite and quartz sandstone.

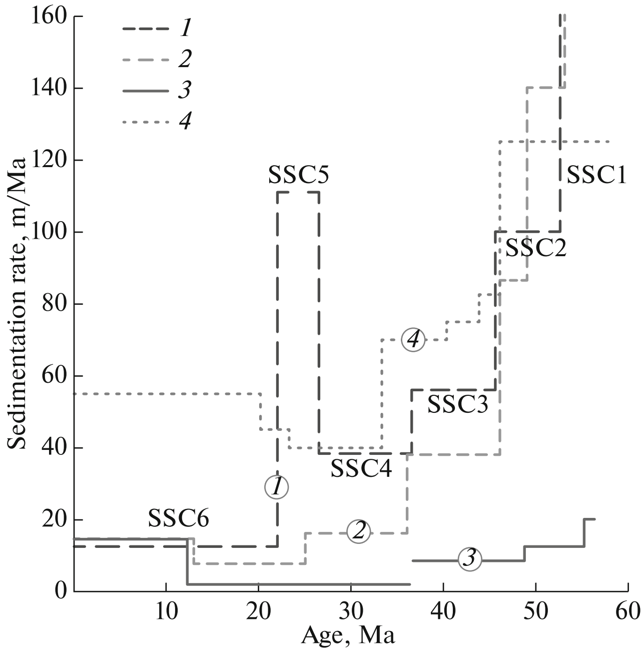

Fig. 3. Comparison of sedimentation rates (m/Ma) in Amundsen Basin ((*1*) from [11]; (*2*) from [24]) and on Lomonosov Ridge ((*3*) this study) with spreading rates in Eurasian Basic ((*4*) from [1]) over the course of the Cenozoic.

Seismostratigraphy and sedimentation rates. As a result of studying new MCS profiles [9, 10], the authors came to a conclusion about the consistency of their earlier proposed model of seismostratigraphic division of the sedimentary cover of the Amundsen Basin [11]. The characteristics of the seismic reflectors, distinguished earlier using seismic sections con-

Table 1. Thickness of lithological units (LUs), number of psephites in LUs, and P/M coefficient values

LU	LC Size, m	Number of psephites	P/M
1/1	M0003A: 1.1	1	0.91
	M0004C: 5.29	3	0.57
1/2	M0003A: 13.9	2	0.14
	M0004C: 18.3	1	0.05
	M0004A: 4.68*	3	0.64
1/3	147.3	25	0.17
1/4	24.4	8	0.33
1/5	5.2	3	0.58
1/6	22.1	2	0.09
2	93.3	3	0.03
3	91.2	1	0.01

* Borehole M0004A passed only part of LU1/2, so P/M coefficient is overstated.

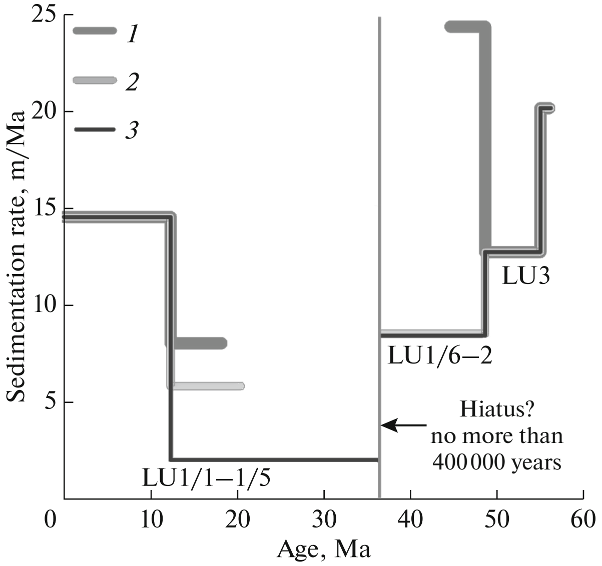

Fig. 4. Sedimentation rates at crest of Lomonosov Ridge in ACEX drilling area: (*1*) from [13]; (*2*) from [11]; (*3*) from results of this study.

structed by results of single soundings during drifting of the Russian "North Pole" stations, differ from the ones on MCS sections. Despite of this fact, these reflectors can be traced in the entire eastern part of the Amundsen Basin. Their age estimated by the above-mentioned method fits well in the reliability intervals in the earlier published model [11], as well. This seismostratigraphic model is represented as column 1 in Fig. 2. To the left of the column are the approximate thickness of the SSCs, calculated with accounting for the averaged interval velocities, as well as the sedimentation rate in m/Ma.

The next three columns in Fig. 2 pertain to the Lomonosov Ridge.

Column 2 is constructed from data [13]. It depicts a simplified lithology of the combined borehole drilled by ACEX and is constructed using stratigraphic model 1. To the right of column 2 are the thicknesses of the LUs and sedimentation rates. There are three hiatuses in the borehole profile. The discussed Middle Cenozoic hiatus encompasses a time interval of 44.4–18.2 Ma according to the model of the cited authors.

Column 3 is a modification of column 2 published in [11]. Based on comprehensive analysis of the geological and geophysical data, the Middle Cenozoic hiatus was decreased to 16.3 Ma. To the right of column 3 are the thicknesses of LUs and sedimentation rates, which varied taking into account other estimates for the boundaries of the hiatus.

Column 4 is also a modification of column 2, but with accounting for stratigraphic model 2, in which the Middle Cenozoic hiatus is less that 400 Ka.

Figure 3 compares the plots of the sedimentation rates on the Lomonosov Ridge (according to column 3 from Fig. 2) and in the Amundsen Basin (two versions, according to data [11] and [24], Fig. 2, column 1), as well as the spreading rates during the Cenozoic according to data [1].

Figure 4 shows the plots of the sedimentation rates on the Lomonosov Ridge near the point of the ACEX borehole, constructed from the above-mentioned three versions of the columns. The rates differ only for complexes above and below the proposed Middle Cenozoic hiatus.

DISCUSSION

From our viewpoint, geodynamic models that attempt to explain the shallow-water conditions on the Lomonosov Ridge by a delay in its subsidence [36] or by its uplift [31] are unlikely plausible. Indeed, all currently available MCS profiles obtained on the Lomonosov Ridge and adjacent structures [9, 10, 23–26], etc., give no evidence for significant tectonic activity in the second half of the Cenozoic (e.g., [25, 26]). There is no evidence of active tectonics of this time at the boundaries of the ridge with the Amundsen, Podvodnikov, and Makarov basins, the continental shelf of Eurasia, or even between individual (in terms of the basement structure) blocks of the ridge. Oligocene–Quaternary units of the sedimentary cover have a draping monotonic character, which testifies their formation in quiescent tectonic regime.

The results of Os dating of ACEX borehole sediments (stratigraphic model 2 [40]) yielded new information for constructing evolutionary models of the Arctic Ocean. First, the hypothesis [11] on the younger age of the lower boundary of the hiatus, 36.7 Ma (36.6 Ma taking into account the Os-isotope data), was confirmed. Indeed, according to stratigraphic model 1 [13], before the hiatus on the Lomonosov Ridge, an almost double increase in the sedimentation rates occurred, which at any rate looks strange (Figs. 2, 4), especially taking into account the low sedimentation rates in the Eocene in the circumpolar zone [8]. From our viewpoint, the hiatus should follow after opposite process, which inferred from the model shown on Fig. 4. The drop in the sedimentation rates on the Lomonosov Ridge and in the central part of the Amundsen Basin was a general trend related mainly to growing distance to source areas during opening of the Eurasian Basin (Fig. 3).

Second, the results of Os dating have shown that the duration of the Middle Cenozoic hiatus was less than 400 Ka [40]. Taking into account this estimate, we constructed column 4 in Fig. 2, where sedimentation on the Lomonosov Ridge began again after the hiatus, starting from 36.2 Ma, and continued for the following ~25 Ma at minimum rates (on average, 2 m/Ma). Thus, if the given model is valid, then

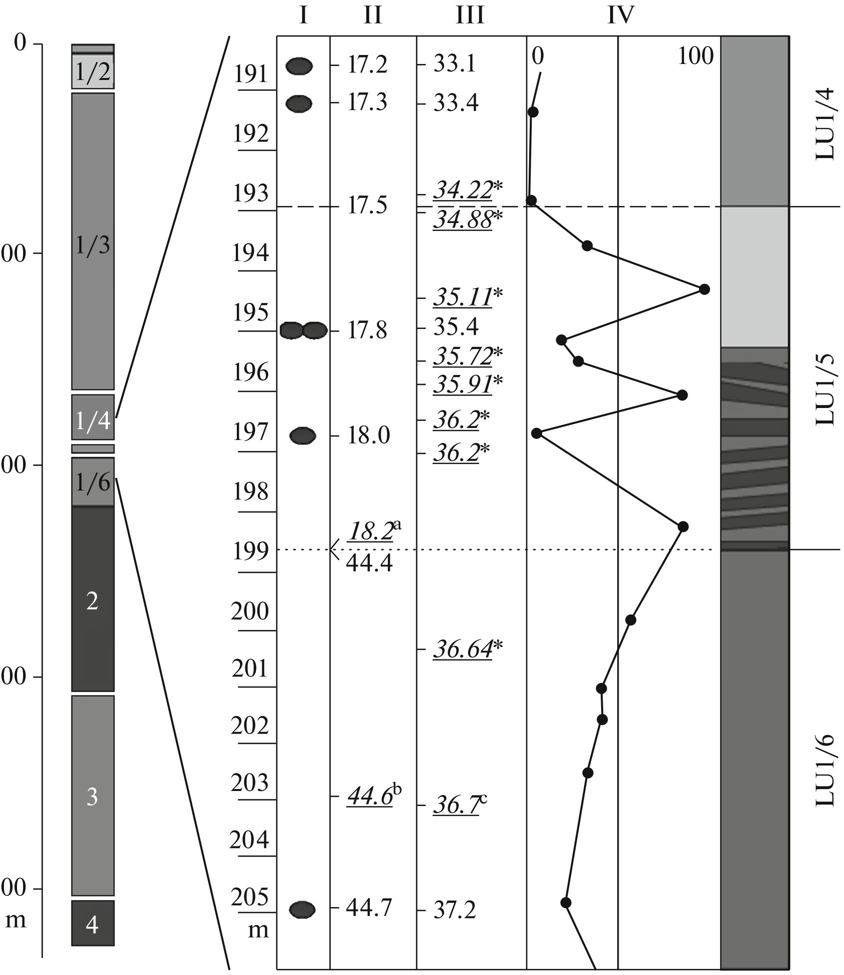

Fig. 5. Distribution of psephitic material in area of Middle Cenozoic hiatus: I, position of psephites in section; II, age (Ma) according to stratigraphic model 1; III, age (Ma) according to stratigraphic model 2; IV, distribution of pyrite in heavy fraction (0.1–0.05 mm), %. Datings underlined and in cursive obtained from biostratigraphy date ((a) middle of Burdigalian stage, (b) last numerous appearance of *Ph. clithridium*, (c) first appearance of *C. aff. tenerrimus* [13]); Os datings, numerals with asterisks [40]. Remaining numerals obtained by extrapolation. Dotted line, position of Middle Cenozoic hiatus between LU1/5 and LU1/6. Dashed line, boundary between LU1/5 and LU1/4.

instead of the earlier existing problem of the difficult-to-explain Middle Cenozoic hiatus which lasted 26 Ma, it is still necessary to find the causes that led to the relatively short-term interval of nondeposition or sediment erosion on the ridge.

Erosion, sometimes significant, may have been a consequence of breaks in sedimentation. Predominant loss of fine silty clay material mainly consisting of clay minerals and light subfraction minerals (quartz, feldspar) accompanies washing out of sediments. However, if clay material is consolidated, its erosion can only occur at significant velocities of near-bottom currents, the magnitude of which should exceed the velocities necessary for the erosion of sandy sediments (which follows from the Hjulstrom diagram ([34], etc.)). Sandy sediments, containing more than 50% sand-sized particles, are almost absent on the crests of ridges in the central Arctic. In intervals accumulated in deglaciation periods, an overall roughening of the grain-size range of deposits is observed everywhere; however, the sand fraction, as a rule, is still contained only in the form of admixtures (sometimes significantly) to the predominant silty clay particles ([5, 7, 43], etc.). Sand interlayers commonly appear on slopes where gravitational (turbidite) flows are active ([5], etc.). The presence of contourites at the foots of slopes is also assumed [7].

Hiatuses, especially short-term ones, are not always accompanied by erosion and may be related to simple nondeposition of sediments. This occurs only if currents prevent particle deposition to the bottom but are not intense enough to wash out earlier accumulated sediments. Both versions (with and without erosion), as a rule, are accompanied by solidification of bottom sediments and the formation of oxidized crusts/interlayers. Indeed, terrigenous or biogenic particles will not be deposited at the crest of a ridge only during active hydrodynamics, which in turn rules out stagnation in the near-bottom layer. It seems highly improbably that over the span of 26 Ma only nondeposition of sediments without bottom erosion could have occurred. If erosion took place, then sediments should have to a particular degree been enriched in coarse-grained material or terrigenous minerals of the heavy fraction. The predominance of authigenic pyrite in the heavy fraction of LU1/6 sediments (17.3–86.6%, on average, 54.5%) indirectly supports weak hydrodynamics in the near-bottom layer. Substantial fluctuations in pyrite contents in LU1/5 (“zebra” layer, 5.7–96.8%, on average, 50.4%; Fig. 5) stemmed from the establishment of a system of currents after opening of the Fram Strait, as a result of which oxygen-rich Atlantic waters began to inflow (in a pulsating regime [22]). As for heavy terrigenous minerals, the distinct peak in the iron oxide distribution at the boundary between LU1/6 and LU1/5 [18] is evidence for the fundamental possibility of a hiatus; however, it is certainly difficult to judge its duration from these data.

When qualitatively solving the problem on the duration of the hiatus, it may help to analyze the psephitic material distribution (Table 1, Fig. 5). Directly in the area of the hiatus, psephites were not found. The specimens nearest to it are located 1.97 m higher (LU1/5) and 6.8 m lower (LU1/6) than the LU1/5-LU1/6 boundary (Fig. 5). In case the hiatus in sedimentation actually lasted 26 Ma and occupied the Oligocene, which is known for an overall cooling of the climate [49] and, presumably, glaciation [48], psephitic material will definitely be concentrated at the LU1/5–LU1/6 boundary due to more intense delivery by ice and icebergs and to erosion/nondeposition of silty clay particles. However, this is not observed. This is a serious argument in favor of a small-term hiatus, which corresponds to stratigraphic model 2.

LU1/5 deposits began to accumulate in the late Eocene (Priabonian) around 36.2 Ma [40]. Thus, the opening of the Fram Strait began not 17.5 Ma [22], but 36.6 Ma [40], which was assumed long before publication of the ACEX drilling results. The presence of a continental rift zone between the Morris Jessup and Ermak plateaus by ~33–35 Ma (C13 magnetochron) is confirmed by the results of identifying striped magnetic anomalies in this part of the Eurasian Basin [1, 16]. The sharp change in the hydrological regime, caused by the infiltration of Atlantic waters, resulted from opening of the strait. They should have followed beneath the less dense Arctic waters. The significant hydrodynamic activation led to relatively rapid replacement of oxygenless reduced near-bottom waters, which were predominant in the Arctic Ocean in the Eocene, with well-aerated waters. As a result of the “collision” of Atlantic waters with the Lomonosov Ridge, short-term (less than 400 Ka) [40] washingout (or nondeposition) of sediments occurred on its crest. Alternation of oxidized and reduced layers in the lower half of LU1/5 (“zebra” layer) testifies to the instability of the hydrological regime and was possibly accompanied by the formation of a set of short-term hiatuses at the contacts between layers [41]. In the Arctic Ocean, the crest and sloping parts of ridges and rises were among the areas subjected to erosion processes. Evidence of erosion at the level of the Middle Cenozoic hiatus has been detected in MCS profiles obtained in the deep-water part of the ocean (e.g., [25]). In addition, transformation of the hydrologic regime led to an instant change in the material (chemical and mineral) composition of sediments reaching the bottom [28, 41].

Thus, to explain the cause of the short-term erosion of sediments at the boundary between LU1/5 and LU1/6, it is totally unnecessary to involve shallow-water (neritic) conditions that are difficult to explain taking into account the above-mentioned facts. Nevertheless, considering the evidence of isolation of the Arctic Ocean in a time interval of approximately 49–36.6 Ma ([15, 30, 35, 40] etc.), it can be assumed that its level was lower than that of the World Ocean. This was due to increasing of size of the Eurasian Basin as a result of spreading. The magnitude of subsidence of the considered part of the Lomonosov Ridge during cooling of the lithosphere by a time of ~36 Ma was ~700 m [32]. However, in reality, the depth of the Arctic Ocean here could have been substantially less. Today, there are insufficient factual data to reliably verify this hypothesis.

The trend of the increase in the level of the Arctic Ocean, beginning from approximately the Oligocene (after a short-term hiatus) is evidenced by growing of prograded complexes in the MCS cross-sections that intersect the continental slope of the East Arctic Margin ([21, 42], etc.). In the period approximately 34–23 Ma, the spreading rates in the Eurasian Basin [1], as well as in the entire North Atlantic [19], were minimal (Fig. 3). This was the time of decelerated spreading on a planetary scale and, at its apogee, on the Rupelian–Hattian border (28.4 Ma), a global regression began [20, 29, 47]. During seismostratigraphic analysis of the cover of the Amundsen Basin, SSC 5 was distingushed, which accumulated at a high rate (~110 m/Ma), supposedly in an interval of ~28–21 Ma (Figs. 2, 3) [11]. This closely corresponds to the mentioned global regression and may be evidence in favor of unity of the Arctic and World oceans by that time.

After establishment of the link with the World Ocean 36.2 Ma, the sedimentation rates on the crest of the Lomonosov Ridge in the area of the ACEX drilling were minimal (Fig. 2, column 4). As a result of cooling of the climate [49] and change in hydrodynamics at the discussed border, the biosiliceous type of sedimentogenesis was replaced by a terrigenous type and its intensity began to be determined by the general laws of sedimentogenesis: by distance from the source areas, the intensity of the ice regime, the availability of material in source regions (for capture by ice or currents), active/quiescent tectonics, the depth of the crest below sea level, etc.

The increase in the sedimentation rates over the last ~10 Ma (Figs. 2, 4) during continuing subsidence of the Lomonosov Ridge and gradual cooling of the climate is related to different factors, among which an increase in the role of ice rafting can be referred as important.

CONCLUSIONS

(1) The available factual material confirms the hypothesis on the absence of a long hiatus in the Middle Cenozoic with a duration of 26 Ma in the area of ACEX drilling. The duration of the hiatus was significantly shorter, less than 400 ka according to stratigraphic model 2.

(2) The likely cause of the hiatus is mainly the onset of the active inflow of Atlantic waters through the Fram Strait around 36.6 Ma, following under the less dense Arctic waters. During contact of the latter with the Lomonosov Ridge, erosion processes or nondeposition of sediments may have occurred. It is also important to note the possible low level of Arctic Ocean waters in the period of its isolation (49–36.6 Ma) as a result of decelerated spreading in the Eurasian Basin.

(3) The presence of a short-term hiatus in sedimentation in the Middle Cenozoic agrees with the "classical" plate tectonics model of natural postrift subsidence of the Lomonosov Ridge.

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